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APPLICABILITY OF THE MAXM METHOD IN THE STATISTICAL ANALYSIS OF OCCUPATIONAL RISKS

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Abstract: *Occupational risk assessment requires rigorous and adaptable tools to reflect the complexity of today's work environment. In this context, the MAXM method – which combines severity, duration of exposure and frequency of risks – offers a structured and visual approach. However, in order to ensure objectivity and validation of the results obtained by this method, the integration of statistical techniques, such as analysis of variance (ANOVA), becomes essential. This article argues the need to apply ANOVA in the analysis of data resulting from MAXM evaluations, highlighting its advantages in detecting significant differences between experimental conditions, categories of personnel or evaluation moments. Thus, a combined statistical-institutional approach is proposed, meant to substantiate efficient decisions in the field of occupational safety and health.*
Keywords*: ANOVA, risk assessment, occupational health, MAXM method, occupational safety, statistical analysis, risk management*

1. INTRODUCTION

In any working environment, the safety and health of personnel are essential aspects to ensure the proper working environment and to prevent occupational accidents and diseases. Risk assessment occupies a central position in the occupational health and safety strategy, and among the factors that the time of exposure of workers to different hazardous agents must be taken into account. This parameter plays a key role in quantifying hazards and implementing appropriate preventive measures [1], EU [2]. Exposure time and its influence on occupational risks

Exposure to occupational risk factors, such as noise, toxic substances, vibration, extreme temperatures or repetitive movements, varies from one field of activity to another. Exposure time is a real indicator in determining the probability of occupational diseases or accidents at work [3].

The longer an employee is exposed to a risk factor, the more it increases

the likelihood of adverse effects on its health.

For example, an employee who works daily in an environment characterized by high noise levels is exposed to an increased risk of hearing loss, compared to an employee who is only occasionally exposed to the same noise source. Similarly, people who work in the chemical industry can develop respiratory or dermatological conditions because of prolonged exposure to toxic substances [4].

To determine the actual level of danger, occupational safety and health specialists use exposure time as a calculation parameter in risk analysis. This process involves the exact measurement of the duration in which an employee is exposed to a hazard, correlating this data with the limits allowed by national and international regulations on occupational safety.

In this context, assessment methods and tools are applied, such as: direct measurement, comparison with safety rules, measures to reduce exposure time and, implicitly, associated risks. Among the most effective strategies are:

staff rotation, process automation, protective equipment, employee training and awareness.

A number of regulations, both at national and international level, set strict limits on the permissible levels of workers' exposure to various risk factors, for example:

European Union regulations set limit values for exposure to chemicals and noise, imposing protective measures for workers.

World Health Organization (WHO) norms recommend strict standards for exposure to radiation, biological agents, and ergonomic factors.

National legislation in various countries regulates the maximum time of exposure to hazardous factors and obliges employers to implement appropriate protective measures [6].

2. MAXM METHOD DESCRIPTION

The MAXM method is a complex tool used for occupational health and safety risk assessment, based on a multi-axial matrix that combines several risk factors to determine the total level of hazard associated with an activity or work position.

The principle of operation is made by assessing the total risk (R) which is calculated by the formula:

R=(R1+R2)×R3,

R = (R1 + R2) \times R3R=(R1+R2)×R3

Where:

R1 – risk determined on the basis of the severity and probability of an event.

R2 – risk determined on the basis of the actual working time in the maximum risk area;

R3 - risk determined by the frequency of undesirable events and the duration of exposure.

The steps of the MAXM method are:

Identification of work processes and critical points (through job description, questionnaires, direct observations).

Risk analysis – job evaluation sheets are filled in for each risk factor.

Application of the MAXM matrix – assign scores on each axis, then calculate the total risk value (R). Classification of risks according to score (e.g. minimal, moderate, significant, major, critical).

Planning of preventive measures – for each risk assessed, concrete measures and actions are proposed.

Transposition into the prevention and protection plan – validated measures are implemented and monitored over time as shown in figure 1.

