# Application of De Novo Programming Approach for Optimizing the Business Process

Z. Babic, I. Veza, A. Balic, M. Crnjac

Abstract—The linear programming model is sometimes difficult to apply in real business situations due to its assumption of proportionality. This paper shows an example of how to use De Novo programming approach instead of linear programming. In the De Novo programming, resources are not fixed like in linear programming but resource quantities depend only on available budget. Budget is a new, important element of the De Novo approach. Two different production situations are presented: increasing costs and quantity discounts of raw materials. The focus of this paper is on advantages of the De Novo approach in the optimization of production plan for production company which produces souvenirs made from famous stone from the island of Brac, one of the greatest islands from Croatia.

**Keywords**—De Novo Programming, production plan, stone souvenirs, variable prices.

#### I. INTRODUCTION

DE Novo programming, initiated by Zeleny [1], presents a special approach to optimization. Instead of "optimizing a given system", De Novo suggests a way of "designing an optimal system". In the De Novo approach the resources are not limited because the necessary resource quantities can be obtained at certain prices. The resources maximum quantity is limited only by the available budget, which is an important element of the De Novo programming.

Most cases can be handled more effectively by using De Novo than using the standard programming model (see [2]-[4]). Changes in prices, technological coefficients, increasing costs of raw materials, quantity discounts and other similar and real production situations can be easily incorporated into the De Novo model and can provide very satisfactory solutions.

## II.DE NOVO PROGRAMMING

The traditional resource allocation problem in economics is modeled via standard linear programming formulation of the single-objective product-mix problem.

In the De Novo formulation, the purpose is to design an optimal system and the following formulation is of interest:

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$$\begin{aligned} & \textit{Max } z = c_1 x_1 + c_2 x_2 + \dots + c_n x_n \\ & \text{s.t. } a_{11} x_1 + a_{12} x_2 + \dots + a_{1n} x_n = b_1 \\ & a_{21} x_1 + a_{22} x_2 + \dots + a_{2n} x_n = b_2 \\ & \dots \\ & a_{m1} x_1 + a_{m2} x_2 + \dots + a_{mn} x_n = b_m \\ & p_1 b_1 + p_2 b_2 + \dots + p_m b_m \leq B \\ & x_i, b_i \geq 0, \ j = 1, 2, \dots, n; \ i = 1, 2, \dots, m \end{aligned}$$

where,  $b = (b_1, b_2, \dots, b_m)$  – set of decision variables representing the level of resource i to be purchased,  $p_i$  – unit price of resource i, B – total available budget for the given system.

Now, the problem is to allocate the budget so that the resulting portfolio of resources maximizes the value of the product mix (with given unit prices of m resources, and with given total available budget).

The main difference of the two models lies in the treatment of the resources which become decision variable  $b_i$  in the De Novo formulation.

## A. Varying Cost of Raw Materials

A frequent phenomenon arising in real production problems is the varying price of the same resource. Namely, if a company needs additional quantities of raw materials it is possible to buy them from another supplier but at a different (usually higher) price. Let us assume that i raw material can be purchased at the price  $p_i$ , but only for the quantity lower (or equal) than Q. To purchase i raw material above that quantity, it is necessary to take another supplier whose price is  $p_i' > p_i$ . Then, the relation for the i raw material is transformed into:

$$a_{i1}x_1 + a_{i2}x_2 + \dots + a_{in}x_n = b_i + d_i,$$
 (2)

with additional constraint  $b_i \leq Q$ , where  $d_i$  is the additional quantity of the *i* raw material with the unit price  $p_i$ .

Let us now consider such production situation when there are quantity discounts granted for bulk orders of raw materials. Therefore, in addition to the increasing cost effect, we have to introduce this possibility into the model. Let us assume that, for the k resource  $(b_k)$ , the valid price is  $p_k$  as long as the purchased quantity is below Q, and the discounted price  $p_k$ ' is valid for the entire quantity if the purchased quantity is higher (or equal to) than Q. Consequently, the assumption is opposite to the one in the previous model, i.e.  $p_k$ '  $< p_k$ .

