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Cognitive structure of occupational risks represented by a perceptual map

Cardoso-Junior, M.M.[a,*] and Scarpel, R.A.[b]
[a] *Office of Occupational Safety, Technological Institute of Aeronautics, Praça Marechal Eduardo Gomes, 50 - Vila das Acácias, CEP 12.228-900 – São José dos Campos – SP – Brasil*
[b]*Department of Industrial Organization, Technological Institute of Aeronautics, Praça Marechal Eduardo Gomes, 50 - Vila das Acácias, CEP 12.228-900 – São José dos Campos – SP – Brasil*

Abstract. The main focus of risk management is technical and rational analysis about the operational risks and by those imposed by the occupational environment. In this work one seeks to contribute to the risk perception study and to better comprehend how a group of occupational safety students assesses a set of activities and environmental agents. In this way it was used theory sustained by psychometric paradigm and multivariate analysis tools, mainly multidimensional scaling, generalized Procrustes analysis and facets theory, in order to construct the perceptual map of occupational risks. The results obtained showed that the essential characteristics of risks, which were initially splited in 4 facets were detected and maintained in the perceptual map. It was not possible to reveal the cognitive structure of the group, because the variability of the students was too high. Differences among the risks analyzed could not be detected as well in the perceptual map of the group.

Keywords: Safety, Multidimensional Scaling, Occupational Environment, Risks.

1. Introduction

The perception of occupational risks is gaining prominence in Brazilian scenario, as we can see in recent works [1,4,12,17] in oil and gas industry. In the same vein a study on risk perception in the port area conducted by [25].

The perception of risk is the subjective assessment of the likelihood of a specific type of accident occurs, and to what degree a person is worried about its consequences. The perception of risk however goes far beyond the individual and the result is a construct that reflects social and cultural values, symbols, history and ideology [26].

The use of an indicator of risk perception among the stakeholders involved in a remote operation is advocated by [12]. The authors suggest measuring the impact of risk perception on safety and resilience when a task is distributed between onshore and offshore. The comparison of safety perception among post-graduate students revealed that oil and gas and aviation are considered safe industries and that nuclear and mining industries are considered unsafe. The students relate risk perception more linked with severity of accidents rather than probability of occurring [10].

Occupational risk perception in relation to safety training and injuries in a printing industry was studied by [14]. Using structural equation analysis the authors confirmed a model of risk perception based on employee's evaluation of prevalence and lethalness of hazards as well as control over hazards the employees gain through training.

The study of risk perception has been developed since the initial work of Starr (1969) cited by [21]. Two theories currently prevail, one represented by the psychometric paradigm, based on psychology and decision sciences and the other represented by cultural theory developed by sociologists and anthropologists.

This paper aims to: i) obtain the perceptual map of the occupational risks, from the standpoint of psychometric paradigm in a group of safety engineering graduate students, ii) testing the hypothesis of re-

*Corresponding author. E-mail: moacyr@ita.br.

gional interpretation of the solution space of perceptual mapping, iii) to test statistical differences between the objects evaluated using multivariate statistical tools.

The expected contribution of the work is to produce a perceptual map which will reveal the cognitive structure of a group. The perceptual map will be obtained using visualization techniques of multidimensional data, known as multidimensional scaling (MDS), aided by tools of shape statistics, the Procrustes. The methodological approach employed in this study was an exploratory research.

2. Risk Perception and the Psychometric Paradigm

The ability to sense and avoid hazardous environmental conditions is necessary for the survival of Human Beings. Survival is also assisted by the ability to encode and learn from past experiences. Humans also have an ability that allow them to change the environment and adapt it. This ability may both decrease and increase risks [24].

The most common strategy for the study of risk perception employs the psychometric paradigm, which uses psychophysical scaling methods and multivariate analysis techniques to produce quantitative representations or also known as the cognitive maps of attitudes and perceptions.

Within the psychometric paradigm people make quantitative judgments about the current and desired risk of various hazards and desired level of regulation of each of the risks. These judgments are then related to judgments about other properties, such as: willingness, fear, knowledge, control, benefits to society, the number of deaths in one year, number of deaths due to a disastrous year [22-23].

Several authors have identified behavioral factors that affect risk perception, that is, whether the risk is natural or anthropic, voluntary or not, whether it generates fear, whether it is familiar or new, whether it can produce chronic effects, (i.e.: the damage is small, but steady in contrast to the catastrophic effects that cause many deaths instantly), whether the person has control over them or memorable situations, due to personal experiences, family situations or well divulgated in the media [16].

