Risk Prediction of Delay in the Execution of Public Works Through Fuzzy Logic: Case Study in the City of Manaus

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Abstract

In Manaus, delays in public constructions are not uncommon as their execution deadlines are often extrapolated, even though such deadlines are obtained through preliminary technical studies. The causes that give rise to such delays are varied ranging from the occurrence of rain to the addition of quantities of existing services or additions of new services. In this research, we sought to obtain a model, using fuzzy logic, to predict the risk of delay that some variables may cause in the period of execution of the work, allowing the public administration or the contracted company to adopt measures they consider essential to mitigate this delay. Initially, documentary and bibliographic research were carried out to identify the causes that most contribute to the occurrence of delays in the works. Once these causes were identified, the construction of the fuzzy inference system was started, with six of the most significant causes identified in the research being considered as linguistic variables, namely: the hiring factor, which corresponds to the quotient between the value of the proposal. of the company and the amount budgeted by the administration; the value of the work, which is the value of the contract for the work; the engineering execution drawing, which are the engineering drawings used in the works; the alteration of quantities, which are changes in the quantities of existing services or addition of new services; authorization from public agencies, which corresponds to the permission or support of any public agency or public company for the execution of the work; and the rain. For the simulation of the created fuzzy inference system, real data from four public works were entered, and the answers of this simulation were satisfactory because they are confirmed by the documentation of the respective works. It is concluded that the system proved to be useful, as it was possible to predict the risk of delay in the execution of public works in the city of Manaus, and it can be used by both the public administration and the contractor to mitigate the causes of delays in the execution of public works.

Keywords: Publics Works; Delay of Works; Causes of Delay; Fuzzy Logic.

1. Introduction

Annually in Brazil, the Brazilian Institute of Geography and Statistics – IBGE, carries out the Annual Survey of the Construction Industry – PAIC. This research identifies the characteristics that exist in this industry and the changes that have taken place over time.

In the last survey carried out, civil construction generated in 2018 the value of BRL 278 billion, of which BRL 87 billion referred to infrastructure works, wherein 50.4% of these works, the public administration was the contracting party, showing in this way, its expressive participation in the Brazilian civil construction

(IBGE, 2020).

The process of contracting public works, which are those in which the applicant is the public administration, is preceded by the bidding process, which, in turn, is subject to the existence of the basic project (Brasil, 2017).

This basic project is not about engineering drawings but a set of documents prepared with an appropriate level of accuracy, which, in addition to characterizing the work, allows the definition of its execution period (Brasil, 2017).

However, despite the deadline for the execution of public works being defined in the basic projects, its non-compliance is not uncommon, as these deadlines are often extrapolated due to stoppages of service stages, need for additions of new services, the occurrence of rain, among others, that is, situations that are not foreseen and that directly impact the execution period of the work.

Therefore, it was identified the need to carry out a study aiming to obtain a model, based on fuzzy logic, for predicting the risk of delay in the execution of public works in the city of Manaus.

2. Literature Review

2.1 Public Works

Public work is any action to build, renovate or expand a property whose property belongs to the public administration, and these actions can be carried out by the public institution itself or by a company hired by it (TCU, 2009).

2.1.1 Deadline Work

Every work, whether public or private, has an execution term and this term is related to the execution time of all services so that each service that constitutes the work has a duration, which can be in hours, days, weeks, or months, duration that depends on the quantity of the service, the productivity of the team involved in its execution and the number of resources allocated for this execution (MATTOS, 2019).

In order to determine the term of the work, it is essential that, initially, it is identified which services will be performed, and this identification must be carried out with great caution, as if one of the services is not identified in the schedule, its absence will reflect on the progress of the work, as the service must be executed, but its execution was not contemplated within the scheduled period, thus compromising the foreseen term of the work (MATTOS, 2019).

After the stage of identifying the services, start obtaining their duration, establishing their interrelationships and determining the services that precede others, and then performing the graphical representation, which is the diagram network, which allows the identification of interconnected services and the sequence of execution (MATTOS, 2019).

Once the network diagram is completed, the necessary calculations are processed to obtain the total term of the work, this term corresponding to the sequence of services in the network diagram that consumes the most time for its realization, where the path that connects these services in this diagram is identified as the critical path, while the services identified in that path are the critical services.

The services of the work, whether critical or not, use labor, inputs and equipment, which are diluted over their period of execution and that no matter how much the construction process is mechanized, regardless of the stage of execution of the work, the hand of work will always be a determining element for the dimensioning of its execution period (LIMMER, 1997).

Although the deadline for the execution of public works is a result of the technical studies that make it possible to define and represent them through the schedule, it is not uncommon for non-compliance to occur, as these deadlines are often extrapolated due to stoppages in stages of services, need for additions of new services, rains, that is, situations that were not previously foreseen and that directly impact the execution period.

2.1.2 Delay of Works

The delay of the work can be defined as “the time overrun, either beyond completion of the date specified in a contract, or beyond the date that the parties agreed upon for delivery of the project” (ASSAF; AL-HEIJI, 2006). Delay has also been defined as “the late execution of a work, exceeding the deadlines foreseen in the programming/distribution for the activities or global deadline of the project foreseen contractually” (COUTO, 2007).

In addition, the delay is also an intrinsic risk to most construction projects, and should not be ignored, but should be taken care of in a similar way in relation to the other risks to which these projects are subject (ZIDANE; ANDERSEN, 2018).

Although the term delay has several definitions, they converge to the meaning of non-compliance with the established execution deadline, with each delay having one or more causes for its occurrence.

2.1.3 Causes of Delay

The big common problem of the civil construction industry in developing countries is the extrapolation of execution deadlines (GUPTA; KUMAR, 2020). These extrapolations can be attributed both to the owner, contractor or can also be attributed to third parties (COUTO, 2007).

These delays may originate from one or more causes, which may occur concomitantly or not, and there is also a versatility of those responsible for their occurrences.

2.1.4 Effects of Delay of the Works

When work is completed and made available to society for use, it reaches the purpose for which it was designed however, the delay in its completion causes negative effects.

These effects are harmful to both the owner and the contractor, and in the case of public works, society is negatively impacted by the delay in using the benefits arising from the work (COLPO et. al, 2018). These effects are not limited only to the unavailability of its use, but also impact the local and national economy (CBIC, 2018).

Generally, the benefit provided by the public work is not exactly associated with the effective cost of its construction, and, in the event of a delay in the completion of the aforementioned work, the social cost of this delay is also not evaluated (ARAGÃO FILHO, 2014).

Thus, it is noted that the social benefit arising from the availability of use of public works and the negative social impact caused by the unavailability of its use due to delays are not measured in financial terms.

In this scenario, where the causes of delays are uncertain and subjective and may originate from the owner, the contractor, or third parties, it is essential that the public administration anticipate their occurrences, in other words, predicting, and the fuzzy logic, shows a way to obtain this prediction, thus helping in the management of public works.

