

PRODUCTION MANAGEMENT ANALYSIS USING MONTE CARLO METHOD

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Abstract

The article presents the simulation method assessment of production management model. Input variables and required assumptions for the simulation are defined based on production requirements. For selected variables both data and expert based distributions are determined. The values of production efficiency coefficients are calculated according to variability of various operating parameters. On the basis of simulation results, the probability of achieving required production output is calculated.

Key words: production management, stochastic optimization, Crystal Ball

1. INTRODUCTION

The main tool for the production planning is linear programming. This method has been widely described in the literature (Dantzig, Thapa 1997, Gottlieb 2013, Hari 2008, Odnoha 2011, Renna 2013). When the optimisation criteria are non-linear and there is more than one criterion, small and medium manufacturers encounter problems when optimizing production. There is a wide variety of methods for solving multi-criteria optimization problems (Chen, Lee 2011, Ehrgott, Gandibleux 2002, Ishizaka, Nemery 2013, Pardalos 2008, Rachev 2008) however, little companies cannot afford to buy the optimization tools and train their staff to use them. Currently multi-criteria optimization is mostly used by big corporations in field such as aerospace, chemical and energy. For the needs of small companies there is a range of simpler tools available which may not have all the features of the corporate versions but still allow to run simple stochastic optimisation. This article shows the stochastic optimisation model (using Monte Carlo method) of production planning using Oracle Crystal Ball, using the example of metal manufacturing company.

2. PROBLEM DESCRIPTION

The medium-sized metal manufacturing company produces containers of various types for automotive and motorcycle parts, communal waste etc. The main part of the production is containers made from steel sheets and mesh. A demand for the containers varies over time. All products are made from three main types of steel materials: AISI 316 steel sheet, AISI 316 corner and SS 316 steel mesh (Table 1). The usage of each type in different products is shown in Table 1.

	AISI 316 Sheet [m ²]	AISI 316 Corner, [m]	AISI 316 Rectangular Mesh, [m ²]
Product 1	1.5	9	0.25
Product 2	1.8	12.6	0.38
Product 3	2.2	11	0.40
Product 4	2.7	16.2	0.45
Product 5	0.25	10.5	1.50
Product 6	0.38	14.4	1.8
Product 7	0.4	15.4	2.2

Table 1. Composition of manufactured products. Source: Author's own research

The company manufactures broader range of products using the same resources, therefore the resources are not only consumed by the seven products shown in the Table 1 and no assumption should be made regarding the changes in the inventory stock base on just those products; the stock inventory is treated as stochastic variable. The company does not own the materials in the stock, they belong to an external company and the prices are changing according to the market prices. Indirect costs vary depending on the total company turnover. The price is calculated according to “costs plus” and it influences the demand which is negatively correlated with the price. The manufacturer has limited storage space so they have to store the not sold containers in the supplier’s warehouse which introduces extra charges. The article presents process of optimization for profit for selected seven typical containers using three materials, taking into consideration stochastic characteristics of material prices, indirect costs, price correlation with stochastically variable demand.

3. ASSUMPTIONS TO PRODUCTION MANAGEMENT MODEL

The source of uncertainty is the steel price. Due to limited storage the company cannot keep reserves for a long period. The steel is used as needed and the producer is charged by the supplier monthly. The AISI 316 steel sheet price follow the Minimum Extreme distribution (Figure 1), the indirect cost factor is consistent with Beta distribution (Figure 2), the mesh and steel corner prices are of similar like steel sheets distribution since all are strictly correlated with market steel price. The inventory distribution was determined based on the stock observation, for AISI 316 sheets it was a triangle distribution with minimum, most likely and maximum values: 1,200; 1,500; 1,700. A mark-up on price distribution is also of triangle shape (minimum, likeliest, maximum values: 0.05, 0.07, 0.15). The demand was determined on the basis of the manufacturer’s research (Poisson distribution, range 0-300, rate 150, Figure 3). The price and the demand correlation coefficient is equal to -0.75 (Figure 4).

