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RELATION OF DRILLING CAPACITY TO MARKET AND PROFIT

Mladen ZELENIKA

Geotehnical Faculty, Halerova 7, 42000 Varaždin, Croatia

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Owner of drilling rigs should employ highly professional officers, who are capable to manage profit-orientated operations at all stages and make accurate analyses of the next three questions: how to deploy drilling crews to achieve the highest financial result; which kinds of equipment are compatible and employable in profitable operations, and how to compute the requirement of each type of equipment, and the number of drilling crews for a defined period and region to have profitable service.

This paper introduce an original mathematical model convenient to compute exact values needed for an answer on these three questions. Application of this model is obvious for research of the relationship among: (i) performance and cost of available drilling rigs, (ii) condition on the market, and (iii) estimated profit. Utilization of this model is possible only if records of market conditions' data, and data relating to progress and cost of operations in different conditions are established. These records will facilitate accurate estimation of input parameters' values and computation of output parameters' values using the Mathematical Model. Results of these computation should give basic data for precise plan of operation, rentability, and figures to decide the strategy of Drilling Company's capacity development.

Ključne riječi: Matematički model, Funkcija cilja, Operacijska istraživanja, Upravljanje operacijama, Granični uvjeti, Bušaće poduzeće, Postrojenje za bušenje, Geološki uvjeti, Tržišni uvjeti

Vlasnici postrojenja za bušenje upošljavaju visoko stručne djelatnike sposobne da profitabilno upravljaju operacijama bušenja u svim fazama rada i analiziraju slijedeća tri pitanja: kako rasporediti raspoložive ekipe u cilju postizanja najpovoljnijih financijskih rezultata; koji su tipovi opreme konkurentni na tržištu za profitabilne operacije, i kako izračunati potreban broj postrojenja/ekipa za svaku od metoda profitabilnog bušenja u određenoj regiji za definirani vremenski period.

Izložen je originalan matematički model primjenjiv za egzaktno računanje vrijednosti potrebnih upravitelju kao odgovor na tri pitanja. Korištenje ovog modela nužno je za istraživanja odnosa: (i) troškova korištenja svakog od raspoloživih postrojenja za bušenje, (ii) uvjeta na tržištu u razmatranom vremenskom razdoblju, i (iii) procjenjenog profita. Egzaktna su istraživanja moguća samo uz sustavno vođenje i analiziranje podataka o uvjetima na tržištu, i podataka koji karakteriziraju učinke i troškove operacija primjenom svakog od raspoloživih postrojenja/ekipa u uvjetima definiranog tržišta.

Redovito registrirani podaci o tržištu, učincima i specifičnim troškovima omogućuju utvrđivanje točnih vrijednosti ulaznih parametara. To je nužan uvjet za točno računanje vrijednosti izlaznih parametara (rezultata) korištenjem matematičkog modela. Rezultati ovih računanja daju osnovne podatke za izradu preciznog plana operacija, podatke o ekonomičnosti i potrebnu osnovu za odlučivanje strateškog razvoja kapaciteta poduzeća.

Introduction

Designers of structure should always consider all technically feasible options, analyze and compare construction and running cost and benefits. The result of these analyses is the facility to select and objectively the best — *optimal solution.* Basic data for these analyses should be adequate and correct figures, the method of analyses and the computation have to be exact and easily repeated and reviewed by other experts (Wagner, 1969). Reliable team of experts should review and scrutinise such an analyze and report the findings clearly. The selected variant should be justified as an *optimal option.* Obviously, the concept of the optimum for a technical solution depends on the basic criteria prescribed by the decision-maker, and understood, agreed and followed-up by involved designers and officers.

Bore-holes may have different depths and diameters, various equipment installed, and a great number of different functions and use. Construction of wells in different geological formations, various climates, topography, and situation of development of the region make technology of drilling a complex one. Though the construction-cost of a standard well comprises all expenses settled by the owner of the well. Commercial price of a drilling company includes all expenses of drilling company and a reasonable value of profit ($p \cong 1.15$).