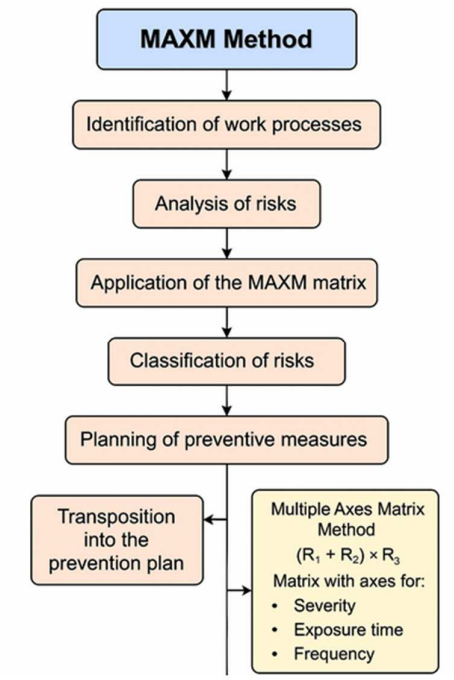

Fig 1. Explanatory diagram of the MAXM method

Advantages of the MAXM method: allows a detailed and nuanced assessment of risks, integrates multiple factors, provides a realistic picture of occupational risk and is based on objective data and previous incidents; It is flexible and applicable in various fields (e.g. local police, public administration, industry).

The MAXM method was applied in the case study for the assessment of occupational risks of civil servants (including local police officers), providing a clear classification of the risks and the measures necessary to reduce them [3].

3. ANALYSIS OF VARIANCE (ANOVA)

With repeated measurements, ANOVA analysis is a valuable tool in investigating and comparing risk or work levels and assessment stages. The MAXM method allows risk

assessment by integrating multiple axes of analysis (severity, exposure, frequency), generating synthetic risk scores. However, in order to verify the statistical significance of variations between different job positions, categories of staff or evaluation periods, the application of an ANOVA analysis becomes justified. It provides a robust framework for:

- testing the differences between the average levels of risks identified according to the organizational structure (e.g. public order police vs. urban control); assessment of changes in risks over time, against the background of the implementation of preventive measures.

Table 1

Questionnaire on worker exposure time

Risk factor hazard	P1	P2	P3
Is there adequate personal protective equipment available for workers?	56	34	0
Is there an evacuation plan and a well-established meeting point in case of an emergency?	56	92	57
Are there warning signs to indicate dangerous areas?	56	66	93
Is there a risk of aggression from the public or criminals?	56	92	100
Is there a risk of exposure to hazardous chemicals?	56	61	79
Is there a risk of being hit by vehicles during traffic missions?	56	82	100
Are bad weather conditions a danger at work?	56	50	93
Is there a risk of being exposed to excessive noise?	56	55	100
Is there a risk of being exposed to biological or infectious substances?	56	63	93
Are the patrol vehicles in good working order?	56	68	93
Are there adequate procedures for the management of weapons and ammunition?	56	76	100
Are patrol vehicles equipped with adequate warning and lighting devices?	56	97	100
Are there adequate procedures for the management of classified information?	56	76	100
Are workers trained in self-defense techniques?	56	89	100
Are workers trained in first aid?	56	58	100
Are regular inspections of service vehicles carried out to check the technical condition?	56	97	100
Are there procedures in place to prevent unauthorised access to service buildings?	56	89	93
Can workers reach their workplace safely?	56	95	100
Can workers control the order in which they perform their tasks?	56	79	100
Is the time spent in front of the monitor interrupted by breaks or by changing activity?	56	66	79
Are the work tasks sometimes contradictory or overlapping?	56	63	93
Are there often interruptions or disruptions during the performance of a work task?	56	66	86
Do you often work under time pressure?	56	84	93
Is there an opportunity to discuss issues with colleagues and superiors?	56	97	100
Is there discrimination based on age, sex, nationality, disabilities, etc.?	56	13	0
Are there any damaged sockets and plugs?	56	53	0
Are fire hazard areas properly signposted?	56	74	100
Is the noise so loud that you have to raise your voice to communicate with colleagues at work?	56	21	0
Is the technical equipment properly maintained to operate safely?	56	63	100
Are there any complaints from workers about low visibility, dazzling or inappropriate light in the workplace?	56	32	0
Is the workload usually very high?	59	79	93
Do you tend to raise your voice unintentionally when you speak, even after you have left work?	44	11	79
Do workers carry out their tasks in isolation?	29	11	0
Do you have contact with dangerous animals (dogs, rodents, etc.)?	49	16	100

Effectiveness of interventions by comparing risk scores before and after the application of measures. In order to determine the exposure time by identifying the work processes, a number of 93 workers were surveyed who answered 34 questions presented in Table 1.