The previous formulation is not applicable since the optimization model will prefer using the less expensive material without satisfying the quota (Q). A different model

has to be formulated with a slightly more complicated procedure.

Let  $b_k$ ,  $p_k$  – the amount and price of k raw material if it is purchased at less than the quantity discount volume;  $d_k$ ,  $p_k$ ' – the amount and price of k raw material if it is purchased at the quantity discount.

The new model, in that case, instead of one equation for k raw material has some more relations, and those are:

$$a_{k1}x_1 + a_{k2}x_2 + \dots + a_{kn}x_n = b_k + d_k$$

$$b_k - Q * y_1 \le 0$$

$$d_k - Q y_2 \ge 0$$

$$d_k - M y_2 \le 0$$
(3)

and, according to this, the budget constraint is:

$$p_1b_1 + p_2b_2 + \dots + p_kb_k + p_k'd_k' + \dots + p_mb_m \le B,$$
 (4)

where M is a very large positive number (M >> 0), or the upper limit for the procurement of the resource k, and  $Q^*$  is a number which is slightly lower than Q. Variables  $y_1$  and  $y_2$  are integer 0 - 1 variables, for which is:

$$y_1 + y_2 = 1 (5)$$

In the above model, there are two 0-1 variables  $y_1$  and  $y_2$ , where only one of them always equals 1, and the other equals zero. Naturally, if the model comprises a number of resources that can be purchased at a discounted price then there are more 0-1 variables.

Since the same raw material has different price variable, the income from end product unit is not constant anymore. Therefore, maximizing the sum of  $c_j$   $x_j$ , would not be an accurate measure of net income. Net income (1) should be recalculated as the difference between sales and total cost of materials, where the objective function will include materials at both prices. Consequently, if  $s_j$  is the sales price of j product, the objective function has the following form:

Max 
$$z = \sum_{i=1}^{n} s_{j} x_{j} - \sum_{i=1}^{m} p_{i} b_{i} - \sum_{k \in K} p_{k} ' d_{k}$$
 (6)

In that equation set, K presents the indices of raw materials that have increasing or discounted prices, and  $d_k$  ( $k \in K$ ) stays for those materials where additional quantities can be bought only at a higher price ( $p_k$ '), or the quantities of raw materials if we bought them with quantity discounts.

In the budget equation, it is also necessary to introduce costs for additional quantities of raw materials, so that it now takes the following form:

$$\sum_{i=1}^{m} p_i b_i + \sum_{k \in K} p_k ' d_k \le B \tag{7}$$

There is no need to specify that  $b_i$  should reach the maximum value of Q first, before allowing  $d_i$  greater than zero. The optimization model ensures  $b_i$  reaching the maximum value of Q because of the lower penalty, i.e. lower price  $p_i$ 

#### III. PROBLEM SETTING

This paper analyses the production planning problem in one production company which produces stone souvenirs made from famous stone from the island of Brac. This company produces 13 different stone souvenirs, and these articles can be seen in Table I. In this table, there are lower bounds for the six-month production and selling prices of all the articles.

Table II presents the list of raw materials that are used in production of these articles. There are 26 different raw materials, and the purchasing prices for every of them are also presented in the table.

The amount of raw materials in one unit of articles  $(a_{ij})$  is also used in production planning problem, and their values are presented in Tables III and IV.

TABLE I LIST OF ARTICLES PRODUCTS

Mark	Article name	Six-month amount production	Selling prices (kn)
		Lower bound	$S_j$
BRM (A1)	Bracelet - metal	900	55
BRSP (A2)	Bracelet - semiprecious stone	700	55
BRR (A3)	Bracelet – rope	6000	15
CRS (A4)	Crown - small	600	40
CRB (A5)	Crown - big	100	125
NECM (A6)	Necklace - metal	120	70
NECSP (A7)	Necklace - semiprecious stone	120	70
NECFM (A8)	Necklace full – metal	80	120
NECFSP (A9)	Necklace full - semiprecious stone	80	120
EMS (A10)	Earrings metal - small	500	20
ESPS (A11)	Earrings semiprecious stone - small	500	20
EMB (A12)	Earrings metal - big	220	30
ESPB (A13)	Earrings semiprecious stone - big	250	30