According to [21], the work of Fischhoff, Slovic, Lichtenstein, Read and Combs, 1978, reproduced in [23] was a landmark of psychometric theory. The authors have compiled nine dimensions from the literature related to perception studies. The first refers to the risk exposure is voluntary or involuntary. The second refers to the immediacy of the consequences or not. The third assesses in which extension risk is known by the person who is exposed. The fourth refers to the potential chronic or catastrophic risk. The fifth dimension involves deciding whether the risk is common, (ie.: A risk already assimilated by the people or causes a great fear). The sixth dimension relates to the severity of the consequences imposed by the risk. The seventh to which extension the risk is known by science. The eighth evaluates the level of control the person has upon risk and the last one if the risk is new to society or not. Several surveys were conducted on a large number of hazardous activities and described with those nine dimensions. Some examples are smoking, use of dyes in food, nuclear operations, vehicles, skiing, among others.

Data was analyzed with factor analysis and the authors identified two major factors that explain most of the data variance, which are: Fear and the Newness of Risk. McDaniels et al. (1995) cited by [21] defined the psychometric paradigm as an approach to identify the characteristics that influence the perception of risk. The approach assumes that risk is multidimensional, with many other characteristics beyond the individual judgments of the likelihood of damage to health or life. The method application in studies of human health risk perception include: - develop a list of hazards based on events, technologies and practices that include a broad spectrum of potential hazards - developing a number of psychometric scales that could reflect the important characteristics of risk to map the human perception in response to these risks - Ask the respondents to evaluate each item on a list of hazards in nine dimensions - using multivariate analysis to identify and interpret a set of latent factors that capture the responses of individuals.

Some analysis take into account up to 18 dimensions, but typically 80% of the variance is explained by only three dimensions by factor analysis and the factors that have been reported in studies of perception are New or Old, Feared or Common and Number of exposed persons [15,20-21]. There are some criticisms to the psychometric paradigm regarding the small number of dimensions evaluated, from 9 to 18 and the fact that it does not include an important dimension which is related to the risk be natural or not, and finally that the analysis is based on average and not in all data collected [15].

3. Method

Aiming to assess the perception of risk of a group of safety engineering students within occupational risks context a questionnaire was applied. The questionnaire included 29 objects divided into four facets: 5 physical agents, 8 chemical agents, 11 activities that involve various hazards and 5 typical office activities, with emphasis on ergonomics. Table 1 shows the objects of research.

Table 1

Objects of Perception Survey of Occupational Risk divided into four Facets.

Physical agents	Noise Heat Vibration Humidity Non ionizing radiation
Chemical agents	Metal fumes Asbestos Silica Lead Gasoline Benzene Mercury Nanotechnology
Activities that involve various hazards	Hospital laundry Working under the sun Forest harvesting Electrical Maintenance Caisson Diving Confined space Working at height X-ray Operator Electroplating Electric Welding
Typical office activities, with emphasis on ergonomics	Labor office Telemarketing operator Bank Teller Posture Exertion

Facets Theory is a way of linking the geometric properties of a Multidimensional Scaling - MDS configuration with attributes of the objects represented on it. This is a regional interpretation of the MDS space based on a theoretical framework [2].

In this study the facets are grouped according to 3 classes of occupational hazards: physical, chemical and ergonomic hazards and a different class, which involves various different hazards.

For each object, the respondents were asked to assign scores on a Likert scale from 1 to 7, in nine dimensions, like Figure 1.

Dimensions	Scale
Willingness to risk. People "take" this risk voluntarily	**Voluntary Involuntary** **1 2 3 4 5 6 7**
Time to Effect. To what extent there is risk of immediate death or the risk of death is delayed.	**Immediate Late** **1 2 3 4 5 6 7**
Knowledge of Risk. – Exposed. To what degree the risk is known by people who are exposed to it.	**Known Not Known** **1 2 3 4 5 6 7**
Knowledge of Risk. - Science To what degree the risk is known to science.	**Known Not Known** **1 2 3 4 5 6 7**
Control of Risk. If you are exposed to risk, to what extent you can, because your skills, avoid death while engaged in activity.	**Incontrolable Controlable** **1 2 3 4 5 6 7**
Newness. This threat is new or old, familiar	**New Old** **1 2 3 4 5 6 7**
Chronic-Catastrophic. This risk kills one person at a time (chronic) or risk kills a large number of people at once (catastrophic)	**Chronic Catastrophic** **1 2 3 4 5 6 7**
Common-Feared. People have learned to live with this risk and may decide to quietly about the same, or is a risk that people have a great fear	**Common Feared** **1 2 3 4 5 6 7**
Severity of Consequences. What is the likelihood that the consequence of that risk is fatal	**Not Fatal Fatal** **1 2 3 4 5 6 7**

Figure 1 - Dimensions of risk perception and Likert scales.

The questionnaires submitted to respondents were arranged in order that the objects were listed in a random way, aiming to eliminate any possibility of systematic error in data collection. To the respondents were only given instructions on how to fill the questionnaire using the Likert scale. No explanation of the meaning of each object was done. The respondent group comprised 13 students from a Safety Engineering course.

