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A FUZZY LOGIC MODEL FOR ENSURING CUSTOMER SATISFACTION AND PREVENTING COMPLAINTS ABOUT QUALITY DEFECTS

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ABSTRACT

Customer satisfaction has become a key element in a competitive business world. This pushes companies to improve the quality of their products in order to meet customers' expectations and ensure their trust and loyalty, as well as to focus their efforts on problems and defects that may lead to complaints or even the loss of customers. This is one of the most critical and decisive issues for companies and a key element in remaining competitive.

The objective of this paper is to develop a fuzzy logic model that facilitates the decision on the defects that are prioritized for actions and solutions by estimating the value of the complaint risk for each defect based on the indicator of occurrence and the indicator of defect detection. Our model has shown the importance of acting mainly on the detection of defects through robust systems of control of the parts in addition to taking action on the reduction of the occurrence of defects, with the proposal of effective Lean tools: 5 Whys, Ishikawa Diagram, Poka Yoke, and Jidoka, to improve the two input indicators. This allows a considerable mastery of the quality of the delivered products, thus maintaining customer satisfaction while remaining safe from the risk of complaints.

The combination of fuzzy logic, which is an artificial intelligence tool, with lean manufacturing tools to prevent the risk of customer complaints is one of the basic advantages of merging Industry 4.0 and lean management within the framework of Lean 4.0 to better achieve operational excellence in companies.

Keywords: *Quality, Customer complaints, Fuzzy logic, Artificial Intelligence, Decision-making, Lean 4.0.*

1. INTRODUCTION

In recent years, quality management and improvement have become a necessity for companies, as they constitute a competitive advantage that allows organizations to make a difference in the economic market [1]. One of the most important and strategic points in the context of profitability and economic benefits for companies is customer satisfaction, which is also a reference point for quality and operational excellence standards for all organizations [2].

The main objective of companies now is to address customer concerns and expectations in order to attract and retain them [3], by providing products with high value and quality and without defects [4], as the quality of a product is defined according to the voice of the customer [5]. If customers receive products with the expected quality, this will make them satisfied, and if they get products that exceed their expectations, they will judge the quality produced by the supplier as excellent, and this will attract other customers [2], while their dissatisfaction is a result of receiving a product containing defects that does not meet their expectations [6].

A defect is a non-conformity generated in the manufacturing process, that leads to a decrease in the value of the product from the customer's point of view, resulting in a waste of resources and time as well as a significant risk of receiving complaints and losing customers [7]. The loss of customers means a great financial loss and negative word-of-mouth for organizations [6].

The first law of product quality is to get it right the first time [8], however, defects can naturally be generated during production for a number of reasons, such as progressive degradation of machines and equipment, manpower errors, or others [9], thus, complaints are a normal result of any manufacturing activity [10], and are usually unavoidable for companies [3].

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A complaint is a form of dissatisfaction expressed verbally or in writing towards a company to announce a non-conformity received and question the quality of a product or service. Nowadays, complaints and their handling have become a central part of customer relations [3], and attention to complaint response is increasing with the emergence of service economies and customer-centered strategies [11].

By making complaints, customers require the company to deal specifically with the non-compliance in order to regain their trust and also require financial compensation to cover the costs caused by the non-compliance [6], while companies often find it difficult to deal with customer complaints and have not yet found complete solutions for dealing with them, for some of them it is a serious problem, and for others it constitutes an opportunity for improvement that should not be missed [3].

However, companies are still struggling to prevent claims and eradicate their potential sources to avoid all the losses caused by customer dissatisfaction expressed in the form of a complaint, hence the need for a clear model or strategy to be followed in order to decide and act correctly with regard to the quality of the delivered products.

The proposed methodology consists of a fuzzy logic model that allows the prevention of customer complaints by calculating the risk of receiving a complaint for each defect based on two inputs: the occurrence of the defect and its detectability. By identifying critical defects, companies must act on their occurrence and detection using basic Lean Manufacturing tools such as the 5 Whys, the Ishikawa diagram, the Poka Yoke, and the Jidoka.

2. LITTERATURE REVIEW

The term "complaint management" means the restoration of the situation that led to the failure by putting in place analysis and actions to prevent customer complaints and regain customer satisfaction [10].

