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A hierarchical approach for designing the downstream segment for a supply chain of petroleum production systems

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Abstract

Strategic decisions in a supply chain are the most important decisions for petroleum production systems. These decisions, due to high costs of transportation and storing, are costly and affected by the tactical and operational decisions in uncertain situations. In this article, we focus on designing a downstream segment for a supply chain of petroleum production systems. For this purpose, we will propose a two-stage approach considering a hierarchical structure, including the mathematical optimization model for determining strategic decisions in a leader problem and a simulation model for determining tactical and operational decisions in a follower problem. In the first stage, strategic decisions are made by solving a new mathematical model to obtain the location of depots and their capacities, transportation facilities, the volume of annual production, annual flow from refinery to depots and from depots to markets regions. In the second stage, we face some queuing systems where we aim to determine the number of loading and unloading platforms and order volume. Finally, the proposed model is applied in a real-world problem. The results show the suitable performance of the proposed model.

Keywords: supply chain, petroleum production systems, simulation-based optimization.

1-Introduction

Strategic decisions play significant role in petroleum supply chains. In such industry, the transportation and installation costs are serious challenges for managers. Hence appropriate strategic decisions reduce the costs of production systems considerably. It is noted that due to dependency and correlation among strategic decisions, these decisions must be made, simultaneously. The aim of this study is to design a hierarchical approach (mathematical model and simulation-based optimization) for a supply chain of petroleum production systems. We focus on a downstream segment of the supply chain network. This segment encompasses refinery, refining processes, products transformation from refinery to depots and from depots to the markets. Particularly, our approach is a two stages method where the major decisions of the network are designed in the first stage and then the remaining decisions are made in the second stage. We create interaction between parameters of mathematical model and simulation models.

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The units of measurement in the mathematical and simulation models are barrel per year and barrel per day, respectively. One of the main assumptions, which are close to real situations, is the existence of demand uncertainty. We also assume that pipelines are multi-product type. The other assumptions will be explained in the next sections.

2-Literature review

Sear (1993) is one of the first researchers who introduced petroleum supply chain. He presented qualitative and quantitative models. He classified the products according to their volume of demand. The objective of his study was to minimize the total costs. Escudero, Quintana, and Salmeron (1999) suggested stochastic model under demand uncertainty. They considered crude oil supply, transportation, and distribution network. Dempster et al. (2000) extended previous model to a multi-stage structure. They concluded that, in the case of uncertain demand, the multi-stage model could motivate previous models. Neiro and Pinto (2004) suggested a model for a sub system in a petroleum supply chain, including the oil field infrastructure, crude oil supply, refinery operations, and transportation.

In uncertain situations for supply chains, sajadifar and pourghannad (2011) proposed an integrated two-supplier supply chain whose suppliers are unreliable. In this study, an unreliable supplier alternates between available and unavailable states which are considered to be independent exponential variables. Some works are studied regarded to the scheduling concepts in supply chain networks (Nikandish, Eshghi and Torabi, 2009). Also, Ghassemi-Tari and Olfat (2009) has been modeled the problem of determining the best schedule for a set of projects in the form of a generalized tardiness flow shop problems (GTF). In their paper, a set of heuristic algorithms for minimizing the total tardiness of jobs in a GTF problem are studied.

Kim et al. (2008) integrated production planning of a multi-site refinery and a distribution network. They integrated a nonlinear model for production planning and a mixed integer nonlinear model for distribution network. These two models constituted an integrated model to respond to demand fluctuates. Pitty et al. (2008) also suggested a dynamic model for a petroleum supply chain. They took into consideration different aspects of a supply chain such as procurement planning, scheduling and operations management. They developed a simulation based optimization model and used genetic algorithm as optimization module. Mir hassani and Noori(2011)presented a stochastic model for distribution network in oil industry under demand uncertainty. They developed a two stage multi period model for capacity expansion problem of distribution network.

Aggregation of simulation and optimization techniques is applied for many times in the literature. Kabirian (2009) proposed a hybrid probabilistic search method for simulation optimization. He introduced an algorithm that merged ranking and selection procedures with a large class of random search method for continuous simulation – optimization problems.

In the present article, we aim to develop a hierarchical framework in order to design the downstream segment for a supply chain of petroleum systems. In the first stage, strategic decisions are made by solving a new mathematical model where these strategic decisions are location of depots and their capacities, transportation facilities, the volume of annual production, annual flow from refinery to depots and from depots to markets regions. In the second stage, where we aim to determine the number of loading and unloading platforms and order volume, we face some queuing systems.

3-Problem description

The refinery operations begin by entering the crude oil to Crude Distillation Unit (CDU). After crude oil processes and performs some operations, the produced products with pre-specified percentages, are transferred to the next units. In fact, the refineries' functions are similar to multi-stage networks, which the output stream of preceding units becomes input of subsequent units. This procedure continues until final products are loaded. The first stage of transportation is transferring products to depots by pipelines, trucks or railways. Then according to the distances between markets, the products are distributed by oil trucks or railway tanks.

Attention to this segment of supply chain is very important, (Cafaro, and Cerda, 2008a, and Cafaro, and Cerda, 2008b).
To transport products from refineries to markets, we consider five types of products: Gasoline, Kerosene, Regular petrol, Super petrol, and Fuel oil. In a real world, these products are the only products which are stored in depots, (Cafaro and Cerda, 2004).

