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Upstream logistic transport planning in the oil-industry: a case study

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A B S T R A C T

Nowadays, oil companies have to deal with an increasingly competitive environment. In this sense, the optimization of operational processes to enhance efficiency is crucial. This article addresses the design of a decision support tool for the inland upstream transport logistics in the oil industry based on a case of study in Argentina. This problem is traditionally difficult to solve for managers due to the large number of demand facilities scattered on a large geographic area that have to be served and the consideration of several operational requirements, such as maximum allowable travel times for vehicles, availability of a limited fleet size with a small number of drivers, plus the usual demand constraints as well as those arising from security risks derived from the incompatibility of chemical products. A novel mathematical formulation and a constructive heuristic are proposed in order to address this problem. The results allow to reduce the time that the company spends for obtaining a feasible distribution plan that minimizes the time horizon of the distribution schedule provided to the clients and enhances customer satisfaction.

1. Introduction

The oil industry handles large amounts of money, either in investments or expected revenues. However, in an increasingly competitive world with new public regulations and an increasing environmental awareness, companies feel the pressure to enhance their efficiency by refining their processes (Ebrahimi et al., 2018). One area in which this is crucial is transport logistics (Hussain et al., 2006). Logistic activities in the oil industry can be classified in two main categories (Aas et al., 2007): upstream logistics, which involves providing the facilities (mainly oil wells) with supplies needed to extract oil; and downstream logistics, which is aimed towards bringing the extracted oil and gas to consumers. Upstream logistics is an area that has not yet been thoroughly researched (Aas et al., 2009). Moreover, the largest part of the literature on upstream logistic, has focused on offshore production and on routing of vessels (see, e.g., Aas et al., 2007; Fagerholt and Lindstad, 2000; Halvorsen-Weare et al., 2012). This paper focuses, instead, on the upstream logistics of the inland operations of a SME (Small and Medium Enterprise) company providing supplies on-site for oil extraction of a client oil company in Argentina.

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As in any supply chain, the amounts and quality of inputs should be delivered with regularity to avoid disruptions in the production process. However, managers that have to plan distribution activities in this context has to deal with several obstacles based on customers' requirements. For example, the demand is scattered over hundreds of facilities that have to be served with different kinds of products; the schedules of drivers of the trucks involved in these distribution trips are regulated by strong labor conventions; and the distances on the actual road network are barely known. Currently, managers design the distribution schedules mainly based on their experience. But the efficiency of distribution plan is not the only goal that matters; the time that takes to present a solution to a client is equally important to increase the client satisfaction.

This work proposes a decision support tool which aims to systematize the process of building a distribution schedule to reduce the time spent in constructing a feasible schedule of provision of chemical supplies to numerous facilities distributed on a large area, making operational decisions at the level of day-to-day logistics (Dempster et al., 2000). The facilities include not only the oil wells but also the related installations used to extract and transport oil. A resolution method for this problem is developed. This work is structured as follows. In Section 2, the target problem is described and the related literature is discussed. In Section 3, a mathematical formulation and a constructive heuristic for this problem are presented. Section 4 presents the main results while Section 5 concludes, discussing possible future work.

2. Problem description

The problem under consideration arises in the upstream logistic supply chain of a company located in southern Argentina. A certain number of products used as inputs in the facilities have to be distributed to several locations. These products are used with various purposes, e.g., for enhancing the flow through pipelines by reducing corrosion, preventing the sedimentation of organic material, such as paraffins and asphaltenes, and the incrustations of bacteria and calcium carbonate, increasing the lifespan of the facilities. A correct supply of these products is required in order to ensure a steady provision of oil. This setting exhibits certain features that make it an interesting real-world problem:

- Demand sites. The demand nodes, i.e., the facilities that have to be served, are not static, problem under consideration particular cases of volatile behavior in the supply chain (Nitsche & Durach, 2018). The location of facilities can vary regularly depending on changes in the operational conditions that may lead to those displacements. The latter are usually due to the required quality of oil, as the differences in temperature, pressure or the proportion of water content. Although the staff of the operational system knows the location of the facilities at ground level (this is necessary for the provision of proper services), the staff at a more tactical level usually lacks this information since the number of facilities is large, the frequency of modifications is high and the personnel is scarce, preventing the company from geo-localizing the facilities and the network of paths connecting them. This data can only be estimated.
- Maximum travel times. Mainly because of the specificity of the job, the workforce has certain benefits not shared with workers in other areas. Although Argentinean oil industry workers enjoy some extra special conditions (Lopez Cattaneo, 2009), they do not differ much from those in other parts of the world (Brešić et al., 2007). In terms of the problem analyzed in this paper, these conditions affect the maximum allowable travel time for drivers, as specified by labor conventions.
- Drivers and heterogeneous fleets. The company has a fleet of three trucks, one which has a larger capacity than the others. But since just two drivers are available, only two trucks can be used simultaneously. The products are distributed in barrels of 200 liters, where each barrel contains only one kind of product. While the capacity of the vehicles is measured in barrels, the demand of the products in the facilities is expressed in liters.
- Safeness restrictions. Due to safety restrictions, some products cannot be loaded on the same truck (even if they are in different barrels). Hereafter, two sites are "compatible" if the products