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TABLE II

LIST OF RAW MATERIALS WITH INCREASING COSTS AND QUANTITY DISCOUNTS

LIST OF RAW MATERIALS WITH INCREASING COSTS AND QUANTITY DISCOUNTS						
	Type of raw materials		Unit price			
b1	Stone 8 mm	0.6	kn/piece			
b2	Stone 10 mm	0.8	kn/piece			
b3	Stone 12 mm	1	kn/piece			
b4	Skullcap small	0.08	kn/piece			
b5	Scullcap big	0.08	kn/piece			
b6	Space big	0.06	kn/piece			
<b>b</b> 7	Space small $\leq 30000$	0,06	kn/piece	Increasing		
<b>d7</b>	Space small > 30000	0.08	kn/piece	costs		
<b>b8</b>	Bead metal 4 mm $\leq$ 25.000	0.04	kn/piece	Quantity		
d8	Bead metal 4 mm > 25.000	0.02	kn/piece	discounts		
ь9	Bead metal 8 mm	0.4	kn/piece			
b10	Bead metal 10 mm	0.6	kn/piece			
b11	Cable	2	kn/m			
b12	Semiprecious stone 4 mm ≤ 3500	0.2	kn/piece	Increasing		
d12	Semiprecious stone 4 mm > 3500	0.25	kn/piece	costs		
b13	Semiprecious stone 8 mm	0.35	kn/piece			
b14	Semiprecious stone 10 mm	0.6	kn/piece			
b15	Semiprecious stone 12 mm $\leq 4.200$	1.2	kn/piece	Quantity		
d15	Semiprecious stone 12mm > 4.200	1	kn/piece	discounts		
b16	Wire	2.5	kn/piece			
b17	Rope	1	kn/m			
b18	Small medal	0.3	kn/piece			
b19	Small cross	0.3	kn/piece			
b20	Big medal	2	kn/piece			
b21	Big cross	12	kn/piece			
b22	Needle	0.5	kn/piece			
b23	Needle	0.7	kn/piece			
b24	Crotchet	0.5	kn/piece			
b25	Buckle	0.3	kn/piece			
b26	Quoit	0.05	kn/piece			

TABLE III THE RECIPES –PART I

	NM-NAR	NP-NAR	NK-NAR	KM-KRU	KV-KRU	OM-OG	OP-OG
Stone 8mm	8	6	2	11	59	16	12
Stone 10mm	2	2	0	0	0	4	4
Stone 12mm	3	0	0	0	0	6	0
Skullcap small	4	4	2	4	14	8	8
Skullcap big	6	6	0	0	0	12	12
Space big	2	2	0	0	0	4	6
Space small	6	6	2	0	0	12	12
Bead metal 4mm	0	0	0	22	81	0	0
Bead metal 8mm	0	2	0	0	0	4	4
Bead metal 10mm	2	0	1	0	0	3	3
Sajla	0,2	0,2	0	0,2	0,6	0,6	0,6
Cable	0	4	0	0	0	0	2
Semiprecious stone 4 mm	0	0	0	0	0	0	4
Semiprecious stone 8 mm	0	0	0	0	0	0	2
Semiprecious stone 10mm	0	3	0	0	0	0	6
Wire	0	0	0,08	0	0	0	0
Rope	0	0	0,3	0	0	0	0
Small medal	0	0	0	1	0	0	0
Small cross	0	0	0	1	0	0	0
Big medal	0	0	0	0	1	0	0
Big cross	0	0	0	0	1	0	0
Needle 20mm	0	0	0	0	0	0	0
Needle 30mm	0	0	0	0	0	0	0
Crotchet	0	0	0	0	0	0	0

According to these data, the production planning problem can be posted as the linear programming model with one or

more objective functions. Here, we will consider the production company which produces stone souvenirs where

we have the varying price of the same resource, i.e. increasing costs of the same raw material or quantity discounts for some of raw materials as can be seen in Table II.

