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Expert systems as a tool to manage accident risks in grain storage facilities

Sistemas especialistas como ferramenta para gerenciar riscos de acidentes em instalações de armazenamento de grãos

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Abstract

Caring for workers' welfare and health is an Engineering basic principle, which comprises scientific studies and aims to achieve a positive result in the end of the processes. Using Grain Processing and Storage Units is advantageous since they permit storing products for long periods. On the other hand, these places offer risks to workers. Currently there are a great number of researches which use expert systems in order to assist decision-makings. Fuzzy Logic is one of the most used, since it presents easy handling and results interpretation. Thus, this study aimed to use Fuzzy Logic in the Occupational Safety Engineering in order to elaborate a mathematical model which represents the accident risk levels in Grain Processing and Storage Units and that could be used as a tool to assist decision-makings. The possibility of accidents; exposure to risk; and workers' experience were considered the input variable. The simulation answer was the risk of occurring occupational accident. In conclusion, it was possible to say that Fuzzy Logic was so efficient as an Engineering tool to represent accident risks. Regulation Norms' (NR) accomplishment and "Workers' Experience" can impact on the "Risk of Accident" in Grain Processing and Storage Units.

Keywords: Fuzzy logic. NR. Occupational safety.

Resumo

Cuidar do bem-estar e da saúde dos trabalhadores é um princípio básico de engenharia, que compreende estudos científicos e visa alcançar um resultado positivo no final dos processos. O uso de unidades de processamento e armazenamento de grãos é vantajoso, pois permite o armazenamento de produtos por longos períodos. Por outro lado, esses locais oferecem riscos aos trabalhadores. Atualmente, existe um grande número de pesquisas que utilizam sistemas especializados para auxiliar na tomada de decisões. A Lógica Fuzzy é uma das mais utilizadas, pois apresenta fácil manuseio e interpretação dos resultados. Assim, este estudo teve como objetivo utilizar a Lógica Fuzzy na Engenharia de Segurança do Trabalho, a fim de elaborar um modelo matemático que represente os níveis de risco de acidentes nas Unidades de Processamento e Armazenamento de Grãos e que possa ser utilizado como ferramenta para auxiliar na tomada de decisões. A possibilidade de acidentes; exposição ao risco; e a experiência dos trabalhadores foram consideradas variáveis de entrada. A resposta da simulação foi o risco de ocorrência de acidente ocupacional. Como conclusão, foi possível verificar que a Lógica Fuzzy foi tão eficiente quanto uma ferramenta de engenharia para representar riscos de acidentes. O cumprimento das Normas de Regulamentação (NR) e a "Experiência dos Trabalhadores"podem impactar o "Risco de acidente"nas unidades de processamento e armazenamento de grãos.

Palavras-chave: Lógica fuzzy. NR. Segurança no trabalho.

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Introduction

The positive evaluation of workers' ergonomics and welfare is the basic principle in Engineering, which comprises scientific studies, methods and behaviors, aiming a positive result in the end of the processes. Noises, vibrations, heat, coolness, gases, dust, among other factors, when exceed specific limits, can cause diseases or affect workers' welfare (KARLTUN *et al*., 2017). These kinds of situations are frequent in agroindustry facilities, and need to be studied in order to assess and quantify their levels and risks of accidents, improving occupational conditions and workers' health.

According to Brasil (2019), Brazilian agriculture is hugely represented in the national GDP, and is increasing year by year. Grains and cereals are among the products produced, intended to supply domestic and external markets.

Using Grain Processing and Storage Units (UA) is advantageous since they permit storing products for long periods, avoiding their loss of quality. On the other hand, these places offer physical, chemical, biological, ergonomic and environmental risks to workers, since they present closed and dusty spaces, permeated by gases, where, usually, there are also machines, equipment and personnel working (COSTELLA; PILZ; BET, 2016).

Second Abedini *et al*. (2019), Fuzzy Logic is used to evaluate parameters which assess uncertainty in the answer, translating inaccurate information into mathematical terms. Such information is expressed by a set of linguistic rules, where the *fuzzyfication* refers to the deterministic output variable that, if correctly calculated, can be used as a tool to assist decision-making.