The customer satisfaction indicator is based mainly on the comparison between the customer's expectations in terms of product quality and the real performance of the product received [12]. Hence, sending non-conforming products containing quality defects reduces customer satisfaction and increases the risk of receiving complaints:

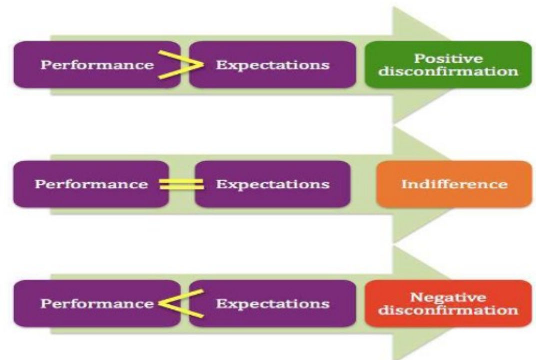

Figure 1: Expectation-Disconfirmation Paradigm [12]

Complaints are too costly for companies, both directly and indirectly, but they can provide them with invaluable knowledge and information about expectations, as the direct voice of the customer is part of the complaint content by default [13].

Prompt handling of negative customer feedback is one of the main recovery strategies aimed at correcting and resolving problems and failures, as customers generally tolerate failure but do not tolerate delayed problem solving by the supplier [2].

The design of an integrated complaints management system enables organizations to capitalize on customer complaints by acting on feedback and information provided in order to improve performance, correct anomalies, and thus avoid future complaints, thereby regaining customer satisfaction and loyalty [6].

Feedback on complaints allows us to highlight the root causes of the problems that led to the complaint. The elimination of these causes in turn allows for the eradication of the problem and hence the improvement of customer satisfaction [13].

8D is a method that requires teamwork to solve problems, following an 8-step approach: D1: team set-up; D2: analysis of the problem; D3: provisional containment actions; D4: root cause analysis; D5: corrective actions; D6: checking the effectiveness of corrective actions; D7: preventive actions; D8: congratulation of the team. The 8D methodology is effective in implementing adequate corrective actions that eliminate the identified root causes of the problems, but it also questions the effectiveness of the control system that has not prevented the escape of the problems, or more precisely, the quality defects [13].

To summarize, most of the previous works show that the process of preventing customer complaints starts with the complaint itself, or at

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least with negative feedback that will provide us with enough information about the failure or non-conformity received by the customer in order to carry out the necessary analysis and investigation to be able to eradicate the source of the problem and ensure customer satisfaction.

Indeed, in the context of industrial quality, what defines a defect as a defect is the customer's point of view, that is to say that the voice of the customer is automatically the starting point that defines the requirements to be taken into account during manufacturing, so the awareness of quality defects not tolerated by customers is already valuable data that allows to work on the prevention of complaints.

However, in aiming to prevent complaints in the context of quality in manufacturing companies, which is one of their major objectives, it must be realized that the notion of eradicating a problem or defect at its root and definitively preventing its recurrence is not sufficiently realistic since the generation of quality defects is quite natural in manufacturing processes that may contain many errors or deviations. Having said that, acting on the occurrence of defects is not enough to avoid customer complaints; it is also necessary to act on a second very important indicator, which is detection. In fact, a good control of the products will help considerably to avoid the escape of defects and nonconforming parts to the customers.

Hence the importance of a model that can guide manufacturers towards appropriate solutions, taking into account all the factors that can influence the risk of receiving customer complaints.

3. MATERIAL AND METHODS

3.1 Presentation of Fuzzy Logic

Fuzzy logic is a logical system developed in 1965 by Professor Lotfi Zadeh that aims to formalize natural human reasoning. Fuzzy logic is a very effective artificial intelligence technique for decision support, especially for problems with fuzzy aspects that are characterized by the interaction of several variables [14].

It is possible in fuzzy sets for elements to belong partially to the same set because the boundaries are not clearly defined. The theory of fuzzy sets is different from the theory of ordinary binary sets and is the basis for modeling fuzzy logic [15]. The classical set considers a limited number of membership degrees, which are generally "0" and "1" [16]. The value of each element of the fuzzy set is assigned by the membership function associated with the fuzzy set [15]:

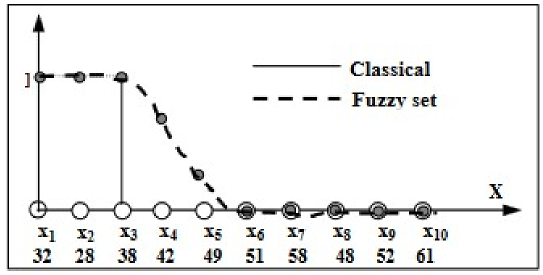

Figure 2: Comparison between classical and fuzzy sets [16]

Membership functions and fuzzy rules are the two main components of fuzzy logic, which make it possible to translate linguistic expressions into mathematical formulas and thus pass from a qualitative description generated by a field expert to a quantitative description via the mathematical model [14].