Table 1 contains in column P1 the answers of 41 police officers from the public order department, column P2 presents the results obtained from 38 workers from the urban control department, the data entered in column P3 representing the information collected from the employees of the animal protection service 14 workers. (results are presented as a percentage for "yes" answers)

ANOVA analysis of variance with repeated measurements is a statistical method used to compare the means of three or more groups to determine if there are statistically significant differences between them [5]. The main purpose of the ANOVA method is to check whether the variations observed in a dataset can be attributed to real differences between groups or just to chance. This method is frequently applied in experiments and studies to test hypotheses related to the effects of some factors on the variables studied.

The ANOVA (Analysis of Variance) method is used when you have more than two comparison groups. when you want to test whether the mean of a variable depends on whether it belongs to a group (e.g. region), and when the data are approximately normal and the variances are equal (for classical ANOVA – a parametric analysis), to compare the mean of a continuous variable between two or more groups. In this case, the answers are in percentages, which means that we are dealing with a proportional variable [6].

To apply ANOVA correctly, we must clarify the following aspects:

- Dependent variable – is a numerical (quantitative) variable usually continuous, in this case it is the percentage of "yes" answers for each question.
- The independent factor is what groups or influences the three groups to which the questions have been asked.

Hypothesis to test – checks if the means of the dependent variable are significantly different between the groups defined by the independent factor, we want to check if there are significant differences between the three groups in terms of the percentage of "yes" answers.

The results suggest (figure 2) that the three groups (P1, P2, P3) do not have identical averages, and the differences observed between them are not due to chance. These results underline the importance of using statistical methods to validate hypotheses and to make decisions based on the available data.

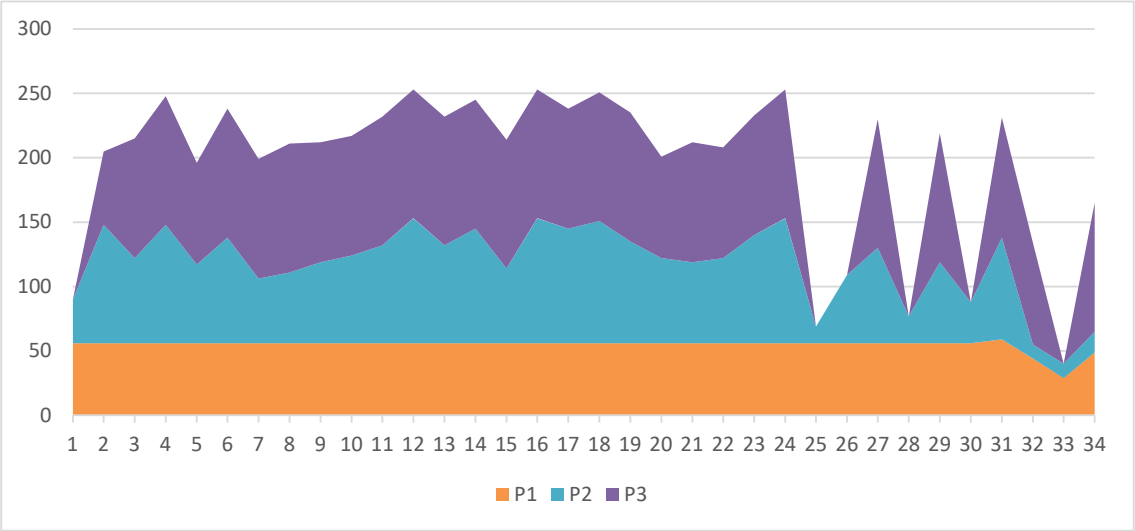

Fig 2. Graphic interpretation for the three groups

The critical value for F(2.60) = 3.15 and F(2.70) = 3.13, so for df = 66, about 3.13. F=9.586 >3.13, so the null hypothesis is rejected. There is a statistically significant difference between the conditions.

In addition, calculating the value p. F=9.586 with df = 2.66 we obtain the value p≈0.00022.

Since p < 0.05, the result is statistically significant, this means that there are significant differences between the groups analyzed (at least one of the averages is different).one can move on to post-hoc tests (Tukey, Bonferroni etc.) to see exactly which groups differ from each other. Therefore, repeated ANOVA measures indicate a significant effect of the condition (P1, P2, P3) on the dependent variable (F(2.66)=9.586, p<0.001)

4. EXPOSURE TIME – AN ESSENTIAL INDICATOR IN RISK ANALYSIS

The use of exposure time as a reference variable in the assessment of the risks of occupational accidents and diseases is a scientifically based practice, with direct relevance in protecting workers' health. Accurate monitoring and correlation of exposure duration with legal thresholds allow for proactive measures to be taken, with beneficial effects on both safety and operational efficiency [4].