2.2 Fuzzy Logic

Fuzzy logic was introduced by Lofti Asker Zadeh in 1965, where the use of this logic helps in characterizing and measuring the value of behavior through the criteria adherence function, with each fuzzy set carrying a membership level ranging from 0 to 1, that is, from non-adherence to complete adhesion, thus contrasting with binary sets, where an element can only be or cannot be part of the set (BHATT; MACWAN, 2016).

In classical set theory there is a markedly established limit to indicate whether an element belongs or not to a set, that is, there is no way an element can belong and not belong to a set simultaneously, but in fuzzy set theory there is no a limit established to indicate whether an element belongs or not to a set, that is, an element can partially belong to a set or it can also partially not belong to this set (CHEN; PHAM, 2019).

In a clear relationship, there are only two degrees of connection between the elements of their sets, which are completely connected and non-connected, and fuzzy relations allow the connection between the elements of two or more sets to receive an infinity of degrees of connection existing between the limits of completely connected and non-connected (ROSS, 2017).

According to ROSS (2017), in binary logic, classical sets have elements that meet the association properties, where an element x in the universe X belongs or not to a certain set A, represented by the number 1, if the element belongs, and, through the number 0, if the element does not belong, it can also be represented by the function:

$$X_A(x) = \begin{cases} 1 \; se \; x \in A \\ 0 \; se \; x \notin A \end{cases}$$

ROSS (2017) also explains that in fuzzy logic, fuzzy sets have elements that meet the imprecise association properties, and, unlike classical sets, which have a single association, fuzzy sets have an infinite number of associations, with a membership of the elements of a fuzzy set A in a universe of discourse X indicated by a membership function μA, which can assume any value included in the interval [0,1], as seen in the function below:

$$\mu_A(x) \in [0,1]$$

2.2.1 The Linguistic Variables

Fuzzy logic offers the ability to interpret linguistic expressions into numerical values, where each expression is translated as a fuzzy subset comprised in the range 0 to 1 (GAVIÃO; LIMA, 2015).

These linguistic expressions, known as linguistic variables, have their values described by terms, terminology, names, or labels, instead of numbers, where these values can be described in primary terms, such as: high, low, short, long, medium, small, large and among others; in terms of modifiers, such as very, little, slightly, extremely, weakly, strongly and among others; they can be combined by logical connectives, which are: and, or, and not (VIEIRA, 2018).

It is thus noted that in fuzzy logic, linguistic variables are essential, as they allow the identification of the degree of veracity in them as well as their interpretation in a mathematical model, that is, it converts linguistic information into a number, being this possible using the fuzzy membership functions.

2.2.1 Fuzzy Functions and Degrees of Fuzzy Membership

The membership functions demonstrate the important characteristics of the theoretical and practical acts of fuzzy systems, which impute fuzzy membership values to discrete values of a variable in its universe of discourse (SIMÕES; SHAW, 2007).

The degree of membership of an element to a given set is determined by the membership function, when it relates the elements to the real numbers in the range between 0 and 1, that is, $0 \leq x \leq 1$, thus showing how much the element is connected to the whole (HORTENGAL, 2016).

These membership functions can have various formats, including triangular, trapezoidal, Gaussian, sigmoidal, among others (LIMA, 2016).

2.2.2 Fuzzy Inference System

The fuzzy inference system can be understood as the use of fuzzy logic in mapping a given data considered as input to a given output, being a process essentially composed of fuzzification, rule base, and inference and defuzzification (ARESE, 2018). Figure 1 shows the steps that constitute a fuzzy inference system.

Figure 1. Fuzzy inference system.
Source: Arese (2018)

2.2.2.1 Fuzzification

Fuzzification consists in transforming a clear quantity into a fuzzy quantity (ROSS, 2017). At this stage, the existence of attribution of linguistic values is identified through the established membership functions (SIMÕES; SHAW, 2007).

2.2.2.2 The Fuzzy Inference Rules

Inference rules are the simplest way to store information in a fuzzy knowledge base, which commonly consists of two parts: if and then, which are the antecedent and the consequent (REZENDE, 2005).

If-then rules are usually described as a deductive form, because if a premise is known, then it is possible to deduce its conclusion, which is convenient in the context of linguistics, due to the manifestation, the proper expression of communication, and knowledge human empirical (ROSS, 2017).

2.2.2.3 The Fuzzy Inference

Fuzzy inference consists of manipulating the fuzzy input data simultaneously with the established inference rules, allowing the generation of propositions that come from the relationship between the model variables and the fuzzy region (HORTEGAL, 2016).

2.2.2.4 Defuzzification

Defuzzification consists of transforming a fuzzy quantity into a clear quantity, that is, into a numerical value, which corresponds to the system's response (ROSS, 2017).

3. Methods

The research aims to develop a fuzzy inference model to predict the delay in the execution of public works in the city of Manaus. For this, it was necessary to carry out documentary research on public works built between 2013 and 2019 in the city of Manaus, with characteristics of open-air works and with contract values of up to BRL 5 million to later identify and select the most significant variables for the development of the fuzzy inference model, and after that, carry out the validation of the model with real data from works. Figure 2 illustrates the steps that were taken to develop the research.

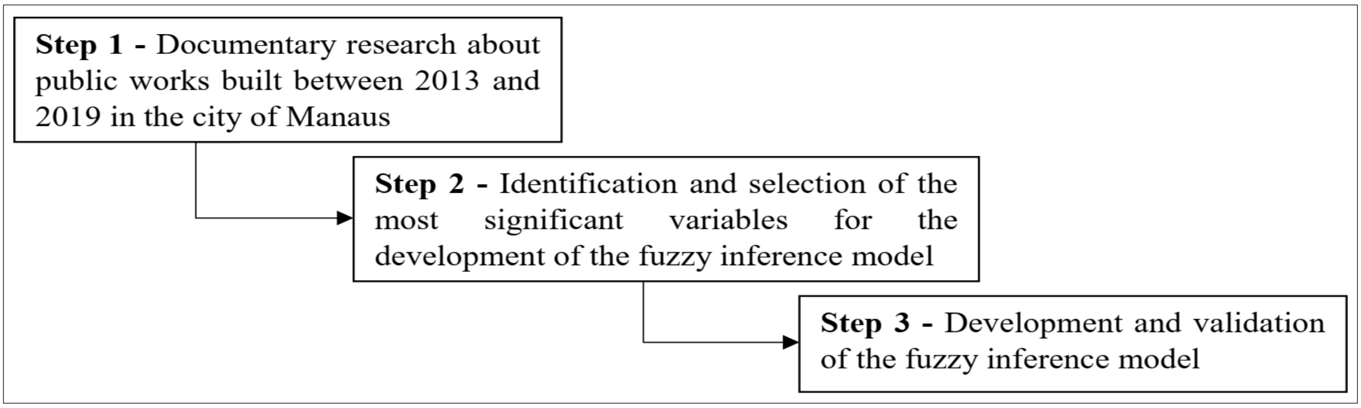


Figure 2. Research steps.
Source: Authors (2021)

3.1 Step 1 – Documentary research on public works built between 2013 and 2019 in the city of Manaus

At this stage, documental research of the works started and completed between 2013 and 2019 was carried out by a public agency of the Municipality of Manaus, to analyze the documents of the contracting processes and execution of the works, as well as carrying out data collection.