Diversity of circumstances at drilling site assumes production and application of various types of drilling rigs. One well trained drilling crew with larger drilling rig (DR) could accomplish wells (bore-holes) of many designs, but the most competitive DR is the *appropriate* one for the considered type of well in the known conditions.

This paper deals with definition of the problem, identification and estimation of input and output parameters relating to improvement of an effecient management in drilling operations. The proposed mathematical model is based on Operational Research — Linear Programming method, using SIMPLEX procedure of calculation and applicaton of a computer.

The correct value of the relevant input parametres, well defined output parameters and accurate application of the method of *Operational Research* provides a scientific framework to analyze and test different applicable variants of management in drilling operations in a exact way.

Definition of problem

A drilling enterprise possesses various types of equipment and tools to carry on drilling operations (Fig. 1), and employs enough of professional staff to drill and complete successfully many types of wells (Fig. 2) in a greater region. It is supposed that such a drilling companu (DC) has established a regular recording of all relevant data concerning market demands for new wells, and data related to cost, procedure and progress in implementation of various designs of bore-holes.

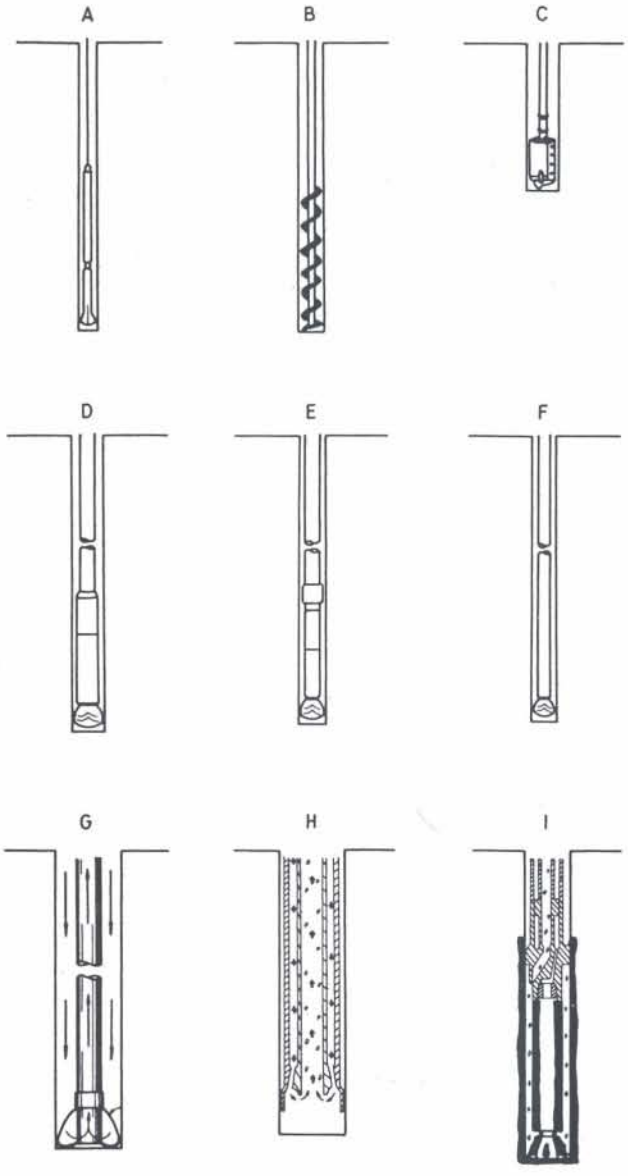

Fig. 1. Various Types of Drilling Tool and Cleaning of Hole a — percussion, b — auger, c — bucket, d — rotary and slim rotary, e — DTH (air), f — DTH (hydraulic), g — reverse (single), h — dual tube (reverse), i — dual tube with DTH (reverse).
a, b and c — mechanical cleaning, c, d, and f — fluid, conventional direction of circulation, g, h and i — fluid, reverse direction of circulation

Due to many types and manufacturers of drilling equipment, it is difficult to define exactly all kinds of drilling rigs, but each drilling company has its own organization of drilling rigs with necessary tool and staff. Teams with relevant equipment and assignment in the market are called drilling crews. By having a convenient organization and regylarly monitoring and evaluating of data reported by drilling crews, it facilitates an easy estimation of cost of crew-operation c_j (financial units/day) and progress (days/bore-hole or meters/day).

