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Optimal Investment Decisions in Oil Industry*

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Abstract

As part of larger research that deals with modeling different aspects concerning the oil and gas industry, this paper explores the possibilities of building operational models for optimal decisions in the oil industry with the aid of mathematical programming, aiming at the analysis of investment efficiency in the oil and gas industry. Hence, in the beginning, a special focus was placed on revealing for a group of oil fields some applications that may help us determine the contribution of each field to the overall flow of the group, so that the cost price of the oil produced by new wells in one stage is minimal. At the end of the first part of the paper, by solving the system consisting of the equations, the inequalities, and the efficiency function earlier introduced, successively in stages, led us to the distribution of the planned global production on the various objectives prepared for exploitation. The second part of the paper was dedicated to some numerical examples in the case of oil fields. As such, the first model presented the problem of determining the optimal number of drilling holes on structures so as to ensure the well production plan with either minimal operating costs or minimal investments. Next, the second model aimed at determining the number of wells on each of the three structure considered, so that the investments are minimal. In the end we argued that this is just one of many examples of applying mathematical programming to optimal distribute investments in the oil extraction industry.

Keywords: oil and gas reserves, oil and gas wells, optimal decisions, operational models, investment efficiency.

Introduction. Literature Review

Sustained development of production and the increase of its economic efficiency involves as a necessity the rational use and exploitation of material resources and energy [Hartwick and Olewiler, 1986; Home, 1979]. Therefore, increasing material and energy resource recovery is a major coordinate for economic growth and improvement in economic efficiency.

On the other hand, viewing the problem from another angle, economic sustainability is not just how to become wealthy as a nation or as individuals [Kula, 1994; Pearce and Turner, 1990]. Besides GDP, exchange rates, inflation, and profits are a part of this image, while economic sustainability is deeper involving production, distribution, and consumption of goods and services as well.

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This concept is addressed to the unavailability of exhaustible resources [Hotelling, 1931], to the global constraints on growth and strategies for implementing proper environmental costs of pollution or other negative impacts generated by the company as a whole. The exchange of goods and services has a significant negative impact on the environment, and this situation will not change as long as the environment serves both as the exclusive source of resources, and is the final destination of waste products.

Despite the fact that oil extraction is achieved in a closed system [Hussein, 2023; Kasukabe, 2023; Chen, 2025], which should enable it to avoid or, at least, substantially reduce all forms of pollution, the exploration and exploitation of oil deposits continue to be among the most polluting industrial activities [Bulearca and Popescu, 2014]. Oil, heavy oil, salt water, and various chemicals contamination of land around drilling and extraction oil-wells is, with all its incidentally character, extremely harmful to soil, surface water, and groundwater. In this respect, the severity of pollution will depend, of course, on the nature of the pollutant, its quantity, and why this pollution occurs.

Efficiency in global petroleum production has become an overriding issue of concern around the world due to harsh competition and the effects of global uncertainties such as the COVID-19 pandemic, sanctions on Iranian oil industry, the Russia–Ukraine war, and the US–China trade war. Needless to say, the oil industry is among the essential industries in the world today. It is the primary source of global energy supply and plays a significant role in long-run economic growth. According to the International Labor Organization (ILO), roughly 6 million people are employed directly, and over 50 million are indirectly employed in the oil industry [Hatami-Marbini *et al.*, 2022].

The industry invariably faces multiple challenges and uncertainties associated with crude oil production and refining petroleum product at the lowest possible cost to keep market competitiveness [Temizel *et al.*, 2019]. These uncertainties range from global demand, price volatility, increasing rise in a global pandemic, international cooperation, technological advantage, and increasing stagnant environmental controls. With this in mind, it is imperative to continuously measure the efficiency and productivity growth of petroleum production activities [Al-Mana, 2020]. Performance measurement brings the strength and vulnerabilities of a production system to the fore to ensure a wider and smarter system, encourage customer satisfaction, enhance internal and external relations, and direct the system objectively [Atris, 2020].