Currently there are a great number of researches which use expert systems in order to assist decision-makings. Fuzzy Logic is one of the most used, since it presents easy handling and results interpretation (HILLETOFTH; SEQUEIRA; ADLEMO, 2019; VIANA; MATTOS, 2017).

According to Oliveira *et al*. (2005), the basic structure of a system based on fuzzy rules includes as main components a "fuzzifier" that translates the input information with linguistic terms, a knowledge base composed of a set of fuzzy rules built according to expert knowledge and information official, an inference method that applies fuzzy reasoning to obtain the fuzzy output, and a "fuzzified" that translates the output into a possible numerical value of interpretation that assists in decision-making.

This study aimed to use Fuzzy Logic in the Occupational Safety Engineering in order to elaborate a mathematical model which represents the accident risk levels in Grain Processing and Storage Units (UA), taking into consideration the continuous nature of the variables involved and its application as a tool useful to decision-making.

Material and Methods

A review of literature was carried out, comprising: theoretical references provided in the database of the Brazilian institution, responsible for the national technical regulations - *Associação Brasileira de Normas Técnicas (ABNT)* -, specially Regulation Norms (NR) (ENIT, 2019), in order to check which regulations should be considered in the Processing and Storage Units (UA); the SciELO (Scientific Eletronic Library Online) and Science Direct scientific database; and relevant articles issued until 2019.

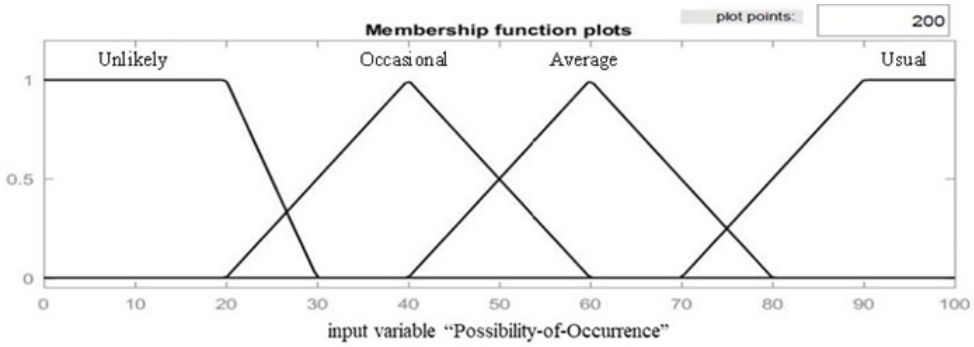
With the bibliographic reference found (MOTA, 2015; NEITZEL; GADOTTI, 2017) and consulting a specialist, an Agricultural Engineer with 20 years of experience who has worked in UA, a postgraduate degree in Occupational Safety Engineering who was already the coordinator of this course for 4 years and is currently a postgraduate coordinator in Agricultural Engineering at the Federal University with post-harvest research and work safety, it was possible to identify for a UA three of the main accident risk variables that workers are exposed to, as well as subdivide each variable into specific linguistic terms.

In order to elaborate the intended mathematical model, the software MATLAB R2015® (MATHWORKS, 2015) was used, which enables to work with the Theory of Fuzzy Set.

According to Rangel Junior (2011), UA present risks such as burying, fall and explosion, which cannot be precisely valued, but impacts on plans and procedures related to safety and intended to assess the risks, therefore avoiding and reducing the chances of accidents and incidents in the working place. Thus, the "Possibility of occurrence" of accidents was chosen as the input variable in this model, presenting its domain ranging from 0 to 100%, in linguistic terms, classified as shown in Figure 1.

When the worker performs a task with a greater or lesser "Possibility of Occurrence" of an accident, the greater the "Accident Risk" included in this service.

Figure 1 – Input variable possibility of occurrence of accident at work.



Source: The authors.

Thus, according to the expert and according to Hulme *et al*. (2019) this variable can be considered as frequent, in confined places and work at height, or unlikely, as accidents resulting from specific adverse situations.

From the legal point of view, there are many specific Regulation Norms which have to be strictly complied with, in order to reduce the time of exposure to risks. Among them there are NR 05, 06, 07, 08, 09, 14, 17, 23, 26, 31, 33, 34 and 35, which provide the minimum requirements and the protection measures intended to be adopted in specific works and activities (MOTA, 2015).