demanded by them can be loaded on the same truck. The magnitude of the daily consumption of products at the facilities varies considerably between different facilities.
- Facilities storage capacity. The storage capacity in each facility differs from that in the others. Obviously, a facility cannot receive load than what it is allowed by its storage capacity.

The company solves this problem on an everyday basis. The staff designs the routes as to build clusters of nearby facilities demanding compatible products. This activity is extremely time consuming, considering that the number of facilities is quite large. The travel time on a route is estimated by the company using an empirical formula. Let $I = \{i_1, \dots, i_{|I|}\}$ be the set of facilities. Then, the experience indicates that the on-the-road travel time on a route r is given by Eq. (1):

$$T_r = \frac{(4\,D_{max} + |I_r|)}{V} + Q\ vb + \sum_{i \in I} s_i \tag{1}$$

where D_{max} is the distance to the farthest "base" in meters. A "base" is a larger facility located in a certain region, responsible for providing essential services to smaller facilities in the same region. I_r is the set of facilities visited by route *r*. V is the average velocity of the vehicle in meters per minute. Q is the total demand of the route in liters. vb is the loading speed of the pump at the depot in liters per minute (therefore, $Q\ vb$ represents the length of time devoted to upload the supplies to be distributes along the route). Once the vehicle has reached a facility i, s_i is the time, measured in minutes, that takes to offload the supply from the vehicle to the tanks in the facility. The company seeks to improve the scheduling process in two ways: reducing the time dedicated to build the schedule and improving the quality and precision of the information used in building the schedule. The satisfaction of the first requirement depends on the responsiveness of the supply chain strategy. In the current context, since the company works for several days to develop a supply schedule, the possibility of adapting rapidly to changing customer needs and changing market demands is severely compromised (Fera et al., 2017; Gligor et al., 2019). The second requirement amounts to collecting information useful to improve the estimation of travel times of the trucks. This problem has certain characteristics that differentiates it from others analyzed in the literature. In the next Section a review of some related works, including the applications of decision support systems in the transportation activities of the oil industry, is performed as to better understand the specificities of the problem under analysis.

2.1 Related Work

Although the design of supply distribution plans in the upstream logistics of the oil industry has not been usually addressed in the literature (Aas et al., 2009), there exist some studies in the field. Most of them present study cases in the Norwegian oil industry, involving the offshore extraction of oil and dealing with maritime routing plans. Fagerholt and Lindstad (2000) presented an optimal routing policy for a fleet of supply vessels serving several offshore installations up from one onshore base. The solution is obtained using a two stages procedure. First, feasible candidate schedules are generated for each vessel by solving a set of Travelling Salesman Problems (TSP) using dynamic programming. Then, in the second stage, an integer programming model is used to define the week plan choosing among the previously generated schedules. The robustness of solutions is assessed with a sensitivity analysis in which the opening hours at which offshore installations can receive supply vessels are varied. A similar analysis yields the solution of a vessel routing problem in Halvorsen-Weare et al. (2012), where the problem of routing vessels is again divided in two similar stages. The first stage consists of enumerating the potential vessel schedules and the second stage that generates the weekly plan using integer programming. Aas et al. (2007) solved a pickup and delivery routing problem for supply vessels serving offshore installations at Haltenbanken, off the Northwest coast of Norway. They present a mixed-integer programming model optimizing the route of one vessel, considering the offshore installations storage capacity. They found that efficiency of the route depends crucially on this capacity.