As a result, this paper will explore the possibilities of building up operational models for optimal decisions in the oil industry through mathematical programming aiming at the analysis of investment efficiency in oil and gas industry. Hence, the remaining part of this paper will largely address these topics.

Modeling problems in the petroleum industry. Mathematical programming applied to oil extraction

The constraints of mathematical modeling problems in the petroleum industry include the following elements:

- ✓ production expenses;
- ✓ qualitative technical conditions regarding the petroleum products;
- ✓ qualitative characteristics of the product, provided for in standards;
- ✓ material balance, etc.

The objective function is generally established by the cost price or profit, reported per unit of material or equipment used.

A model will be developed for a group of oil fields to determine the contribution of each field to the overall flow of the group, so that the cost price of the oil produced by new wells in one stage is minimal.

Let's consider a large geological unit, within which several objectives are prepared for exploitation. From the analyses it is estimated that I objectives could be exploited by water injection to maintain pressure in the reservoir, J with gas injection, and F without injection.

In a first calculation stage, it is assumed that from the known deposits, but not yet put into industrial exploitation, the production of a quantity of crude oil *P* must be ensured. The condition for satisfying the global production load from new wells, *P*, will be:

$$\sum_{i=1}^{I} X_i + \sum_{j-=1}^{J} Y_j + \sum_{f=1}^{F} Z_f = P \tag{1}$$

With respect to the types of drilling installations available at the considered stage, the achievable footage cannot exceed $\overline{M}, M^*$, M^{**}, respectively small, medium, and large depths. Grouping of the deposits, of the exploitation objectives according to the depths of the wells to correspond to the types of drilling installations, and taking into account the maximum permissible flow rates of fluids possible to extract and inject from a technical point of view, all allow the formulation of restrictive conditions regarding drilling availability:

$$\sum_{k=1}^{K} \left\{ \sum_{i=1}^{I'} H_{Ri} \left[\frac{1}{q'(1/f_a)} - + \frac{1+R_a}{\overline{q_a}} \right] (btx)_i + \sum_{j=1}^{J'} H_{ij} \left[\frac{1}{q^{**}(1/fg)} + \frac{1+Rg}{q_g} \right]_j (b_t J)_j + \sum_{f=1}^{F'} H_{Rf} (\frac{1}{qt})_f Zf \right\} \leq \overline{M} \tag{2}$$

$$\sum_{l+1}^{L} \left\{ \sum_{i=I'}^{I''} Hl_i \left[\frac{1}{q^*(1/fa)} + \frac{1+Ra}{\overline{q_a}} \right]_i * btx)_i + \sum_{j=J'}^{J''} Hl_j \left[\frac{1}{q^{**}(1-fg)} + \frac{1+Rg}{\overline{q_g}} \right]_j (btJ)_j + \sum_{f=F'}^{F''} Hlf \left[\frac{1}{q_t} \right]_f Zf \right\} \leq M^* \tag{3}$$

$$\sum_{m=1}^{M} \left\{ \sum_{i=I''}^{I} H_{mi} \left[\frac{1}{q^*(1-fa)} + \frac{1+Ra}{\overline{q_a}} \right]_i (btx)_i + \sum_{J=J''}^{J} H_{mj} \left[\frac{1}{q^{**}(1-fg)} + \frac{1+Ra}{\overline{q_g}} \right]_J (b_{tJ})_J + \sum_{f=F''}^{F} H_{mf} (\frac{1}{q_t})_f Zf \right\} \leq \overline{M^{**}} \tag{4}$$