In engineering applications, the degree of reliability is generally inaccurate and qualitative and therefore the "Risk of Accident Exposure" determined by a specialist, such as the one who participated in this study, Occupational Safety Engineer, Doctor in Agricultural Engineering, who agreed with the uncertain low, medium and high exposure terms proposed by Kabir and Papadopoulos (2018). For this reason, when either employers or workers do not comply with an NR, the "Exposure to risk" rises, which is, then, considered the model input variable, presenting a domain ranging from 0 to 100% of exposure in linguistic terms classified as Figure 2.

Second Oah *et al*. (2018), training programs and experiences with accidents at work influence directly on leadership safety. However, they negatively influence on cognitive and emotional risk perception, since people can develop overconfidence. Amount of work, leadership position and performance of safety when working on tasks influence more on the risks realized than the experience with accidents, especially regarding emotional risk perception. Considering a company and an eventual emotional uncertainty each worker might be facing, this model was elaborated classifying these workers as limited experience, common and long experience.

According to NR 9 – Environmental Risk Prevention Program -, environmental risks are physical, chemical and biological agents present in work environment, which, based on their nature, concentration and time of exposure are able to influence on workers health. Thus, since NR-9 is one of the most present in UA, "Workers Experience" was considered the third input variable, presenting domain ranging from 0 to 100% in linguistic terms, according to Figure 3.

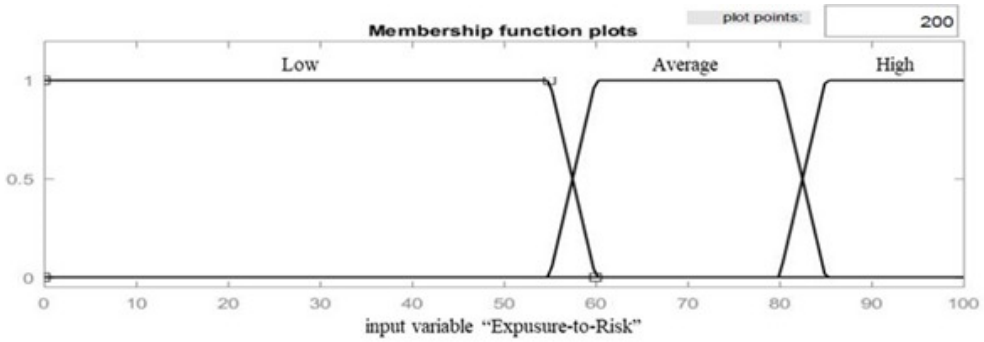
The causes of accidents at work are, most of times, complex. Nevertheless, there are three factors which direct or indirectly influence on any accident occurrence: unsafe acts, unsafe conditions and personal insecurity (BARSANO; BARBOSA, 2013). Therefore, the linguistic term for answer of this model was the Risk of Accident at work, presenting amplitude ranging from 0 to 100%, and which took into consideration the interaction among all input variables, according to Figure 4.

The mathematical tool MATLAB R2015a® and its additional Fuzzy Logic toolbox provided several edition possibilities, which permitted to build a Fuzzy Inference System, as carried out by Gallab et al. (2019). It also permitted qualitatively simulate possible real situations involving risks of accident at work inside grain processing and storage unities.

The inference method used to link input to output variables was Mandani, enabling accidents at work risk analysis for each specific situation. The "non-fuzzification" was carried out by the center gravity method, as suggested by Arun and Mohan (2017).

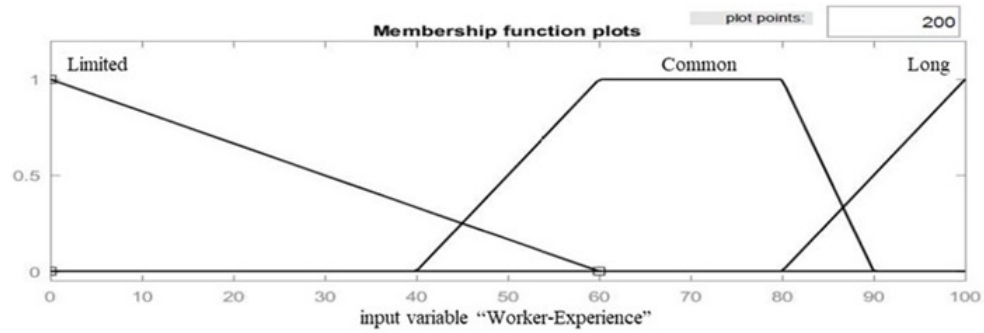
The combination of input variables with the output variable as a response gave rise to 36 rules, in the form "if" Possibility of Occurrence (Unlikely; Occasional; Average; Usual) and Exposure To Risk (Low; Average; High) and Workers' Experience (Limited; Common; Long) Then Risk Of Accident (Unlikely; Unusual; Average; High).