The modeling of a process according to fuzzy logic requires that the variables of the model belong to fuzzy classes and are managed by rules of the form IF...THEN to allow for the establishment of a result for each combination of the fuzzy classes that contain the variables [15].

3.2 Fuzzification

The fuzzification step allows for the translation of classical or crisp data into fuzzy data [16], defining the membership functions for the input and output variables, which enable numerical data to be transformed into linguistic variables by determining the form of the membership functions and the degree of membership in each of the states that must be defined and specified [17]. The most commonly used forms of functions are trapezoidal and triangular:

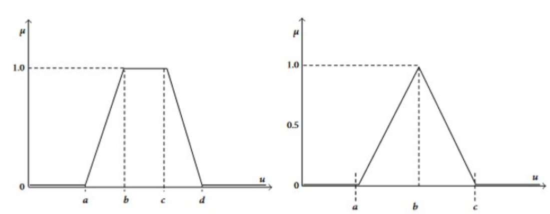

Figure 3: Membership function of a triangular and trapezoidal fuzzy number [14]

The membership functions should be defined by domain experts, and then, using the center of gravity method, the model should generate the output variable [17].

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3.3 The Fuzzy Inference engine

The fuzzy inference step consists of combining the fuzzy rules with the membership functions already defined to obtain the fuzzy output data [16].

That is to say, after having defined the linguistic variables, it is a question of exploiting them in the inference engine, and this is done by determining the rules resulting from the field expertise and by stating them in natural language to allow formalizing human reasoning, which is one of the objectives of fuzzy logic [17]:

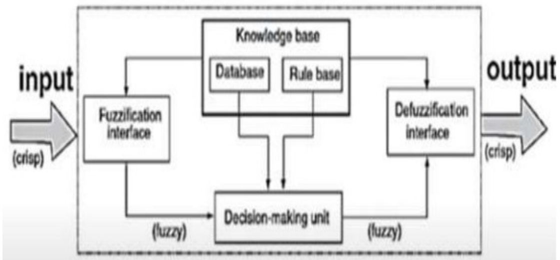

Figure 4: Fuzzy inference system [18]

3.4 Defuzzification

Once the inference is completed, this last phase allows for the determination of the set of fuzzy outputs, with the necessity of a transition from the "fuzzy world" to the "real world" to be able to use the results of the model with precision [17].

The calculation of the "center of gravity" of the fuzzy set is the most widely used method for this purpose [17], in addition to the maximum output method [14]:

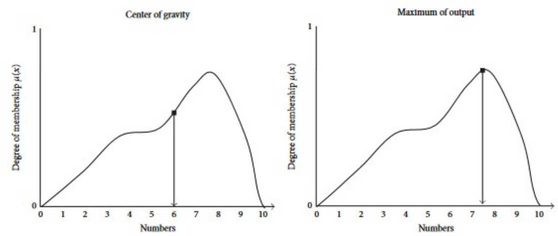

Figure 5: Defuzzification common methods [14]

3.5 Summary of fuzzy logic modelling

After the explanation of the different steps of fuzzy logic modeling, these can be summarized in the form of the diagram presented in the figure below:

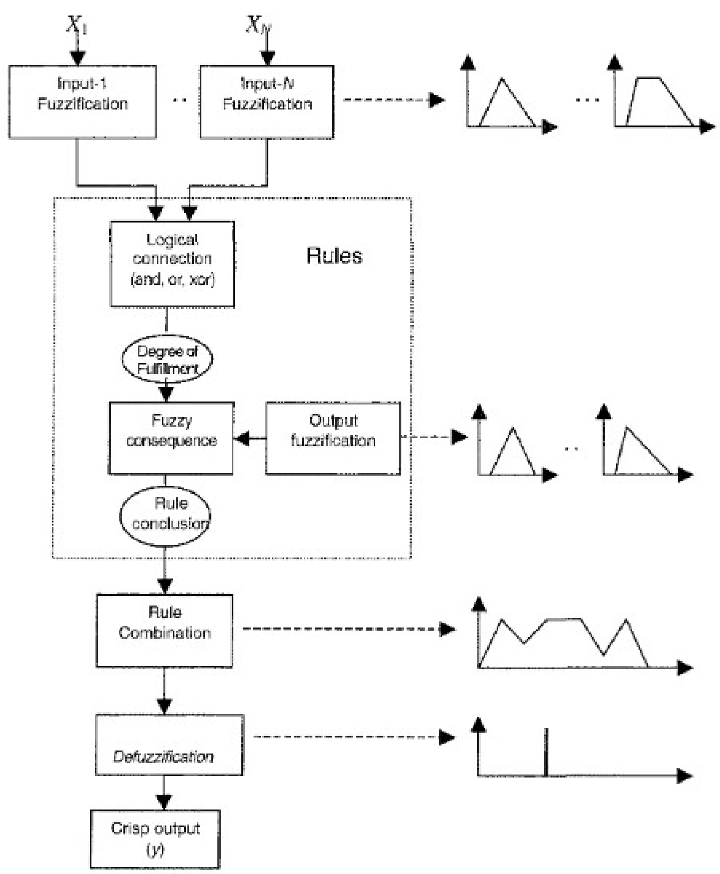

Figure 6: Schematic of a fuzzy logic-based model [15]

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4. CASE STUDY

4.1 Proposed method for complaint risk estimation

The risk of a complaint is often linked to the occurrence of defects as the root cause of the claim; however, since quality defects are generally unavoidable, it is necessary to secure the parts delivered to the customer. Indeed, a defect with a high detectability rate will not have a high risk of escaping to the customers, even if the occurrence is not low.

The interaction between occurrence and detection for each of the defects makes it somewhat complicated to decide which defects are more likely to cause a claim, hence the importance of using fuzzy logic.

In this article, we present a methodology based primarily on a fuzzy logic model that allows us to calculate the complaint risk for each defect, using the terms "low", "medium" and "high" to describe both the input variables "occurrence" and "detection" and also the output variable "complaint risk". Based on the results, it is possible to know the priority defects that require action on occurrence, or detection, or both. In this paper, we also propose effective lean management tools and techniques to reduce defect occurrence and improve their detection.

4.2 Indicators definition

The complaint risk as an output indicator will be estimated on the basis of the following two indicators:

Occurrence: which means the probability of occurrence of the defect, and which can be calculated by the formula of the rejection rate, which is the number of rejected parts containing the defect out of the total production:

Occurrence = Number of rejected parts / Number of produced parts

Detection: which means the number of parts detected by the usual control systems out of the total number of parts produced containing the defect. This number can be determined through specific controls and inspections, and it is more strengthened to question the effectiveness of the usual control systems; hence:

Detection = Number of detected parts / Number of defective parts generated

Therefore, the proposed model could be presented as shown in the following figure:

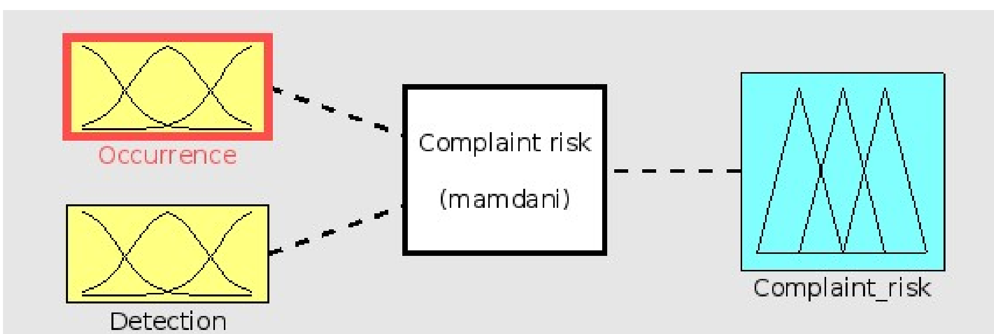

Figure 7: Proposed fuzzy model

4.3 Modeling of indicators

Having defined the proposed method and the input and output indicators, the next step is to model them by determining the membership functions for each variable, as shown in the figures below:

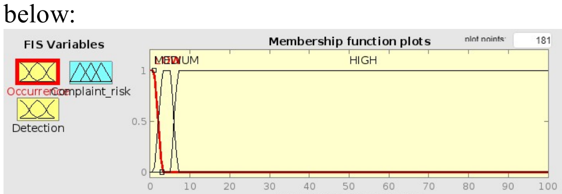

Figure 8: Membership function for "Occurrence"