3.1. Perceptual Map

The method used to draw the perceptual map of risk was the non-metric Multidimensional Scaling - NMDS. The MDS also called classical was introduced by Torgerson (1952, 1958) and Gower (1966), as quoted by [2,27]. Classic MDS is also known as Torgerson Scaling or even Torgerson-Gower Scaling [2]. Classic MDS starts with a distance matrix D with elements dij, where i, j = 1 ,.... n, and the goal is to find a configuration of points in p-dimensional space from the distances between the points so that the coordinates of n points along the dimension p will produce a matrix whose elements are Euclidean distances as close as possible to the elements of distance matrix D. After MDS, the configurations were submitted to Generalized Procrustes Analysis - GPA, a shape statistical analysis. The term shape is defined by [3] involving the geometric properties of a configuration of points that are invariant to changes in translation, rotation and scale. Direct analysis of a set of points is not appropriate due to the presence of systematic errors such as position, orientation and size, and usually to conduct a reliable statistical analysis GPA is used to eliminate factors not related to shape and to align the settings for a common coordinate system [3]. The GPA, a multivariate statistical technique in which three empirical dimensions are involved: the objects of study, people who value the objects and attributes in which the objects are evaluated. In the case of this study p attributes, with (p=1,...,9), represented by the dimensions of risk perception, was measured on n objects, with (n=1,...,29), which in this case are represented by four facets, with (m=1,...,13), evaluators. The GPA is an ideal method to analyze data from different individuals [9].

The objective of the GPA is to determine to what extent the m configurations are consistent. This problem can be described as the measure of similarity between the m configurations, or interrater reliability [19].

The mathematical formulation of the GPA can be described as follows, Tj is an nxp matrix with all n rows equal to tj (1xp row vector), an orthogonal matrix Hj (pxp), and ρj a scalar (j=1,...m). The translation to the origin is given by adding the same row vector (1xp) tj to all line of Xj. The scaling, rotation and translation can therefore be expressed by the transformation given by Eq. (1).

$$X_j \longmapsto \rho_j X_j H_j + T_j \qquad \text{Eq. (1)}$$

The NMDS ordinal is a special case of MDS, and possibly the most important in practice [6]. It is normally used when, for example, we want to get the trial, placing the objects in ascending or descending order of importance from the perspective of an evaluator. The algorithm used was proposed by [7], known as SMACOF. SMACOF minimizes Eq. (2), [13].

$$Stress = \left(\frac{\sum_{i<j} \left(d_{ij} - \hat{d}_{ij} \right)^2}{\sum_{i<j} d_{ij}^{\ 2}} \right)^{\frac{1}{2}} \qquad \text{Eq. (2)}$$

Stress function represents and evaluates the inadequacy (admissible transformation) of proximities and the corresponding distances. Stress is very similar to the correlation coefficient, except that it measures the misfit and not the adjustment of a model. A comparison with the correlation coefficient is because the researchers know that a correlation may be artificially high by the presence of outliers, and also very low due to, for example, the linear model is not the most appropriate. What is done in these circumstances is to examine the scatter plot. The same practice is advocated in the NMDS, by means of a graph with the proximities in the abscissa axis against the corresponding distances in the y-axis. Typically a regression shows how the proximity and distance estimates are related. This chart is known as the Shepard diagram [2].

Another way is to determine the space dimensionality from which do not occur a significant reduction in the value of stress, (ie.: solve the NMDS for several dimensions and plot the values of stress as the ordinate and dimension in the abscissa axis). This chart is known as "Scree Plot". The curve shape is generally monotonic downward, but at a very low rate as it increases the size (convex curve). What is sought is the "elbow", the point where a decrease in stress is less pronounced [2].

Finally, the trial dimension for use in the final configuration of points uses the criterion of interpretability, as cited by [13], (ie.: m dimensions provides a satisfactory interpretation, and m+1 in no way improves the interpretation, it makes perfect direction set in m-dimensions). That is the Stress obtained is only a technical measure and the NMDS. Evaluation of NMDS should be made knowing the theory that explains the behavior of the data.

In the specific case of this study it was defined a priori that two dimensions is a good representation, and relying on the Facets theory described by [2] it was analyzed the differences between objects obtained in the final configuration of consensus.

The SMACOF solution was achieved using SMACOF package [8]. The GPA was determined by FactoMineR package [11]. Both implemented in R - CRAN Version 2.9.2 [18].

4. Results

4.1. Cognitive Structure

The final consensus configuration is shown in Figure 2. The objects were grouped under the same initial Facets, (same color). As a first approximation it was proved that the initial hypothesis can be accepted for MDS low dimensional space (ie.: the original facets are mirrored in the configuration obtained). The only exceptions occurred with the humidity (Hum), Nanotechnology and Work under the Sun, because those risks remain located outside their original facet.