In this study, different transportation modes from refinery to depots are considered. The decision variables are: transportation mode and its capacity, number of trucks for each depot, location of depots, and volume of products assigned to depots or markets, the volume of production, the number of loading and unloading platforms in depots and so on.

4-Conceptual model

In our approach, some of the mathematical model parameters' such as capacities, demands and etc. are computed based on the both uncertain and certain daily parameters and operational constraints. For instance, it is assumed that the daily demand follows normal distribution. The mean of the distribution is multiplied with 365 (days) and fed to the model as a parameter. The probability distribution function itself is used in simulation model.

We present a mathematical optimization model for refinery production planning and strategic decisions of distribution network in the leader problem. These strategic decisions are location of depots and their capacities, transportation facilities, the volume of annual production, annual flow from refinery to depots and from depots to markets regions. As mentioned earlier, the simulation model is built according to the outputs of the mathematical model and operational constraints (Figure 1). Since, there exist many operational constraints in practice, such as prioritizing products based on the product types and stochastic failure in trucks, the simulation method is applied to the follower problem. This model concentrates on distribution network to overcome all of these constraints.

From Figure 1, the outputs of the first section (i.e. mathematical modeling) are the number of loading and unloading platforms and the flow rate of stream from refinery to depots. At the end of this stage, by combining the results of the simulation model, we can reach the optimal structure of the distribution network. In this procedure, we tried to utilize the modeling tools in appropriate place with regard to their capabilities. In the adoption of strategic decisions in supply chain network, the mathematical models are superior tools than simulation models either in solution and CPU time. Also, form Figure 1, for the follower problem in the second stage, where we aim to determine the number of loading and unloading platforms and order volume, we face some queuing systems. Since these queuing systems are complicated and have many stochastic parameters, the simulation models, which are powerful tools to analyze these systems and to find the number of servers, are employed.

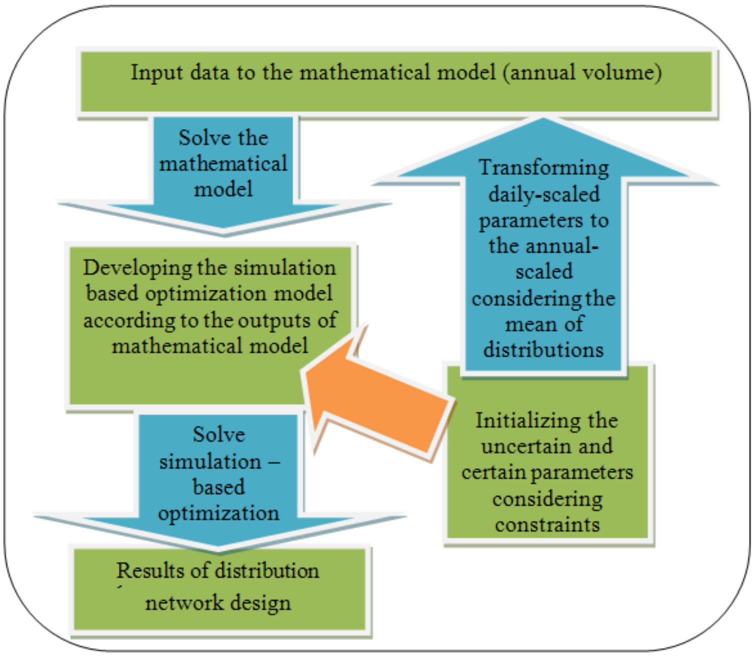

Figure. 1. Conceptual model

4-1-Mathematical formulation

We develop a mixed integer linear program to integrate production planning for refinery and strategic decisions for distribution network design. Concurrent deciding on the strategic decisions like location and capacity of oil depots, transportation facilities and their capacities, is remarkable property of this model. These decision variables are inserted in the model together because of dependency between these variables. Any independent decisions for these variables will increase costs and decrease efficiency of distribution network.

4-1-1- The model's parameters and variables

Indices

u, u'	Unit
i	Stream number
r	Transportation mode
d	depot
m	market
s	Capacity of depot tank
q	Capacity of pipeline

Sets

U_u	All units
UR_u	All operating units
P_u	All products
I	Number of streams
PD_u	Products transported to depots and markets
PM_u	Products not transported to depots and markets

R	Transportation modes
D	Depots
DA_m	All markets
D_m	Markets feed from depots
UD_m	Markets feed directly from refinery
S	Candidate capacities for tanks in depot
Q	Candidate capacities for pipelines