Expected daily progress (M/D), as well as cost of a drilling crew in operations and/or unemployed (FU/D), could not be precisely calculated. The estimation of values of progress and the cost of a new bore-hole in unknown geological formation at unseen sides are particularly difficult. Though, DC should require all available data from the owner of new wells in the phase of bidding and during the negotiation of contract's stipulations. DC's professional staff should have their own *data-bank* relating prices and market circumstances in the region. It is taken for granted that many types of well-design could be demanded on the market. Officers responsible for research of the market should develop a practical number of choices of defined standardized well-designs (types — b_i), and required time to accomplish each type of bore-hole using one of applicable drilling crew (days/bore-holes — d_{ij}).

Management of a drilling company has to be efficient and profit-orientated at all stages. Practical problems of operational officers in a drilling company could be summarized as following:

1. How to deploy (own) drilling crews to achieve the highest financial results?
2. Which kinds of equipment are compatible and employable in profitable operations?
3. How to compute the requirement of each type of equipment and number of drilling crews for a defined period and region to have profitable service?

Formulation of mathematical model

Answers on above three questions may give a convenient solution of the defined problem. Achievement of the highest financial results could be expressed and analyzed by the SIMPLEX METHOD developed and applied by George Dantzing (Martić, 1979; Dantzing, 1951). Main variables, input and output parameters relating to the rational management of drilling process are illustrated in Fig. 3 and Table 1.

Computation of out-put parameters:

Meaning of all terms are explained in the special list.

P_j — Computed income for accomplished wells by j-type of rig/crew.