3.2 Step 2 – Identification and selection of the most significant variables for the development of the fuzzy inference model

At this stage, the causes that contributed to the occurrence of delays in the works were identified and classified. The selection of the most significant variables for the development of the fuzzy inference model was also performed.

In the analysis carried out in the documentation of the works, delays were identified arising from various causes, which, due to their variety, were separated into the following categories: financial, which included aspects related to financial resources, both of the contractor and the contractor; project and budget, which included aspects related to the identification of necessary services, their quantitative and engineering drawings; climate, which included issues related to weather conditions; public agencies, which included any manifestation of any public agency, public companies or concessionaires of public services, considered essential for the work to take place; management and execution, which understood the matters about the completion of the work by both the owner party and the contractor party; and the other factors, which understood the issues distinct from the others mentioned above.

In the financial category, the following causes were identified: late payment by the owner, the contractor's low price to carry out the work, and the contractor's financial capacity concerning the value of the work. In the project and budget category, the following causes were identified: inaccurate quantities of services, incomplete engineering drawings at the bidding stage, alterations in the engineering drawings, and additions of new services.

In the climate category, only occurrences of rain were identified as causes for the delay. In the category of public agencies, the following causes were identified: delay in the interruption of traffic on the construction site lane and slow approval of projects by public service concessionaire companies.

In the management and execution category, the following causes were identified: slow decision-making by the owner, suspension of the execution of the work by the owner, rework, and low productivity of the contractor. Finally, in the other factors category, the following causes were identified: the lack of material in local stores and unforeseen subsoil conditions.

Afterward, the most significant causes were selected to compose the linguistic input variables of the inference system.

As for the financial aspect, the following causes were selected: the low price of the contractor to carry out the work and the financial capacity of the contractor concerning the value of the work. The low price of the contractor to carry out the work was represented in this work by the linguistic variable *Contracting Factor*, which referred to the percentage of discount given by the contractor on the price of the work, which corresponded to the quotient between the contracted value and the budgeted value by the administration, so that the smaller this factor, the greater the discount, therefore, the lower the price. This variable proved to be important, since, for its price composition, it involved the use of labor, equipment, and inputs in the production of contracted services.

The financial capacity of the contractor concerning the value of the work, on the other hand, referred to the financial difficulty of the contractor to carry out the work due to its contracted value, this cause being represented by the linguistic variable *Value of the Work*s. This variable was also important, as the higher the value of the work, the greater would be the financial resources that the contractor would have to dispose of for the execution of the programmed stages, if they did not have these resources, the stages of the services could be interrupted or delayed.

Regarding the design and budget aspect, the following causes were selected: incomplete engineering drawings and inaccurate amounts of services. The cause incomplete engineering drawings showed the need to prepare projects for the completion of the work, since they were not elaborated in their entirety in the planning stage, that is, in the preparation of the basic project, and it was necessary to prepare them during the execution of the work. In this work, this cause was represented by the linguistic variable *Engineering Drawings*, which, similarly to the other variables, proved to be important, as the drawings, in addition to having graphically represented the construction, served as guidance for the team in carrying out the services, and, its elaboration during the execution of the work, compromised the previously foreseen execution schedule.

The cause of inaccurate quantity of services, on the other hand, corresponded to the quantity of services that were budgeted in smaller quantity in relation to what was really needed

This cause was represented by the linguistic variable *Change in Quantities*, which in turn proved to be important, as the services detailed in the engineering drawings needed to be performed in the quantities described therein, however, it happened that the budget spreadsheet did not reflect this necessary quantity, but a smaller quantity, and it was necessary to add new services and add quantities to existing services, and these additions compromised the originally foreseen term.

Concerning the aspect of public agencies, the selected causes were: delay in the interruption of traffic on the construction site lane and slow approval of projects by public service concessionaire companies. This cause identified the need for authorization or support from public agencies, public companies, or public service concessionaires so that the work could be carried out, and this variable was represented by the linguistic variable *Authorization of Public Agencies*. This variable proved to be important, because when services required authorization or support from one of Organs public agencies, the response was not timely, compromising the scheduled deadline.

Regarding the climate aspect, the selected cause was rain. About this cause, the occurrence of rain was considered in the foreseen period of execution of the work, and this cause was represented by the linguistic variable *Rain*. This variable proved to be important, as the occurrence of rain, during the execution of the services, interrupted the progress of the same, which impacted the deadline for the execution of the work. Table 1 presents the list of linguistic variables.

Table 1. Linguistic variables

Input Linguistic Variables
Contracting Factor
Value of the Works
Engineering Drawings
Change in Quantities
Authorization of Public Agencies
Rain
Output Linguistic Variable
Risk Prediction of Delay

Source: Authors (2021)

3.3 Step 3 – Development and validation of the fuzzy inference model

After selecting the linguistic variables, the task of determining their membership functions as well as their numerical ranges was performed.

The input linguistic variable *Contracting Factor* was considered to have three linguistic values, which were: low, medium, and high, where its range ranged from 0 to 100%, being considered low the value of up to 80%, medium the value of 77.5% to 87.5% and a high value above 85%.

The input linguistic variable *Value of the Works* was also considered to have three linguistic values, which were: low, medium, and high, where the range of this linguistic variable ranged from BRL 0.00 to BRL 5,000,000.00. Considered low the value of up to BRL 750,000.00, medium the value of BRL 500,000.00 to BRL 1,500,000.00 and high the value above BRL 1,250,000.00.

The input linguistic variable *Engineering Drawings* was considered to have two linguistic values, which were: incomplete and complete, where its range ranged from 0 to 1.5, being considered incomplete the value from 0 to 1 and complete the value of 0.5 to 1.5.

The input linguistic variable *Change in Quantities* was also considered to have two linguistic values, which were: does not change and changes, where the range of this variable ranged from 0 to 1.5, being considered does not change the value from 0 to 1 and changes the value from 0.5 to 1.5.

As for the input linguistic variable *Authorization of Public Agencies*, it was considered to have three linguistic values, which were: low, medium, and high, where its range varied from 0 to 6, being considered low the value from 0 to 2, medium o value from 1 to 3 and high the value from 2 to 6.

The input linguistic variable *Rain* was considered to have three linguistic values, which were: low incidence, medium incidence, and high incidence, where the range of this variable ranged from 0 to 12, being considered low incidence the value from 0 to 3, average incidence the value of 2 to 6 and high incidence the value of 5 to 12.

For the output linguistic variable *Risk Prediction of Delay*, five linguistic values were considered, which were: low, medium-low, medium, medium-high and high, where its range ranged from 0 to 100, the value of being considered low 0 to 20, a medium-low value from 20 to 40, a medium value from 40 to 60, a medium-high value from 60 to 80, and a high value above 80.

Table 2 shows the input and output linguistic variables with their respective linguistic and numerical values and membership functions.