One important feature common to these works is the relatively small number of demand sites. For example, Fagerholt and Lindstad (2000), Aas et al. (2007) and Halvorsen-Weare et al. (2012) considered seven, ten and fourteen demand points, respectively. This allowed them to find exact solutions to their problems. In recent years some works have introduced competitive heuristics to deal with larger instances. For example, Kisialiou et al. (2018a) used an Adaptive Large Neighborhood Search (LNS) to solve a maritime routing problem while considering different possible departures times with real instances of up to 31 installations. A similar study with LNS was carried out in Shyshou et al. (2012). Cuesta et al. (2017) used the same approach to simultaneously determine the routes of multiple vessels in instances up to 60 offshore platforms. Uncertainty has been also considered in the context of this problem, mainly related to weather conditions affecting the service and travel times (see, e.g., Kisialiou et al., 2018b; Maisiuk & Gribkovskaia, 2014). While, as said, the majority of these applications were developed to solve Norwegian cases, there are a few analyzing similar offshore distribution problems in Brazil (Friedberg & Uglane, 2013), Mexico (Kaiser, 2010) and Russia (Milaković et al., 2015). While offshore provision problems have been, as indicated, solved in various guises, there are no, as far as we know, applications of decision support tools to inland transport operations in the oil industry. Moreover, there has been done comparatively little research on real-world supply chain problems in Latin American countries, other than those in agricultural production processes (Fritz & Silva, 2018).

2.1 Solution approach

The problem addressed in this paper involves many complicated real-world constraints. The requirement of the company, namely to improve the formula for estimating the travel time (Eq. (1)), was addressed with a partial digitalization of the regional distribution of sites. The full digitalization of the individual facilities and of the network of paths between them is out of question due to the large number of elements involved (the large quantity of sites can be seen in Fig. 1). Moreover, since these facilities vary constantly, this information, which requires a lot of effort to be obtained, becomes obsolete in a short period of time. Instead, the bases, which are more stable, were geo-localized the QGIS software. This allowed us to improve the original empirical formula of estimation of travel times: when a route includes facilities supplied by two different bases, the Euclidean distance between those bases is added. In fact, since more than two bases can be included in one tour, the solution of the Euclidean TSP of the bases included in r (B_r) and the main depot, i.e., $TSP_{B_r \cup depot}$, is calculated. The resulting expression is:

$$T_r = V(4\, D_{max} + |I_r|) + Q\ vb + \sum_{i \in I} s_i + TSP_{B_r \cup depot}\,. \tag{2}$$

Then, the other requirement of the company, namely reducing the time to build a schedule, is addressed by the design of a constructive heuristic which uses the aforementioned formula and aims to minimize the planning horizon. Thus, to further describe the problem addressed in this work, first, a mathematical formulation is presented in Section 3.1 and, then, in Section 3.2 the constructive heuristic for solving the model is devised.

3.1. Mathematical formulation

A mathematical formulation that aims to minimize the number of days required for fulfilling the supply of the products to the facilities is presented. The proposed formulation has the following sets and parameters:

- I: set of facilities (demand points).
- B: set of bases without the depot.
- B^0: set of bases including the depot, $B^0 = B \cup depot$.
- I^b: subset of facilities that belong to base $b \in B$.
- K: set of types of products.
- L: set of vehicles.
- D: set of days in the week.

and the following parameters:

- V: average speed of the vehicles.
- vb: loading speed of the pump at the depot.
- q_{ki}: amount of product k required by facility i in liters.
- s_i: service time required by facility i.
- C_l: capacity in barrels of vehicle l.
- T_{max}: maximum allowable route time.
- $w_{kb'}$: a binary parameter that is 1 if products k and k'' are compatible, 0 otherwise.
- $dist_{bb'}$: distance between bases b and b'.

Then, formulation has the following variables:

- Q_{kld}: number of barrels of product k in vehicle l on day d.
- t_{ld}: distance to the facility that is served by vehicle l on day d.
- x_{ild}: 1 if vehicle l serves the facility i on day d, 0 otherwise.
- H: makespan of the planning horizon.
- $y_{b'b}^{ld}$: 1 if vehicle l serves the facility $b \in B^0$ after base $b' \in B^0$ on day d, 0 otherwise.
- p_b^{ld}: 1 if vehicle l on day d serves base $b \in B$, 0 otherwise.
- u_b^{ld}: continue variable for subtour elimination in the TSP.

Then, the mathematical formulation can be outlined as:

$$\min H \tag{3}$$

subject to:

$$\sum_{l \in L} x_{ild}\, d \leq H, \forall\, i \in I, d \in D \tag{4}$$

$$\sum_{\substack{l \in L \\ d \in D}} x_{ild} = 1, \forall\, i \in I \tag{5}$$

$$Q_{kld} \geq \frac{\sum_{i \in I} q_{ki}\, x_{ild}}{200}, \forall\, k \in K, l \in L, d \in D \tag{6}$$

$$Q_{k_1 ld} Q_{k_2 ld} \leq w_{k_1 k_2} C_l^2 \text{ }, \forall\, k_1, k_2 \in K, k_1 \neq k_2, l \in L, d \in D \tag{7}$$