Parameters

$s_{u,u',i}$	Binary parameters, 1 if stream number *i* goes from unit *u* to unit *u'* $u,u' \in U_{\mathrm{u}}$
$Pe_{u,u',i}$	Binary parameters, 1 if percentage flow rate of stream number *I* goes from unit u to unit *u'* $u,u' \in U_{\mathrm{u}}$
A_u	Upper bound for input flow rate for unit *u* (bbl/year) $u \in UR_{\mathrm{u}}$
B_u	Lower bound for input flow rate for unit *u* (bbl/year) $u \in UR_{\mathrm{u}}$
De_u	Demand for product u $u \in PM_u$
VW_d	Capacity of products transported to depot *d* by a truck (bbl/year)
VT_d	Capacity of products transported to depot *d* by a multiproduct train (bbl/year)
$VP_{d,q}$	Capacity of products transported to depot *d* by a multiproduct pipeline with capacity *q* (bbl/year)
$VD_{d,s,u}$	The capacity of tank*s* for product *u* in depot *d* (bbl/year)
$VWM_{d,m}$	The capacity of products transfer by a tank from depot *d* to the market *m*(bbl/year)
NW_d	Upper bound for the number of trucks transporting products to the depot *d*
NT_d	Upper bound for the number of multiproduct trains transporting products to the depot *d*
XCW_d	Variable cost for transforming products from refinery to the depot *d* by a tank (toman/bbl)
$XCP_{d,q}$	Variable cost for transforming products from refinery to the depot *d* by a pipeline with capacity *q* (toman /year)
XCT_d	Unit variable of railway transportation cost from refinery to depot d (toman/year)
CW_d	Cost of renting or buying a truck to transfer products from refinery to the depot *d* (toman/year)
$CP_{d,q}$	Fixed establishment cost of multi product pipeline with capacity *q* to transfer products from refinery to depot *d*
CT_d	Cost of renting or buying a multiproduct train to transfer products from refinery to depot d
$Dem_{m,u}$	Demand for product *u* at the market *m* (bbl/year) $m \in DA_m$, $u \in PD_u$
$YC_{d,m}$	Transportation cost to transfer products from depot d to market *m* $m \in DA_m$

XCD_m	Transportation cost to transfer products from refinery to market m (toman/bbl) $m \in UD_m$ $m \in UD_m$
RC_u	Operating cost for unit *u* (toman/bbl) $u \in UR_u$ $u \in UR_u$
CBW_d	Fixed cost of using trucks to transfer products from refinery to depot d (toman)
CBT_d	Fixed cost of using railway to transfer products from refinery to depot d (toman)
C_d	Fixed establishment cost for depot *d*
CV_d	Variable cost for depot *d* (toman /year)
$F_{d,s}$	Variable cost of a tank with capacity *s* to transfer products from refinery to depot d (toman/bbl)
E_u	Penalty cost for extra production at refinery.

Continues variables

$X_{u,u',i}$	Amount of stream number *i* flows from unit *u* to unit *u'*
SI_u	Input flow rate to unit *u*
Y_u	Final volume of product *u* at the refinery
$ZW_{d,u}$	Volume of product *u* carrying by truck to depot *d*
$ZT_{d,u}$	Volume of product *u* carrying by railway to depot *d*
$ZP_{d,u,q}$	Volume of product *u* carrying by multiproduct pipeline with capacity to depot *d*
$YD_{d,m,u}$	Volume of product *u* delivered from depot d to market *m*
$YD_{m,u}$	Volume of product *u* delivered directly from refinery to market *m*

binary variables

N_d	Binary variable for establishment depot *d*
$N_{d,s,u}$	1, if tank *u* with capacity s is established in depot *d*. 0 o/w
BW_d	1, If a road transportation is chosen from refinery to depot *d*. 0 o/w
BT_d	1, If a railway transportation is chosen from refinery to depot *d*. 0 o/w
$P_{d,q}$	1, If a pipeline with capacity *q* is chosen from refinery to depot *d*. 0 o/w

Integer variables

W_d	Number of trucks between refinery and depot *d*
t_d	Number of multiproduct train between refinery and depot *d*
$WM_{d,m}$	Number of trucks between depot *d* and market *m*

$$minz = \Bigg[\sum_{d\in D}\sum_{u\in PD_u} XCW_d . ZW_{d,u} + \sum_{d\in D}\sum_{u\in PD_u} XCT_d . ZT_{d,u} + \sum_{d\in D}\sum_{u\in PD_u}\sum_{q\in Q} XCP_{d,q} . ZP_{d,u,q}$$
$$+ \sum_{d\in D} CW_d . W_d + \sum_{d\in D} CT_d . T_d + \sum_{d\in D} \mathrm{CBW_d} . BW_d + \sum_{d\in D} \mathrm{CBT_d} . BT_d$$
$$+ \sum_{d\in D}\sum_{q\in Q} CP_{d,q} . P_{d,q}\Bigg]$$
$$+ \Bigg[\sum_{d\in D}\sum_{m\in UD_m}\sum_{u\in PD_u} YC_{d,m} . YD_{d,m,u} + \sum_{d\in D}\sum_{m\in UD_m} CW_d . WM_{d,m}$$
$$+ \sum_{m\in D_m}\sum_{u\in PD_u} XCD_m . YD_{m,u}\Bigg]$$
$$+ \Bigg[\sum_{d\in D} C_d . \mathrm{N_d} + \sum_{d\in D}\sum_{s\in S}\sum_{u\in PD_u} \mathrm{F_{d,s}} . VD_{d,s,u} . N_{d,s,u}$$
$$+ \sum_{d\in D}\sum_{u\in PD_u}\sum_{q\in Q} \mathrm{CV_d} . (ZW_{d,u} + ZT_{d,u} + ZP_{d,u,q})\Bigg]$$
$$+ \Bigg[\sum_{u\in UR_u} RC_u . SI_u + \sum_{u\in PM_u} E_u . (Y_u - De_u)$$
$$+ \sum_{u\in PD_u}\sum_{m\in DA_m} E_u . (Y_u - Dem_{m,u})\Bigg] \quad (1)$$

$$Pe_{u,u',i} . SI_u = s_{u,u',i} . X_{u,u',i} \qquad u \in UR_u \quad , u' \in U_u , \mathrm{i} \in \mathrm{I} \quad (2)$$

