DETERMINATION OF OPTIMAL PRODUCTION VOLUME RESPONDING ENVIRONMENTAL CRITERIA

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Environmental protection, quality requirements for products, eco –design of materials, increasing of production volume and market competition force the manufacturers to adapt to these requirements and also to economic issues.

A mathematical method is applied to the solution of this problem. The individual factors of environmental and economic character are expressed by means of different equations having universal validity. The most important factor of the given ones is the so called natural capital, alias natural resources. They are derived from the environment. Each of summarized criterions is represented by its graphical form. An application to the automotive industry closes the paper.

KEYWORDS

optimal production volume, environmental criteria, mathematical modelling, eco-design, environment

1 INTRODUCTION

Determination of the optimal production volume, applying mathematical methods and eco-design principles is a significant step towards the presentation of environmental and economic problems at source and hence towards a more sustainable society. Integration of environment aspects into the familiar product development process is important from both the environmental and business perspective. Eco-design projects, including exact methods, carried out all over the world have shown that besides helping improve the environment, eco-design and its mathematical tools also often offer business financial benefits [1], [2].

Exact access of the developing engineering products is one of the possibilities, how to achieve the environmental and economic objectives. There are a lot of different analytical tools, by means of it can be carried out. One of such tools is described in this paper.

2 ENVIRONMENTAL AND ECONOMIC FACTORS AND THEIR EXPRESSION

Preferably let us consider a production complex (for example, an engineering factory), situated in some locality, manufacturing x products during a time unit. The different harm-full components are created in that process, too, having impact on the environment. The disposable quantity of the so called natural capital is necessary to the activity of the considered production system. Natural capital is classifying to the non-renewable natural resources, and is derived from the environment. Minerals and fossil fuels are included in this category [3, 4, 5].The structure of natural capital can be the following:

- ores and their concentrates,
- raw material of energetic character (except of natural gas and
- crude oil,
- natural gas,
- crude oil.

Some sources and authors include selected metals and their semi-finished products, selected plastics and their semi-finished products, consumption of electric energy per year. [3, 6, 7, 8]

Let C_1 is a disposable quantity of natural capital during a year, for production of x products [9, 10].If the value of x is increasing; of course, the value of C_1 will be decreasing. The following formulas can express this situation - $C_1/x \rightarrow 0$, and

$$K_1(x) = \frac{C_1}{x} \tag{1}$$

The factory must carry out activities for environment protection according to the valid legislature. Starting from the environment protection structure [1, 11, 12, 13] these costs can be expressed as

$$T_{cep} = E_e + E_{ep} + E_s \tag{2}$$

where: T_{cep} -total costs for environmental protection,

E_e, E_{ep}, E_s - main cost components of economic, environmental, and social character.

The economic part consists of these particular ones:

$$E_e = E_{ccep} + E_f + E_{ded} \tag{3}$$

where: E_{ccep} - capital expenditure in connection to the environment protection,

E_f - over-heads of the factory,

E_{ded} - costs depending from the environment degradation (fines, fees, etc.).

The over-heads depend from the quantity of manufactured products *x*, so

$$E_f = M_c * x \tag{4}$$

where: M_c - manufacturing costs per one unit of product.

Environmental part of the total costs consists of two items:

$$E_{ep} = EC_o + EC_i \tag{5}$$

where: EC_o and EC_i are environmental costs from the point of view of so called outside and inside environment, if

$$EC_o = Q_{sw} + Q_e + Q_{lw} \tag{6}$$

and

$$EC_i = Q_i * x \tag{7}$$

where: Q_{sw} - quantity of solid wastes,

Q_e - quantity of emissions,

Q_{lw} - quantity of liquid wastes,

Q_i - quantity of imissions inside the factory

All the presented items are incipient during the manufacturing of one product.
Particular result for the ENV is:

$$E_{ep} = (Q_{sw} + Q_e + Q_{lw} + Q_i) * x \tag{8}$$

If the total costs for environment protection will be signified as $K_2(x)$, then after some derivations,

$$K_2(x) = C_2 * x + E_{ccep} + E_{dcd} \tag{9}$$

where:

$$C_2 = M_c + Q_{sw} + Q_e + Q_i + Q_{lw} \tag{10}$$

The total costs for the manufacturing of x products in a factory, can be expressed as $K(x) = K_1(x) + K_2(x)$, and applying the substitutions, the following equation is obtained:

$$K(x) = \frac{C_1}{x} + C_2 * x + E_{ccep} + E_{ded} \tag{11}$$

The optimal number of products x is can be obtained after the differentiation of the equation (11) - i.e.

$$\frac{dK(x)}{dx} = -\frac{C_1}{x^2} + C_2 = 0 \tag{12}$$

and

$$x_{opt} = \sqrt{\frac{C_1}{C_2}} \tag{13}$$

If $x = x_{opt}$ and $E_{ccep} + E_{dcd} = C_3$, after substituting these expressions to the equation (11), the minimal value of the function $K_{(x)}$ is determined as

$$K_{\min} = \frac{C_1}{\sqrt{\frac{C_1}{C_2}}} + C_2\sqrt{\frac{C_1}{C_2}} + C_3 \tag{14}$$

The graphical interpretation of these results is given in Fig. 1.