$$C_l \geq \sum_{k \in K} Q_{kld} \text{ }, \forall\, l \in L, d \in D, \tag{8}$$

$$t_{ld} \geq p_b^{ld}\, dist_{bdep}, \forall\, l \in L, d \in D, b \in B \tag{9}$$

$$T_{max} \geq V\left(\sum_{i \in I} x_{ild} + 4 t_{ld}\right) + \sum_{i \in I}\left(\sum_{k \in K} q_{ki}\, vb + s_i\right) x_{ild} + \sum_{\substack{b \in B^0 \\ b' \in B^0, b' \neq b}} dist_{bb'}\, y_{bb'}^{ld} \text{ }, \forall\, l \in L, d \in D \tag{10}$$

$$|I| p_b^{ld} \geq \sum_{i \in I^b} x_{ild} \text{ }, \forall\, l \in L, d \in D, b \in B \tag{11}$$

$$p_b^{ld} \leq \sum_{i \in I^b} x_{ild} \text{ }, \forall\, l \in L, d \in D, b \in B \tag{12}$$

$$|I| p_{depot}^{ld} \geq \sum_{i \in I} x_{ild} \ , \forall\, l \in L, d \in D \tag{13}$$

$$p_{depot}^{ld} \leq \sum_{i \in I} x_{ild} \ , \forall\, l \in L, d \in D \tag{14}$$

$$\sum_{b' \in B^0, b' \neq b} y_{bb'}^{ld} = p_b^{ld}, \forall\, l \in L, d \in D, b \in B^0 \tag{15}$$

$$\sum_{b' \in B^0, b' \neq b} y_{b'b}^{ld} = p_b^{ld}, \forall\, l \in L, d \in D, b \in B^0 \tag{16}$$

$$u_b^{ld} - u_{b'}^{ld} + \sum_{b'' \in B^0} \left(p_{b''}^{ld}\right) y_{b'b}^{ld} \leq \sum_{b'' \in B^0} \left(p_{b''}^{ld}\right) - 1, \forall\, l \in L, d \in D, b, b' \in B^0, b' \neq b \tag{17}$$

$$0 \leq u_b^{ld} \leq \sum_{b' \in B^0} \left(p_{b'}^{ld}\right) - 1, \forall\, l \in L, d \in D, b \in B^0 \tag{18}$$

$$t_{ld} \geq 0, \forall\, l \in L, d \in D \tag{19}$$

$$Q_{kld} \in \mathbb{Z}_0^+, \forall\, k \in K, l \in L, d \in D \tag{20}$$

$$H \in \mathbb{Z}_0^+ \tag{21}$$

$$x_{ild} \in \{0,1\}, \forall\, i \in I, l \in L, d \in D \tag{22}$$

$$y_{b'b}^{ld} \in \{0,1\}, \forall\, b, b' \in B^0, l \in L, d \in D \tag{23}$$

$$p_b^{ld} \in \{0,1\}, \forall\, b \in B^0, l \in L, d \in D \tag{24}$$

Eq. (3) aims to minimize the time horizon makespan. Eq. (4) fixes the makespan of the planning horizon to the last day that a vehicle is used. Eq. (5) indicates that a facility can only be assigned to one trip. Eq. (6) establishes the load per product in number of barrels for each trip. Eq. (7) ensures that two incompatible products cannot be included in the same trip. Eq. (8) limits the amount of barrels per trip to the capacity of the vehicle. Eq. (9) fixes the furthest base from the depot that is visited on each trip. Eq. (10) enforces the duration of each trip to less than the allowable time limit estimated by the proposed formula, which includes the solution of the TSP (hereafter "tour") between the bases that are included and the depot. Eq. (11) and (12) enforces that if a facility from a base is included in trip, that base is considered for the TSP tour. Eq. (13) and (14) enforces that if a facility is included in trip, the depot is considered for the TSP tour. Eq. (15) and (16) enforces that if a base is included in trip, it is visited and left just once in the TSP tour. Eq. (17) and (18) are the subtour elimination constraints for the TSP according to the Miller-Tucker-Zemlin formulation for the TSP (Miller et al., 1960). Eq. (19) establishes the non-negative continuous nature of the variable. Eqs. (20) and (21) define the non-negative integer nature of the variables. Finally, Eqs. (22) to (24) establish the binary nature of variables.

