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SUPPLY CHAIN RISK ASSESSMENT WITH FUZZY LOGIC APPLIED TO THE FAILURE MODE AND EFFECT ANALYSIS METHOD

[1]LAKHOUIL HATIM, [2]SOULHI AZIZ

National Higher School of Mines, Morocco

ORCID: [1]0009-0001-6781-6915 , [2]0000-0003-1904-513X

E-mail : [1]H.Lakhouil@enim.ac.ma , [2]Soulhi@enim.ac.ma

ABSTRACT

The context of crisis caused by unpredictable events and lack of visibility has given rise to a new concept: the uncertainty , induced by the supply chain disruptions , As a result, decision-making has become increasingly a complicated operation, which has motivated supply chain managers to look for others new tools adapted to unclear circumstances to measure risks and define priorities . in this work, supply Chain risk assessment has been modelled using the famous FMEA method, which has become a method widely used by industrialists, however the originality of this work lies in its merge with the fuzzy approach initiated by LOTFI ZADEH in 1965, and which will allow us to pass from real data to linguistic sentences that are better understood by humans brains and also close to reality by introducing the membership functions and inference rules that will allow us to measure risk through defuzzification, which will support decision-makers in judging all the alternatives and scenarios that can be found in their analysis.

Keywords : *Supply Chain Uncertainty , Decision-Making , FMEA , Fuzzy Logic , Risk Assessment*

1. INTRODUCTION :

Decision-making has become something that is not obvious, especially in the context of rapid and abrupt changes caused by unpredictable events and global crises (pandemics, closing borders, shortage of raw materials, war, … etc.). All of this poses real challenges for supply chain managers who often seek to understand market behavior , to mitigate risks and keep profitability. and since every decision is a risk-taking exercise, the decision-makers and managers of the supply chain often seek the acquisition of new know-how and techniques that aim to generate information that allows a user (decision-maker) to evaluate the consequences of a decision made and judge the impact based on multiple criteria, and it is in this context that the FMEA method is used as a tool to identify the potential failure modes and their effects, thus through the calculation of these three indices (severity , Probability and non-detection) we can trace the priorities and know where we need to put more focus. However, in the mathematical modelling of an optimization or decision problem, there is a tendency to assume that the data are exacts . This hypothesis is unrealistic because the context of crisis and lack of information has given rise to a new concept: the uncertainty occurred by the logistic disturbances that result from the combination of an involuntary and unforeseen triggering event **(1)** . therefore data can be imprecise with vagueness of a fuzzy nature, or uncertainty of their variability , in this light linguistic terms seems more significative to evaluate risks , this technique is based on the calculation of the membership function which varies between 0 and 1 by indicating the degree of truth , from 0 as an index of sure false until 1 as totally true and this gradual and progressive evolution what makes fuzzy logic match well with the vagueness and uncertainty typical of many real world problems. This is what motivated the

introduction of fuzzy logic in the supply chain risk assessment **(10)** .

2. RISK PRIORITY NUMBER :

The method that is required today in terms of risk management is the FMEA , which is of course not a problem solving method but it helps to ask the right questions to look for potential problems , this logic is sub-tensed by four questions **(2)** :

1- Failure modes, answer to the basic question: "What could go wrong?"

2- possible effects answer the question: "what could be the effects of this potential failure mode?"

3- possible causes, answer to the question: "what could be the causes of this potential failure mode?"

4- means of detection, answer to the question: "how to see if this happens?"

In addition to our four core questions, priority-setting questions will help the organization sort out what is important and what is less important . above all, these questions will help to know where to start the work .

the identification of priorities is mainly done by the three criteria **(2)**:

Severity: rating the severity of the effects, first ranking that will allow us to weight your response according to the consequences imagined for each potential problem listed .

Probability: The probability of occurrence rating, also known as occurrence, is used to estimate whether the potential failure mode is likely to occur and at what frequency.

