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Choosing the IR Sealing Equipment of Automotive Wiring Using the ELECTRE Method

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Abstract
For any vehicle the electrical equipment is a basic component, the operation of which has repercussions on consumption, pollution, driving comfort, road safety, etc. Automobile manufacturers pay particular attention to improving the price-quality ratio and customer satisfaction. In this sense, they are constantly concerned with the use of the best performing equipment in the production processes. This paper deals with aspects regarding the sealing operation in the technological process of manufacturing car wiring, the use of IR technology in sealing and the use of the ELECTRE method for the decision regarding the replacement of a sealing equipment, the Minipack TAD oven, with a modern version that uses IR technology.

Keywords
IR technology, car wiring, ELECTRE method, sealing oven

1. Introduction

Seals represent assemblies of machine parts whose essential purpose is to close as tightly as possible a space containing an environment under pressure, to separate two or more spaces with environments under different pressures, respectively the tight protection of some spaces containing lubricants, against their loss or against the penetration of foreign bodies. The term sealing is also the name of the process by which different media or particles are prevented from passing through the interstices between the parts that separate neighboring media [1].

There is a very wide variety of sealing methods. Depending on the configuration of the place of application, the nature of the media to be separated, the pressures involved, the relative movements of the parts, different principles of operation of the seals are highlighted, hence resulting in different types. The main properties of the seal are: tightness, resistance, reliability, impermeability, durability, compatibility.

Sealing electrical connections involves heating the shrink hoses placed on the welded ends of the conductors until they reach a diameter that ensures complete protection of the weld against external factors.

2. Use of IR Technology in Sealing

Infrared radiation (IR) is an electromagnetic radiation that is part of the electromagnetic spectrum, Fig. 1, whose wavelength is longer than that of visible light (400 - 700 nm), but shorter than that of microwaves (~30000 μm). The electromagnetic spectrum represents the totality of electromagnetic radiation existing in the Universe. Electromagnetic radiations are generally natural physical phenomena, they are formed by an electric and a magnetic field in the same space, and which generate each other as they propagate. Infrared radiation starts at the visible edge of the spectrum, more precisely from the extreme red color, with a wavelength from 700 nm to 1 mm.

IR was discovered in 1800 by astronomer William Herchel and behaves as a wave of radiant energy, but also as a quantum particle (the photon). Infrared radiation is a type of electromagnetic radiation like radio waves, ultraviolet radiation, X-rays or microwaves. Anything above five degrees Kelvin emits infrared radiation. This is invisible to the human eye, but people can feel it as heat. Humans, at normal body temperature, radiate at a wavelength of 10 micrometres. Infrared radiation is used in industrial, scientific or medical applications.

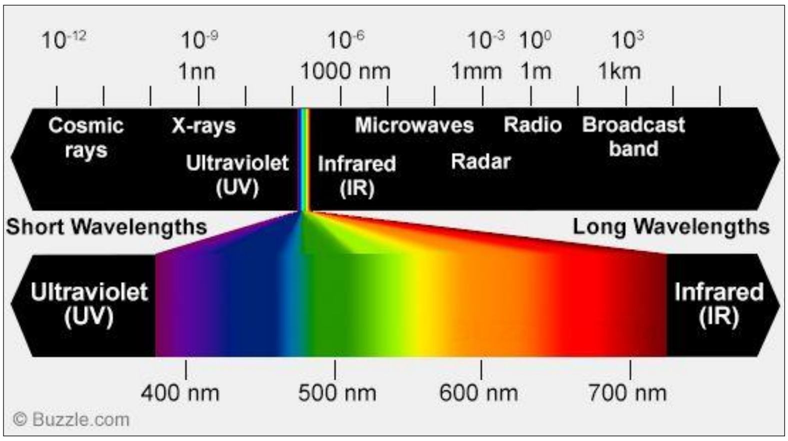

Fig. 1. Infrared radiation within the electromagnetic spectrum [2]

Infrared radiation can be used in industry as a deliberate source of heat, becoming more and more popular in manufacturing. With its help, plastic materials can be formed and deformed, sealing, printed drying, annealing, preservation of layers, etc. can be carried out. In these applications infrared heaters replace convection ovens helping the contact heating operation [2].