Table 2. Input and output linguistic variables with their values

Input Linguistic Variables	Linguistic Value	Numerical Range	Numerical Value	Membership Functions
Contracting Factor	Low	[0 to 100]	value of up to 80%	[0 0 77.5 80]
	Medium		77.5% to 87.5%	[77.5 82.5 87.5]
	High		85% to 100%	[85 87.5 100 100]
Value of the	Low	[0 to 5E^{6}]	value of up to BRL	[0 0 5.0E^{5} 7.5E^{5}]

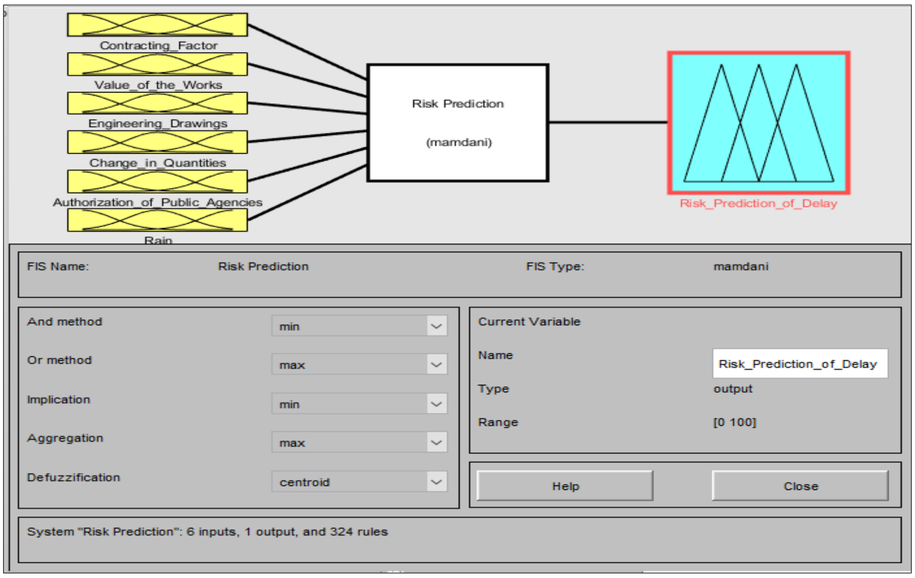
Works			750,000.00	
	Medium		BRL 500,000.00 to BRL 1,500,000.00	$[0\ 5E^5\ 1E^6\ 1.5E^6]$
	High		BRL 1,250,000.00 to BRL 5,000,000.00	$[1.25E^6\ 1.5E^6\ 5E^6\ 5E^6]$
Engineering Drawings	Incomplete	[0 to 1,50]	0,00 to 1,00	[0 0 0,5 1]
	Complete		0,50 to 1,50	[0.5 1 1.5 1.5]
Change in Quantities	Not Change	[0 to 1,50]	0,00 to 1,00	[0 0 0.5 1]
	Change		0,50 to 1,50	[0.5 1 1.5 1.5]
Authorization of Public Agencies	Low	[0 to 6]	0 to 2	[0 0 1 2]
	Medium		1 to 3	[1 2 3]
	High		2 to 6	[2 3 6 6]
Rain	Low Incidence	[0 to 12]	0 to 3	[0 0 2 3]
	Medium Incidence		2 to 6	[2 3 5 6]
	High Incidence		5 to 12	[5 6 12 12]
Output Linguistic Variable	**Linguistic Value**	**Numerical Range**	**Numerical Value**	**Membership Functions**
Risk Prediction of Delay	Low	[0 to 100]	value of up to 20	[0 0 10 20]
	Medium-Low		20 to 40	[20 30 40]
	Medium		40 to 60	[40 50 60]
	Medium-High		60 to 80	[60 70 80]
	High		80 to 100	[80 90 100 100]

Source: Authors (2021)

To build the fuzzy inference model proposed for this research, the Fuzzy Logic Design of Matlab R2020b software was used. In this software, the data of the input and output linguistic variables described in table 2 were inserted.

The number of inference rules used in the software was 324 (3x3x2x2x3x3) rules of type if-then with and as logical connective

Figure 3 shows the inference model to predict the risk of delay in the execution of public works in the city of Manaus.



FIS Name: Risk Prediction
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Current Variable
Name: Risk_Prediction_of_Delay
Type: output
Range: [0 100]
System "Risk Prediction": 6 inputs, 1 output, and 324 rules

Figure 3. Inference model.
Source: Authors (2021)

In this figure, it is possible to identify the six linguistic input variables and the only output linguistic variable. It is also possible to identify the fuzzy inference model used, which was the Mamdani, and also the defuzzification method, which was the centroid. Figure 4 shows the input linguistic variable *Contracting Factor* with its linguistic and numerical values and membership functions.

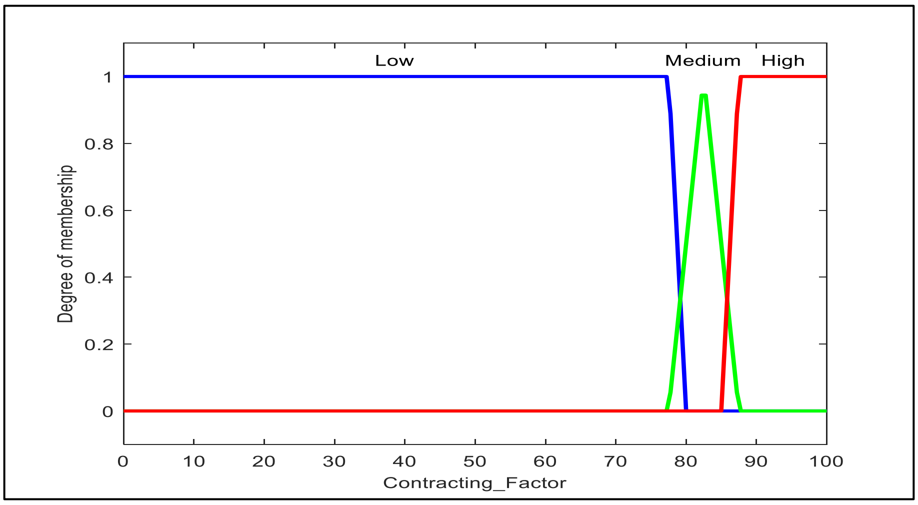


Figure 4. Input linguistic variable contratcting factor.
Source: Authors (2021)

This figure shows that the formats of the membership functions of the low and high linguistic values are trapezoidal, while that of the average linguistic value is triangular. It is also possible to see that in the range from 0 to 80 the linguistic value is considered low, in the range from 77.5 to 87.5 it is considered medium and above 85 is considered high. Figure 5 shows the input linguistic variable *Value of the Works* with its linguistic and numerical values and membership functions.