Detection: the listing of non-detection, which will allow you to assess the possibility and capacity of the planned control actions to detect the appearance of problems .

the synthesis of the questioning is carried out by a quotation which repeats the three preceding criteria after multiplying them between them, in order to produce the RPN : **Risk Priority Number :**

RPN = Severity × Probability × Non Detection

The calculation of this index will guide the managers of the supply chain, to make the right decisions, and define the priorities based on the identification of the potential risks and the judgement of the magnitude of their impacts (severity) as well as the estimation of the probability of the appearance of these problems (Probability) and the measurement of the tightness of the control plan that allows the detection of threats and dangers that can disrupt the supply chain, and since human brain often reason with linguistic terms (serious / negligible , detectable / not detectable , probable / not probable) we will add the fuzzy approach to the method FMEA , and that is the objective of the rest of this article .

3. PROPOSED APPROACH :

1. Fuzzy Logic :

LOTFI ZADEH the founder of fuzzy approach gave a complete definition of fuzzy logic: "Fuzzy

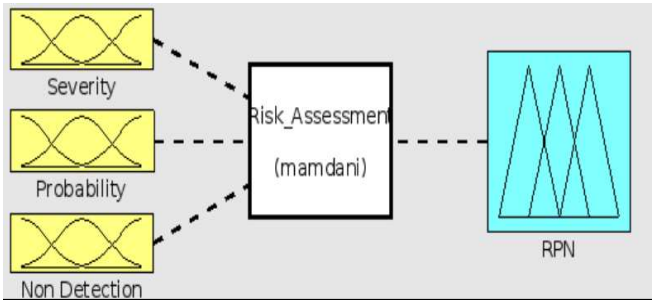

Figure 2 : Fuzzy Model

Logic is determined as a set of mathematical principles for knowledge representation based on degrees of membership rather than on net membership of classical binary logic" **(3)**, Indeed, the fuzzy logic reasoning mode is more intuitive than classical logic. It allows designers to better understand imprecise and difficult-to-model phenomena by relying on the definition of rules and membership functions of sets called "fuzzy sets" **(4)** .

The mechanism of fuzzy logic revolves around three main stages: fuzzification, fuzzy inference and defuzzification :

Fuzzification is the step that allows the transition from the real world to the fuzzy world, that is to say to assign to real data a qualification in natural language , The transformation of numerical variables into linguistic variables is not enough. Therefore, the inverse passage must be made in order to know the exact value of the variable. This

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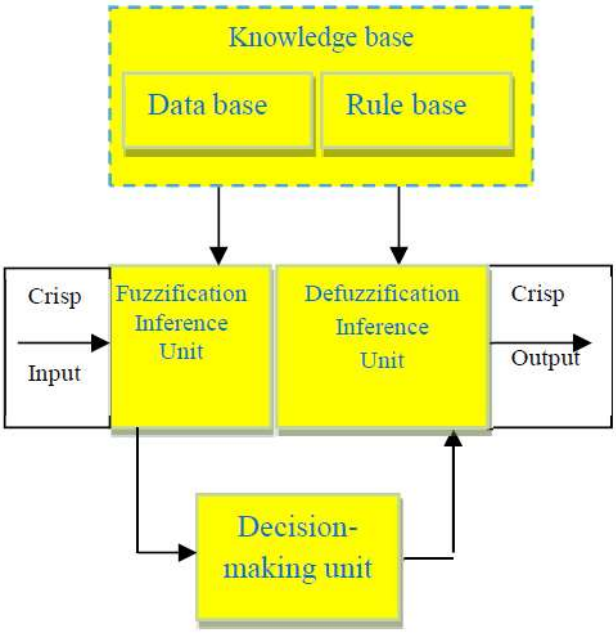
phase of transition from the linguistic to the real is entitled "The Defuzzification" . Inference is the real brain of the "fuzzy" approach. It simply links the belonging functions of the inputs to the outputs. it is based primarily on predefined rules called inference rules , concerning our case, we will establish a fuzzy model that takes as inputs the three risk indices that are mainly set by the decision-maker, and with the fuzzy inference that is fed by rules, we will estimate the risk with linguistic terms (Low, Medium and High Risk) to be converted to one digit after defuzzification .