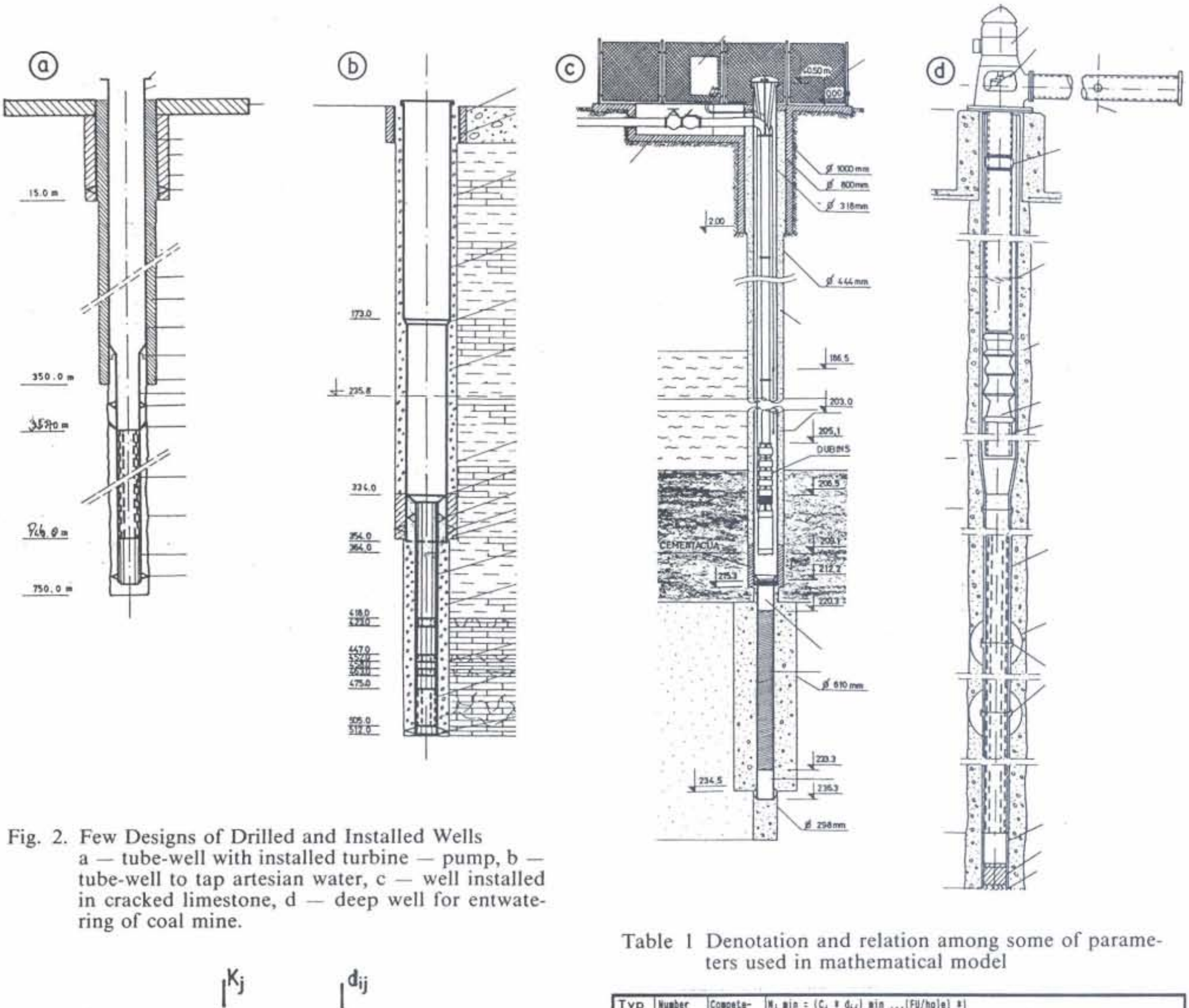

Fig. 2. Few Designs of Drilled and Installed Wells
a — tube-well with installed turbine — pump, b — tube-well to tap artesian water, c — well installed in cracked limestone, d — deep well for entwatering of coal mine.

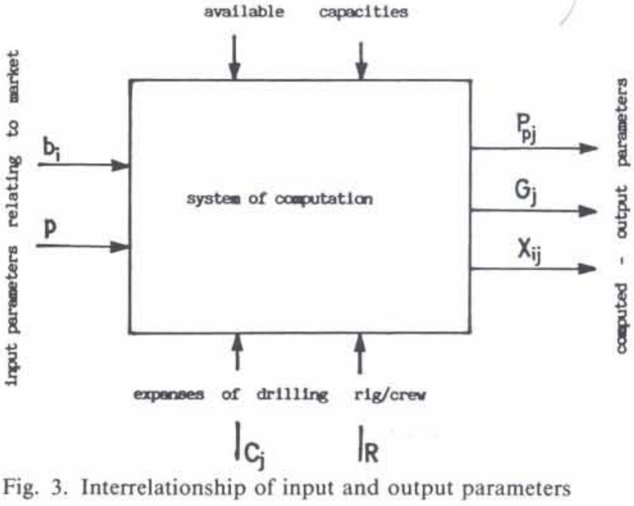

Fig. 3. Interrelationship of input and output parameters

$$P_j = \sum_{i=1}^{m} M_i \cdot X_{ij} \cdot p \ldots (FU/Year). \qquad (1)$$

G_j — Computed loss of income due to shortage of holes at the market for j-type of rig/crew, (FU/year).

$$G_j = R \cdot C_j \cdot K_j - \sum_{i=1}^{m} X_{ij} \cdot d_{ij} \ldots (FU/Year) \qquad (2)$$

Table 1 Denotation and relation among some of parameters used in mathematical model