$$SI_u \geq A_u \qquad u \in UR_u \quad (3)$$

$$SI_u \leq B_u \qquad u \in UR_u \quad (4)$$

$$SI_{u'} = \sum_{i\in I}\sum_{u\in UR_u} X_{u,u',i} . s_{u,u',i} \qquad u' \in UR_u \quad (5)$$

$$Y_{u'} = \sum_{i\in I}\sum_{u\in UR_u} s_{u,u',i} . X_{u,u',i} \qquad u' \in P_u \quad (6)$$

$$Y_u \geq De_u \qquad u \in PM_u \quad (7)$$

$$ZW_{d,u} + ZT_{d,u} + \sum_{q\in Q} ZP_{d,u,q} \leq \sum_{s\in S} VD_{d,s,u} . N_{d,s,u} \qquad d \in D, u \in PD_u \quad (8)$$

$$BW_d + BT_d + \sum_{q\in Q} P_{d,q} = N_d \qquad d \in D \quad (9)$$

$$\sum_{u\in PD_u} ZW_{d,u} \leq W_d . VW_d \qquad d \in D \quad (10)$$

$$\sum_{u\in PD_u} ZT_{d,u} \leq T_d . VT_d \qquad d \in D \quad (11)$$

$$\sum_{u\in PD_u}\sum_{q\in Q} ZP_{d,u,q} \leq \sum_{q\in Q} P_{d,q} . VP_{d,q} \qquad \mathrm{d} \in \mathrm{D} \quad (12)$$

$$\sum_{d\in D} YD_{d,m,u} \geq Dem_{m,u} \qquad m \in D_m \quad , u \in PD_u \quad (13)$$

(14)

(15)

(16)

$$\sum_{m\in UD_m} YD_{m,u} + \sum_{d\in D} ZW_{d,u} + \sum_{d\in D} ZT_{d,u} + \sum_{d\in D}\sum_{q\in Q} ZP_{d,u,q} = Y_u \qquad u \in PD_u \qquad (14)$$

$$\sum_{s\in S} N_{d,s,u} \leq N_d \qquad d \in D, u \in PD_u \qquad (16)$$

$$ZW_{d,u} + ZT_{d,u} + \sum_{q\in Q} ZP_{d,u,q} \geq \sum_{m\in D_m} YD_{d,m,u} \qquad d \in D, u \in PD_u \qquad (17)$$

$$\sum_{u\in PD_u} YD_{d,m,u} \leq WM_{d,m}.VWM_{d,m} \qquad m \in D_m \quad, \mathrm{d} \in \mathrm{D} \qquad (18)$$

$$WM_{d,m} \leq NWM_{d,m}.N_d \qquad m \in D_m \quad, \mathrm{d} \in \mathrm{D} \qquad (19)$$

$$W_d \leq BW_d.NW_d \qquad \mathrm{d} \in \mathrm{D} \qquad (20)$$

$$T_d \leq BT_d.NT_d \quad \mathrm{d} \in \mathrm{D} \qquad (21)$$

$$\sum_{q\in Q} P_{d,q} \leq N_d \qquad \mathrm{d} \in \mathrm{D} \qquad (22)$$

Continuos variables: $X_{u,u',i}$, SI_u , Y_u , $ZW_{d,u}$, $ZT_{d,u}$, $ZP_{d,u,q}$, $YD_{d,m,u}$, $YD_{m,u}$

Binary variables: N_d , $N_{d,s,u}$, BW_d , $P_{d,q}$

Integer variables: $P_{d,q}$, t_d , $WM_{d,m}$

The objective function is to minimize the total costs. The first bracket indicates transportation costs from refinery to depots. It includes variable and fixed cost for transportation and the costs of renting or buying transportation facilities. The second bracket denotes the transportation cost from depots to markets or from refinery to markets directly (the cost of renting trucks between depots and markets). The third bracket represents the depot-related costs including the initial fixed cost, variable costs, installation costs which expressed as a function of the capacity. The fourth bracket represents the refinery costs, which includes operations of a unit and surplus production.

The input stream to a unit will split into the subsequent units with pre-specified proportions. Set constraint (2) shows that the input stream to refinery should be greater or equal than minimum value. Set constraint (3) indicates that the input stream to each unit should not exceed its capacity. Set constraint (4) forces that the input stream to each unit in the refinery must be equal to the sum of output streams of its predecessor units. Set constraint (5) denotes that the total final product equals to sum of input streams to depots. Set constraint (6) shows that the demands should be satisfied. Set constraint (7) illustrates the capacity constraint, if a depot of a product is located in the distribution center. Set constraint (8) indicates that if a candidate location "*d*" is chosen, only one transportation mode will be assigned to it. We add this constraint to reduce the costs by preventing multi assignment of transportation facilities. Notice that, all transportation modes in petroleum industry are able to transfer different products. , (11) and (12) Set constraints (9) - (12) show the capacity constraints for trucks, railways, multi-product pipelines respectively which are assigned to depot "*d*". Set constraint (13) indicates that the flow rate from depots to market should satisfy demands. Set constraint (14) is the balance constraint at refinery between the volume of production and transferring to depots and markets. In the petroleum industry, the surplus production is stored in depots. One reason is, the inventory cost at refinery is considerable. On the other hand, the location and capacity decisions for depots are considered together; hence, any change in these decisions will impose cost. Therefore, it is better to convey surplus production to depots. Set constraint (15) shows that at most one value for capacity can be selected for each depot. Set constraint (16) shows that the input stream to depots should be greater or equal than the output stream. Set constraint (17) shows the capacity constraint of trucks which transport products from depot "*d*" to market "*m*". Set constraint (18) shows the maximum number of trucks between depot and market. Set constraint (19) shows the maximum number of trucks between refinery and depot. Set constraint (20) shows the maximum number of multiproduct train between refinery and depot. Set constraint (21) shows the capacity constraint of the pipelines.