The adoption of a coherent risk management strategy, supported by technology, professional training and legislative updating, contributes not only to compliance with the regulations in force, but also to the consolidation of employee well-being and organizational productivity [2]. In a constantly changing professional context, the implementation of innovative solutions and constant adaptation to new standards in the field of occupational safety and health will be essential for setting up a sustainable and safe work environment.

The longer the exposure time, the greater the risk of occupational diseases or accidents. For example, an employee who constantly operates in a high-noise environment is much more prone to hearing loss than a colleague who is occasionally exposed to the same sound level. Similarly, workers who frequently handle toxic substances can develop respiratory or skin conditions, especially in the absence of adequate protective measures.

Risk assessment naturally involves quantifying the duration during which an employee is exposed to a certain danger, correlating this duration with the limits provided by the legislation in force (e.g. Law 319/2006, GD 1091/2006, European Directives). This approach allows the identification of non-compliance situations and the establishment of effective prevention measures.

To carry out a rigorous assessment, a number of specific methods and tools are used, such as:

Direct measurement – monitoring exposure by specialized equipment (e.g. dosimeters, sound level meters, sensors for chemical agents);

Risk calculation – applying formulas that include the intensity of the risk factor and the duration of exposure;

Comparison with reference values – verification of compliance with the permissible legal limits, according to national and international standards.

Strategies for reducing the time of exposure to occupational risk factors

Reducing the time of exposure to occupational risk factors is one of the most effective ways to prevent occupational diseases and accidents. Following the risk assessment process, employers have the responsibility to adopt concrete measures to minimize the duration of employees' contact with dangerous agents, thus contributing to improving safety and health at work.

Based on the risk assessment, employers can adopt measures to reduce the exposure time and, implicitly, the associated risks. Among the most effective strategies are:

Staff turnover – redistributing tasks so that individual exposure is limited, reducing the accumulation of physical or chemical stress among workers.

Process automation – integration of automation technologies to reduce the direct interaction of personnel with risk sources;

Use of personal protective equipment (PPE) – implementation of specific technical solutions (e.g. hearing, respiratory or mechanical protection) to mitigate the effects of exposure;

Scheduling regular breaks – including physiological recovery periods in the work schedule, essential for maintaining work capacity;

Continuous training of employees – developing an organizational culture oriented towards prevention, through risk awareness and constant training in the field of OSH.

The implementation of these measures requires a collaborative approach between employers, workers' representatives and institutions empowered in the field of occupational safety. In addition, constant monitoring of exposure and regular adjustment of control strategies are fundamental to maintaining the effectiveness of these interventions.

Advantages of applying ANOVA analysis with repeated measurements in scientific research

Repeated Measures ANOVA is an advanced statistical technique used to compare the means of three or more datasets collected from the same participants, in different experimental contexts or at successive time points. This method is frequently used in fields such as psychology, medicine, behavioral sciences and social research, due to its ability to increase the accuracy of analysis and the efficiency of statistical interpretation [7]. Among the main advantages of this method are the following:

- Control of inter-individual variability-One of the most important characteristics of ANOVA with repeated measurements lies in its ability to eliminate the effects of inter-individual variation, since the same subjects are evaluated under all experimental conditions. Therefore, differences between participants no longer contribute significantly to model error, leading to a more accurate estimate of the effects of the intervention or treatment.
- Increased statistical power by controlling for variability between subjects, this technique increases the statistical power of the test, making it easier to identify real effects even when they are subtle. This helps to reduce the likelihood of committing type II errors (false negatives), significantly increasing the sensitivity of the analysis.
- Reduced need for participants Unlike ANOVA between independent groups, the variant with repeated measurements requires a smaller sample size to achieve the same level of statistical significance. This is particularly advantageous in research where access to participants is limited or where recruitment involves high logistical and ethical costs.
- Analysis of evolution over time-A major methodological advantage lies in the ability to investigate changes in time-dependent variables. ANOVA with repeated measurements allows the evaluation of temporal trends and the identification of any significant differences between the measurement points, providing a longitudinal perspective on the effect of the factors studied.
- Increased sensitivity to treatment effects—Using each participant as their own control, the variability associated with inter-individual differences is significantly reduced. Thus, the analysis becomes more sensitive to the changes produced by the treatment, making it easier to detect the effects even in the case of low-impact interventions.
- Flexibility in examining interactions-This technique allows the investigation of complex interactions between factors, such as the combined effect of time and an intervention on a dependent variable. The ability to analyze such interactions provides a more nuanced understanding of the mechanisms underlying the phenomena investigated [1].