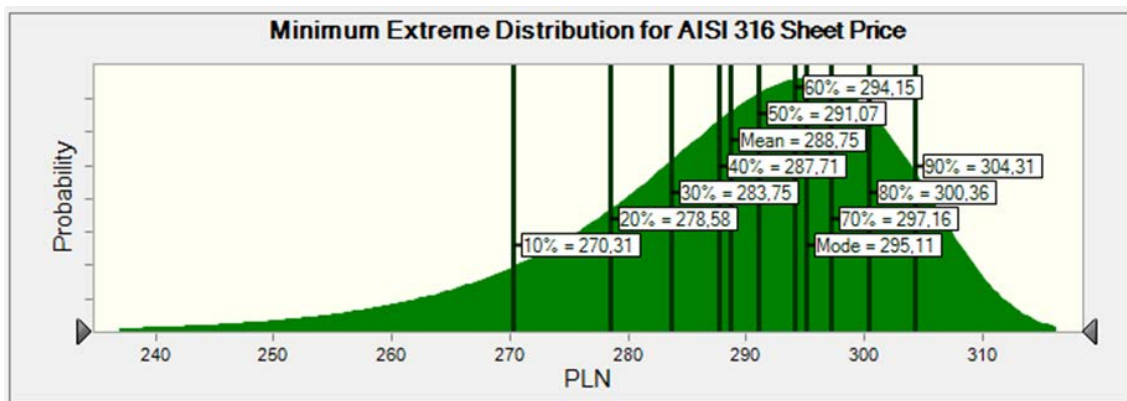


Figure 1. AISI 316 steel sheet price Minimum Extreme distribution.

Likeliest value: 295.11; scale: 11.02. Source: Author’s own research

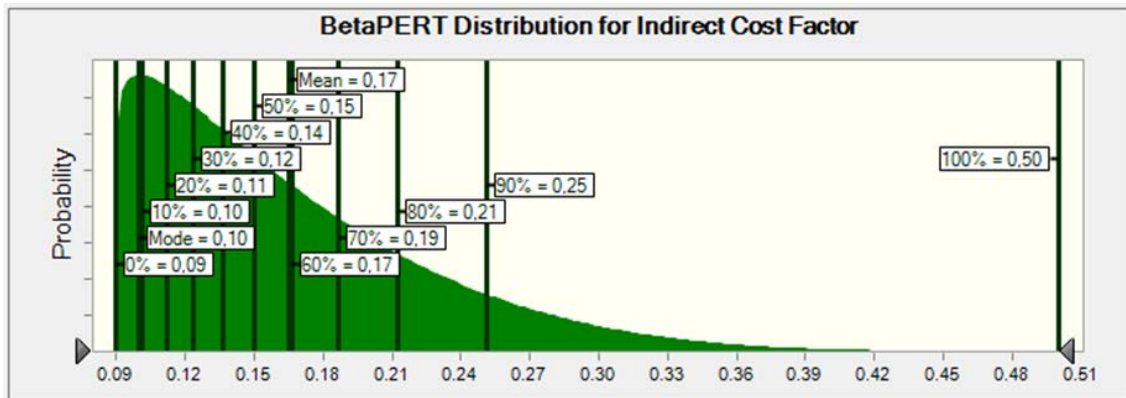


Figure 2. Indirect costs distribution.

The characteristic values: minimum 0.09, likeliest 0.1, maximum 0.5. Source: Author's own research

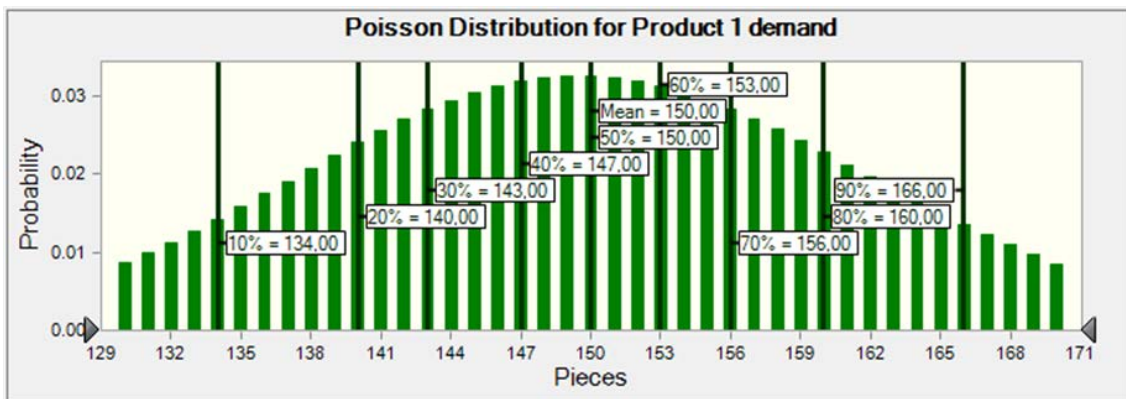


Figure 3. Poisson distribution for Product 1 demand.