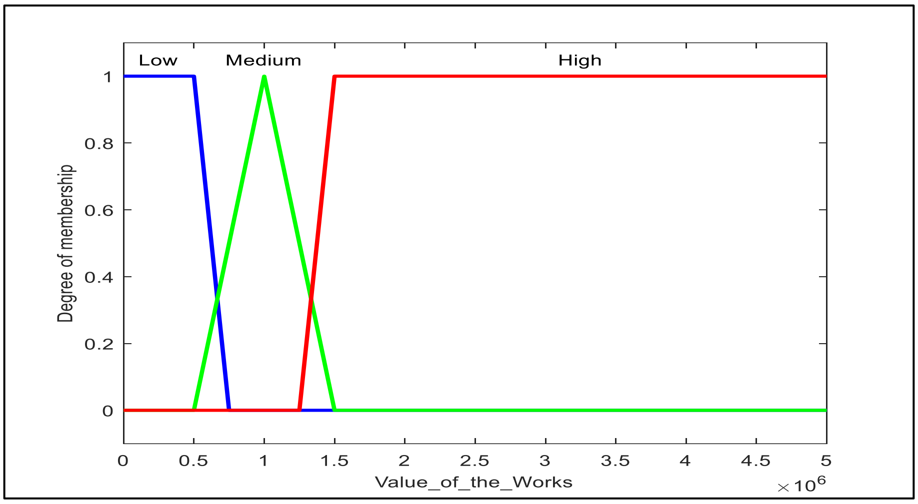


Figure 5. Input linguistic variable value of the works.
Source: Authors (2021)

In this figure, it is possible to see that the formats of the membership functions of low and high linguistic values are trapezoidal, while that of the average linguistic value is triangular, and it is possible to interpret that, in the range from 0 to 0.75x106, the linguistic value is considered low, in the range of 0.5x10^6 to 1.5x10^6 is considered medium and above 1.25x10^6 is considered high. Figure 6 shows the input linguistic variable *Engineering Drawings* with its linguistic and numerical values and membership functions

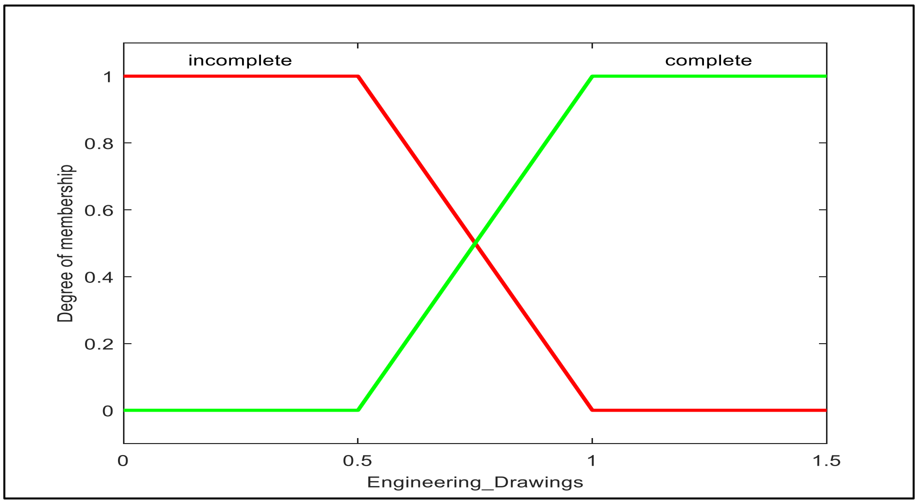


Figure 6. . Input linguistic variable engineering drawings.
Source: Authors (2021)

In this figure, the formats of the linguistic values membership functions are trapezoidal, so that it is possible to identify that in the range from 0 to 1 the linguistic value is defined as incomplete and in the range from 0.5 to 1.5 it is defined as complete. Figure 7 shows the input linguistic variable *Quantities Change* with its linguistic and numerical values and membership functions.

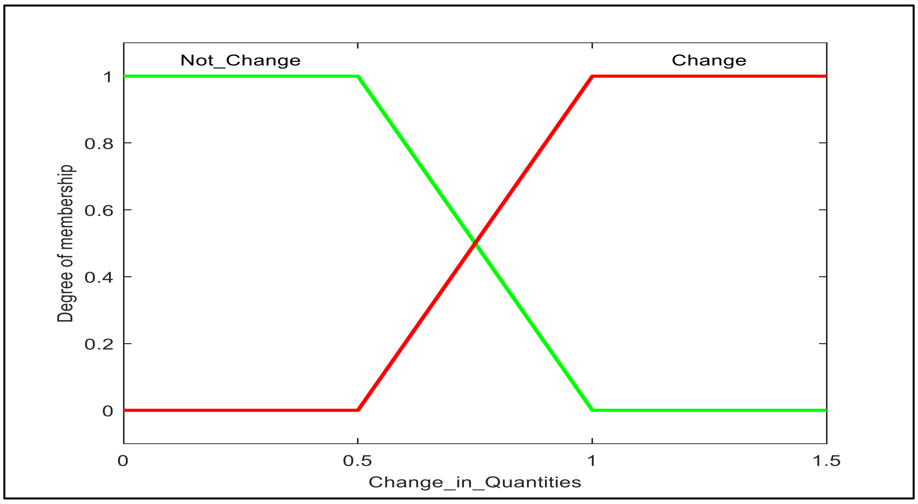


Figure 7. Input linguistic variable quantities change.
Source: Authors (2021)

In this figure, the formats of the membership functions of the linguistic values are trapezoidal, so that it is possible to interpret that in the range from 0 to 1 the linguistic value is defined as not change and in the interval from 0.5 to 1.5 it is defined as change. Figure 8 shows the input linguistic variable *Authorization of Public Agencies* with its linguistic and numerical values and membership functions.

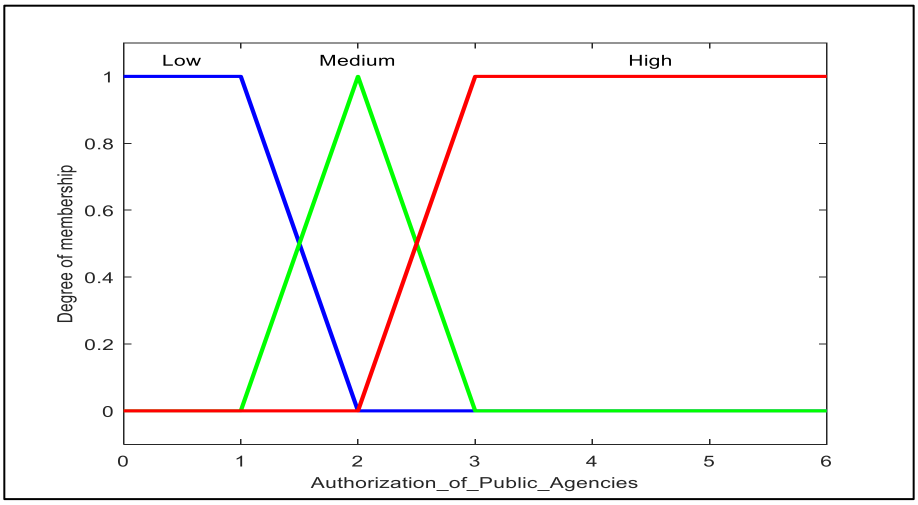


Figure 8. Input linguistic variable authorization of public agencies.
Source: Authors (2021)

In this figure, the formats of the membership functions of low and high linguistic values are trapezoidal, while that of the average linguistic value is triangular, and it is possible to interpret that, in the range from 0 to 2, the linguistic value is considered low, in the range of 1 a 3 is considered medium and above 2 is considered high. Figure 9 shows the input linguistic variable *Rain* with its linguistic and numerical values and membership functions.