4. MODELLING OF RISK INDICES BY FUZZIFICATION :

Figure 1 : Processus of Fuzzy Logic

in this sense, the categories of each criticality index have been fixed, for example concerning the severity, the fact of having a shortage in the raw material or a shutdown of the customer lines is considered catastrophic, and criticism is to have sold all of safety the stock … etc. to summarize this we have consolidated the table below which indicates all the levels (linguistics) of the severity:

Table 1 : The Levels Of The Severity

Catastrophic	Stopping the customers line, Shortage of raw material
Critical	Have zero safety stock
Moderate	Start consumption of safety stock
Negligeable	Consume the objective stock

and the same process was done to establish the probability and non-detection tables :

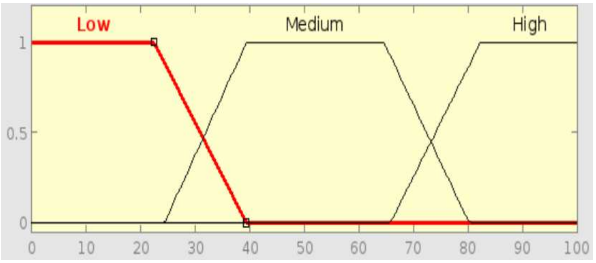
Table 2 : The Levels Of The Probability

Frequent	often occurs in the course of logistic operations
Likely	Occurs several times
Seldom	May Occur in the course of logistic operations
Unlikely	So unlikely you can assume it will not occur

Table 3 : The Levels Of The Non Detection

High	the problem is not detectable
Medium	the problem is not easily detected
Low	the problem is easily detectable

And to clearly visualize the degree of truth of each variable, we will make use of the membership functions ,traced by the supply chain managers, the indicators are modeled by a trapezoidal membership functions using linguistic terms appropriate to each indicator :



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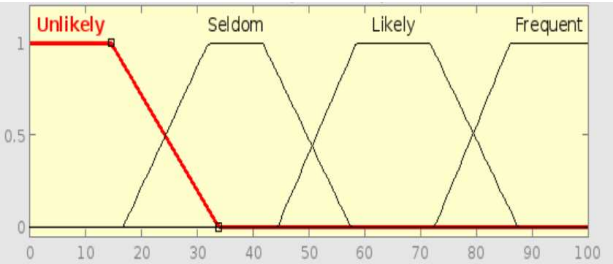

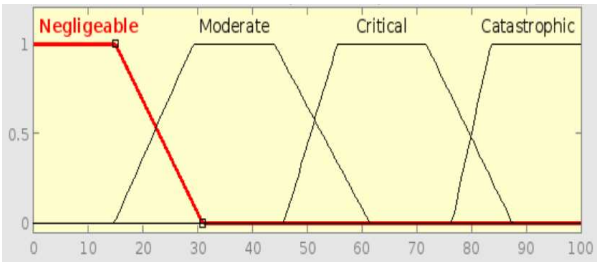

Figure 3 : Non Detection Membership Function

5. FUZZY INFERENCE :

the "linguistic variables are linked together by rules and allow us to draw inferences" **(4)**. Thus, the inference engine is a step consisting of defining the decision rules (If. Then) established by the experts to the input variables using the fuzzy operators OR or AND or both **(7)**.