The characteristic values: range 0-300, rate 150. Source: Author's own research

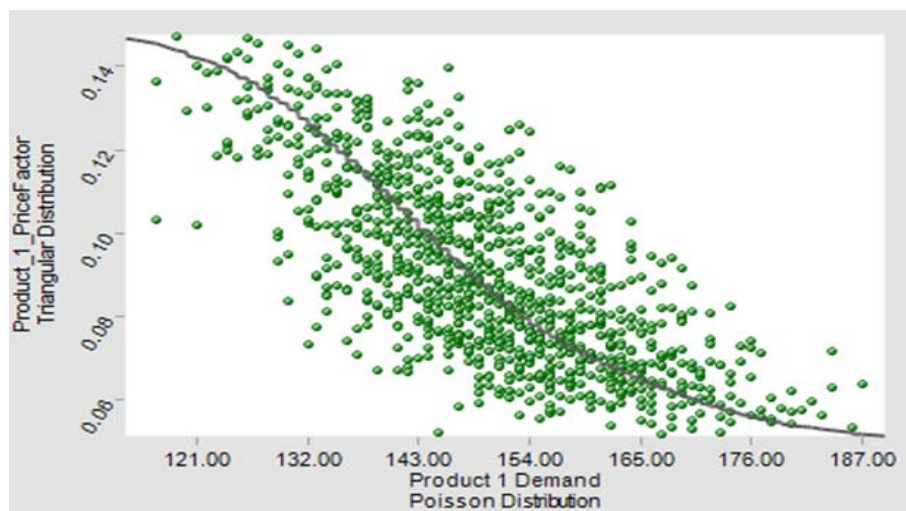


Figure 4. Correlation chart for price factor and the demand of Product 1. Source: Author's own research

The aim of the optimization model was to maximize the mean value of profit P calculated as a total sum of profits for all products calculated as a sum of costs of: materials M , man-hour M_h , and machines M_{ch} increased by indirect costs, multiplied by price factor p_i and decreased by total cost C :

$$P = \max \sum \left(\left(\sum (M, M_h, M_{ch}) + I_c \right) p_i - C \right)$$

The decision variables: the quantity Q_i of manufactured products which were adjusted in order to achieve maximum profit.

Constraints, understood as relationships of decision variables were:

- total number of manufactured products $\sum Q_i$ cannot exceed the demand,
- profit P must be greater than zero,
- if not sold, products are sent to the stock, the quantity cannot exceed the stock capacity,
- the material used must not be greater than the inventory.

Requirements regarding forecasts:

- 5th percentile of total profit must be greater than zero,

The model cannot be solved using simple linear programming because many variables are stochastic. To find the best solution the Oracle Crystal Ball's OptQuest tool was used. The tool uses the Monte Carlo method for simulating the results. All simulation assumptions have been presented in Figure 5.

Best Solution:			
Objectives		Value	
Maximize the Mean of Total profit		299884,16	
Requirements		Value	
The 5% Percentile of Total profit must be greater than or equal to 0,00		251377,41	
Constraints		Left Side	Right Side
Total amount on stock must not exceede stock capacity		0	100
Profit of Product 1 must be greater then or equal to 0		24839,49888...	0
Profit of Product 2 must be greater then or equal to 0		2702,425160...	0
Profit of Product 3 must be greater then or equal to 0		43752,78888...	0
Profit of Product 4 must be greater then or equal to 0		58859,13106...	0
Profit of Product 5 must be greater then or equal to 0		37647,54237...	0
Profit of Product 6 must be greater then or equal to 0		62644,72355...	0
Profit of Product 7 must be greater then or equal to 0		84870,64496...	0
Quantity of Product 1 must be smaller than Demand		120	155
Quantity of Product 2 must be smaller than Demand		10	139
Quantity of Product 3 must be smaller than Demand		160	191
Quantity of Product 4 must be smaller than Demand		190	307
Quantity of Product 5 must be smaller than Demand		160	197
Quantity of Product 6 must be smaller than Demand		250	257
Quantity of Product 7 must be smaller than Demand		280	289
Sheet used must be less than inventory		1310	1322,791956...
Comer used must be less than inventory		15636	15750,26097...
Mesh used must be less than inventory		1489,3	1858,522950...