Type of Wells (i)	Number of Wells (b_i)	Competetive value of well M_i min	M_i min = (C_j * d_{ij}) min ...(FU/hole) *)									
			Crew/Rig K_1		Crew/Rig K_2		Crew/Rig K_3		...		Crew/Rig K_n	
			X_{11}	d_{ij}	X_{12}	d_{ij}	X_{13}	d_{ij}	.	.	X_{1n}	d_{ij}
1	b_1	M_1	X_{11}	d_{11}	X_{12}	d_{12}	X_{13}	d_{13}			X_{1n}	d_{1n}
2	b_2	M_2	X_{21}	d_{21}	X_{22}	d_{22}	X_{23}	d_{23}			X_{2n}	d_{2n}
3	b_3	M_3	X_{31}	d_{31}	X_{32}	d_{32}	X_{33}	d_{33}			X_{3n}	d_{3n}
...	...	...	..	...	...	...	...	...			...	...
m	b_m	M_m	X_{m1}	d_{m1}	X_{m2}	d_{m2}	X_{m3}	d_{m3}			X_{mn}	d_{mn}
TOTAL:			**	***								
Cost of Rig C_j (FU/day)												
Available Capacity K_j (Days/Year)												

* Construction-time d_{ij} (Days/hole) for various available Drilling-Rig/Crew (K_j)
** Total number of holes/wells computed for a type ofdrilling Rig/Crew (holes/Year)
*** Total computed time necessary to implement all holes/wells (Days/Year) using one type of Rig/Crew.

Management of a drilling company has direct influence on values of input parameters C_j and R, d_{ij} and smaller influence on K_j, b_i and p — input parameters for the running year. Values of the output — computed parameters P_j, G_j and X_{ij}, depend of the quality of estimation of input parameters' values and justification of the mathematical model, (Zelenika, 1988).

After a precise estimation of input parameters shown in Fig. 3 and in Table 1, an experienced engineer or a professional team is able to analyze the *Time-Table* and allocate planned wells (after an adequate market-investigation) with their own drilling rigs as well as compute the total income (FU/year) using a pocket calculator. Such analyses could be useful, but allocation of wells to the most competitive drilling rig and calculation of income may comprise various errors, sub-optimums and reduction of a possible profit (FU/year), (Wagner, 1965).

Application of a clearly defined mathematical model, which is easy to be checked and used by other experts too, and convenient to be run by application of computer are demands of research to ensure the optimal decisions (Wagner, 1969). The value of the *rectified income* in drilling process P_k should be analyzed and maximized in this mathematical model.

$$P_k = P - G \ldots (FU/year) \qquad (3)$$

The values of P and G are explained by expresions as follows:

$$P = \sum_{j=1}^{m} P_j \ldots (FU/year) \qquad (4)$$

and

$$G = \sum_{j=1}^{m} G_j \ldots (FU/year) \qquad (5)$$

After substituting and putting in order values of: P, P_j, G and G_j in the expression for the rectified income P_k we will have the *Objective Function* as follows:

$$P_k = \sum_{i=1}^{m} \sum_{j=1}^{n} (M_i \cdot p \cdot C_j \cdot d_{ij} \cdot R) \cdot X_{ij} - R \sum_{j=1}^{n} C_j \cdot k_j = > P_{k\,max} \ldots (FU/year) \qquad (6)$$

$$p = \frac{C_{jp} \cdot d_{ip}}{(C_j \cdot d_{ij})_{min}} \qquad (7)$$

$$R = \frac{C_j}{C_{jo}} \qquad (8)$$

Systems of the Constraints:

Limitations at the market due to restriction of demands for new wells in the region, shortage of financial capacity to invest, and/or reduction of compatibility of drilling company, can be expressed as follows:

$$\sum_{j=1}^{n} X_{ij} < b_i \qquad i = 1, 2, 3, \ldots m \quad j = 1, 2, 3, \ldots n \qquad (9)$$

Limitations of capacity due to the insufficiency of compatible drilling rigs with crews is expressed by inequality as follows:

$$\sum_{i=1}^{n} X_{ij} \cdot d_{ij} < K_j \qquad i = 1, 2, 3, \ldots m \quad j = 1, 2, 3, \ldots n \qquad (10)$$

Limitation of values X_{ij} in domain as follows:

$$X_{ij} > 0 \qquad i = 1, 2, 3, \ldots m \quad j = 1, 2, 3, \ldots n \qquad (11)$$

Mathematical expressions from (1) to (11) and Fig. 3 delineate a *mathematical model* convenient to analyze the present and future rentability of a drilling company. Users of this model should carefully calculate values of coefficients in linear equations respecting the lowest commercial prices on the market — $p \cdot M_i$.

