Statistical Decision in the Automotive Material Selection

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Abstract The objective of the research is the ranking of materials applied to an example from the automotive industry (material candidates for the car body construction). The variety of properties/attributes imposes different evaluations for metrical/ordinal scales and the necessary statistical calculus. Heterogeneity of the characteristics imposes the separation of the attributes into mainly two classes: functional (mechanical, physical, etc.), usually with metric scale and technological and environmental attributes with frequently ordinal scale. The paper analyses a practical case of the material for the car body by Multi Criteria Decision Making (MCDM) procedures like primary ranking and preference index value applied to mechanical, technological and ecological, respective all attributes, etc. All these methods are principally based on the variance, viewed as a risk measure. The final comparison has as result the most valuable materials: Titanium sheet, Glass Reinforced Plastics (GRP) and Carbon Fiber Composite.

Keywords Materials ranking · Correlation · Variance analysis

Introduction

In multicriteria processes, different methods may produce a ranking of the alternatives of a decision that is normally in the same way. Anyway a variability in ranking should be possible on the basis of requirements, respectively weights and is, therefore, acceptable, to arrive at a compromise or consensus. Numerous authors have investigated problems of ranking and decision: (Kemeny and Snell 1962; Cook 2006; Heiser and D'Ambrosio 2013; Singh and Kumar 2012) etc., including the material selection (Ashby 2002; Târcolea and Paris 2008; Paris and Târcolea 2009). The continued development of automotive industry implied the extended

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study of new materials utilized for parts production and many researches for a better decision: (Wilhelm 1993; Antunes and Lopes de Oliveira 2014; Davies 2012; Fuchs et al. 2008; Savkin et al. 2014).

Practical Material Ranking

The general idea of this paper is to present a simpler method (Singh and Kumar 2012; Paris and Târcolea 2015), developing an example for automotive material selection. Material candidates for the car body construction are: Forming grade steel EN 10130 DCO4 + Z, HSS EN 10292 H300YD + Z, UHSS–martensitic, Aluminium 5xxx, Aluminium 6xxx, Magnesium sheet, Titanium sheet, Glass Reinforced Plastics (GRP) and Carbon Fiber Composite. The considered attributes (properties) are: Yield Strength (YS) [MPa], Ultimate Tensile Strength (UTS) [MPa], Elongation A80 [%], Elasticity Modulus (EMod) [MPa], and Density (D) [kg/dm^3], Forming, Joining, Paint, CO2 + emis, Disposal and Costs (Davies 2012). The variety of those attributes imposes different evaluation for metrical/ordinal scales. The mechanical properties took into account cover a metrical scale (numerical values of the attributes) and the others use an ordinal scale.

The technological attributes are based on range: 1—difficult to process; 10—production without difficulty. The ecological properties are evaluated on ease with which prevailing legislation can be met: 1—extensive development required; 10—without difficulty. Not all attributes are shown and it is easy to subdivide any of the columns shown (Davies 2012).

For a real model the values must be reordered; there are properties for which the greatest value is the best (for example the tensile strength), and others with the smallest value as the best (for example density); this is a reason for the handling of the marks from 1 to 10 (10 is the best) for an a priori elimination of these inadvertences. Another possibility is the Likert scale, analog to the German scores system, with the marks from 1 to 5 (1 is the best), which will indicate directly the position in the hierarchy.

In the present case the solution can be easy perceived because the materials are well known and only a few and it is useful if the number of the objects and attributes is very high, very different and less known. When the Sheller-Globe Corporation, maker of heavy truck cabs, wanted to design a new cab, asks the potential customers to rank the opposition on seven scales covering gasoline mileage, case of steering, durability, etc. (Toffler 1991).

The ranking of the analyzed materials can be obtained rigorously using statistical tools. In the paper it is applied computer aided correlation and variation analysis. The general idea to reduce the calculus volume imposes the study of the correlation matrix of the attributes, to avoid the possible redundancies. So the first step is the calculus of the correlation matrix of the attributes (without costs).

A brief analysis of results shows that some attributes are strong correlated. As working hypothesis it will be:

Materials' Ranking Considering Mechanical Properties (YS, UTS, A80, EMod and D)

The properties YS and UTS have a very good correlation, equivalent with a redundancy, and it permits the elimination one of them. In the same way are EMod si D, and finally it is enough to use only 3 properties: YS (max), A80 (min) and D (min).

To continue the analysis it is necessary to reorder the properties so that they will vary in the same logic, with maximal the best, and then, keeping in mind that A80 and D are minimal the best attributes, the values were inversed.

The applied algorithm (Singh and Kumar 2012; Paris and Târcolea 2014) contains: normalized of the values, the computing of the variances and weights of the characteristics (Table 1, column 2) (the weighting is an important step for the decision maker); it results the ranking of materials (Table 1 column 3).

The Materials' Ranking Based on Technological and Ecological Properties

The considered technological properties are: Forming, Joining, Painting and the ecological properties are: CO_2+emis and Disposal. The elementary ranking is based on the sum of range values (Table 2).

The scoring of the material employing technological and ecological properties, with the same algorithm (preference index) (Table 3), furnishes another ranking: Forming grade steel EN 10130 DCO4 + Z, HSS EN 10292 H300YD + Z and Carbon Fiber Composite, with comparable results with the elementary ranking (Table 2).

