Using the decisions theory for establishing the site of a new manufacturing sector

N Rachieru¹, N Belu¹, L M Ionescu² and D C Anghel³

¹University of Piteşti, Faculty of Mechanics and Technology, Department of Manufacturing and Industrial Management, 110040 Pitesti, Targu din Vale, no. 1, Argeş, Romania
²Faculty of Electronics, Computers and Electrical Engineering, University of Pitesti, Targu din Vale, No.1, Pitesti, Romania

E-mail: nadia_belu2001@yahoo.com

Abstract. Making any investment is an important decision that produces effects with material, financial and human implications, most of the time significant ones. The paper aims to argue, by using the methods of the decision theory, the variant chosen for the expansion of a company in order to introduce new benchmarks required by the market in production. After an analysis of the existing situation, it was noted that the company did not have sufficient capacity, regardless of the improvements made, so an expansion was necessary and justified. Depending on the space and financial resources the company has at its disposal, there are several possibilities for expansion and each implies certain elements. There are three physical variants of expansion, namely: the construction of a new bay, the expansion of the company’s central building or the expansion of an outbuilding. Considering that for the possible variants the decision consequences are known, in order to solve the case study the methods for optimizing the decisions under certainty conditions will be used, namely: ELECTRE method, one of the most complex and used methods of optimizing multi-criteria decisions; Onicescu method which solves the same type of problems by means of specific algorithms and the method of coefficient K, using relations from the theory of fuzzy sets.

1. Introduction
The constantly changing market environment provided by the market economy requires companies producing material goods, permanent adaptation to the new conditions, increased efficiency and high productivity. This involves, first of all, introducing new products in production in order to meet customer requirements, which must be made with minimal investment. Introducing a new benchmark into production involves either adapting an existing production line or organizing a new line. The second situation occurs when either no technical adaptation can be made, or the existing production capacity does not allow for expansion. The organization of a new line or a new section implies increasing the production capacity and solving the problem, but in both situations, first of all, their spatial location has to be analyzed. In order to achieve increased efficiency in production systems it is necessary to design the location of the company subunits based on detailed studies aimed at:

- the most judicious use of space;
- minimum distances between workplaces;
- minimum handling and transshipment of materials, parts and subassemblies.

Location studies focus on two levels:
- the location of new companies, plants and factories;
- relocation of jobs within the company or factory according to the new production requirements. Given the dynamic nature of production in the market economy, location solutions must have an adequate degree of flexibility, be adaptable to future changes regarding the products and production technology. The basic objective of the location is to develop a production system that best sets the capacity and quality requirements, namely to ensure:
- the space needed for the machines, workstations and storage required for existing and possible production programs;
- a rational flow of materials;
- the space required for the auxiliary services required by the normal development of the production process.
- adaptability to new products and to the improvement of the manufacturing process;
- protection against fire;
- compliance with technical and sanitary requirements in relation to the degree of nuisance of the company.

The analyses and studies on the location of a new production line or section contain mandatory elements of management decision theory \[1\], \[2\]. In today’s complex and contradictory world, the adoption and enforcement of a performing decision is increasingly difficult and, at the same time, absolutely necessary.

2. Presentation of the methods use

2.1. ELECTRE method

Elimination and Choice Expressing Reality - ELECTRE, developed by Bertrand Roy in 1967 \[3\], \[4\] is a tool for optimizing decision-making under certainty conditions. The method is used to solve very complex decision problems, both in terms of the number of variants \(V_i\) \((i = 1, m)\) possible to achieve an objective, and in terms of the decision criteria \(C_j\) \((j = 1, n)\) that influence the decision consequences of each variant. Applying the method involves going through the following steps \[5\], \[6\]:

**Step 1:** Establishing the decision variants and the related consequences materialized in their “dimensions”.

**Step 2:** The utilities are set for each variant and criterion; the results are presented in the form of a matrix, table 1.

**Table 1. Utilities Matrix.**

| \(V_i\)/\(C_j\) | \(C_1\) | \(C_2\) | \(\ldots\ldots\) | \(C_{in-1}\) | \(\ldots\) | \(C_n\) |
|-----------------|--------|--------|-----------------|------------|--------|--------|
| \(V_1\)         | \(U_{11}\) | \(U_{12}\) | \(\ldots\ldots\) | \(U_{1n-1}\) | \(\ldots\) | \(U_{1n}\) |
| \(V_2\)         | \(U_{21}\) | \(U_{22}\) | \(\ldots\ldots\) | \(U_{2n-1}\) | \(\ldots\) | \(U_{2n}\) |
| \(V_n\)         | \(U_{n1}\) | \(U_{n2}\) | \(\ldots\ldots\) | \(U_{nn-1}\) | \(\ldots\) | \(U_{nn}\) |

\(C_j\) = criteria for conditioning the decision consequences
\(V_i\) = decision variants
\(U_{ij}\) = the utility of variant i, conditioned by criterion j.