In the event that, at the stage considered, the quantities of water and gas are limited, the following relationships are added to the restriction system:

$$\sum_{i=1}^{I} \left[(btx)(1+Ra) \right]_i \leq Q_a \tag{5}$$

$$\sum_{j=1}^{J} \left[(btj)(1+Rg) \right]_j \leq b_g Q_y \tag{6}$$

Among the exploitation objectives there may be some whose flow rates must be limited in order to achieve rational exploitation (the flow rates of hydrodynamic units must not exceed the values that ensure gravitational displacement, etc.):

$$Z \leq \pi \tag{7}$$

Regarding the configurations of the productive areas, the geological, and physical characteristics, limiting conditions can also be formulated regarding the distance between wells, respectively the maximum number of wells on a productive surface (the number of wells could be limited by the condition of obtaining at least a certain cumulative amount of crude oil on each well):

$$\left(\frac{1}{qt} \right)_i X_i \leq N_{si} \tag{8}$$

$$\left(\frac{1}{qt} \right)_j J_i \leq N_{sj} \tag{9}$$

$$\left(\frac{1}{qt}\right)_j Z_f \le N_{sf} \tag{10}$$

It is assumed that the efficiency function is expressed by the minimum cost conditions of the crude oil brought up to date and pumped to the oil parks.

Under these conditions, the objective function has the form:

$$\sum_{i=1}^{I}(btx)_i\{(c_{ex}+a_{ex}+v_{ex}+\Gamma)\}\frac{1}{q^*(1-f_a)}+(c_{dr}+c_{pt}+c_t\int_t+c_{er})+\left[(c_{ir}+a_{ir}+v_{ir}+\Gamma_{ci})*\frac{1}{\bar{q}_a}+*(C_{pa}+C_a)\right]$$
$$(1+Ra)-\bar{R}(P_{rg}-P_{cq})\ \}_i+\sum_{J=1}^{J}(btJ)_J\left\{(c_{ex}+a_{ex}+v_{ex}+\Gamma_c)\frac{1}{q^{**}(q-fq}+(C_{dr}+C_{pt}+C_t\int_t+C_{er})+\right.$$
$$+(C_{dr}+C_{pt}+C_t\int_t|+C_{er})+\left[(C_{ir}+a_{ir}+v_{in}+\int_{ci})*\frac{1}{qg}+(C_{cg}+C_g)\right](1+Rg)-\bar{R}(P_{rg}-P_{cg})\ \}_j+$$
$$+\sum_{f=1}^{F}Zf\left\{(C_{ex}+a_{ex}+v_{ex}+\Gamma_c)\frac{1}{qt}+(c_{dr}+c_{pt}+c_t\int_t+c_{er})-\bar{R}(P_{vg}-P_{cg})\right\}_f=\min im \tag{11}$$

Solving the system consisting of equations (1) and inequalities (2) thru (10), together with the efficiency function (11), successively in stages, leads to the distribution of the planned global production on the various objectives prepared for exploitation. The production tasks thus resulting for the known deposits will ensure in each stage considered the minimum cost (inside the oil park) of the crude oil produced by the new wells and pumped into the oil parks.

The notations used in the equations/relationships previously introduced in the model are as follows:

a = depreciation rates of well installations, monetary unit (MU)/well x stage

b = volume factor

c = expenses, MU/m^{3}stage, MU/well x stage

c_{dr} = expenses for reserves discovery, MU/m^3 x stage

f = fraction of oil displacing agent in the flow stream

q_t = maximum technically permissible crude oil flow rate on the average performance well, expressed in standard conditions, m^3/stage

q^* = maximum technically permissible liquid flow rate (water + crude oil) on the average performance well, expressed in reservoir conditions, m^3/stage

q^{**} = maximum technically permissible fluid flow (oil + gas) per well, expressed in reservoir conditions, m^3/stage

$\bar{q}$ = maximum possible injection flow rate on the well of average behavior, expressed in reservoir conditions, m^3/stage

Γ_c = capital repairs quota, MU/well x stage

V = depreciation rate for the well value, MU/well x stage

X, J, Z = quantity of crude oil obtained from new wells affected in the calculation stage of the fields exploited with water, gas, and without injection, m^3/stage

F = total number of distinct hydrodynamic units exploitable without injection (f = 1, 2, ..., F', …, F”, …, F)