3. Choosing the Solution to Solve the Problem - The ELECTRE Method

The ELECTRE method (Elimination et Choix Traduisant la Realité) appeared in 1965, when a group of French researchers from SEMA (Société d'économie et de mathématiques appliquées) laid the foundations for a ranking and choice method in the presence of points of multiple vision [3, 4, 5].

The method is used in solving decision-making problems that include a number of options V_i (i = 1, n) possible to achieve an objective, but also decision criteria C_j (j = 1, m) that influence the decision-making consequences of each option. The application of the method involves going through the following stages:

- **Stage 1**: establishing the decision options and the related consequences;
- **Stage 2**: for each variant and criterion the utilities are established, and the results are presented in the form of a matrix (Table 1);

Table 1. Utility matrix

C_j / V_i	C_1	C_2	....	C_{n-1}	....	C_m
V_1	U_{11}	U_{12}	....	$U_{1(n-1)}$	....	U_{1m}
V_2	U_{21}	U_{22}	....	$U_{2(n-1)}$	....	U_{2m}
.	.	.		.		.
.	.	.		.		.
V_n	U_{n1}	U_{n2}	....	$U_{n(n-1)}$	....	U_{nm}

In table 1, the notations represent:

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

- **Stage 3**: establishing the concordance indicators $C(V_g, V_h)$ between two variants. The relationship is used:

$$C(V_g, V_h) = \frac{\sum k_j}{k_1 + k_2 + \cdots + k_m}, \tag{1}$$

where:

k_j(j=1...m) – the importance coefficients of the considered criteria;
Σk_j – the sum of the importance coefficients of the criteria for which the condition is met $U(V_g) \geq U(V_h)$.

- **Stage 4**: establishing discordance indicators $D(V_g, V_h)$, using the relationship (2). For $U(V_g) < U(V_h)$, α is the maximum difference between the maximum and the minimum utility.

$$D(V_g, V_h) = \begin{cases} 0, & if\ U(V_g) \geq U(V_h) \\ \frac{1}{\alpha} \cdot max\{|U(V_g) - U(V_h)|\} \end{cases} . \tag{2}$$

- **Stage 5**: determining the optimal variant. It takes place through successive operations of superclassing the variants with the help of superclassing relations of the form:

$$\begin{cases} C(V_g, V_h) \geq p \\ D(V_g, V_h) \leq q \end{cases} , \tag{3}$$

where p and q are thresholds, values between 0 and 1 (p is as close as possible to 1, q is as close as possible to 0). From the superclass relations, a series of graphs $G(p, q)$ result from which the optimal variant is deduced. As p decreases and q increases, one obtains that variant that outclasses all others.

4. Choosing the Equipment for Sealing Car Wiring. Case Study

Sealing (Shrinking) involves heating shrink hoses in ovens and shrinking (Figure 2) until they reach a diameter that ensures complete protection of the weld against external factors. For this process, at the moment, the Minipack TAD oven is used (Figure 3).

Fig. 2. Sealed cables

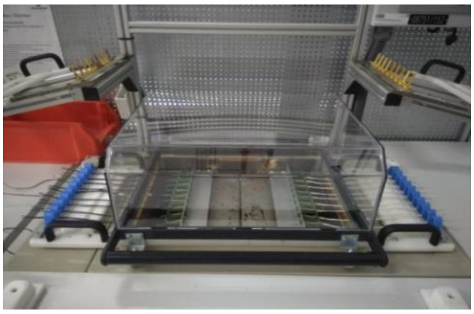

Fig. 3. Minipack TAD oven

4.1. The equipment used at the time of the study

Within an elementary technological system, the most important place is occupied by the equipment used [6]. Its characteristics determine the defining characteristics of the technological system.

A semi-automatic Minipack TAD oven using convection heating was in use at the time the study was initiated. This is specific to ovens that use heated air as the transfer medium between the heat source and the object to be heated.