The first dimension, "risk of death," divides the perceptual map of occupational risks at high risk to the right and low to the left. Chemical agents (in red) are seen by students as more deadly when compared to physical agents (in blue).

The separation, however, is not perfect once that the facet of chemical risks tends to invade the facet of physical risks. This fact can be explained by the low level of knowledge about the risks posed by nanotechnology among the respondents. Although many already have heard about nanotechnology, they are not aware of the risks.

In relation to dimension 2, the map is divided between activities/operations and environmental agents.

In the inferior quadrant (left) activities related to office, bank teller, telemarketing operator, posture and physical effort compose the facet of activities with a predominance of ergonomic hazards and in the other quadrant (right) facet of activities with various risks are allocated.

Again one cannot obtain a perfect facet, since that work under the sun tends to be more distant from the group. The humidity, as reported above, stands out in terms of the dimension 2. It is isolated at the bottom of the map.

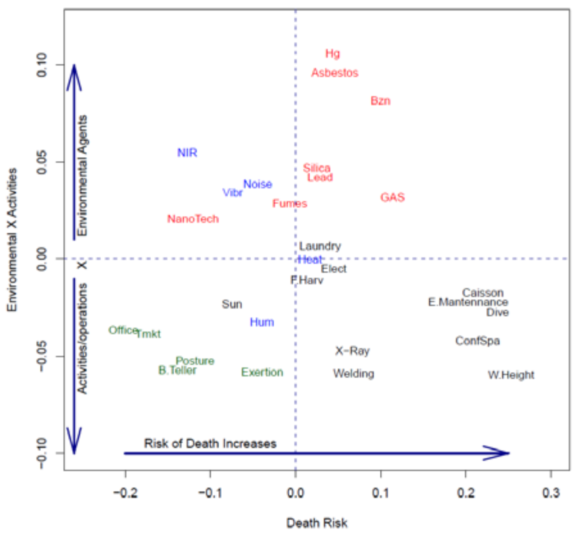

Figure 2 - Perceptual Map of Occupational Risks

4.2. Validation of Group Cognitive Structure

The next step was to test the hypothesis that it is possible to represent the cognitive structure of a group, using MDS and other multivariate methods. In the same time test statistically if an object belonging to a particular facet can be separated from others, which would reinforce the initial hypothesis that the representation in four facets could be demonstrated in the perceptual map.

After the MDS reduction and GPA´s alignment of the finals configurations, confidence regions were generated in order to represent the variability of the students in the map, and to test both hypothesis as stated in the previous paragraph above.

The confidence regions were generated using Bootstrap, a non parametric way of estimating the covariance matrix, once the coordinates distribution are not multivariate Normal [5].

The results showed that it is not possible to isolate objects, because when comparing the ellipses from one object to another it is observed that the ellipses are overlapped and thus any two objects do not show statistically significant differences.

In Figure 3, the traced confidence regions isolate the major part of objects, but only with 5% of confidence, which is too low. For higher confidence levels like 75%, 90% and 95% there are no separation of the objects, which means they are all the same in a group interpretation.

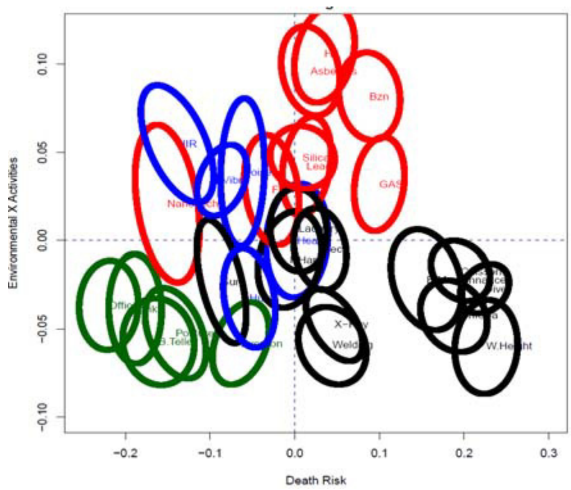

Figure 3 - Perceptual Map with confidence regions.

This finding refutes the possibility of determination of the cognitive structure of the group. It is not possible to evidence the Facets Theory as well.

5. Final remarks

The objectives of this paper were partially achieved, once the first objective of obtaining the perceptual map of occupational risks was successful. However the hypothesis of a regional interpretation of the cognitive structure and differences among objects were not possible, once there is no significantly statistical differences between objects.

This achievement reveals that the cognitive structure of a group is not feasible, once the differences between students are too large.

Future works include the attempt to cluster the judges in order to produce more than one perceptual map to represent the cognitive structure of the occupational risks.

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