4-2-Simulation model

The mathematical model in the previous section specifies the general structure of distribution network design and some additional details. Two of the important variables are the number of loading and unloading platforms in depots and the volume of orders that are sent by refinery. The existence of loading platforms in depots is deterministic factor because according to the assumptions, the trucks are the only available transportation mode between depots and markets. We assume the platforms function as either loading or unloading terminals.

In this study, the simulation model is built from two major sub-models. The first sub-model affiliates to demand satisfaction and product transfer to the markets. The second one covers depots and product transfer from refinery to depots. In the following sections, we will discuss in more details.

4-2-1-The first sub-model: Products transfer from depots to markets

On the first day, market demand is sent to the depots by a short delay (uncertain time). The sent information of demand encompasses the type and volume of the product and market location. The demand is considered stochastic. At this point, the mathematical model has characterized the markets assignment to depots. In the case of multi assignments, the demand is met by a depot with a shorter queue. The depots ask for trucks to convey product to markets according to demands volume and trucks capacity. Then, the trucks will join queues for loading. The required time for loading is uncertain. After loading, the trucks will be dispatched to markets. After unloading (uncertain time), the trucks will return to depots for the next service. In some cases, the trucks may encounter failure or mandatory stop. Meantime, any delay more than 24 hours will be penalized.

4-2-2-The second sub-model: products transfer from refinery to depots

The second model pertains to products transfer from refinery to depots. Whenever the level of the product drops under 0.3 of the tanks capacity, the depot send orders to refinery. According to the orders, the refinery allocates trucks to paths. Then the trucks wait for loading. They move with uncertain speed and moreover any probabilistic failure or mandatory stop may occur. After unloading (uncertain time) in depots, trucks return to refinery for new services. We build a model for each depot separately; hence we will have as many depots as the mathematical sub-models.

4-3-The optimization based simulation

We employ this model to find out the optimal value of the variables for the simulation model. These variables are the number of loading and unloading platforms, locations of depots and volume of depots order. It is noted that, some of the variables in mathematical model becomes input parameters in following simulation model.

$$min z = \sum_{\mathrm{d}\in \mathrm{I}} DP_{\mathrm{d}}.\mathrm{CDP}_{\mathrm{d}} + \sum_{u\in PD_u} (B_{\mathrm{u}} + \mathrm{WB}_{\mathrm{u}}).\mathrm{CB}_{\mathrm{u}} \quad (22)$$

$$1 \le DP_{\mathrm{d}} \le \sum_{m\in D_m} WM_{d,m} + W_d \qquad d \in I \quad (23)$$

$$\left[\frac{N}{VD_{d,s,u}.N_{d,s,u}} + 0.3\right] \le QP_{d,u} \le 1 \qquad d \in I\ ,s \in S, u \in PD_u \quad (24)$$

1) The objective is to minimize the costs. The first expression is the installation fixed cost of loading platform and the second one is the cost of unfulfilled orders (including those that has or has not received the trucks)

2) The number of loading platform in depot should not exceed the number of trucks.

3) In depots, the volume of orders is proportional to difference between the capacity of tanks and current oil level in tanks. Only the orders, more than tank capacity are accepted.

Sets

PD_u	Products transported to depots and markets
S	Candidate capacity of tank in depot
I	Selected depots
D_m	Markets feed from depots

Parameters

$\mathrm{CDP_d}$	unit establishment cost of loading and unloading platform in depot d
$\mathrm{CB_u}$	Unit penalty cost of unfulfilled demand of product u (toman/bbl)
N	Capacity of a truck
$N_{d,s,u}$	If tank u with capacity s is chosen for depot d
$VD_{d,s,u}$	Capacity s of product tank u in depot d (bbl/year)
$WM_{d,m}$	Number of selected trucks from depot d to market m
W_d	Number of selected trucks from refinery to depot d

Variables

B_u	Volume of product *u*, not loaded with truck until end day (bbl/year)
$\mathrm{WB_u}$	Volume of product *u* loaded with truck but not delivered to market (bbl/year)
$QP_{d,u}$	Percentage tank's capacity for product *u* in depot *d*
DP_d	Integer variable for number of unloading and loading platform in depot *d*

5-Case study description

As the case study, we consider Shiraz refinery in Iran. This refinery has 12 operating units and is producing 12 products. In oil industries, ordinary gasoline, super gasoline, petroleum gas, white oil, and furnace petroleum are the main products which are either stored in depots or directly transported to the adjacent markets by tank trucks. Only these 5major products are considered in this example. There are five candidate locations for depots with different capacities for tanks and different fixed costs. We ignore the internal market structure (a market is massive cluster of oil stations) and direct assignment of markets to the refinery. We discuss three transportation modes from refinery to depots: multiproduct pipeline, multiproduct tank rail and tank trucks. The refinery data are real data from Shiraz refinery in Iran (Farahibilavi, 2010).

6- Computational results

The mathematical model described in section 2.1.1was implemented in a mathematical software in order to optimize strategic decisions variables of the model. The main input parameters for the mathematical model are described in Table 1and Table 2. The results which are found are displayed briefly in Figure 2.