Necessity and applicability of ANOVA analysis in the context of occupational risk assessment.

ANOVA analysis, this is extremely valuable for the scientific validation of the results obtained through MAXM and can be subsequently integrated into the expansion of the research [3]. ANOVA becomes important for:

• Comparing risk scores between different positions or departments (e.g. civil servants vs. police officers);

• Analyzing changes in risks over time, following the implementation of preventive measures.

• Determining the statistical significance of differences between the risks recorded.

• Reducing interindividual error, when the same employees are evaluated at multiple intervals.

In addition to the classic forms (unifactorial, multifactorial, repeated measures), there are also:

ANCOVA (Analysis of Covariance)

Integrates continuous covariates to control for other factors that influence the outcome (e.g. age, initial stress level).

MANOVA (Multivariate ANOVA)

It is used when there are multiple dependent variables simultaneously.

Ex: comparing 3 groups according to stress level and job satisfaction.

MANCOVA – combines MANOVA with ANCOVA.

For ANOVA results to be valid, the following conditions must be met:

- Independence of observations – each participant/group is separate.
- Normality – the data in each group must be approximately normal.
- Homogeneity of variance – the variances in all groups must be approximately equal (tested with Levene's test) [8], [9].

5. CONCLUSIONS

In complex processes of occupational risk assessment, such as the one described in the article on the application of the MAXM method in local police structures, the need to integrate advanced statistical methods to support decisions and objective validation of the collected data is noted. In this sense, analysis of variance (ANOVA) with repeated measurements is a context or one wants to identify the main effect and interaction between several factors. The application of this method contributes to reducing inter-individual error and increasing the sensitivity of the analysis to subtle variations in the level of risks. Valuable tool in investigating and comparing risk levels or the effectiveness of preventive measures applied in various working conditions and assessment stages. The MAXM method, as opposed to other methods [10], allows risk assessment by integrating multiple axes of analysis (severity, exposure, frequency), generating synthetic risk scores. However, in order to verify the statistical significance of variations between different job positions, categories of staff or evaluation periods, the application of an ANOVA analysis becomes justified. It provides a robust framework for testing differences between average levels of identified risks, assessing changes over time, validating the effectiveness of interventions and supporting strategic decisions. ANOVA analysis with repeated measurements is particularly useful when the same employees are evaluated in different contexts or one wants to identify the main effect and interaction between several factors. The application of this method contributes to reducing inter-individual error and increasing the sensitivity of the analysis to subtle variations in the level of risks.

By applying MAXM to distinct categories of civil servants (general positions vs. local police officers from different structures), the paper generates a valuable dataset, based on quantifiable risk scores, that reflect the real level of dangerousness associated with professional activities.

However, in order to statistically validate the differences between the analyzed categories and to support organizational decisions with an additional level of scientific rigor, the integration of ANOVA analysis is not only advisable, but necessary in the next stage of the research

In conclusion, ANOVA analysis proves to be an essential tool for statistical validation and deepening in a methodological framework that uses multi-axial matrices for risk identification. It allows for a rigorous interpretation of data and supports the substantiation of occupational health and safety decisions.

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Aplicabilitatea metodei MAXM în analiza statistica a riscurilor ocupaționale

Evaluarea riscurilor ocupaționale necesită instrumente riguroase și adaptabile pentru a reflecta complexitatea mediului de muncă actual. În acest context, metoda MAXM – care combină severitatea, durata expunerii și frecvența riscurilor – oferă o abordare structurată și vizuală. Totuși, pentru a asigura obiectivitatea și validarea rezultatelor obținute prin această metodă, integrarea tehnicilor statistice, precum analiza variației (ANOVA), devine esențială. Acest articol argumentează necesitatea aplicării ANOVA în analiza datelor rezultate din evaluările de tip MAXM, evidențiind avantajele acesteia în detectarea diferențelor semnificative între condiții experimentale, categorii de personal sau momente de evaluare. Se propune astfel o abordare combinată, statistic-instituțională, menită să fundamenteze decizii eficiente în domeniul securității și sănătății în muncă.

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