Suppose that the available budget for six-month production is equal to the last year's costs for the raw materials, i.e. B = 99430 kn.

TABLE IV THE RECIPES – PART II

	OPM-OG	OPP-OG	NMM-NAU	NPM-NAU	NMV-NAU	NPV-NAU
Stone 8mm	32	24	0	0	2	0
Stone 10mm	8	8	2	2	2	4
Stone 12mm	12	0	0	0	0	0
Skullcap small	16	16	4	4	8	8
Skullcap big	24	24	0	0	0	0
Space big	8	12	2	2	4	4
Space small	24	24	0	0	0	0
Bead metal 4mm	0	0	0	0	0	0
Bead metal 8mm	8	8	2	0	0	0
Bead metal 10mm	6	6	0	0	2	0
Sajla	0,6	0,6	0	0	0	0
Cable	0	4	0	0	0	0
Semiprecious stone 4 mm	0	8	0	0	0	0
Semiprecious stone 8 mm	0	4	0	2	0	2
Semiprecious stone 10mm	0	12	0	0	0	0
Wire	0	0	0	0	0	0
Rope	0	0	0	0	0	0
Small medal	0	0	0	0	0	0
Small cross	0	0	0	0	0	0
Big medal	0	0	0	0	0	0
Big cross	0	0	0	0	0	0
Needle 20mm	0	0	2	2	0	0
Needle 30mm	0	0	0	0	2	2
Crotchet	0	0	2	2	2	2

Since raw materials are now of different costs, variable prices of end product are not constant any more. Therefore, maximizing the sum of  $c_j$   $x_j$ , where  $c_j$  is the unit profit for article  $A_j$ , would not be an accurate measure of profit. Rather, profit equation should be recalculated as sales income less total cost of materials.

If  $x_j$  is the production quantity of i stone product, the model which will take this increasing costs and quantity discounts into consideration is as follows:

Objective function (total contribution) which has to be maximized is:

Max 
$$z = \sum_{j=1}^{13} s_j x_j - \sum_{i=1}^{26} p_i b_i - \sum_{k \in K} p_k ' d_k , K = \{7,8,12,15\}$$
 (8)

In that equation set, K presents the indices of raw materials that have increasing or discounted prices. In our case, that happens for  $S_7$ ,  $S_8$ ,  $S_{12}$  and  $S_{15}$ . Let us consider such situation for our souvenirs production model. The eight and fifteenth raw material (S8 - Bead metal 4 mm and S15 -Semiprecious stone 12 mm) can be purchased at a discounted price if the bought quantity is  $Q_1 > 2500$  pieces and  $Q_2 > 4200$  pieces, and this reduced price is valid for the entire quantity supplied, i.e.  $p_1' = 0.02$  kn and  $p_2' = 1$  kn. In addition to this, let us assume increasing costs for Small space (S7) and Semiprecious stone 4 mm (S12) in this way:

The limit of S7 purchased at a lower price is 30000 pieces, while this limit in S12 is 3500 pieces. The purchasing price of the additional quantity of S7 is  $p_7' = 0.08$ , and of S12  $p_{12}' = 0.25$  currency units. Assuming that the budget level is B = 99 430 kn, and selling prices as in Table I, the constraints in the production model are:

Raw material constraints:

$$\sum_{j=1}^{13} a_{ij} x_j - b_i - d_i = 0, \quad i = 1, \dots, 26$$
 (9)

where  $d_i = 0$  except for  $i \in K$ , and  $a_{ij}$ , are the amount of raw materials in one unit of specific article. Constraints for the discounted prices for the eighth and fifteenth raw material:

$$b_8 - 24990 \ y_1 \le 0, \ d_8 - 25000 \ y_2 \ge 0, \ d_8 - M \ y_2 \le 0$$
 (11)

$$b_{15} - 4190 y_3 \le 0, d_{15} - 4200 y_4 \ge 0, d_{15} - M y_4 \le 0$$
 (12)