Figure 2 – Input variable exposure to risk of accident at work.



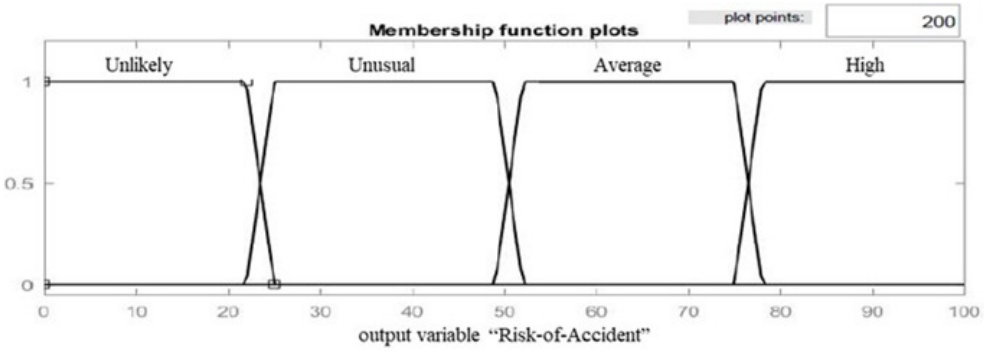
Source: The authors.

Figure 3 – Input variable workers' experience.



Source: The authors.

Figure 4 – Linguistic term risk of accidents at work.



Source: The authors.

Of the 36 rules, 17 Unlikely, 12 Unusual, 5 Average, and 2 High were generated.

Results and Discussion

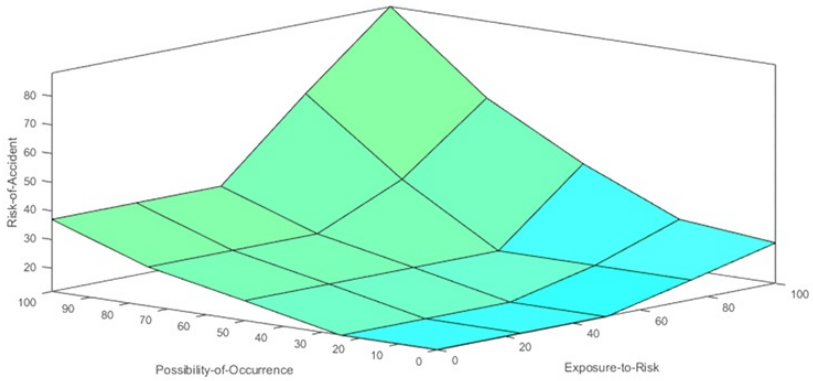
According to Mota (2015), there are many specific Regulation Norms which have to be strictly complied with, in order to reduce the possibilities of accidents in Processing and Storage Units (UA).

A problem description is made by indicating the characteristics which describe an input fact, which results in an output situation. The modeling of the relation between inputs and outputs is carried out by linguistic concepts (AGHAEIPOOR; JAVIDI, 2019). Based on this statement, the values Possibility of Occurrence, Exposure to Risk and Workers' Experience were chosen to be represented in this study as a base of activated rules, simulating risk situations and creating a scenario where the output variable Risk of Accidents could be observed.

Second Hilletofth *et al.* (2019), Fuzzy reasoning method is based on IF...,THEN... conditions, in order to infer an output diagnosis. For this reason, the rules that related input to output variables were created based on the specific expert's knowledge, after his access to the revised literature information.

Figure 5 shows the graphic representation of "Accident Risk" at work if a worker is performing a task with a greater/lesser "Possibility of Occurrence" of an accident, such as work at height (NR-35) or confined space (NR-33), depending on the level of "Risk Exposure" to this work.