**Step 3:** Establishing the *indexes of concordance* between two variants given the equation (1):
\[
C(V_i, V_h) = \frac{\sum k_j}{k_1 + k_2 + \ldots + k_m}
\]  

(1)

where:
\(k_j\) (j = 1 \ldots m) = the coefficients of importance of the criteria considered.
\[\sum k_j = \text{the sum of the coefficients of importance of the criteria for which the condition is met:} U(V_i) \geq U(V_h)\]

**Step 4:** Establishing the *indexes of discordance* with the equation (2):

\[
D(V_i, V_h) = \begin{cases} 0, & \text{dac} \ U(V_i) \geq U(V_h) \\ \frac{1}{\alpha} \max \{U(V_i) - U(V_h)\}, & \text{daco} \end{cases}
\]  

(2)

for \(U(V_i) \geq U(V_h), \alpha = \text{the maximum difference between maximum and minimum utility.}\)

**Step 5:** determining the optimal variant takes place by successive outranking operations of the form:

\[
\begin{cases} C(V_i, V_h) \geq p \\ D(V_i, V_h) \leq q \end{cases}
\]

(3)

where p and q are some thresholds, a pair of values between 0 and 1 (p is as close to 1, q is as close to 0). From the outranking relations results a series of graphs \(G(p,q)\) from which the optimal variant is deduced. As p decreases and q increases, the variant that outranks the others is obtained.

Countering some ELECTRE method drawbacks has been the concern of specialists in the field, which has led to the emergence of other methods.

### 2.2. ONICESCU method

The ONICESCU method [6], [7] tries to solve the same type of decision problems through specific algorithms. The method involves going through the following steps [7], [8]:

**Step 1:** determining the consequences of decision variants and inserting them into matrix A

**Step 2:** arranging decision variants for each criterion, depending on the level of consequences, the result being also presented in matrix form (matrix B).

**Stage 3:** developing matrix C, by specifying how many times a variant i occupies the place j. It will have the following configuration:

\[
C = \begin{pmatrix} \alpha_{11} & \alpha_{12} & \ldots & \alpha_{1m} \\ \alpha_{21} & \alpha_{22} & \ldots & \alpha_{2m} \\ \ldots & \ldots & \ldots \\ \alpha_{m1} & \alpha_{m2} & \ldots & \alpha_{mm} \end{pmatrix}
\]  

(4)

where \(\alpha\) – whenever the variant i occupies the place j

**Step 4:** prioritizing variants after an aggregate function of the form:

\[
f: V \rightarrow \mathbb{R}_+, \ f(V_i) = \frac{\alpha_{11}}{2} + \frac{\alpha_{12}}{2^2} + \ldots + \frac{\alpha_{1m}}{2^m}
\]

(5)

**Step 5:** choosing the best option - the option with the highest \(\hat{f}(V_i)\)

This method attempts to eliminate the most important limit of the ELECTRE method that of the incompatibility of the means to substantiate the discordance and concordance indexes used in determining the optimal variant.
2.3. The method of coefficient $K$

When using this method, start from the matrix of decision consequences [8]. Based on this, the matrix of “degrees of distance” is determined by the relations of the theory of fuzzy sets. So,

- for the maximization criteria, the degree of distance of the decision variant $V_i$, compared to the best variant for the decision criterion $C_j$, is in equation (6):

$$x_{ij} = \frac{(a_i)_\text{max} - a_{ij}}{(a_i)_\text{max}}$$

(6)

- for the minimization criteria, the degree of distance of the decision variant $V_i$, compared to the best variant for the decision criterion, $C_j$, is in equation (7):

$$x_{ij} = \frac{a_{ij} - (a_j)_\text{min}}{(a_j)_\text{min}}$$

(7)

With the help of these, a matrix of the degrees of distance is made, which allows for the determination of each decision variant of the coefficient $K^*$.

$$K^* = \sum_{j=1}^{n} x_{ij} K_j,$$

(8)

where $K_j$ is the coefficient of importance of criterion $j$.

Choose the optimal variant, the one for which $K$ has the lowest value. The advantage of the method is that it also operates with the coefficients of importance of the decision criteria and the limit is given by the fact that only quantifiable decision criteria can be used.