Table 1. Amount of demand for main products

Product / Market	Regular gasoline	Super Gasoline	Kerosene	Fuel oil	Gas oil
1	4367600	2269350	6051000	1416650	4873950
2	130000	120000	110000	310000	569700
3	110000	50000	320000	90000	230000
4	450000	180000	90000	370000	510000
5	200000	90000	130000	180000	270000
6	590000	250000	80000	470000	840000
7	380000	130000	91000	120000	570000
8	290000	90000	140000	270000	610000
9	4267600	2216350	6091000	1366650	4693950

Table 2. Transportation cost for transportation from depots to markets

Market / Depot	2	3	4	5	6	7	8
1	7380	8856	14760	11808	29520	44280	41328
2	10332	14760	7380	5904	17712	29520	41328
3	17712	14760	29520	7380	14760	22140	17712
4	26568	29520	14760	4428	7380	14760	11808
5	29520	26900	22140	11808	7380	7380	14760

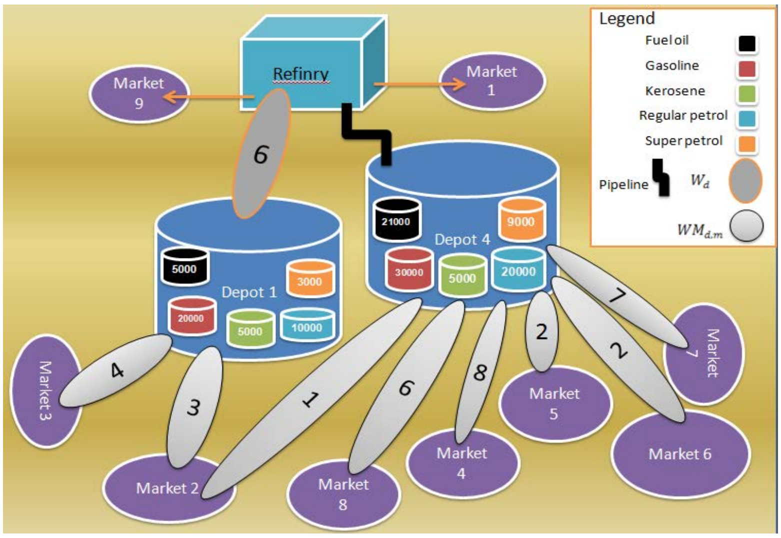

Figure 2. Products transfer from depots to markets

By solving the proposed mathematical model, the following results are achieved. From Table 3, number of required trucks between each market and each depot is shown. For example, number of required trucks from market 2 to depot 1 is four and number of used tracks from market 2 to depot 4 is one. In addition, market 4 supplies its demand only from depot 4 by using eight trucks. In Table 4 amount of capacity for each depot for each product is computed. In Table 5 amount of transported products form refinery is illustrated.

Table 3. Number of required trucks

Market \ Depot	1	4
2	4	1
3	3	
4		8
5		2
6		2
7		7
8		6

Table 4. Amount of capacity for each depot for each product

Depot	Product	Capacity
1	Fuel oil	5000
	Gas oil	20000
	Kerosene	5000
	Regular gasoline	10000
	Super Gasoline	30000
4	Fuel oil	21000
	Gas oil	30000
	Kerosene	5000
	Regular gasoline	20000
	Super Gasoline	9000

Table 5. Amount of transported products form refinery

Amount of product \ Depot	1	4
Regular gasoline	9342500	3353355
Super Gasoline	4788700	2332555
Kerosene	121435555	665555
Gas oil	2255255	2332555
Fuel oil	335555	3353355

6-1-The simulation model of example

In this section, we build simulation model according to the mathematical model outputs. As it can be found from figure 2, depots 1 and 4, 6 trucks and a multiproduct pipeline were selected. The tanks' capacity for each product is shown in depots. The Figure 3 displays simulation features of the products transferred to the markets.

We assume that the demands are received at the beginning of each day (24 hours) and follow uniform distribution. We allocate a unique property (name) to each demand, which encompasses information about type, volume, and demand origin. The products are transported to the depots with delay, which has uniform distribution from 1 to 30 minutes. When we assign a demand to both depots, it would be supplied by depot with shorter queue. To transfer them, the orders are divided into 125 barrels batches. The available trucks join queue, if any, for loading. The loading and unloading times in platforms follow uniform distribution from 25 to 35 and 20 to 40 min, respectively. The trucks travel with uniformly distributed speed from 50 to 70 km/h.

One of noticeable events in the problem is trucks failure (inactivity). We assume that the interval time between failures is exponential with mean 30 days and fixing time is uniformly distributed from 60 to 90 min. In addition, to have more accurate results, we take into account the unfulfilled demands at the end of days, either those are in queues or in ways.

The second model of the simulation, which belongs to transportation segment from refinery to depots, includes two models. The first model pertains to depot 1, which has been selected in mathematical model (Figure 4). The simulation model makes an entity (truck) for each tank. It waits until the level of products drops under 0.3 of tank capacity, then allocates product (equal to difference between full capacity and current level) through free entities. The cargoes are divided into 125 barrels batches. This procedure continues until reaching depots. The trucks stand in the queue in front of the tanks in depots for unloading. Finally, the entities will return to the first place. This loop repeats until the level of products drops under 0.3 of tank capacity.

The second model of the simulation process belongs to the depot 4. All stages are similar to the first model except, the transportation mode which is the multiproduct pipeline. The capacity of the pipelines and daily transfer volume can be two constraints in this model.