At the Minipack TAD oven, Figure 4, it is identified:

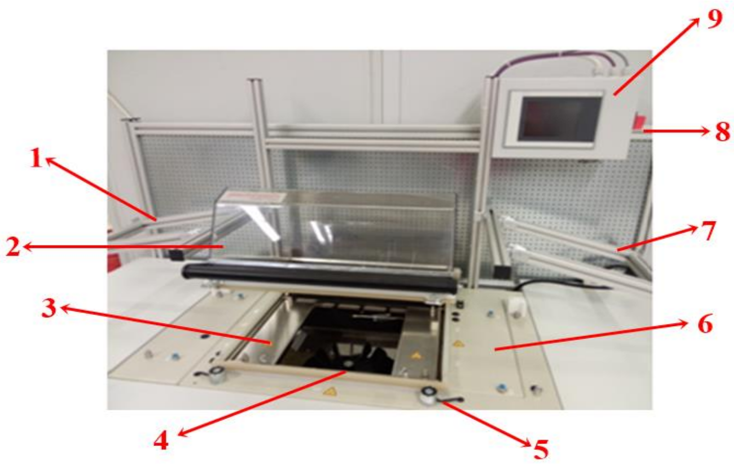

Fig. 4. Minipack TAD oven at the workstation

- 1; 7 - Place for mounting the frames where the cables will be inserted;
- 2 - Cover for hermetically sealing the sealing area;
- 3 - Plates used to separate the fan from the sealing area;
- 4 - Fan. It supplies warm air to the sealing area;
- 5 - Electromagnet – with its help the cover is kept closed;
- 6 - Internal electrical system;
- 8 - The main switch;
- 9 - The display control system of the machine.

Characteristics of the Minipack TAD oven are shown in Table 7 [7]. The Minipack TAD oven costs: €15,000.

The invariable parameters of the oven are:

- Resistance heating temperature: 240 °C;
- Starting temperature of the contraction process: 120 °C;
- The temperature at which the heating process is stopped: 160°C;
- Core-to-conductor temperature: 125 °C ±10 °C.

The duration of a cycle is adjustable.

4.2. The use of IR technology at the sealing station and the proposed options for replacing the equipment

Making any investment is an important decision, which produces effects with material, financial and human implications that are often significant. For the studied case, the options proposed for the sealing job were researched using a decision theory method in order to use a new equipment to increase productivity. It was found that the equipment used at the time of the study should be replaced. Three types of performant ovens are available on the market as possible solutions, all based on IR technology:

- The oven Mecalbi STCS VMir, Figure 5a [8];
- The oven RBK-ILS, Processor MkII, Figure 5b;
- The oven Model 19 Belt Heater, Figure 5c.

a) b) c)

Fig. 5. Ovens proposed as options for replacing existing equipment
a) Mecalbi STCS Vmir; b) RBK- ILS Processor MkII; c) Model 19 Belt Heater

4.3. Establishing the optimal variant using the ELECTRE method

- **Stage 1**:

The selection criteria considered are:

C_1: electricity consumption (A);
C_2: purchase price (€);
C_3: maximum baking time (sec).

The consequences of the variants depending on the established criteria are presented in Table 2.

To determine the coefficients of importance K_j, a team of three specialists was formed: economist, production specialist, and test laboratory head. They awarded, for each consequence, a grade from 1-10. The results are presented in Table 3.

Table 2. The consequences of the variants for each criterion

	C_1 (A)	C_2 (€)	C_3 (sec)
V_1	7	20 000	40
V_2	5	30 000	50
V_3	20	50 000	80

Table 3. Grades awarded by specialists

	C_1	C_2	C_3	
V_1	9	10	10	$\Sigma n_{1j} = 29$
V_2	10	9	9	$\Sigma n_{2j} = 28$
V_3	7	7	6	$\Sigma n_{3j} = 20$
	$\Sigma n_{i1} = 26$	$\Sigma n_{i2} = 26$	$\Sigma n_{i3} = 25$	$\Sigma\Sigma n_{ij} = 77$