Figure 5. Simulation assumptions and best solution of the simulation. Source: Author's own research

4. SIMULATION RESULTS

The products that are the subject of discussion are not manufactured for any specific customer. There is relatively stable demand and the producer decided to have some products in stock. They have a relatively small werehouse (just for one month production and the not sold products have to be stored in the supplier's stock, which costs 50 PLN for every product per month), that is why the producer would like to prepare only the optimal quantity of products. Before they rated the demand they produced only 100 pieces of each product. They achieved a profit of 100,106 PLN monthly even though they could have achieved the average 178,312 PLN (Figure 6). The difference between the demand and production was on average 850 pcs. (Figure 7) which resulted in lost revenue of 123,816 PLN. After a demand evaluation the best results turned out to be achieved when supply met demand however, due to limited amount of raw materials in stock this was not possible. Additionally the stock capacity was unknown. On the basis of observations only the probability distribution was known. After simulation the optimal solution for maximising profit was determined. The best solution results were presented in Figure 5. After simulation the new quantity of products allowed to achieve optimal solution. The profit value calculated for this exact products quantity was 168,537 PLN, but the mean value resulted from the simulation was 299,884 PLN (Figure 8).

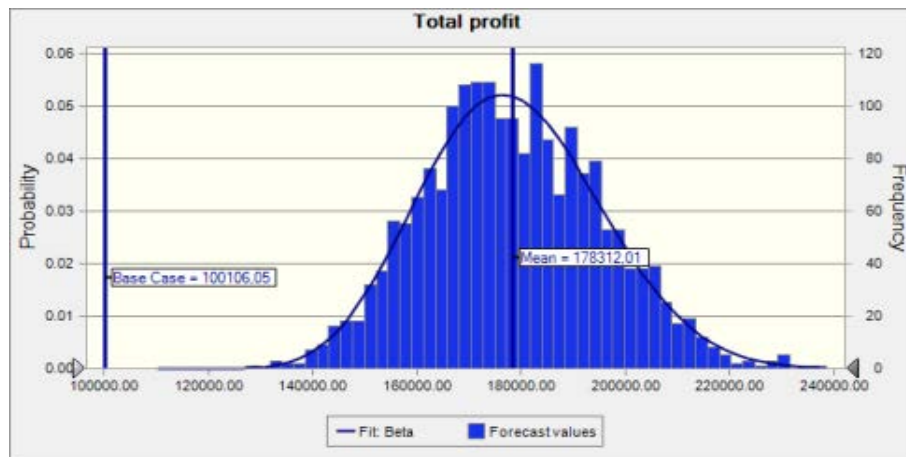


Figure 6. Distribution of total profit assuming production of 100 pcs. of each product.

Source: Author's own research.

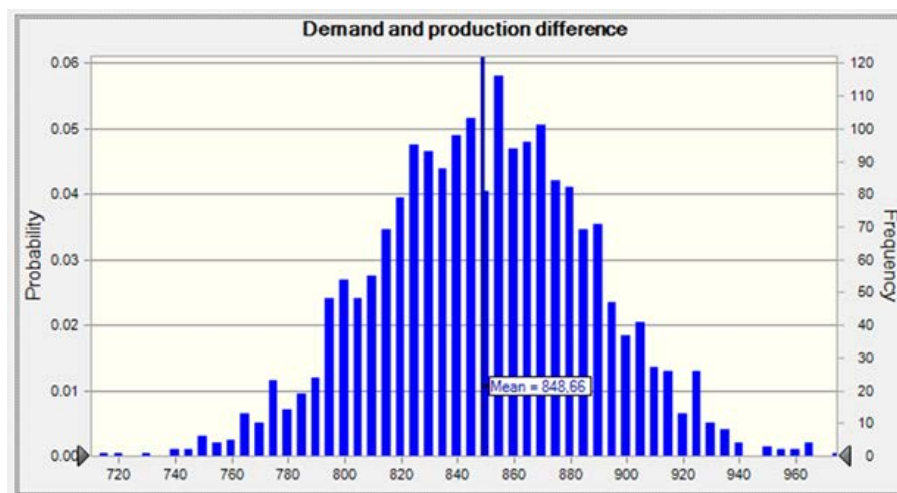


Figure 7. Distribution of the difference of the demand and the quantity of production assuming manufacturing of 100 pieces of each product. Source: Author's own research