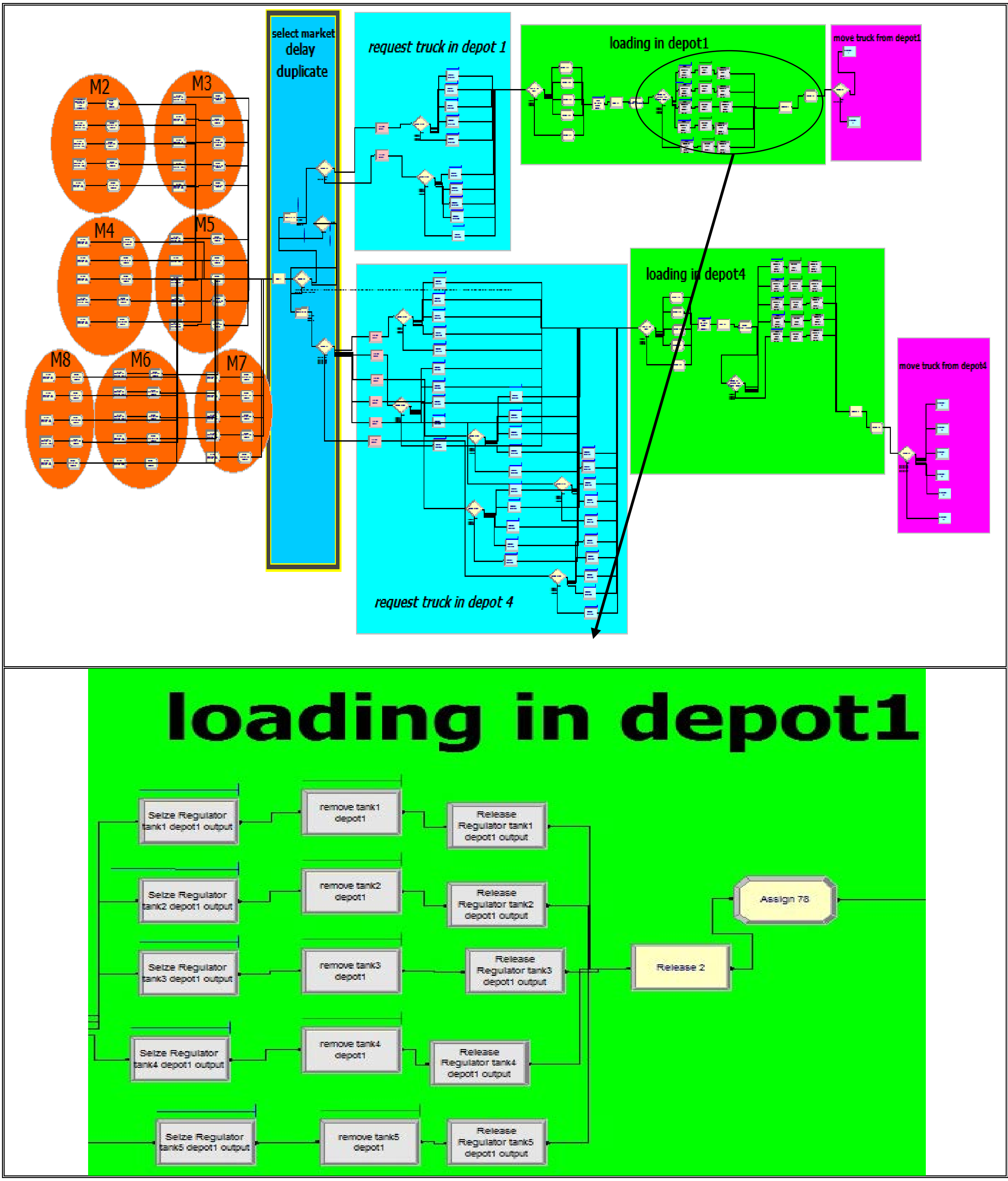

Figure 3. Example of simulation approach

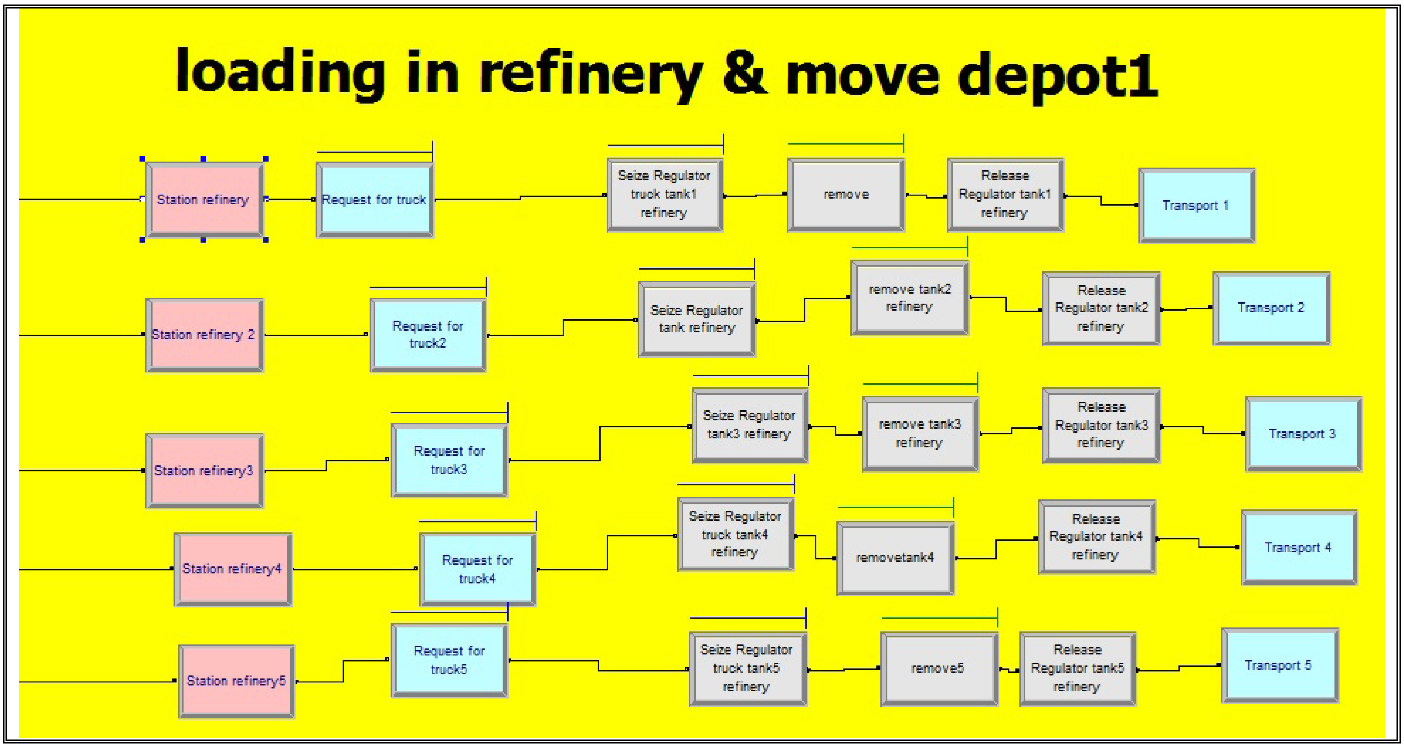

Figure 4. Sample of diagram for Products transfer from refinery to depot 1

6.2. Running optimization package during simulation process (inputs)

We implement the optimization model for 365 days (one year) with five replications. In the following the input data including fixed costs for platforms (Table 6 and the costs associated with unsatisfied demand (Table 7) are described.

Table 6. Fixed costs for platforms

Type of platform	Fixed costs
Dual purposes for loading and unloading	300000000
Single purpose for loading	200000000

Table 7.The costs associated with unsatisfied demand

Type of product	Cost
Regular gasoline	395000
Super Gasoline	495000
Kerosene	75000
Fuel oil	39500
Gas oil	75000

6-3- The optimization model results

The optimization model (section 4.3) was solvedand tables 6 indicate the number of platforms in depots and percentage of orders, respectively. Weuse Tabu search and Scatter search algorithms to find an optimal solution. After 160 runs with 5 replications, the results converge to stable solutions which are presented in Table8 (number of selected platforms) and Table 9 (Percent order for each product from each depot).

Table 8. Number of selected platforms

Depot	Number of platforms
1	12
4	7

Table 9. Percent order for each product from each depot

Product type	Percent order from depot 1	Percent order from depot 4
Regular gasoline	0.996	0.551
Super Gasoline	0.807	0.888
Kerosene	0.939	0.748
Fuel oil	0.742	0.565
Gas oil	0.351	0.357

6-4- Validation of mathematical and simulation models

In the previous sections, we designed comprehensive plan of a network. This plan integrated the mathematical and simulation models results. Now, to verify the solutions and strategic decisions, we enter the simulation model outputs to simulator again, and run it for 365 days. Then, we calculate the costs (Table 10) and trucks efficiency (Table 11). These values indicate whether the number of trucks is optimal and they are busy most of the times. The reasons that we choose these parameters as a criterion are that they are good representatives of the mathematical and simulation models outputs.