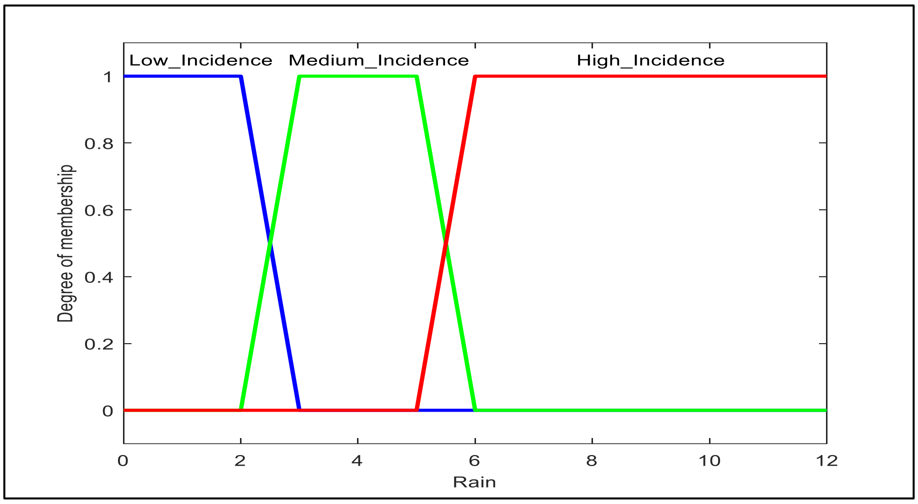


Figure 9. Input linguistic variable rain.
Source: Authors (2021)

In this figure, the formats of the membership functions of linguistic values are trapezoidal, so that it is possible to interpret that the linguistic value in the range 0 to 3 is considered low incidence, in the range 2 to 6 it is considered medium incidence and above 4 is considered high incidence. Figure 10 shows the output linguistic variable *Risk Prediction of Delay* with its linguistic, numerical values, and membership functions.

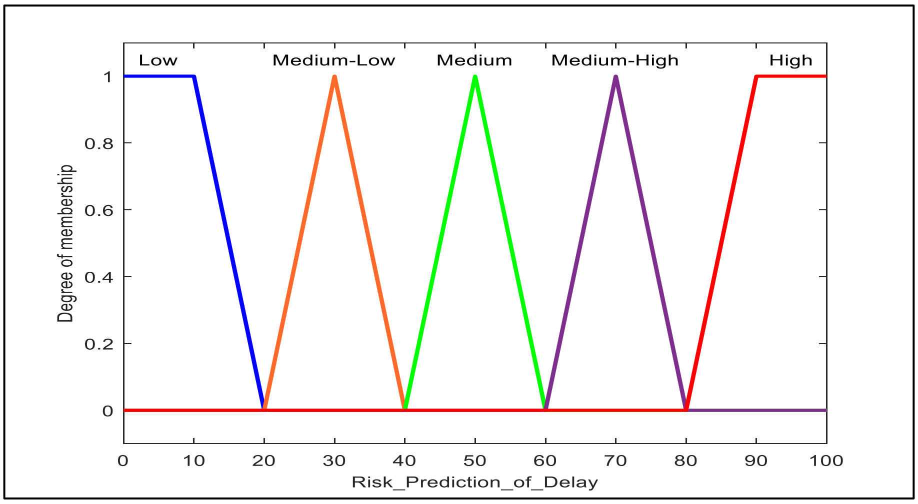
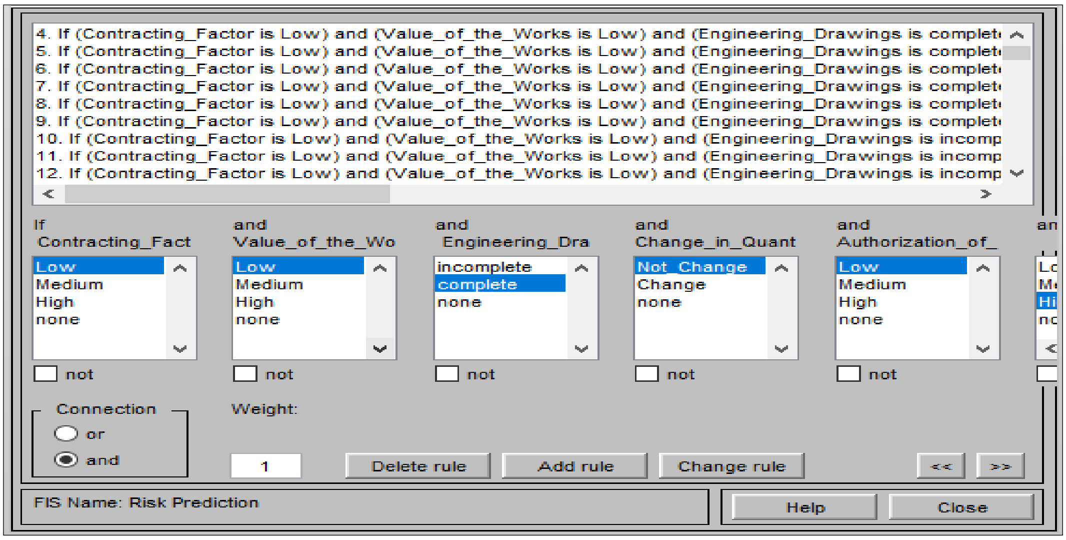


Figure 10. Output linguistic variable delay risk prediction of delay.
Source: Authors (2021)

In this figure, the formats of the membership functions of low and high linguistic values are trapezoidal, while the others are triangular, so that it is possible to interpret that the linguistic value in the range 0 to 20 is considered low, in the range 20 to 40 it is considered medium-low, in the range of 40 to 60 it is considered medium, in the range 60 to 80 it is considered medium-high and above 80 it is considered high.

After inserting the input and output linguistic variables with their linguistic, numerical values, and membership functions in Matlab, the 324 created inference rules were inserted. In Figure 11, part of these inference rules can be seen.



```
4. If (Contracting_Factor is Low) and (Value_of_the_Works is Low) and (Engineering_Drawings is complet
5. If (Contracting_Factor is Low) and (Value_of_the_Works is Low) and (Engineering_Drawings is complet
6. If (Contracting_Factor is Low) and (Value_of_the_Works is Low) and (Engineering_Drawings is complet
7. If (Contracting_Factor is Low) and (Value_of_the_Works is Low) and (Engineering_Drawings is complet
8. If (Contracting_Factor is Low) and (Value_of_the_Works is Low) and (Engineering_Drawings is complet
9. If (Contracting_Factor is Low) and (Value_of_the_Works is Low) and (Engineering_Drawings is complet
10. If (Contracting_Factor is Low) and (Value_of_the_Works is Low) and (Engineering_Drawings is incomp
11. If (Contracting_Factor is Low) and (Value_of_the_Works is Low) and (Engineering_Drawings is incomp
12. If (Contracting_Factor is Low) and (Value_of_the_Works is Low) and (Engineering_Drawings is incomp
```

If Contracting_Fact: Low
and Value_of_the_Wo: Low
and Engineering_Dra: complete
and Change_in_Quant: Not_Change
and Authorization_of_: Low

Connection: ○ or ● and

Weight: 1

FIS Name: Risk Prediction

Figure 11. Part of the rules of inference.