Aplication of the mathematical model

The mathematical model has been tested through analyses of operations' rentability in a drilling company (Zelenika, 1988). The computation of maximum P_k value has been conducted in "Pascal" language (15 iterations). Values of input parameters relate to the market's opportunity are estimated after detailed analyses of collected information received from all existing designers and owners/users of wells; 150 wells/year — classified in 8 different types ($i=1$ to $i=8$). The capacity should be decided after a careful analyze of all interior data recorded by a drilling company's professional team. In the analyzed example the planned capacity ($K_1 + K_2 + K_3 + \ldots K_6$) of 14 studied drilling rigs classified in six types was estimated on 2,800 working days/year (Tables 2, and 3).

Table 2 Values of input and output parameters — K_j, P_j, G_j and P_k

PARAMETERS	TYPES OF DRILLING RIGS WITH SPECIAL TRAINING OF CREWS FOR VARIOUS OPERATIONS						
	K_1	K_2	K_3	K_4	K_5	K_6	TOTAL
CAPACITY PLAN K_j (Days/Year)	200	750	550	600	500	200	2.800
CAPACITY UTILIZ. (Days/Year)	200	433,14	550	600	500	161,67	2.444,81
% OF UTILIZATION	100	58	100	100	100	81	87
INCOME P_j (000FU/Y)	32.857	99.623	59.033	241.450	13.800	74.366	521,18
LOSS G_j (000FU/Y)	0	31.686	0	0	0	7.667	39.352
RECT.INCOME P_j (000FU/Year)	32.857	67.937	59.033	241.500	13.820	66.700	481.828

Table 3 Values of X_{ij} and input parameters b_i and K_j

WELL-TYPE b_i	EXPECTED NUMBER OF WELLS/YR	OPTIMAL ARRANGEMENT OF AVAILABLE WELLS/DRILLING RIGS/YEAR							
		K_1 WELLS/Y	K_2 WELLS/Y	K_3 WELLS/Y	K_4 WELLS/Y	K_5 WELLS/Y	K_6 WELLS/Y	TOTAL WELLS	TOTAL %
b_1	30	28,57	1,43	0	0	0	0	30	100
b_2	50	0	50	0	0	0	0	50	100
b_3	10	0	3,33	0	0	6,67	0	10	100
b_4	6	0	6	0	0	0	0	6	100
b_5	20	0	0	18,33	0	0	1,67	20	100
b_6	10	0	0	0	0	0	10	10	100
b_7	15	0	0	0	5,57	0	0	5,57	37
b_8	9	0	0	0	9	0	0	9	100
TOTAL:	150	28,57	60,76	18,33	14,57	6,67	11,67	140,57	94

Table 2 shows values of few input parameters — K_j (values of planned and utilized capacities — for each of drilling rigs' type — days/year), and output parameters P_j, G_j and P_k. Available capacity of drilling rigs (K_j) is utilized only 87% due to shortage of wells' — type b_2 and type b_6 on the available market. On the other side, due to insufficiency of K_4 — type (drilling rigs with crews) capacity, 10 out of 15 available wells of b_7 — type, could not be accomplished.

Table 3 shows values of the estimated input parameters b_i and computed values of X_{ij} — optimal solution for time-table for each of drilling rigs-/crews. Out of expected 150 wells (on the market) only 94% could be accomplished with available structure of the drilling company's capacity.