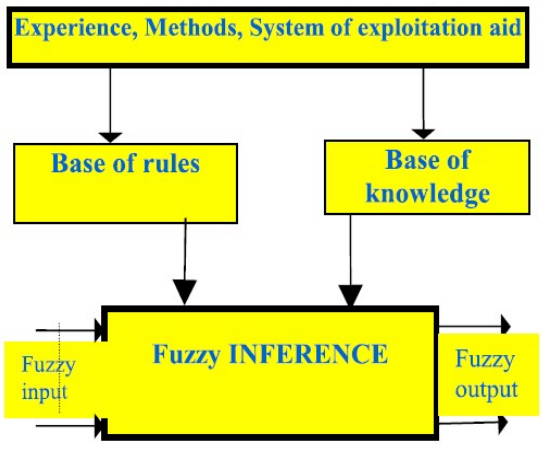

Figure 4 : Probability Membership Function

$$Y_0 = \frac{\int_y y \times \mu(y)\,dy}{\int_y \mu(y)\,dy}$$

Figure 5 : Severity Membership Function

Rule1 : If **S** = Negligeable and **P** = Unlikely and

ND = Low then **RPN** = Low Risk

Rule2 : If **S** = Negligeable and **P** = Seldom and **ND** = High then **RPN** = Low Risk

Rule3 : If **S** = Negligeable and **P** = Seldom and **ND** = High then **RPN** = Low Risk

Figure 6 : Fuzzy Inference

Rule4 : If **S** = Negligeable and **P** = Seldom and **ND** = High then **RPN** = Low Risk

Rule5 : If **S** = Moderate and **P** = Seldom and **ND** = High then **RPN** = Low Risk

Etc.

ultimately, we introduced 48 rules because there are 4 levels in severity and probability and 3 in non-detection, which gives at the end 48 rules.

6. THE DEFUZZIFICATION :

As explained before, fuzzification is a transformation of linguistic data to real data. because without risk measurement we cannot define the priorities, and we cannot properly simulate the alternatives and the potential scenarios that can be generated , in this sense there are several methods that can be used, such as the most widely used :Centroid technique which we will use in the rest of our study **(5) (6) :**

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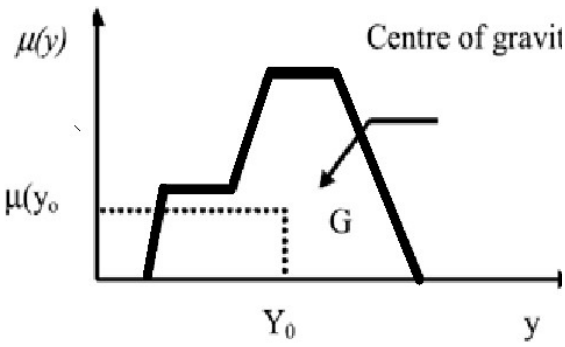

Figure 7 : Centre of Gravity

7. SIMULATION :

Simulation is a modelling technique that consists of reproducing the behavior dynamics of a system in order to better understand it, to better control its evolution in relation to the change of dimensions **(11)**, in this light we simulate our fuzzy model by introducing the rules already shown, to see the surface in view that describes the relationship of two axes that represents the input :Severity, Probability or Non- detection (that we will choose in different cases below) with the RPN index , and then we will interpret them to understand the experts' opinions and justify their choices **(9)**:

Case N°1 : [Input1 = **Severity ;** Input2 = **Probability]**

The index of non-detection is fixed in advance in

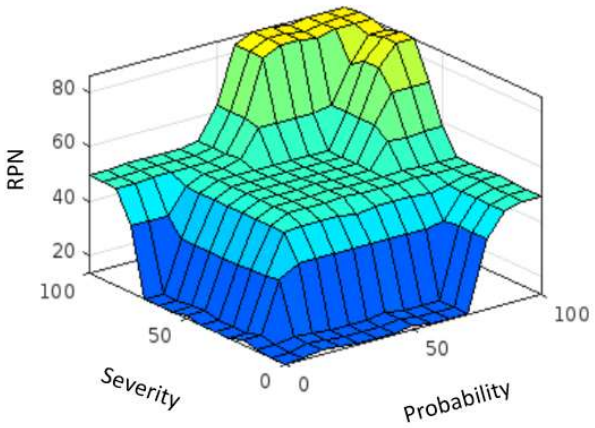

Figure 8 : The curve of the Case N°1

Medium

Interpretation :