3.2. Heuristic

In real-life problems, where large-dimension search spaces and/or a variety of hard constraints are included, classical exact solution methods can be highly time-consuming (Nesmachnow, 2014; Toncovich et al., 2019). Therefore, designing heuristics can be a valuable approach for constructing fast feasible solutions. In this work, a three-stage constructive heuristic for the addressed transportation problem is devised. This heuristic allows reducing the time invested in building a schedule and, therefore, increases the flexibility of the company to coup with changes in its client's demand and enhance customer satisfaction (Singh et al., 2018). The first stage involves conforming "clusters" of facilities corresponding to the same base and requiring the same product, respecting the requeriments on the maximum travel time and the capacity of the trucks. Despite being a simple procedure, it allows us to reduce considerably the size of the problem. The second stage consists in designing the routes, satisfying the constraints on maximum allowable traveling time, the capacity and the incompatibility restrictions. First, a route is initiated by selecting the unassigned cluster with the largest demand, the so-called "seed" cluster. Then, the algorithm iteratively adds to the route the unassigned cluster with the next largest demand compatible with the seed cluster, belonging to the same base. This is repeated until the capacity of the route is fulfilled, either by reaching the maximum allowable time or the maximum vehicle capacity, or alternatively, there is no feasible extra addition. If the latter is the case, the algorithm adds the compatible unassigned cluster with largest demand belonging to the base that is closest to the base of the seed cluster. The distance between bases is approximated by the Euclidean distance. This is repeated until, again, either the maximum value of time or capacity is reached. At that point the route is completed. Then, a new route is started and the procedure is reiterated. These steps are repeated until all the clusters are assigned to a route. When constructing the routes, the focus is on maximizing the usage of the truck with the largest capacity but also on balancing the times the two different truck capacities are used, i.e., if all the routes require the largest truck, one driver (and two trucks) will remain idle and the schedule horizon will be too long. Finally, in the third stage, the routes are scheduled in a temporal horizon, i.e., they are assigned to a certain truck and driver. The pseudo code algorithm of the entire procedure is as follows:

```
Algorithm Constructive Heuristic procedure
procedure Heuristic(I , P, J, H )
    Create initial group of facilities $G_0 = \{i_0\}$;
    for $t_1$: 1 to $|I|$ do
        if facility $i_{t_1}$ can be inserted in one created group then    Comment: It is compatible and the insertion does not make the group infeasible (capacity and travel time).
            Insert $i_{t_1}$ in that group;
        else
            Create a new group $G_{|G|}$; $size_{groups}++$;
        $t_1++$
    Order groups $G$ according to descending demand;
    Initialize a route $R_0$ with $G_0$;
    while $t_1$: 1 to $|G|$ do
        if $G_{t_1}$ is not assigned then
            Create $R_{|R|}$ with $G_{t_1}$;
            Mark $G_{t_1}$ as assigned;
            If $\frac{k_1}{k_2} \geq 2$ then    Comment: $k_1$ and $k_2$ are the capacities of small and (the) large truck, respectively;
                Consider capacity $k_2$ for $R_{|R|}$;
            else
                Consider capacity $k_1$ for $R_{|R|}$;
            while $t_2$: 1 to $|G|$ do
                if $G_{t_2}$ is not assigned then
                    if $G_{t_2}$ is compatible with $R_{|R|}$ and belongs to same base then
    Comment: the maximum capacity and the time limit are also checked
                        Add $G_{t_2}$ to $R_{|R|}$;
                        Mark $G_{t_2}$ as assigned;
                $t_2++$
            while $t_2$: 1 to $|G|$ do
                if $G_{t_2}$ is not assigned then
                    if $G_{t_2}$ is compatible with $R_{|R|}$ and belongs to a near base then
    Comment: the maximum capacity and the time limit are also checked.
                        Add $G_{t_2}$ to $R_{|R|}$;
                        Mark $G_{t_2}$ as assigned;
                $t_2++$
        while $t_1$: 0 to $|R|$ do
            $t_2$= 0;
            if $t_2 \leq 1$ then
                if Capacity of $R_{t_1} > k_1$ then
                    Schedule large truck to do $R_{t_1}$ on day $d$;
                else
                    Schedule a small truck to do $R_{t_1}$ on day $d$;
                $t_2++$;
            else
                $d++$;
            $t_1++$
    return set of routes $R$
```

4. Experiments

In this Section the results of solving two real instances of the company with the constructive heuristic are presented. These are Instance I and Instance II. Both instances involve the set of complex real-world constraints described in Section 2 and the aim is to design the monthly schedule. These instances are based on what the company called as “LMLP DIVISION”, represented in Fig. 1, which is one of the largest regions where the company operates. The products that are used and system codes assigned to the products are presented in Table 1. As mentioned before, if two products share the same system code, they can be transported in the same trip. The heuristic was coded in C++. The Euclidean TSP included in Eq. (2) was solved with the Lin-Kernighan-Helsgaun heuristic (Helsgaun, 2000; Lin and Kernighan, 1973). As indicated, there are three trucks available for dispatching the products with capacities of 26, 26 and 28 barrels, respectively. Each barrel has, as said, a capacity of 200 lts. The time limit of the workday set by labor conventions is 450 min.