where M is a very large positive number (M >> 0), or the upper limit for the procurement of the specific resource k. Variables  $y_1$ ,  $y_2$ ,  $y_3$  and  $y_4$  are integer 0 - 1 variables, for which  $y_1 + y_2 = 1$  and  $y_3 + y_4 = 1$  is valid. In the above model there are four 0-1 variables, where due to the upper relations only one of them in each pair always equals 1, and the other equals zero. Naturally, if the model comprises a number of resources

that can be purchased at a discounted price then there are more 0-1 variables. Last is the budget constraint:

$$\sum_{i=1}^{26} p_i b_i + \sum_{k \in K} p_k ' d_k \le 99430 \tag{13}$$

In addition to that the model has 13 integer variables (units of articles -  $x_j$ ). Of course due to the data from Table I, all articles have the lower bounds which are 13 more constraints. There are two more constraints for the raw materials which have increasing costs:

$$b_7 \le 30000, b_{12} \le 3500 \tag{14}$$

In addition to that, we have some production lines (capacities) constraints and that is:

$$x_1 + x_2 \le 1800$$
 (bracelet production line) (15)

$$x_6 + x_7 \le 300$$
 (necklace 1 production line) (16)

$$x_8 + x_9 \le 200$$
 (necklace 2 production line) (17)

$$x_{10} + x_{11} \le 1000$$
 (earrings 1 production line) (18)

$$x_{12} + x_{13} \le 500$$
 (earrings 2 production line) (19)

TABLE V

OPTIMAL SOLUTION						
Variables	Optimal solution	Variables	Optimal solution			
X1	900	b1	48860			
X2	900	b2	9900			
X3	6000	b3	5220			
X4	600	b4	36880			
X5	120	b5	19200			
X6	180	b6	10960			
X7	120	<b>b</b> 7	30000			
X8	120	<b>d</b> 7	1200			
X9	80	<b>b8</b>	22920			
X10	500	d8	0			
X11	500	<b>b</b> 9	5600			
X12	250	b10	10400			
X13	250	b11	852			
b12	3500	b23	1000			
d12	660	b24	3000			
b13	1120	b25	8900			
b14	2060	b26	18760			
b15	0	y1	1			
d15	4380	y2	0			
b16	480	y3	0			
b17	1800	y4	1			
b18	600					
b19	600					
b20	120					
b21	120					
b22	2000	z* =	= 228 682.20			

It should be remarked that it is the mixed integer programming problem with thirteen integer variables  $(x_i)$ , 30 continuous variables (26  $b_i$  and 4  $d_i$ ), and four binary variables  $(y_i)$ . Its optimal solution is obtained by MATLAB and is presented in Table V. Optimal value of the objective function is:  $z^* = 228682.20$  and for that production the available budget is not completely spent. The reason for that is the production lines constraints that do not allow higher production. In this table, we can see the required quantities of raw materials. For the fifteenth raw material (S15), we have the quantity discount because we purchase this raw material (semiprecious stone of 12 mm) over the limited quantity ( $Q_{15}$ = 4200 pieces). In our model, of course, the binary variables  $y_1$ and  $y_4$  are equal to 1. The seventh raw material (Small space) have to be purchased over the limited quantity and so the quantity over the limit ( $Q_7 = 30000$ ) is purchased at a higher price. The same happens for the twelfth raw material (Semi precious stone 4 mm), and we purchase additional quantity at the higher price (0.25 kn/piece).

# IV. CONCLUSION

In this paper, the De Novo programming model in the production plan optimization of the production of stone souvenirs is considered. The efficiency of the proposed model is investigated on the case of a company that produces 13 various souvenirs. The De Novo approach does not limit the resources as most of the necessary resource quantities can be obtained at certain prices. Resources, of course, are actually limited because their maximum quantity is controlled by the budget, which is an important element of De Novo.

The obtained results indicate a high application efficiency of the proposed model by using the De Novo programming in solving the production plan optimization problem in various production companies. Using the De Novo approach, most varied cases can be handled more effectively than by the standard programming models and in this paper increasing costs of raw materials and quantity discounts for some raw materials in souvenirs production are investigated.

The future work on this issue will investigate the possibilities of introducing new objective functions in the model, and solving this production problem as the multi-criteria ones [4]-[6].

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