Source: Authors (2021)

4. Results and Discussions

After inserting the inference rules, the system generated as a response a surface graph showing the interaction between the linguistic variables. Figure 12 shows this graph generated with the input linguistic variables *Contracting Factor* and *Value of the Works*.

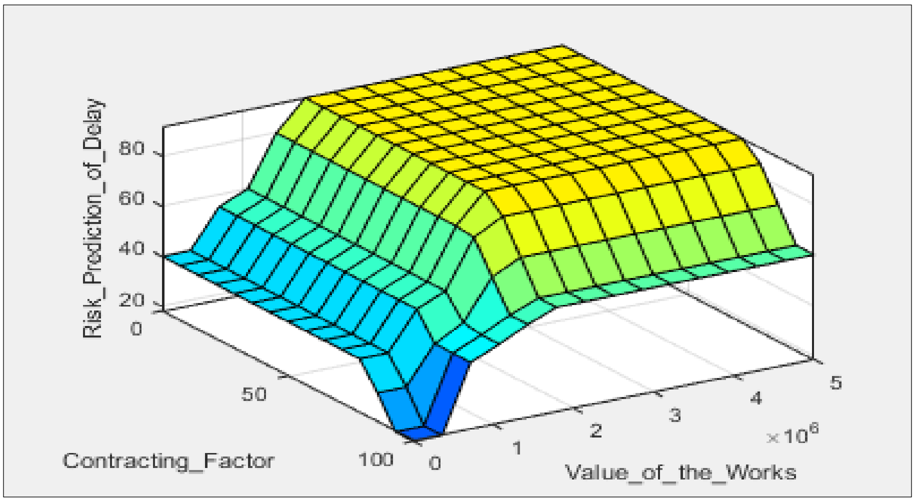


Figure 12. Surface graph

Source: Authors (2021)

In this figure, it is possible to identify that, even though the *Contracting Factor* is close to 100, the risk of delay will increase as the *Value of the Works* also increases.

It is also identified that, even though the *Value of the Works* is low, the risk of delay will increase when there is a reduction in the *Contracting Factor*, in other words when there is a significant discount in the contracted company's price proposal.

To simulate the model created, in order to confirm its operation, data from public works built in the city of Manaus, with a contract value of up to BRL 5,000,000.00 were inserted. In table 3 can see the data that were entered.

Table 3. Public works data entered in the system

Construction	**Contracting Factor**	**Value of the Works (BRL)**	**Engineering Drawings**	**Change in Quantities**	**Authorization of Public Agencies**	**Rain**
1	75%	1.138.268,06	Incomplete	Change	Low	High incidence
2	98%	1.307.641,32	Incomplete	Change	Low	High incidence
3	79%	126.337,59	Complete	Not Change	Low	Medium incidence
4	83%	80.560,63	Complete	Not Change	Low	High incidence

Source: Authors (2021)

For construction 1, the proposed inference system generated the numerical value 70 as a response. Figure 13 illustrates the response generated by the system.

```
Contracting_Factor = 75
Value_of_the_Works = 1.14e+06
Engineering_Drawings = 0.5
Change_in_Quantities = 1
Authorization_of_Public_Agencies = 1
Rain = 6
Risk_Prediction_of_Delay = 70
```

Input: [75;1.138e+06;0.5;1;1;6]

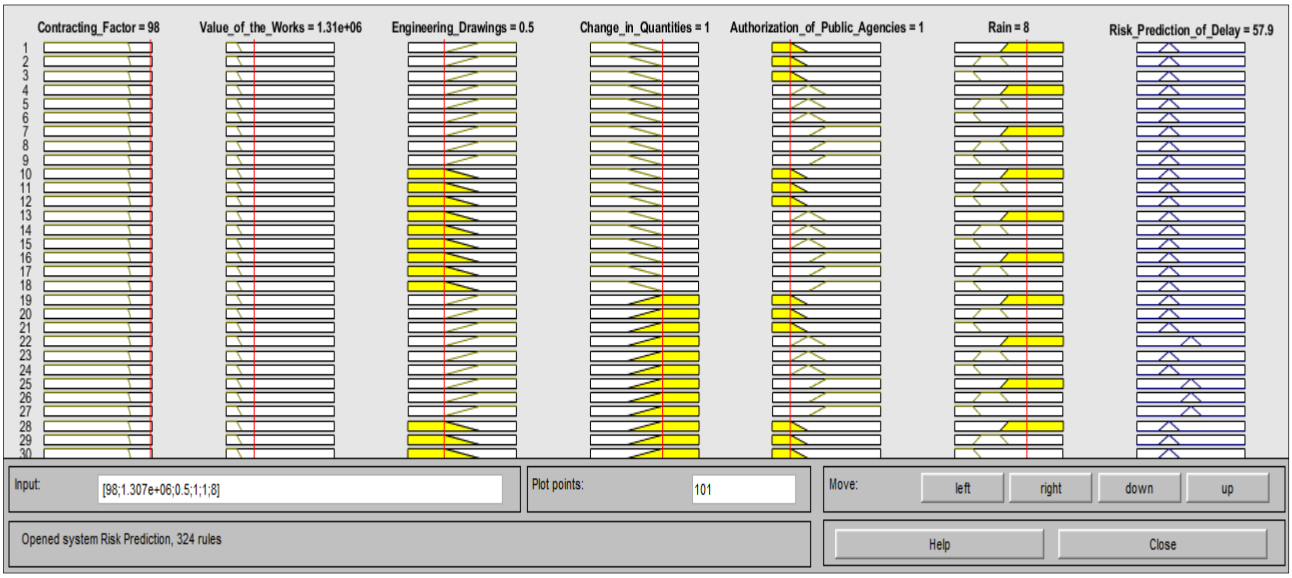
Plot points: 101

Opened system Risk Prediction, 324 rules

Figure 13. Inference system response for construction 1.

Source: Authors (2021)

For construction 2, the proposed inference system generated the numerical value 57.9 as a response. Figure 14 illustrates the response generated by the system.



Input: [98;1.307e+06;0.5;1;1;8]

Plot points: 101

Opened system Risk Prediction, 324 rules

Figure 14. Inference system response for construction 2.

Source: Authors (2021)

For construction 2, the proposed inference system generated the numerical value 20.1 as a response. Figure 15 illustrates the response generated by the system.