Using the relation:

$$k_j = \frac{\sum n_{ij}}{\sum\sum n_{ij}}, \tag{4}$$

the importance coefficients k_j were calculated:

$k_1 = \Sigma n_{i1} / \Sigma\Sigma n_{ij} = 0.337;$
$k_2 = \Sigma n_{i2} / \Sigma\Sigma n_{ij} = 0.337;$
$k_3 = \Sigma n_{i3} / \Sigma\Sigma n_{ij} = 0.326.$

- **Stage 2**: Determination of the utility matrix

In this stage, the consequences of the variants for each criterion are expressed in the same unit of measure. According to utility theory, linear interpolation between extreme values is used, respectively the relationship:

$$U_{ij} = \frac{a_{ij} - (a_j)_{u=0}}{(a_j)_{u=1} - (a_j)_{u=0}}, \tag{5}$$

where:

- a_{ij} is the consequence of variant V_i depending on C_j;
- $(a_j)_{u=0}$ is the consequence of the unfavorable variant of criterion j;
- $(a_j)_{u=1}$ is the consequence of the favorable variant of criterion j.

The results are presented in the utility matrix, Table 4.

Table 4. Utilities matrix

	C_1	C_2	C_3
V_1	0.86	1	1
V_2	1	0.86	0.75
V_3	0	0	0

The values are retained: $U_{11} = 0.86$; $U_{22} = 0.86$; $U_{23} = 0.75$.

- **Stage 3**: Calculation of concordance indicators $C(V_g, V_h)$

The relation (1) is used for the calculation, and the results are listed in Table 5.

Table 5. Matrix of concordance indicators $C(V_g, V_h)$

V_g \ V_h	V_1	V_2	V_3
V_1		0.337	1
V_2	0.337		1
V_3	0	0	

➢ **Stage 4**: Calculation of discordance indicators $D(V_g, V_h)$.

The relation (2) is used for the calculation, and the results are presented in Table 6. It is taken into account that α = 1.

Table 6. Matrix of discordance indicators $D(V_g, V_h)$

V_g \ V_h	V_1	V_2	V_3
V_1		0.14	0.86
V_2	0.14		0.75
V_3	1	0.86	

➢ **Stage 5**: Choosing the best option

To choose the optimal variant, enter threshold values, p~1 and q~0 according to relation (3). For each pair of values (p, q), a graph $G(p,q)$ can be constructed that expresses the superclass relations introduced by the threshold values. Thus, for the pair p=0.3 and q=0.7, the graph in Figure 6 is obtained, which shows that variant V_1 is the one that outranks the others, $C(V_g, V_h) \geq 0.3$ and $D(V_g, V_h) \leq 0.7$, so it is the optimal variant.

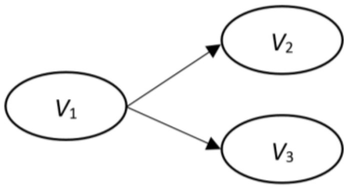

Fig. 6. The graph of overranking

4.4. Comparative analysis of the oven in use and the proposed one

The main objective of this comparison is to determine whether the Mecalbi STCS VMir oven is superior to the Minipack TAD oven in use at the time of the study, but also whether the replacement is beneficial to the company from an economic point of view. Some technical data of the two ovens are presented in Table 7.

Table 7. Sealing ovens Mecalbi STCS VMir and Minipack TAD. Some technical data

Technical data	Mecalbi STCS VMir	Minipack TAD
Operating system	STCS - RTC	TAD
Interface	Touchscreen & LED	Touchscreen & LED
Weight	~32 kg	~60 kg
Dimensions	525×495×390 mm	1340×540×965 mm
Power	2.8 kW	2.8 kW
Supply	230 V @ 50 Hz	230 V @ 50 Hz
Consumption	Max. 7 A	Max. 16 A
Supply pressure	6 bar	6 bar
Baking time	40 s	100 s
Working temperature	140 °C	140 °C
Time to reach 140 °C	2 min	15 min
Price	20,000 €	15,000 €

The comparative analysis of the data presented and not only shows that:

➢ Mecalbi STCS VMir is lighter than Minipack TAD by 28 kg;

➢ Mecalbi STCS VMir has smaller dimensions and takes up less space;

➢ More cables can be processed simultaneously with Minipck TAD (18 cables) than with Mecalbi STCS VMir (10 cables);

- Mecalbi STCS VMir is more ergonomic, the design of the frames is consistent with the size of the cables, which can be better positioned;
- The energy consumption of the Mecalbi STCS VMir is much lower than that of the Minipack TAD.