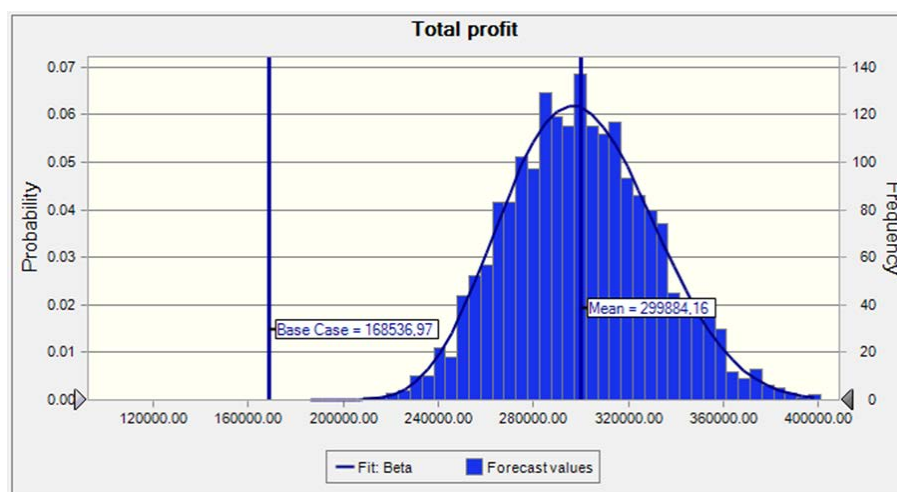


Figure 8. Distribution of total profit after the optimisation. Source: Author's own research

5. SUMMARY

Using OptQuest Oracle Crystal Ball tool allowed to choose the best quantity of manufactured products. The optimization results are presented in the Table 2.

	Products quantity calculated during the simulation	Mean value of the demand	Difference between the demand and sold products	Lost revenue	Profit
Product 1	120	150.00	35	4503.32	15439.97
Product 2	10	150.00	129	19246.32	1491.96
Product 3	160	200.00	31	4784.20	24692.64
Product 4	190	300.00	117	22042.94	35796.22
Product 5	160	200.00	37	3899.00	16860.55
Product 6	250	250.00	7	948.26	33866.30
Product 7	280	300.00	9	1256.62	39094.73
Total				56680.66	167242.37

Table 2. Optimisation results. Source: Author's own research

The difference of mean profit value before and after the optimization is higher than 120,000 PLN. Each time when running the simulation one can achieve different optimal combination of the manufactured products, however, the profit remains constant. The mean value of the difference between the demand and the number of produced goods is 318. The only possibility for minimizing it is to set this value less or equal to, for example, 100 pcs., but during the simulation the mean value, in this particular case, does not change and remains the same. The distribution of this mean value is presented in the Figure 9. Nonetheless using the stochastic model of the production and optimizing the number of manufactured products allows the company to nearly double its profit.

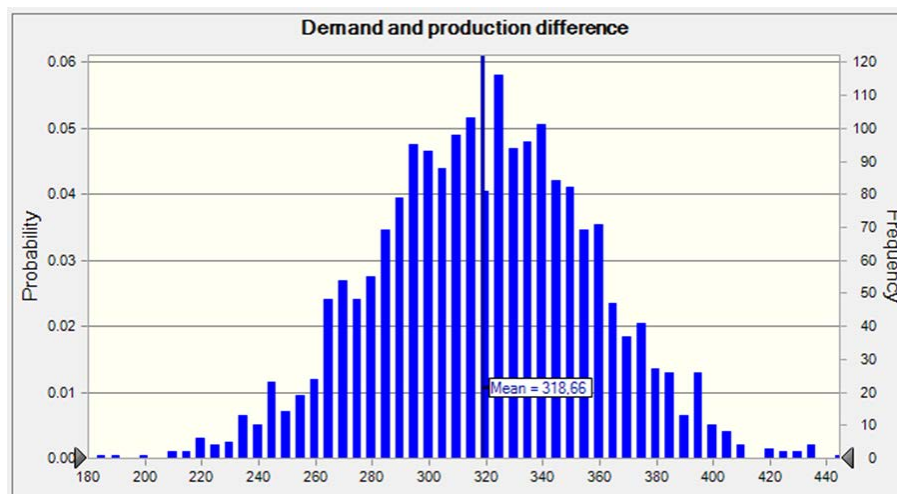


Figure 9. Distribution of the difference of the demand and the quantity of production after the simulation. Source: Author's own research.

In the long run the manufacturer would like to minimize the lost profit resulting from not meeting the demand, for that they introduced a new factor – the lost revenue. They would like to sell the goods to as many customers as possible, because when the customers cannot buy the product from this manufacturer, they could change the supplier and never come back, however, simple optimization tool only allow to optimising for one criteria therefore to solve that problem the company have to invest in high optimisation tools.

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