Input: [79;1.263e+05;1;0.5;0;3]

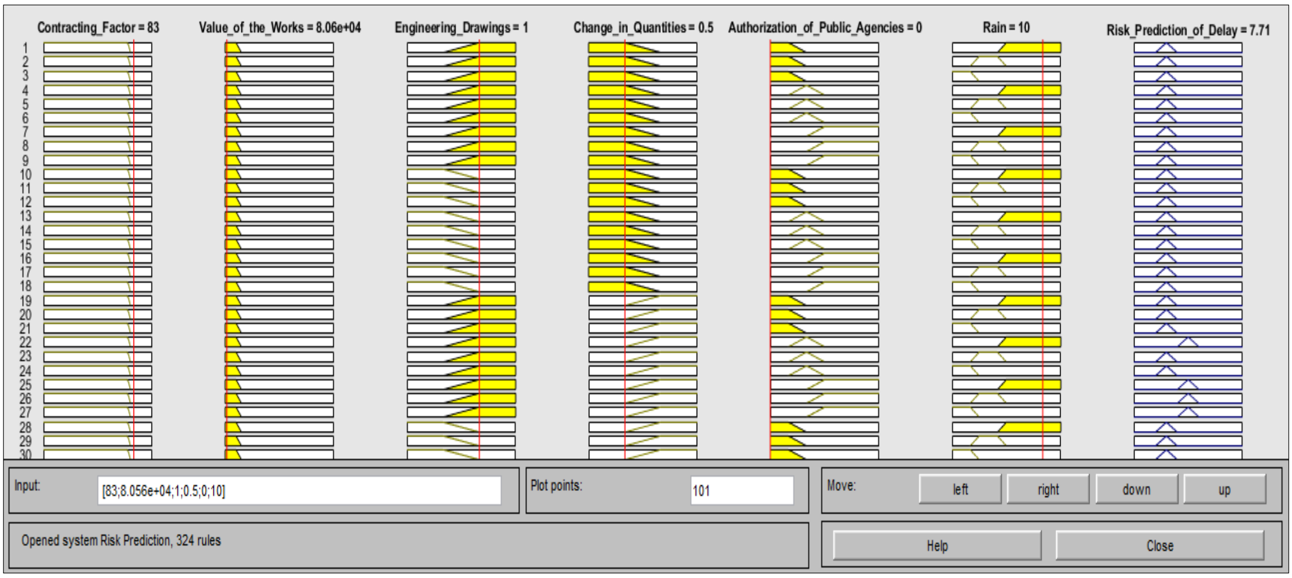
Plot points: 101

Opened system Risk Prediction, 324 rules

Figure 15. Inference system response for construction 3.

Source: Authors (2021)

For construction 4, the proposed inference system generated the numerical value 7.71 as a response. Figure 16 illustrates the response generated by the system.



Input: [83;8.056e+04;1;0.5;0;10]

Plot points: 101

Opened system Risk Prediction, 324 rules

Figure 16. Inference system response for construction 4.
Source: Authors (2021)

With the results generated by the system, it was possible to obtain a risk prediction of delay of the respective works. Table 4 shows the responses generated by the inference system and their respective linguistic value.

Table 4. Inference system responses

Construction	**Parameters**	**Fuzzy System Response**	**Risk Prediction of Delay**
1	60 a 80	70	Medium-High
2	40 a 60	57.9	Medium
3	20 a 40	20.1	Medium-Low
4	0 a 20	7.71	Low

Source: Authors (2021)

After obtaining these responses, we sought to compare them with information from the administrative processes of the respective constructions, and it was found that constructions 1 and 2 suffered delays in their execution deadlines, while constructions 3 and 4 had their conclusions within the deadline programmed. Table 5 shows these comparisons.

Table 5. Comparison between the execution deadline.

Construction	**Execution Deadline Programmed (days)**	**Risk Prediction of Delay**	**Execution Deadline Registered (days)**
1	150	Medium-High	178
2	150	Medium	314
3	60	Medium-Low	60
4	60	Low	60

Source: Authors (2021)

Comparing the answers given by the inference system with the information from the administrative processes of these constructions, it was found that, in relation to construction 1, the delay occurred due to an increase in the number of services and incomplete engineering drawings. In relation to work 2, it was found that the delay was due to the need for authorization from a public agency, incomplete engineering drawings, the occurrence of rain, and an increase in the quantities of services.

For construction 1, the response of the fuzzy inference system was a medium-high risk of delay, which was confirmed because the work had a delay in the execution period of 28 days, where one cause gave rise to another, in other words, the engineering drawings were elaborated during the execution of the work, as they were incomplete when the bidding process took place, and these elaborated projects implied an increase in the quantity of services. This risk could be minimized if the public administration had provided such projects before the bidding.

For construction 2, the response of the inference system was an average delay risk, which was also confirmed, as there was a delay in the execution time of 164 days, and part of this delay was due to incomplete engineering drawings, generating the need for its elaboration during the execution of the work, implying an increase in the quantity of services. Part of this delay was also due to the rains that occurred and the need for support from a public agency to interdict traffic on the street. This risk could also be minimized if the public administration had provided such projects in the internal phase of the bidding process.

For construction 3, the inference system's response was a medium-low delay risk, which was confirmed as the build was completed on schedule. In this work, it was found that the executive projects were complete and that the quantities of services were measured based on these projects, thus minimizing the risk of delay for these reasons. It was also found that there was good productivity in the execution of the services, as those did not have previous services, they were performed simultaneously with the others, considerably reducing the risk of delay.

For construction 4, the response of the inference system was a low risk of delay, which was also confirmed as the work was completed on schedule. In this work, it was found that the engineering drawings were complete and that the quantities of services were also measured according to these projects, which reduced the risk of delay due to these causes. It was also found that there was good productivity in the execution of services, and those that did not have previous services were performed simultaneously with the other services, which also reduced the risk of delay.

5. Conclusion

During the research, it was found that many causes contribute to the occurrence of delays in works in the city of Manaus and that, as a result of this diversity, the responsibility for its origin can be attributed to the public administration, the contractor, or third parties. Within this variety of delay causes, the most significant were selected for the construction of the fuzzy inference model for risk prediction of delay.

In the conception of the fuzzy inference system, six input and one output parameters were created, with membership functions in triangular and trapezoidal formats and with 324 inference rules. In this inference system, simulations were carried out using real data from works that were contracted and executed.

The result provided by the fuzzy inference system through the simulation proved to be useful, as it was possible to obtain a prediction of the risk of delay in the execution of the work, which prediction was confirmed by the documents relevant to the works considered in the simulation.

Thus, the proposed fuzzy inference system can be used by the public administration in the basic project elaboration phase, where the elaboration of the engineering drawings can be considered as a service in the budget spreadsheet to be done by the contracted company or it can be attributed to the public administration its elaboration, and the start and end months can also be planned, considering the occurrence of rains.

It also allows the public administration to anticipate the necessary authorizations and support from other public bodies, minimizing the impact as a result of this need. During the execution of the work, the inspection will be able to observe whether the productivity proposed in the physical-financial schedule is being fulfilled by the contracted company, especially in those works where the Contracting Factor is low since the offered price approaches an unfeasibility presumed. As for the contracted company, it can serve as a basis for decision-making in whatever is within its competence to mitigate the causes of delays, such as optimization of labor and materials, service schedule, purchase, and delivery of inputs.

Thus, it is concluded that the research carried out achieved the purpose of obtaining a model based on fuzzy logic for predicting the risk of delay in the execution of public works in the city of Manaus.

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