The decision-maker in a drilling company may give comment and/or decide as follows:

1. Reduce unemployable capacities K_2 — and K_6 — type through reduction of equipment and staff employed.

2. Expand K_4 — type of drilling rig/crew capacity.

In that case the analyzed drilling company would succeed to correct planned capacities as follows:

- reduction of capacity K_2 — type from 550 to 400 days/year, the corrected value of K_{2d} = 150 days/year
- reduction of capacity K_6 — type from 200 to 170 days/year, the corrected value of K_{6d} = 30 days/year
- increment of capacity K_4 — type from 600 to 750 days/year, the corrected value of K_{4d} = 150 days/year

Respecting the mathematical model and other input data including prices: C_2 = 200 FU/day, C_4 = 600 FU/day and C_6 = 200 FU/day, we could calculate the increament of the value of *rectified income* P_k as follows:

$$P_{kd} = p \cdot K_{4d} \cdot C_4 + R \cdot (K_{2d} \cdot C_2 + K_{6d} \cdot C_6) = \\ = 1{,}15 \cdot 150 \cdot 600 + 0{,}5 \cdot (150 \cdot 200 + 30 \cdot 200) \\ = 103.500 + 18.000 = 121.500 \text{ FU/year.} \quad (12)$$

This is an increment of income for more than 25%, it is 25.2% related to the original P_k value (Table 3).

The comprehensiveness of the utilized parameters makes the application of this mathematical model easy in various processes. Construction management of standardized drilled pilots, cut-walls, water-wells, petroleum-wells, various investigation- wells/bore-holes, and many other processes could be analyzed. The final product in the analyzed processes should be the most convenient unit (m, m^2, m^3, working hour of drilling rig/crew, installation of a standard equipment or the complete well).

Conclusion

The proposed mathematical model belongs to method of linear programming — *Simplex* procedure of computation. It should be an useful tool for analyses and improvements of the management in larger drilling companies. Variations in values of input parameters and reflected changes of rectified income P_k — the main target in the *objective function* ask decision makers in the analyzed drilling company to restudy in details all possibilities of useful improvements. Correction of drilling rigs or crews' structures (see Equation No. 12), and active cooperation with designers of wells as well as with clients on the market, may facilitate improvement of economy of a drilling company.

Regular use of this mathematical model facilitates due improvements in monitoring and evaluation procedure of reported data relating to accomplished wells and surveys with analyzes of the market of drilling operations. Improvements in monitoring of relevant data provide: (i) precise estimation of input parameters' values, (ii) justification of values of output parameters, and (iii) better control of processes.

The comprehensiveness of utilized parameters makes easy an extensive application of this mathematical model. Model could be used to analyze rentability of various companies for any interval time. Results of computation with an input-data of three, five, or ten years interval will facilitate renumerable and profitable investment in employable drilling rigs, necessary equipment and definition of training and retraining of needful professionals. If results of long term analyses show a grater risk to employ own expensive drilling capacities on a traditional market, the company should make effort to expand the market or change the structure of specialized drilling rigs/crews to survive safely.

List of Terms and Explanation of Meanings

d_{ij} — required time to accomplish i-type of hole/well using j- type of drilling rig/crew, (days-/hole), i=0 to i=m; j=0 to j=n.

K_j — available time of j-type of drilling rig-/crew, (days/year).

b_i — multitude of new holes in the market, (holes/year).

p — factor of profit

$C_{jp} \cdot d_{ip}$ — commercial price of the most competitive rig with crew, (FU/hole).

C_{jp} — price of service of a competitive rig with crew (FU/day)

d_{ip} — required time to accomplish i-type of hole using selected drilling rig (days/hole)

$(C_j \cdot d_{ij})_{min} = (M_i)$ — cost of the most competitive rig with crew to construct i-type of hole/well, (FU/hole).

C_j — cost of operation of j-type of rig/crew, (FU/day).

R — relation of cost of a rig in operation to cost of a available rig out of operation.

C_{jo} — cost of j-type of rig/crew out of operation, (FU/day).

X_{ij} — computed number of i-type design of holes/wells allocated to be drilled using the most economical j-type of drilling rig/crew, (holes/year).

P_j — computed income for accomplished wells by j-type of rig/crew.

G_j — computed loss of income due to shortage of holes at the market for j-type of rig/crew, (FU-/year).

P_k — rectified value of income, (FU/year).

FU — financial unit (unit of any currence).

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