3. Case study

The case study company has more than 35 years of experience in manufacturing plastic products. The products of the company are primarily meant for consumers in the hospitality industry, accounting for 72% of total sales, but also for individual 22% and industrial 6% consumers. The largest share in the sales structure is represented by: plates, cutlery, finger food dishes, and glasses. On the mentioned market, the company proposes a wide range of items designed to fully satisfy the requirements of the distribution channels: Catering, Specialized Wholesale Network, Parties and Entertainment, and the large distribution organized network. It is a point of reference in terms of precision and professionalism due to the combination of tradition, professionalism, stylistic research and innovation.

The products of the company are made of high quality raw materials, performing a production process with efficient machinery and equipment, having qualified personnel and complying with hygiene, environmental and quality assurance standards.

In view of all these aspects, and in order to continue to maintain its market share, the company aims to introduce new products in the production. Because the existing capacity no longer allows for this, regardless of how many upgrades would be made on the current production lines, there is the problem of expanding the capacity, or setting up a new section. This involves establishing, first of all, the new location, the location of the new section. There are three possible technical and economical variants to solve this problem, figure1.
The decision-making management techniques in the previous chapter will be used to make a professional decision.

3.1. ELECTRE method

**Stage 1:** The production section can be located in 3 possible variants:

- **V₁:** expansion of the company’s central building;
- **V₂:** construction of a new building;
- **V₃:** expansion of a company outbuilding.

The selection criteria considered are:

- **C₁:** distance from raw material warehouse (m)
- **C₂:** construction cost (€)
- **C₃:** distance from other sections (m)

The consequences of the variants according to the established criteria are presented in table 2:

|    | V₁  | V₂  | V₃  |
|----|-----|-----|-----|
| C₁ | 100 | 150 | 10  |
| C₂ | 15,000 | 20,000 | 10,000 |
| C₃ | 5   | 145 | 260 |

In order to determine the coefficients of importance \( K_j \), a team consisting of the following specialists was formed at the company level: economist, production specialist, logistics specialist. They gave, for each consequence, an appreciation materialized by a mark from 1 to 10. The results are presented in table 3.

|    | V₁  | V₂  | V₃  |
|----|-----|-----|-----|
| C₁ | 8   | 10  | 10  |
| C₂ | 10  | 7   | 8   |
| C₃ | 9   | 9   | 7   |

\[ \sum_{nij} = 78 \]
Based on these, the coefficients of importance were calculated using the equation (9):

\[ K_j = \frac{\sum n_{ij}}{\sum \sum n_{ij}} \]  

(9)

The following coefficients were obtained: \( K_1 = 0.346, K_2 = 0.334, K_3 = 0.320 \)

**Step 2:** Determining the Utility Matrix. At this step, the consequences of the variants for each criterion are expressed in the same unit of measure. According to the theory of utilities, the linear interpolation between the extreme values is used, namely the equation (10):

\[ U_{ij} = \frac{a_{ij} - (a_j)_{w=0}}{(a_j)_{w=1} - (a_j)_{w=0}}, \]  

(10)

where:
- \( a_{ij} \) is the consequence of the \( V_i \) variant according to \( C_j \);
- \( (a_j)_{w=0} \) is the consequence of the unfavorable variant of the criterion \( j \);
- \( (a_j)_{w=1} \) is the consequence of the favorable variant of the criterion \( j \).

All three criteria are minimal. The results are presented in the utilities matrix, table 4.

**Table 4. Utilities Matrix.**

|       | \( C_1 \) | \( C_2 \) | \( C_3 \) |
|-------|----------|----------|----------|
| \( V_1 \) | 0.357    | 0.5      | 1        |
| \( V_2 \) | 0        | 0        | 0.151    |
| \( V_3 \) | 1        | 1        | 0        |
| \( K_g \) | 0.346    | 0.333    | 0.320    |

**Step 3:** Calculating the concordance indexes \( (C_{VgVh}) \). The equation (1) is used to calculate and the results are in table 5.

**Table 5. Matrix of concordance indexes.**

| \( V_1 \) | \( V_2 \) | \( V_3 \) |
|----------|----------|----------|
| \( V_1 \) | 1        | 0.320    |
| \( V_2 \) | 0.320    | 0.320    |
| \( V_3 \) | 0.680    | 0.680    |

**Step 4:** Calculating the discordance indexes \( (D_{VgVh}) \). The equation (2) is used to calculate and the results are in Table 6.

**Table 6. Matrix of discordance indexes.**

| \( V_1 \) | \( V_2 \) | \( V_3 \) |
|----------|----------|----------|
| \( V_1 \) | 0        | 0.643    |
| \( V_2 \) | 0.849    | 1        |
| \( V_3 \) | 1        | 0.151    |
Step 5: Choosing the optimal variant. In order to choose the optimal variant, threshold values for p are introduced as close to 1 and for q as close to 0. For each pair of values (p, q) a graph G (p, q) can be constructed which expresses the outranking relations introduced by threshold values. Thus, for the pair: p = 0.3 and q = 0.7 the graph from figure 2 is obtained, where it is observed that variant V_1 is the one that outranks the other, C (V_g, V_h) \geq 0.3 and D (V_g, V_h) \leq 0.7.