We can see in the surface view that as long as the severity and probability are close to zero the RPN also has the same value, and when we increase either the severity or the probability or both at the same time, the RPN index also follows them in their trend , on the other hand we can notice that the graph is not symmetrical, is due to the judgement of experts who stipulate that having a high severity index is worse than having it in the probability index and this reflects the importance given to customer satisfaction ,thus for them, if the severity is high, automatically it gives a high RPN regardless of the low probability, medium or high probability, so always the severity is critical. This judgment clearly reflects the importance given to customer satisfaction .

Case N°2 : [Input1 = **Severity ;** Input3 = **Non Detection]**

The index of Probability is fixed in advance in Medium

Interpretation :

As noted in the first case, this simulation also shows us the great consideration given to the severity , however for non-detection , it must be high with a high severity index to say that the RPN is high .

Case N°3 : [Input2 = **Probability ;** Input3 = **Non Detection]**

The index of severity is fixed in advance in Medium

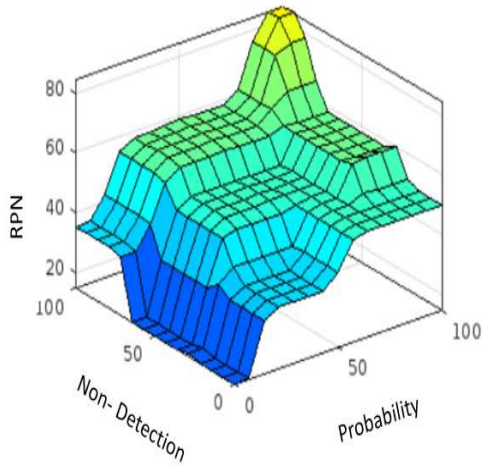

Figure 9 : The curve of the Case N°2

Interpretation :

this graph is more or less symmetrical when compared with the first two , and it is always the judgement of experts that indicates that the evolution of the RPN follows the trend of probability and non-detection in the same way.

8. CONCLUSION :

In this work, we merged the fuzzy logic with the FMEA method, which remains the most used tool for analyzing risks, and we also saw the surface view simulation by doing the variation of the three axes To clearly visualize the risk and see its variation compared to other indices, and this simulation is not feasible with the Boolean approach which shows the utility and strength of fuzzy logic .

the usefulness of this work lies in the support of

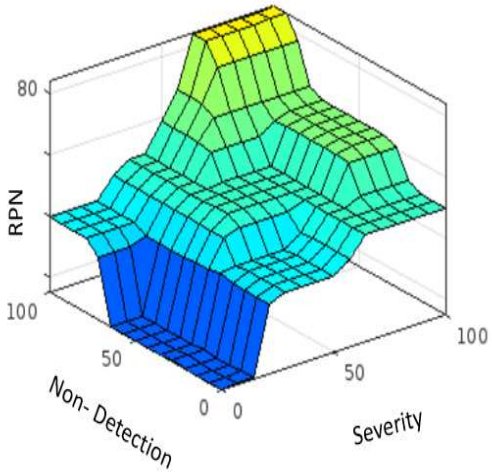

Figure 10 : The curve of the Case N°3

managers in decision-making , especially in a very complicated field such as the Supply Chain which exceeds several variables and which is sensitive to change and disruption induced by sudden and unexpected changes , and it has been shown that the deal between fuzzy logic and FMEA can transform uncertainty into a measure of risk that will guide decision-making, which will allow them to mitigate risks and become more flexible with disruptions, because managers can visualize the risk with its three criticality indices and moreover we can work on planning with more visibility on the impact.

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