H = average depth of injection and reaction wells on a reservoir

I' = total number of hydrodynamic units intended to be exploited with pressure maintenance by water injection (i = 1, 2, ..., I'm, …., I”, …., I)
J = idem, by gas injection (j = 1, 2, ..., J', ..., J", ..., J)
K = total number of deposits or targeted ones with shallow wells (k = 1, 2, ..., K)
L = idem, with medium depth wells (l=1, 2, ..., L)
M = idem, with deep wells (m=1, 2, ..., M)
$\overline{M}$ = average length for shallow wells, m/stage
M^*= idem, for average depth, m/stage
M^{**}= idem, for deep depth, m/stage
N_s = maximum number of new wells in the reservoir, in the stage
P = global production from new wells, expressed in standard conditions, m^3/stage
P_{cg} = price of gas compression from degassing to transport pipelines, MU/m^3 x stage
P_{rg} = usable gas recovery price, MU/m^3 x stage
Q = maximum quantities of injection agent available per stage, expressed in standard conditions, m^3/stage
R = ratio between the quantity of working agent and the quantity of crude oil produced per stage, and expressed in reservoir conditions
$\overline{R}$ = ratio between the quantity of usable gas, expressed in standard conditions, and the quantity of crude oil also produced per stage, expressed in reservoir conditions
π = maximum admissible production per hydrodynamic unit, established so that the crude oil is displaced by gravity, m^3/stage
$\int t$ = ratio between the quantity of crude oil to be treated and the total quantity of crude oil produced per stage

Consequently, **the indices** used in the equations/relationships previously introduced in the model are as follows:
a = water
cg = gas compression by injection
dr = reserves discovery
en = energy resources
ex = exploitation
f = sequence number of the field exploited without injection
g = gases
i = sequence number of the reservoir exploited with water injection
in = injection
j = idem as i, with gas injection
k = shallow deposit sequence number
l = idem as k, for medium depth
m = idem as k, for deep depth
pa = injection water pumping
pt = pumping crude oil
t = crude oil

Numerical example: The case of oil fields

Through similar linear program models, various production problems can be solved, as follows:
- ✓ Optimizing the distribution of investments on new structures;
- ✓ Optimizing production distribution within a group of fields;
- ✓ Optimizing the distribution of crude oil types that need to be processed in a refinery to produce the required petroleum products;
- ✓ Optimizing of petroleum product mixtures;

- ✓ Optimizing the overall production value in a crude oil distillation plant.

We shall present, as an example, a problem that requires determining the optimal number of drilling holes on given structures so as to ensure the well production plan with either minimal operating costs or minimal investments.

Model 1

Study Case I. Let's assume a maximum existing investment fund of 300 million MU, and a planned annual production of 700,000 t.

Initial conditions are given in Table 1:

Table 1: Initial conditions for the 5 oil structures analyzed

Oil structure	**Unit measure**	**1**	**2**	**3**	**4**	**5**
Maximum number of wells per structure	wells	70	50	40	30	25
Average production per well	thousand t/year	5	6	6.5	7	8
Investments per well	million MU	2	2.5	3	3.5	4.2
Operating expenses	thousand MU/year	400	430	460	480	520

Let $x_1, ..., x_5$ be the number of wells we are seeking per structure.

The constraints of the problem are:

- Achieving the annual production plan:

$$5\, x_1 + 6\, x_2 + 6.5\, x_3 + 7\, x_4 + 8\, x_5 \geq 700 \text{ thousand tons}$$

- Not exceeding the investment fund:

$$2\, x_1 + 2.5\, x_2 + 3\, x_3 + 3.5\, x_4 + 4.2\, x_5 \leq 300 \text{ million MU}$$

- Not exceeding the maximum possible number of wells per structure:

$$\begin{cases} x_1 \leq 70 \\ x_2 \leq 50 \\ x_3 \leq 40 \\ x_4 \leq 30 \\ x_5 \leq 25 \end{cases}$$

