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:

Zoran Babic is with the Faculty of Economics, Department for Quantitative Methods and Decision Theory, University of Split, Cvite Fiskovića 5, 21000 Split, Croatia, (e-mail: babic@efst.hr, phone: +385 21 430 643)

Ivica Veza, Anđela Balić, and Marina Crnjac are with the Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split, R.Boškovića 32, 21000 Split, Croatia, (e-mail: iveza@fesb.hr, abalic@fesb.hr, mcrnjac@fesb.hr).

$$Max \ z = c_1 x_1 + c_2 x_2 + \cdots + c_n x_n \quad (1)$$
$$\text{s.t.} \ a_{11} x_1 + a_{12} x_2 + \cdots + a_{1n} x_n = b_1$$
$$a_{21} x_1 + a_{22} x_2 + \cdots + a_{2n} x_n = b_2$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$
$$a_{m1} x_1 + a_{m2} x_2 + \cdots + a_{mn} x_n = b_m$$
$$p_1 b_1 + p_2 b_2 + \cdots + p_m b_m \le B$$
$$x_j, b_i \ge 0, \ j = 1, 2, \ldots, n; \ i = 1, 2, \cdots, m$$

where, $b = (b_1, b_2, \cdots, b_m)$ – 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:

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

with additional constraint $b_i \le Q$, 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

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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:

$$a_{k1}x_1 + a_{k2}x_2 + \cdots + a_{kn}x_n = b_k + d_k \qquad (3)$$
$$b_k - Q^* y_1 \leq 0$$
$$d_k - Q\, y_2 \geq 0$$
$$d_k - M\, y_2 \leq 0$$

and, according to this, the budget constraint is:

$$p_1 b_1 + p_2 b_2 + \cdots + p_k b_k + p_k' d_k' + \cdots + p_m b_m \leq B, \qquad (4)$$

where M is a very large positive number ($M \gg 0$), 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:

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

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:

$$\text{Max } z = \sum_{j=1}^{n} s_j x_j - \sum_{i=1}^{m} p_i b_i - \sum_{k \in K} p_k' d_k \qquad (6)$$

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:

$$\sum_{i=1}^{m} p_i b_i + \sum_{k \in K} p_k' d_k \leq B \qquad (7)$$

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 Lower bound	Selling prices (kn) 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

	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	
b7	**Space small ≤ 30000**	**0,06**	**kn/piece**	**Increasing**
d7	**Space small > 30000**	**0.08**	**kn/piece**	**costs**
b8	**Bead metal 4 mm ≤ 25.000**	**0.04**	**kn/piece**	**Quantity**
d8	**Bead metal 4 mm > 25.000**	**0.02**	**kn/piece**	**discounts**
b9	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 ≤ 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

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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. $B = 99\ 430$ 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:

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

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:

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

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:

$$b_8 - 24990\ y_1 \leq 0, d_8 - 25000\ y_2 \geq 0, d_8 - M\ y_2 \leq 0 \quad (11)$$

$$b_{15} - 4190\ y_3 \leq 0, d_{15} - 4200\ y_4 \geq 0, d_{15} - M\ y_4 \leq 0 \quad (12)$$

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:

$$\sum_{i=1}^{26} p_i b_i + \sum_{k \in K} p_k 'd_k \leq 99430 \qquad (13)$$

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:

$$b_7 \leq 30000, b_{12} \leq 3500 \qquad (14)$$

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

$$x_1 + x_2 \leq 1800 \qquad \text{(bracelet production line)} \qquad (15)$$

$$x_6 + x_7 \leq 300 \qquad \text{(necklace 1 production line)} \qquad (16)$$

$$x_8 + x_9 \leq 200 \qquad \text{(necklace 2 production line)} \qquad (17)$$

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

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

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	**b7**	**30000**
X8	120	**d7**	**1200**
X9	80	**b8**	**22920**
X10	500	**d8**	**0**
X11	500	b9	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_j), 30 continuous variables (26 b_i and 4 d_i), and four binary variables (y_j). 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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Zoran Babic was born in Zagreb, Croatia, on December 24, 1948. He earned a bachelor's degree in 1973, at Faculty of Natural and mathematical Science, University of Zagreb, Croatia and master's degree in 1982, Faculty of Economics, University of Zagreb in Croatia. He earned a PhD degree in 1991 at Faculty of Economics, University of Split, Croatia.

Today, he is a full professor for Decision Theory, Business Decision Making, Quantitative Methods for Management and Mathematics at Faculty of Economics, University of Split, Croatia.

Dr. Babic was Head of the Department for Quantitative Methods and he is a member and former president of the Croatian Operational Research Society.

Ivica Veza was born in Split, Croatia, on August 26, 1951. He earned a bachelor's degree in 1975, master's degree in 1985 and a PhD degree in 1991 at Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Croatia

Today, he is a full professor for Operational Management, Project management, Organization, Logistic and Plant Layout at Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split.

Dr. Veza is Head of the Department for Industrial Engineering, a member of European Academy for Industrial Management, Croatian Academy of Engineering, Verein Deutscher Ingenieure VDI ect.

Anđela Balic was born in Split, Croatia, on November 24, 1989. She earned her master's degree in 2016, in Industrial Engineering at Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split.

Today, she works as an advisor at Splitska Bank

Marina Crnjac was born in Split, Croatia, on April 29, 1991. She earned a bachelor's degree in 2013, and master's degree in 2015, in area of Science in Industrial Engineering at Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split. She is a PhD student at Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, her field of research is production engineering.