Table 10. Final costs for simulation process

Type of cost	Amount of cost
The costs associated with unsatisfied demands	55010000
The costs for establishing platforms	5000000000

Table 11.Truck utilization

Market \ Depot	1	4
2	0.7	0.92
3	0.79	
4		0.85
5		0.84
6		0.82
9		0.82
7		0.79
8		0.84

8-Conclusion

In this paper, we developed a hierarchical approach in order to design the downstream segment for a supply chain of petroleum system. In the first stage, strategic decisions were made by solving a new mathematical model where these strategic decisions were location of depots and their capacities, transportation facilities, the volume of annual production, annual flow from refinery to depots and from depots to markets regions. In the second stage, where we aimed to determine the number of loading and unloading platforms and order volume, we faced some queuing systems.

The simulation model was built according to the outputs of the mathematical model and operational constraints. Since, there exist many operational constraints in practice, such as prioritizing products based on the product types and stochastic failure in trucks, the simulation was applied in the follower problem. This model concentrated on distribution network to overcome all of these constraints. The outputs of this section were the number of loading and unloading platforms and the flow rate of stream from refinery to depots. At the end of this stage, by combining the results of the simulation model, we could reach the optimal structure of the distribution network.

Also, for future directions the following suggestions are suitable areas:

- Considering multiple refineries in the network and evaluating collaboration between them,
- Developing the proposed model under robust optimization framework,
- Applying time series in order to forecast demands for products,
- Comparing different loading platforms in the simulation model,
- Applying design of experiments in the simulation in order to indicate the most important parameters.

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