Table 1 Ranking by 3 selected mechanical properties

Materials	Weights	Rank
Forming grade steel EN 10130 DCO4 + Z	0.024191	9
HSS EN 10292 H300YD + Z	0.03759	8
UHSS—martensitic	0.129931	4
Aluminum 5xxx	0.044398	7
Aluminum 6xxx	0.044822	5
Magnesium sheet	0.084647	4
Titanium sheet	0.193059	3
GRP	0.21365	2
Carbon fiber composite	0.227713	1

Table 2 Elementary ranking based on technological and ecological properties

Materials	Sum	Elementary rank
Forming grade steel EN 10130 DCO4 + Z	42	1
HSS EN 10292 H300YD + Z	39.5	2
UHSS—martensitic	36.5	6
Aluminum 5xxx	37	4
Aluminum 6xxx	37	4
Magnesium sheet	30.5	9
Titanium sheet	33	8
GRP	36	7
Carbon fiber composite	37	4

Table 3 Ranking based on technological and ecological properties

Materials	Preference index rank
Forming grade steel EN 10130 DCO4 + Z	1
HSS EN 10292 H300YD + Z	2
UHSS—martensitic	7
Aluminum 5xxx	5.5
Aluminum 6xxx	5.5
Magnesium sheet	9
Titanium sheet	8
GRP	4
Carbon fiber composite	3

The Ranking of Materials upon the Two Groups of Properties (Mechanical, Technological and Ecological)

It is obvious that the two rankings are completely different, practically opposed. The shortest way is to average the two rankings. A more consistent solution is to compute ranking considering the eight above mentioned properties (Table 4).

The ranking is identical with the one of the mechanical properties because of the significant bigger variance of this kind of properties.

Ranking Including Costs Too

The analysis based on the nine selected properties makes use of weights and ranks (Table 5).

Table 4 Ranking with all analyzed properties

Materials	Weights	Rank
Forming grade steel EN 10130 DCO4 + Z	0.05436264	9
HSS EN 10292 H300YD + Z	0.060251017	8
UHSS—martensitic	0.124384837	4
Aluminum 5xxx	0.061893473	7
Aluminum 6xxx	0.06220602	5
Magnesium sheet	0.084416164	4
Titanium sheet	0.167786358	3
GRP	0.187007522	2
Carbon fiber composite	0.197692421	1

Table 5 Material ranking including costs

Materials	Weights	Rank
Forming grade steel EN 10130 DCO4 + Z	0.040276	9
HSS EN 10292 H300YD + Z	0.04462	8
UHSS—martensitic	0.090397	4
Aluminum 5xxx	0.052236	7
Aluminum 6xxx	0.054685	6
Magnesium sheet	0.067999	5
Titanium sheet	0.251218	1
GRP	0.148718	3
Carbon fiber composite	0.24985	2

Ranking Based on 11 Properties

The analysis based on the eleven selected attributes (Table 6).

To find out the best ranking it is necessary a comparison of the five rankings with the correlation matrix. The results permits the remark that the arranging upon the technological + ecological properties is discordant, as it was already explain. In automotive industry, steel is still very used as consequence of the big weight of the implicit costs, but there is a significant trend to reduce its importance.

The quality of the selection as a whole is assessed by estimating its internal consistency reliability with Cronbach's alpha test (Wessa 2015).

For each omitted property (V1–V11, Table 7) the coefficients score is over the minimum reliability of 0.7, which consolidates the general Cronbach's alpha score, which indicates over a 70 % consistency in the scores that are produced in the model.

Table 6 Material ranking with 11 properties

Materials	Weights	Rank
Forming grade steel EN 10130 DCO4 + Z	0.040884	9
HSS EN 10292 H300YD + Z	0.046639	8
UHSS—martensitic	0.101436	7
Aluminum 5xxx	0.059089	6
Aluminum 6xxx	0.061176	5
Magnesium sheet	0.078856	4
Titanium sheet	0.221089	2
GRP	0.160051	3
Carbon fiber composite	0.230779	1

Table 7 Measure of the internal consistency reliability

Cronbach alpha and related statistics		
Items	Cronbach alpha	Std. alpha
All items	0.7773	0.8367
V1 excluded	0.7263	0.8273
V2 excluded	0.7073	0.8069
V3 excluded	0.7295	0.8
V4 excluded	0.7801	0.8632
V5 excluded	0.7815	0.8372
V6 excluded	0.7778	0.8073
V7 excluded	0.7805	0.8249
V8 excluded	0.7557	0.792
V9 excluded	0.7516	0.8078
V10 excluded	0.7316	0.83
V11 excluded	0.8008	0.843

Conclusion

The ranking of the analyzed materials can be obtained rigorously using statistical tools. The variety of those attributes imposes different evaluation for metrical, ordinal scales or both. The general consideration of the properties points out Carbon Fiber Composite as the best, and only the technological and ecological properties reveal steel on the first place, but with Carbon Fiber Composite on the third place. It is of interest the whole comparison, but for practical applications only the first places are important, like in the sports competitions. For the classical materials the selection has usually a simple solution, but for new materials and many properties the ranking is very difficult and unclear without statistical tools. Another possibility of measure of the variation of attributes is the computing of the eigenvalues. Essential for the hierarchy are the properties with the big variance, where the ranking becomes more consistent. The paper should be seen as a technique that learns by example. The statistical tools applied in the paper seems here to complex for the materials range, however they offer a more exactly image for rational decisions.

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