- The variables must be non-negative:

$$x_i \geq 0, \text{ with } i = \overline{1,5}$$

For **the objective function** we have to minimize the operating costs:

$$\min (0.4\, x_1 + 0.43\, x_2 + 0.46\, x_3 + 0.48\, x_4 + 0.52\, x_5).$$

The solution is obtained with the SIMPLEX algorithm, and are as follows:

$$x_1 = 32;\ x_2 = 50\ ;\ x_3 = 37.$$

Through this relationship, we get:

$$Production = 5 * 32 + 6 * 50 + 6.5 * 37 = 700.5 \text{ thousand t}$$

$$Investments = 2 * 32 + 2.5 * 50 + 3 * 37 = 300 \text{ million MU}$$

Consequently, operating expenses (as the objective function) are as follows:

$$0.4 * 32 + 0.43 * 50 + 0.46 * 37 = 57.32 \text{ million MU}$$

Study Case II. A model can also be established for minimizing investment funds under the conditions of a given production as a production plan.

The function to be minimized (as the objective function) will be:

$$Fmin = 2\ x_1 + 2.5\ x_2 + 3\ x_3 + 3.5\ x_4 + 4.5\ x_5$$

With restrictive conditions:

$$5\ x_1 + 6\ x_2 + 6.5\ x_3 + 7\ x_4 + 8\ x_5 \geq 700 \text{ thousand t}$$

These conditions are related to achieving the production plan:

$$\begin{cases} x_1 \leq 70 \\ x_2 \leq 50 \\ x_3 \leq 40 \\ x_4 \leq 30 \\ x_5 \leq 25 \end{cases}$$

(conditions regarding the maximum number of wells that can be placed on a structure).

Solving the model (also with SIMPLEX in integers), we get the following result:

$$\begin{cases} x_1 = 70 \\ x_2 = 50 \\ x_3 = 8 \\ x_4 = 20 \\ x_5 = 0 \end{cases}$$

Which leads to:

$$Production: 5 * 70 + 6 * 50 + 6.5 * 8 = 702 \text{ thousand t}$$

$$Investments: 2 * 70 + 2.5 * 50 + 3 * 8 = 289 \text{ million MU}$$

Operating expenses:

$$0.4 * 70 + 0.43 * 50 + 0.46 * 8 = 53.18 \text{ million MU}$$

In this situation (Case b), investments decrease by 300 – 289 = 11 million MU, while expenses increase by 53.18 – 51.32 = 1.86 million MU/year, and production increases by 700.5 – 702 = 1,500 t/year. The additional production will therefore cost 930 MU/t (excluding depreciation).

If these two solutions are compared, the following results are obtained (see Table 2):

Table 2: Comparative results for the two cases analyzed

No.	Indicator	Unit measure	Variant:	
			V1	V2
1	Number of new wells	wells	119	128
2	Production	thousand t	700.5	702
3	Depreciation (10% of investments)	million MU	30	28.9
4	Operating expenses	million MU	51.32	53.18
5	Cost, of which: -depreciation -operating expenses	MU/t	118.74 42.83 75.91	116.93 41.17 75.76

Analyzing data in the table, it turns out that the second option ***V2 is more advantageous***.

Model 2

It is assumed that the issue of locating wells on various structures arises, so that investments to be minimal (see Table 3).

Table 3: Initial conditions for the three oil structures analyzed

Structure	The number of wells that can be drilled on each structure	Drilling cost per well, mil. MU	Annual production per well, t
1	20	1.2	4,000
2	30	1.4	5,000
3	50	2.0	6,000

Let's assume that the production that will have to be obtained by exploiting new wells by the 3 structures is 210,000 t.

The problem is to determine the number of wells x_1, x_2, x_3 on each structure, so that the investments to be minimal.