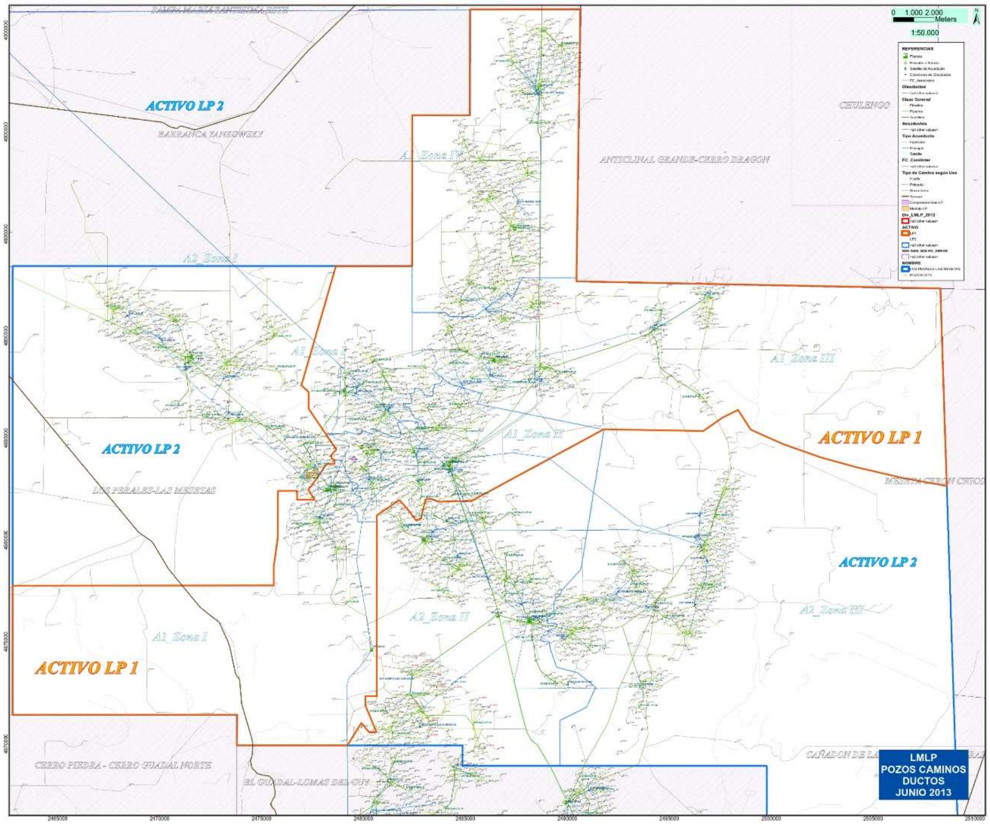

Fig. 1. Map of area under consideration

Table 1
Chemical products for both instances.

Product Code	System Code	Product Code	System Code
P_1	0	P_{11}	3
P_2	1	P_{12}	3
P_3	3	P_{13}	0
P_4	3	P_{14}	0
P_5	3	P_{15}	0
P_6	3	P_{16}	0
P_7	0	P_{17}	2
P_8	0	P_{18}	2
P_9	0	P_{19}	0
P_{10}	3		

4.1. Instance I

This instance includes 742 facilities demanding eighteen different chemical products with four system codes. In the first clustering phase of the heuristic, 236 clusters are conformed. The second phase of the heuristic yields 54 routes. In Table 2 information about each route is outlined, particularly the number of facilities that are included, the total time required, the total service time on the route (required to unload the product in the facilities), the driving time, the time necessary to load the truck at the depot, the number of barrels carried on the truck, the system codes of the products included, and the number of different products delivered.