The tests carried out with the two machines show that:

- In each individual test, 20% more compliant samples were obtained using the Mecalbi STSC VMir oven;
- The adhesive of the samples was more evenly distributed with Mecalbi STCS VMir than with Minipack TAD;
- The sealing hose shrinks more slowly with the Minipack TAD and the adhesive tends to overflow at both ends;
- The sealing temperature is reached in a much shorter time with the Mecalbi STCS VMir (it reaches 500 °C in 6 minutes), compared to the Minipack TAD (it reaches 158 °C in 15 minutes);
- The Mecalbi STCS VMi cooling system is much more efficient than the Minipack TAD;
- Mecalbi STCS VMir has a much simpler interface than Minipack TAD;
- Mecalbi STCS VMir can communicate with the ultrasonic welding machine;
- Mecalbi STCS VMir can be set to the user's language and provides a better understanding of commands;
- The cost of performing the sealing operation using Minipack TAD is higher by approx. 5% over cost using Mecalbi STCS VMir;
- The Mecalbi STCS Vmir oven is more expensive (20,000 €) than the Minipack TAD (15,000 €), but the advanced technology and the low costs of the processing operation recommend it.

5. Conclusions

Increasing the performance of a technical-economic system is largely the result of appropriate decisions. Choosing the appropriate technical equipment is an important part of the decision-making act. The ELECTRE method is a handy tool and provides relevant results in a short time.

The paper presents a concrete application of the method, applied in detail step by step in order to substantiate the decision of choosing a more efficient equipment for performing the "Sealing electrical connections" operation. The chosen equipment, the Macalbi STCS VMir oven, uses infrared radiation technology, clearly superior to convection heating, has low energy consumption and increased productivity.

References

1. Fălticeanu C., Ciortan S., Fălticeanu L., Manea M., Mircea I. (2001): *Etanşări cu contact mobil. Ghid pentru proiectarea etanşărilor cu presgarnitură* (*Seals with movable contact. Guide for the design of gasketed seals*). Editura Evrika, ISBN 973-641-011-0 (in Romanian)
2. https://www.process-heating.com/articles/86736-7-questions-and-answers-about-infrared-ovens. Accessed: 05.07.2022
3. Nicolescu O. (1998): *Sistemul decizional al organizaţiei* (*The decision-making system of the organization*). Editura Economică, Bucureşti, ISBN973-590-049-1 (in Romanian)
4. Roy B. (1968): *Classement et choix en présence de points de vue multiples (la méthode ELECTRE)*. Revue Française d'Informatique et de Recherche Opérationelle (RIRO), Tome 2, no. 8, pp. 57-75, http://www.numdam.org/item/RO_1968__2_1_57_0/
5. Roy B., Bouyssou D. (1993): *Aide Multicritère à la Décision : Méthodes et Cas*. Economica, SÉRIE: Production et Techniques quantitatives appliquées à la gestion, Paris, https://www.researchgate.net/profile/Denis-Bouyssou/publication/265441342_Aide_Multicritere_a_la_Decision_Methodes_et_Cas/links/5a9575e0aca27214056922b6/Aide-Multicritere-a-la-Decision-Methodes-et-Cas.pdf?origin=publication_detail
6. Niţu E.L. (2002): *Managementul producţiei* (*Production management*). University of Pitesti Publishing House, ISBN 973-690-084-3 (in Romanian)
7. https://www.MinipackTAD.com. Accessed: 08.06.2022
8. https://www.mecalbi.com/assets/uploads/20180402_022738_027615-80-002-R04.pdf