![Figure 2. Outranking graph.](image)

Given the two values p = 0.3 and q = 0.7 where variant V_1 outranks the other two, the outranking relation is not very strong. For this reason, verification continues by applying another method, the Onicescu method, which was developed precisely to eliminate some drawbacks of ELECTRE method.

3.2. ONICESCUC method

Step 1: Establishing the matrix of consequences of decision alternatives:

\[
A = \begin{pmatrix}
100 & 15000 & 5 \\
150 & 20000 & 145 \\
10 & 10000 & 260
\end{pmatrix}
\]  

(11)

Under certainty conditions, there is only one state of objective conditions, so for each variant only one consequence will be determined within each decision criterion. The values of matrix A are those calculated for the specified criteria and variants.

Step 2: Arranging variants for each criterion in descending order of consequences:

\[
B = \begin{pmatrix}
C_1 & C_2 & C_3 \\
V_3 & V_3 & V_1 \\
V_1 & V_1 & V_2 \\
V_2 & V_2 & V_3
\end{pmatrix}
\]  

(12)

For criteria where optimization involves maximizing the consequences, the arrangement is in descending order of the numerical values in A. For those in which optimization involves minimization, the arrangement will be in the ascending order of numerical values in matrix A.

Step 3: Defining the authorization matrix (its elements indicate when a variant is in the 1st, 2nd or 3rd place):

\[
C = \begin{pmatrix}
1 & 2 & 3 \\
V_1 & 1 & 2 & 0 \\
V_2 & 0 & 1 & 2 \\
V_3 & 2 & 0 & 1
\end{pmatrix}
\]  

(13)
Step 4: Establishing the aggregate function and prioritizing the variants:

Function \( f: \mathcal{V} \rightarrow \mathbb{R}^+ \) has the form:

\[
f (V_i) = \alpha_{i1} \cdot \frac{1}{2} + \alpha_{i2} \cdot \frac{1}{2^2} + \alpha_{i3} \cdot \frac{1}{2^3} \tag{14}\]

Coefficients \( \alpha_{ij} \) represent the number of times \( i \) occupies the position \( j \) and are found in matrix \( C \).

For each variant, the aggregate function will have the following values:

\[
f (V_1) = 1 \cdot \frac{1}{2} + 2 \cdot \frac{1}{2^2} + 0 \cdot \frac{1}{2^3} = 1
\]

\[
f (V_2) = 0 \cdot \frac{1}{2} + 1 \cdot \frac{1}{2^2} + 2 \cdot \frac{1}{2^3} = 0.5 \tag{15}
\]

\[
f (V_3) = 2 \cdot \frac{1}{2} + 0 \cdot \frac{1}{2^2} + 1 \cdot \frac{1}{2^3} = 1.12
\]

Step 5: Establishing the optimal variant. The variants are prioritized by the decreasing values of the aggregate function, so the order will be: \( V_3, V_1, V_2 \).

3.3. The method of coefficient \( K \)

Step 1: Calculating the distance degrees and constructing the distance degrees matrix. Since the criteria considered are minimization criteria, equation (7) will be used to calculate the degrees of distance of the decision variant \( V_i \) compared to the best variant, related to the decision criterion \( C_j \).

The matrix is obtained:

\[
\begin{pmatrix}
C_1 & C_2 & C_3 \\
V_1 & 9 & 0.5 & 0 \\
V_2 & 14 & 1 & 28 \\
V_3 & 0 & 0 & 51
\end{pmatrix}
\]

(16)

Step 2: Calculating the \( K \) coefficient

Equation (8) is used and the following values are obtained:

\( K_{1^*} = 3.287; K_{2^*} = 14.36; K_{3^*} = 16.32; \)

Step 3: Establishing the optimal version. The variants are prioritized by the increasing values of the coefficient \( K^* \), so the order will be: \( V_1, V_2, V_3 \).

4. Conclusion

It can be noticed that both the ELECTRE method and the method of the coefficient \( K \) recommend \( V_1 \) as optimal variant, so the most suitable way of building the section is by expanding the central building with the following advantages:

- low construction cost;
- rapidly shifting the staff responsible for quality from one section to another;
- rapidly shifting the staff responsible for maintenance;
- low transport time of raw material and molds;
- easy movement of the staff involved in the production process from one section to another.
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