Table 2
Description of routes in solution of Instance I

Route	Number of facilities	Total time (min)	Service time (min)	Transport time (min)	Loading time (min)	Demand in barrels	System Code	Number of products
1	1	383	186	57	140	28	1	1
2	1	428	155	153	120	24	1	1
3	1	428	155	153	120	24	1	1
4	16	443	171	137	135	27	0	3
5	23	448	160	163	125	25	0	3
6	11	449	142	197	110	22	0	2
7	19	442	131	211	100	20	0	2
8	22	448	163	154	130	26	0	3
9	26	445	142	189	115	23	0	5
10	1	206	103	22	80	16	1	1
11	1	206	103	22	80	16	1	1
12	1	199	103	15	80	16	1	1
13	1	199	103	15	80	16	1	1
14	1	281	103	98	80	16	1	1
15	1	281	103	98	80	16	1	1
16	19	447	177	135	135	27	0	2
17	15	449	161	163	125	25	0	3
18	22	443	157	161	125	25	0	4
19	19	417	176	101	140	28	0	3
20	21	444	158	166	120	24	0	2
21	18	447	172	141	135	27	0	3
22	15	380	162	87	130	26	0	3
23	9	442	129	207	105	21	0	3
24	22	447	162	154	130	26	0	2
25	21	411	180	91	140	28	0	3
26	20	437	163	144	130	26	0	2
27	11	443	125	218	100	20	0	2
28	21	445	152	173	120	24	0	4
29	7	448	83	300	65	13	0	2
30	19	449	118	231	100	20	0	5
31	19	445	169	135	140	28	0	5
32	19	443	117	231	95	19	0	3
33	27	433	178	115	140	28	0	3
34	8	381	168	82	130	26	3	4
35	23	378	178	60	140	28	0	3
36	18	440	143	182	115	23	0	4
37	16	444	116	233	95	19	0	4
38	7	446	158	163	125	25	3	4
39	13	449	128	221	100	20	0	4
40	10	415	166	113	135	27	3	6
41	8	441	123	213	105	21	3	5
42	22	448	107	250	90	18	0	5
43	10	432	131	195	105	21	0	3
44	8	448	141	192	115	23	3	4
45	13	449	168	146	135	27	0	4
46	27	400	162	108	130	26	0	3
47	33	424	152	153	120	24	0	2
48	23	449	96	273	80	16	0	2
49	7	444	109	245	90	18	3	4
50	19	403	72	266	65	13	0	3
51	5	74	25	29	20	4	0	1
52	13	450	110	255	85	17	2	1
53	6	314	62	202	50	10	2	1
54	3	242	18	204	20	4	3	3

The proposed schedule is reported in Table 3, which, for each day, indicates the route followed by each truck. Trucks T1 and T2 are the ones with a capacity of 26 barrels, while truck T3 has a capacity of 28 barrels.

Table 3
Solution of Instance I

Day	Route	Truck		
		T1	T2	T3
1	1			1
	2	1		
2	3	1		
	4			1
3	5	1		
	6		1	
4	7	1		
	8		1	
5	9	1		
	10		1	
6	11	1		
	12		1	
7	13	1		
	14		1	
8	15	1		
	16			1
9	17	1		
	18		1	
10	19			1
	20	1		
11	21			1
	22	1		
12	23	1		
	24		1	
13	25			1
	26	1		
14	27	1		
	28		1	
15	29	1		
	30		1	
16	31			1
	32	1		
17	33	1		
	34		1	
18	35	1		
	36		1	
19	37	1		
	38		1	
20	39	1		
	40			1
21	41	1		
	42		1	
22	43	1		
	44		1	
23	45			1
	46	1		
24	47	1		
	48		1	
25	49	1		
	50		1	
26	51	1		
	52		1	
27	53	1		
	54		1	

4.2. Instance II

In Instance II, some simplifications had to be made due to the relation between the monthly demands and the storage capacities of the facilities. There are facilities that have a storage capacity smaller than its product consumption in a month and, therefore, have to be visited more than once during a month. It is assumed that the facilities requiring more than one visit in the month will be visited fortnightly. Thus, two sets that constitute two different instances of the same problem are formed. One set includes only the facilities that require a reinforcement visit in the middle of the month, i.e., a “reinforcement” schedule. The other one is constituted by all the facilities, i.e., it is the “complete” schedule. For the facilities that belong to both sets, their monthly demand is divided to be expressed in a biweekly basis. With this strategy the problem can be conceived as being two separated problems. For the complete instance, the 702 facilities are reduced to 234 clusters in the first stage and, finally, 34 routes are built. Seventeen chemical products from the four system codes are demanded. The description of the different measured times and the demand products is presented in Table 4 while the schedule for each truck along the planning horizon is outlined in Table 5.