Figure 5 – Graphic 1 – Fuzzy system.



Source: The authors.

Figure 5 shows that the results of Fuzzy classification method express the reality qualitatively. In this case, if "Exposure to Risk (any specific situation)" is low and this same risk presents low "Probability of Occurrence", the simulator shows the answer of minimum possibility of "Risk of Accident", next to 10% - never 0 (zero), since even in situations that all safety measures were taken, there is still an intrinsic eminent risk aggregated to the work activities. Also, in situations of maximum Exposure and Probability of Occurrence, Fuzzy method presented a coherent classification, next to 90%, demonstrating its interesting characteristics.

According to the expert, and confirmed by Gasques *et al*. (2018) even taking all accident prevention measures and having experience of the worker, approximately 10% should be considered as mild occurrences, resulting from low-quality equipment provided to employees or equipment that has a defect in the work environment. Likewise, an increase in Accident Risk is not a total possibility of occurrence, since even new employees receive minimal training, need to respect NRs, and are constantly monitored.

Considering Figure 5 as a tool used to decision-making in an UA, a risk map is indicated to recognize each work place. According to NR 5, The Internal Accident Prevention Committee (*Comissão Interna de Prevenção de Acidentes* – CIPA) has the attribution of elaborating such document, preferably carried out by its staff together with a Specialized Work Safety and Medicine Service (Serviço Especializado em Engenharia de Segurança e em Medicina do Trabalho - SESMT), if existent, so that a better attention and concern about the details are guaranteed.

Aiming to reduce the "Risk of Accidents", the form indicated to minimize "Exposure to Risk" is the usage of Personal Protective Equipment (EPI), which should be carried out when there is no possibility of eliminating working environment risks or when collective safety measures are not feasible, efficient or enough in order to avoid them (BONATTO *et al*., 2017).

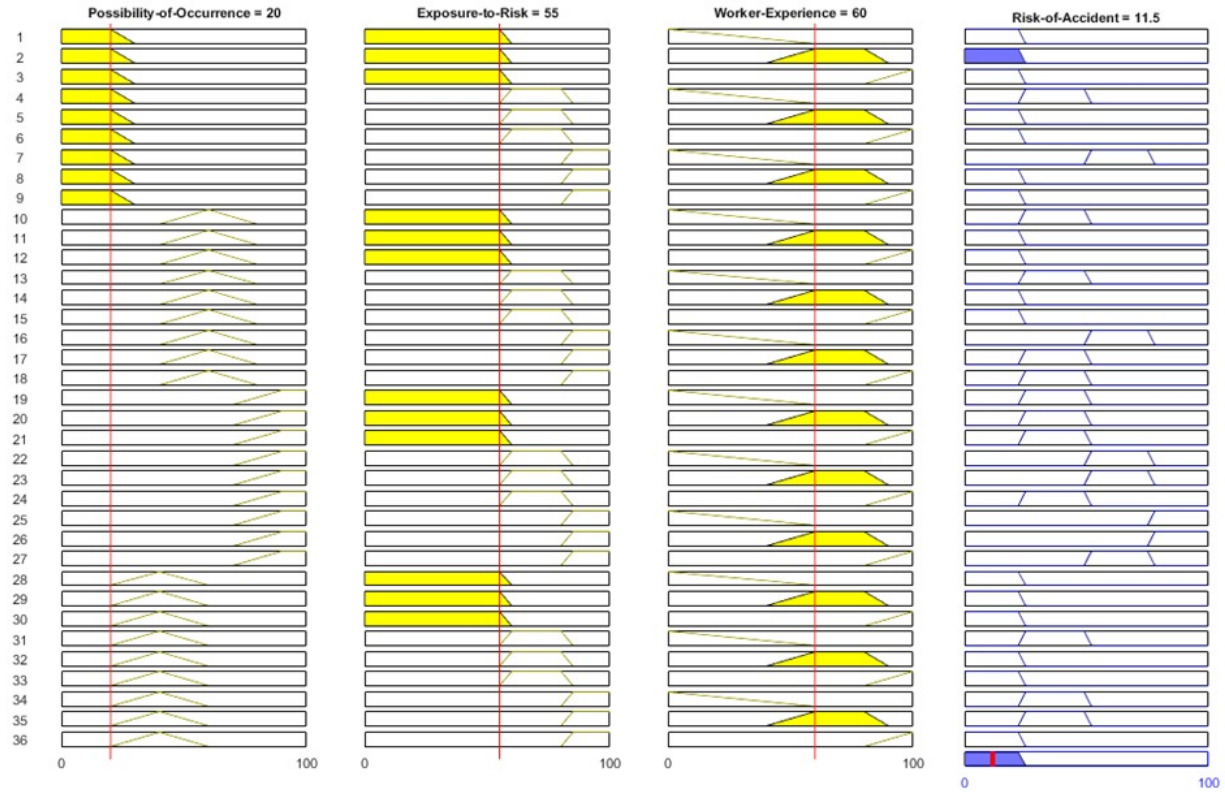
Figure 6 shows the Rules Base activated with the input linguistic variables assuming hypothetically ideal limits and resulting in the Accident Risk for this proposed scenario.