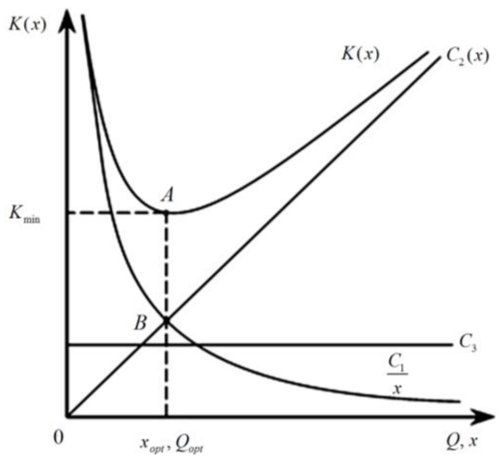

Figure 1. Graphical interpretation of the compromise solution between the economic and the environmental demands in the mechanical engineering industry

3 DISCUSSION

The discussion deals with:

- The curve K(x) sometime called as the curve of the sustainable development - has its minimum (point A), and represents, according to some approach, the compromise solution between the economic and the environmental demands on the micro-economic level.
- Consumption of the natural capital (habitually per annum) is gradually reduced by growing production, which is compensated with costs - to eliminate this consumption. Point B represents equality of both - costs and thus the economic optimum of the environment quality - Q_{opt}.
- The environment protection costs have their initiation part of the constant value, which consists of the capital expenditure part E_{ccep} and constant payments E_{ded}. It is presumed that E_{ded} = const., to the $x = x_{opt}$ value. If $x > x_{opt}$, it will probably depend from the other concrete conditions.
- Perhaps, the presented method and approach can be applied to some parts in the LCC (Life Cycle Costing) analysis.

4 AN APPLICATION IN THE AUTOMOTIVE INDUSTRY

An European redoubtable car producer has provided some important input data to test the method described in this paper. These data are intentionally misrepresented (because of the firm secret). According to the provided data, the particular values of the function K(x) = f(x) have been computed for a passenger car - vehicle weight ~ 1200 kg, and the following material structure [in %]: Ferrous 66, Aluminum and other light alloys 12, Plastics 12, Rubber 4, Glass 4, Zinc 1,5, Copper and its alloys 0,5 [7, 13]. The computed data are illustrated in Tab. 1.

Table 1 The particular values of the function K(x) = f(x), the numbers in the right side of the columns are the exponents y, the particular values in the left side of the columns are multiplied by 10y.

x	y	C_1/x	y	$C_2.x$	y	K(x)	y
1		5,00	11	8,50	9	5,08	
2		2,50	11	1,70	10	2,67	
3		1,66	11	2,55	10	1,92	
4		1,25	11	3,40	10	1,59	
5		1,00	11	4,25	10	1,42	
6		8,33	10	5,10	10	1,34	
7	5	7,14	10	5,95	10	1,31	11
8		6,25	10	6,80	10	1,30	
9		5,55	10	7,65	10	1,32	
10		5,00	10	8,50	10	1,35	
11		4,54	10	9,35	10	1,38	
12		4,16	10	1,02	11	1,43	
13		3,84	10	1,10	11	1,48	
14		3,57	10	1,19	11	1,54	
15		3,33	10	1,27	11	1,60	
16		3,12	10	1,36	11	1,67	

The graphical representation of the function K(x), and its relevant parts, is illustrated in Fig.2.

The C_3 part is not illustrated in Fig. 2, because of its irrelevant influence and constant value. Some comments to the Fig. 2:

- Value K_{min} of the curve $K_{(x)}$ expresses a compromise between the economic and the environmental demands.
- The curve C_1/x is the curve of the natural capital consumption during the car production in the factory.

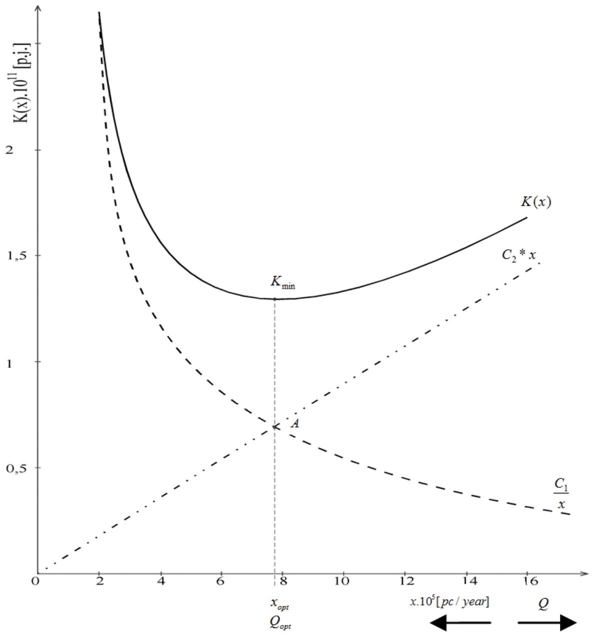

Figure 2. The curve of the sustainable development for the presented application (the passenger car production) [5]. Abbreviations: m.u. - monetary unit pc - pieces.

- x_{opt} is the optimal car production volume per year (about $7.8.10^5$) for the given conditions.
- Q_{opt} is the optimum value of the environment quality for the given production process character.
- Point A represents the compromise solution.

5 CONCLUSION

There is the need for systematic approach to organize a factory in such a way that improving the environmental and economic performance of their products across product life cycles becomes an integrated part of operations and strategy. Determination of optimal production volume has operational and strategic purpose, too. The described method represents the way , how to determine it. An application in the automotive industry, this approach can bring not only environmental, but also economic benefits, as shown in the paper.

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