Table 4
Description of routes in solution of Instance II: complete schedule

Route	Number of	Total time (min)	Service time	Transport time	Loading time	Demand in barrels	System Code	Number of
1	1	445	133	213	100	20	0	1
2	11	447	136	195	115	23	0	4
3	9	447	166	151	130	26	0	3
4	17	447	149	178	120	24	0	4
5	8	448	146	177	125	25	0	6
6	0	421	145	166	110	22	1	1
7	8	448	145	183	120	24	0	3
8	0	433	132	201	100	20	1	1
9	13	450	160	165	125	25	0	3
10	6	449	119	235	95	19	0	4
11	20	442	180	122	140	28	0	5
12	6	406	164	111	130	26	0	5
13	4	450	108	252	90	18	0	5
14	11	449	136	202	110	22	0	3
15	12	446	141	190	115	23	0	3
16	0	398	174	84	140	28	3	4
17	5	444	154	165	125	25	0	5
18	13	441	152	165	125	25	0	4
19	3	446	95	271	80	16	0	3
20	15	412	180	93	140	28	0	4
21	17	449	161	158	130	26	0	3
22	0	446	78	309	60	12	0	2
23	10	449	138	201	110	22	0	4
24	0	440	121	219	100	20	3	4
25	0	441	112	235	95	19	0	4
26	0	446	109	247	90	18	3	4
27	15	449	114	240	95	19	0	4
28	16	435	131	204	100	20	0	1
29	0	294	52	202	40	8	0	1
30	11	410	164	111	135	27	0	5
31	0	436	134	192	110	22	3	4
32	0	450	97	273	80	16	0	3
33	6	259	39	185	35	7	0	4
34	2	284	26	238	20	4	0	1

Table 5
Solution of Instance II: complete schedule

Day	Route	Truck		
		T1	T2	T3
1	1	1		
	2	1		
2	3	1		
	4		1	
3	5	1		
	6		1	
4	7	1		
	8		1	
5	9	1		
	10		1	
6	11			1
	12		1	
7	13	1		
	14		1	
8	15	1		
	16			1
9	17	1		
	18		1	
10	19	1		
	20		1	
11	21	1		
	22		1	
12	23	1		
	24		1	
13	25	1		
	26		1	
14	27	1		
	28		1	
15	29	1		
	30			1
16	31	1		
	32		1	
17	33	1		
	34		1	

In the reinforcement instance, with an initial number of 35 facilities, 11 clusters and 6 routes are constructed. These routes demanded ten chemical products from the four system codes. The description of the routes is presented in Table 6 while the schedule for the trucks is in Table 7.

Table 6
Description of routes in solution of Instance II: reinforcement schedule

Route	Number of	Total time (min)	Service time	Transport time	Loading time	Demand in barrels	System Code	Number of
1	9	444	158	166	120	24	1	2
2	4	377	96	206	75	15	1	2
3	8	422	114	213	95	19	3	5
4	2	291	49	202	40	8	3	3
5	5	318	41	242	35	7	2	2
6	7	292	41	211	40	8	0	4

Table 7
Solution of Instance II: reinforcement schedule.

Day	Route	Truck		
		T1	T2	T3
1	1	1		
	2		1	
2	3	1		
	4		1	
3	5	1		
	6		1	

5. Conclusion and further research

The upstream transport logistics in oil industries that operate inland has not yet been thoroughly studied. This paper addressed such a problem in a company with a particular distribution planning problem where the sites to be supplied vary due to operational conditions. This case has presented specific technical and labor constraints, e.g., products that cannot be transported jointly in the same trip and a limited fleet and number of drivers. This article proposes a novel mixed-integer programming formulation for this problem. Moreover, a constructive heuristic to solve this problem is devised. Real-world instances provided by the company including up to 700 facilities (demand points) were solved. The proposed heuristic allows the automatization of the decision-making process reducing the time required to build a feasible plan. As a lateral consequence, the geo-localization of the bases was useful for the company to improve the estimation of the travel time of the routes. Main lines for future work include trying to improve the solution strategy with the inclusion of more powerful mataheuristics, as for instance, simulating annealing. This algorithm can start from the proposed solution and improve it. However, to achieve this the input information should be enhanced since the improvements should exhibit a larger sensitivity than the one that is currently obtainable with the formula for travel times developed by the company.

Therefore, designing better procedures to help the company obtain more precise information also constitutes a major line for future work. These procedures can include, in a first stage, the digital mapping of the network of paths between the different bases in order to have more precise knowledge of the distances between them, improving the formula of travel time estimation. The same procedure, applied to the facilities (and the roads connecting them to the bases) is far from being feasible for Small and Medium Enterprises like the target company in this work. The reason is the continuous variation of the locations of the extensive network of oil wells and internal paths due to operational reasons. Thus, digitalization would require a large investment in Information and Communication Technologies and/or of personnel that has to be to this task.

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