The well production can be expressed as follows:

$$4{,}000\ x_1 + 5{,}000\ x_2 + 6{,}000\ x_3 = 210{,}000\ \text{t}$$

The restriction regarding the maximum number of wells that can be drilled on each structure is:

$$\begin{cases} x_1 \le 20 \\ x_2 \le 30 \\ x_3 \le 50 \end{cases}$$

The objective function is formulated in the form of minimum investments:

$$\min F = 1.2\ x_1 + 1.4\ x_2 + 2.0\ x_3$$

The SIMPLEX algorithm yields the result:

$$\begin{cases} x_1 = 15 \\ x_2 = 20 \\ x_3 = 0 \end{cases}$$

Consequently, the required investment (F) will be:

$$15 \times 1.2 + 30 \times 1.4 = 60 \text{ million MU.}$$

This is just one of many examples of the application of mathematical programming that has been used to distribute investments in the oil extraction industry.

Problems may also arise regarding the optimal distribution of equipment and material depots in the oil field area where the wells are drilled, the maximum efficiency of geological works, the optimal distribution of these works in the various geological areas, etc.

Conclusions

This paper had explored the possibilities of building up operational models for optimal decisions in the oil industry through mathematical programming aiming at the analysis of investment efficiency in oil and gas industry. In doing this, the present paper has aimed to build up a range of more econometric models applicable in oil industry that may be useful for managers working in this field.

In the beginning, a special focus was placed on revealing for a group of oil fields some applications that may help us determine the contribution of each field to the overall flow of the group, so that the cost price of the oil produced by new wells in one stage to be minimal.

We started the analysis from a large geological unit, within which several objectives are prepared for exploitation. In doing this, we first grouped the deposits, the exploitation objectives according to the depths of the wells to correspond to the types of drilling installations, and the maximum permissible flow rates of fluids possible to extract and inject from a technical point of view, that allowed us identifying the restrictive conditions regarding drilling availability.

Then we added to the restriction system equations as the quantities of water and gas are limited, the same as the flow rates, in order to achieve rational exploitation. Consequently, we took into account the configurations of the productive areas, the geological, and physical characteristics, while limiting conditions were also formulated regarding the distance between wells, respectively the maximum number of wells on a productive surface.

Following that, and assuming that the efficiency function is expressed by the minimum cost conditions of the crude oil brought up to date and pumped to the oil parks, we then introduced the objective function of the model.

In the end of the first part of the paper, by solving the system consisting of the equations, the inequalities, and the efficiency function earlier introduced, successively in stages, led us to the distribution of the planned global production on the various objectives prepared for exploitation. We argued that the production tasks thus resulting for the known deposits will ensure in each considered stage the minimum cost (inside the oil park) for the crude oil produced by the new wells and pumped into the oil parks.

The second part of the paper was dedicated to some numerical examples in the case of oil fileds. With the aid of two models presented in this section of the analysis we demonstrated that various production problems can be solved, like: optimization the distribution of investments on new structures; optimization production distribution within a group of fields; optimization the distribution of crude oil types that need to be processed in a refinery to produce the required petroleum products; optimization of petroleum product mixtures; and optimization the overall production value in a crude oil distillation plant.

As such, the first model presented the problem that requires determining the optimal number of drilling holes on structures so as to ensure the well production plan with either minimal operating costs or minimal investments.

To do this, two cases were introduced; by comparing the results of these two situations, we could decide in favor of variant V2, which proved more advantageous from the same premises.

Next, the second model aiming to determine the number of wells on each of the three considered structure, so that the investments to be minimal. In the end we argued that this is just one of many examples of applying mathematical programming to optimal distribute investments in the oil extraction industry.

Nevertheless, we stated that problems might also arise regarding the optimal distribution of equipment and material depots in the oil field area where the wells are drilled, the maximum efficiency of geological works, the optimal distribution of these works in the various geological areas, etc.

Finally, we may say that the obtained results and drawn conclusions can be useful for further analysis. As such, for deepening the analysis related to these issues, in the following papers other models that solve the problem of optimal decisions in the oil industry through programming aiming at the analysis of investment efficiency in oil and gas industry will be introduced.

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