Advances in health and safety at work are not equivalent to the demand for performance in production, working conditions in a storage and processing unit. Such carelessness has favored the occurrence of accidents caused by unsafe conditions and unsafe behavior by some workers, reaching an order of 20% of occurrence even in minimal conditions (BUCKLIN *et al*., 2019) (BUCKLIN et al., 2019).

According to the literature consulted for this study, it is necessary to anticipate and recognize the risks of accident-prone environments, to carry out the assessment and control before the workers enter or perform the activity and verify that the environment is safe. Continuously assessing and monitoring work during execution allows workers to remain safe, reducing the risk of any accident that will be predicted by more than half (BUCKLIN *et al*., 2019; SCHOENINGER *et al*., 2019).

According to Kawai *et al*. (2019) large grain processing units are more concerned with labor issues, more concerned with occupational safety, investing in activities that arouse motivation for work and considering that the worker's experience influences the environment. In the study carried out by these authors, it was found that the "best fit" among employees, tasks, technology and environment, depends on the experience of each individual, considering a healthy environment when more than 60% of the previous experience in decision making that prevails reflects possible accident risks.

Figure 6 – Rules base activated with ideal values of the fuzzy system



Source: The authors.

A study conducted by Oliveira (2013) with 92 AU in the state of Rio Grande do Sul, found after analysis through interviews and data collections carried out between July and October 2012 that for workers some type of work accident is routine, and between 18% suffered minor work accidents in the last 36 months, without the need for leave. Thus, if the input variables in Figure 6 are with ideal values, the output variable, 11.5% fits in the response to a real situation.

Laal *et al*. (2020) and Rostamabadi *et al*. (2020) document the importance of studies like the one presented here, that use fuzzy logic for security analysis in process systems, as it is an ideal tool considering the uncertainties involved, as technical, human and organizational factors.

For UA, to avoid the minimum degrees of Risk of Accidents in both Figure 5 and Figure 6, it is necessary to have a minimum exposure, combined with a low possibility of this happening and a high experience of the worker, which may reflect a good training. Thus, besides the specific NR already mentioned, is clear the importance to continuously complying with NR 6 – Personal Protective Equipment, highlighting that is up to workers follow the employer's instructions regarding its correct usage, and NR 9 - Environmental Risk Prevention Program (PPRA), which is intended to maintain workers' health and physical well-being in the work environment.

Conclusions

For the simulation carried out with the proposed model, the variable "Accident Risk" presented coherent values as a result of the combination between "Possibility of Occurrence" of accidents and "Exposure to Risk" of accidents, which represented efficiency of the model.

Due to the dynamic nature of the variables that affect the risk of accidents and the static nature of the grain processing routines, the adequacy of the variables for each specific situation can make the fuzzy model more realistic and reduce uncertainty, serving as a tool that helps in making administrative decisions involving Workplace Safety in Storage Units.

When representing ideal values in the fuzzy system, the model demonstrated coherence of the output variable, because if the worker is in favorable working conditions the Accident Risk is classified as Improbable.

Using Fuzzy Logic to elaborate qualitative thematic figures which show scenarios of exposure to "Risk of Accidents" at work makes this kind of modelling an Engineering tool which can be used to manage Grain Processing and Storage Units.

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