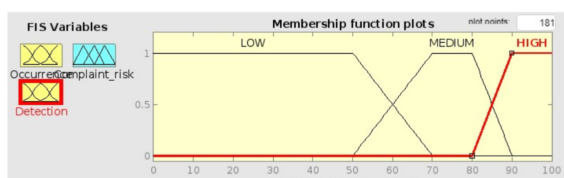

Figure 9: Membership function for "Detection"

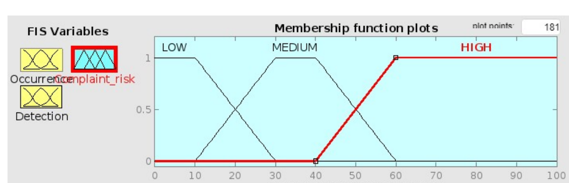

Figure 10: Membership function for "Complaint risk"

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4.4 Fuzzy inference

At this stage, it is necessary to define inference rules based on field expertise to frame the interaction between the different input variables.

These are nine fuzzy rules (3*3) using the <<AND>> operator:

1. If (Occurrence is LOW) and (Detection is LOW) then (Complaint_risk is MEDIUM) (1)
2. If (Occurrence is LOW) and (Detection is MEDIUM) then (Complaint_risk is LOW) (1)
3. If (Occurrence is LOW) and (Detection is HIGH) then (Complaint_risk is LOW) (1)
4. If (Occurrence is MEDIUM) and (Detection is LOW) then (Complaint_risk is HIGH) (1)
5. If (Occurrence is MEDIUM) and (Detection is MEDIUM) then (Complaint_risk is MEDIUM) (1)
6. If (Occurrence is MEDIUM) and (Detection is HIGH) then (Complaint_risk is LOW) (1)
7. If (Occurrence is HIGH) and (Detection is LOW) then (Complaint_risk is HIGH) (1)
8. If (Occurrence is HIGH) and (Detection is MEDIUM) then (Complaint_risk is HIGH) (1)
9. If (Occurrence is HIGH) and (Detection is HIGH) then (Complaint_risk is MEDIUM) (1)

Figure 11: Fuzzy inference rules presentation

4.5 Defuzzification

During the defuzzification step, it is possible to transform the fuzzy set containing occurrence and detection into a precise numerical value of the complaint risk using the center of gravity method, as shown in the following figure:

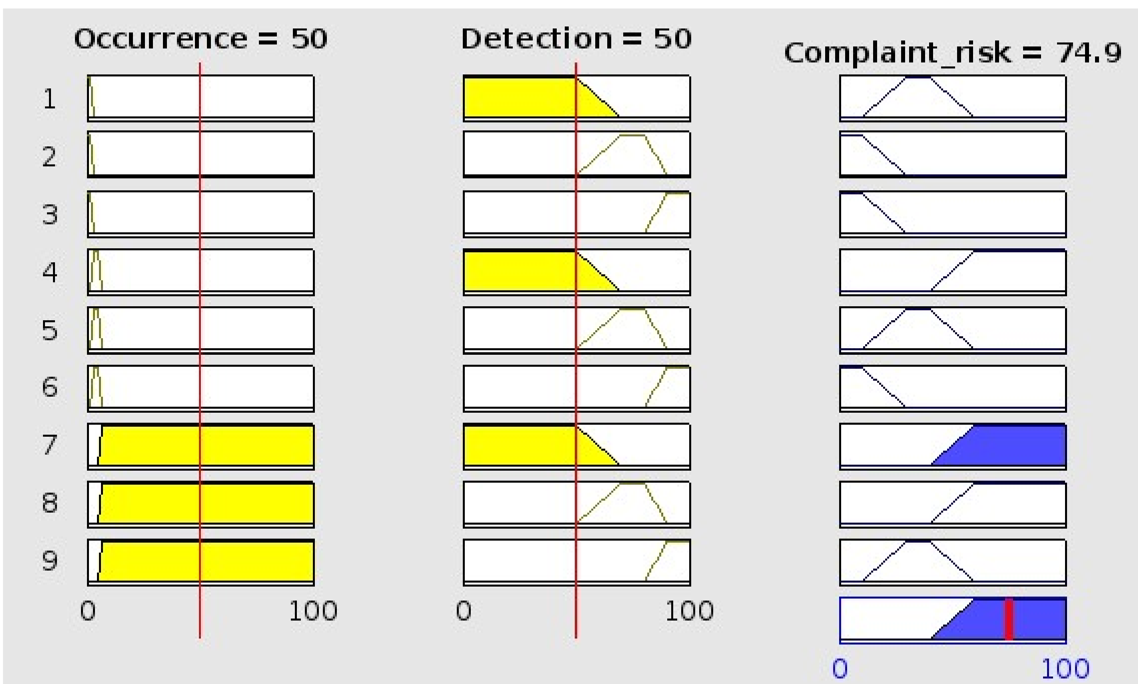

Figure 12: Deffuzification process

Once the priority defects that can lead to claims are known, they must be treated immediately.

4.6 Effective tools to reduce the occurrence

The 8D methodology is an approach to problem solving developed within Ford Motor Company in the 1990s. It consists of the application of eight steps or eight disciplines that identify the root causes of problems in order to eradicate them and avoid their recurrence through effective solutions in the short and long term [19]. This approach is based mainly on two Lean tools, the 5 Whys and the Ishikawa diagram, which are widely used for root cause analysis.

The 5 Whys is an iterative questioning tool developed by Sakichi Toyoda at the Toyota Motor Corporation. It makes it possible to determine a chain of causes and effects at the origin of a given problem and constitutes an essential element of the problem-solving process. It is based on the question "Why?" which must be asked repeatedly until the root cause of the anomaly is known. The identification of this root cause is the main objective of the 5 Whys, which then facilitates the proposal of corrective actions. Each answer to the question "Why?" is the basis for more questions [20].

The Ishikawa diagram is a tool represented in the form of a graphic diagram that is similar to the skeleton of a fish and that shows the relationship between a specific effect and its causes, such that the "head of the fish" positioned on a horizontal axis signifies the effect under study and the other segments, which lie on the horizontal axis of the "fishbone", contain its causes and potential sub-causes [21]. There are generally five segments that are reserved for five categories of causes: machine, manpower, method, material, and environment [22], so their representation is as shown in figure 13 below:

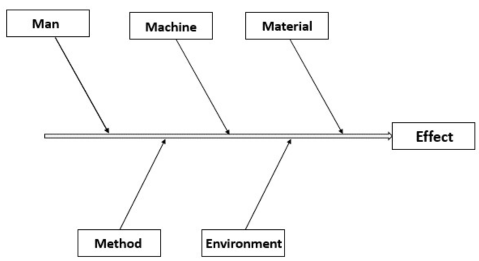

Figure 13: Ishikawa diagram

The distribution of causes by category makes the Ishikawa diagram more powerful and facilitates the identification of root causes, especially by integrating the 5 Whys tool, and thus the determination of different solutions and actions capable of eradicating all the sources of the defect or anomaly studied [21].

4.7 Effective tools to improve detection

Among the best lean tools capable of ensuring robust control and high defect detection, we find Poka-Yoke and Jidoka.

Poka-Yoke is a tool that means "error-proofing" or "error-resistance" [23]. It is a technique developed by Shigeo Shingo in 1961 that relies on mechanisms and devices related to production equipment to prevent defects and any causes capable of creating them [24]. According to Shingo, the Poka-Yoke allows the operator to detect errors and control the totality of the parts independently of the operator's follow-up [25]. A good design of the Poka-Yoke mechanism is able to considerably prevent the fall in output due to the production of defective parts [24].

Indeed, the probability of the production of defects and the possibility of the generation of errors are always present at all phases of the process and also at each stage of the product life cycle. On the other hand, customer satisfaction depends essentially on the quality of the delivered products, which requires companies to adopt Poka Yoke devices that help them to succeed in the challenge of producing with 0% defects [23], which is not really the case with statistical tools that will never be able to ensure a production delivered to the customer with 100% good-quality parts and without any defects [26].

Jidoka is a main technique in the philosophy of lean manufacturing; it is a system that is both automated and autonomously integrated into the machines and that allows to stop the production automatically once a defect or an anomaly is detected and also allows to signal the situation to the operators by means of "Andon" alarms [27]. This system interrupts the flow of defective parts and prevents their passage to other stations in the process [28], because it is better to stop production to analyze the defect and its causes than to continue producing useless defective parts. The two principles of automation and autonomy used simultaneously in Jidoka give rise to a new and more global principle, which is autonomation [29].

5. RESULTS AND DISCUSSION

The next step after the construction of the inference system is the analysis and interpretation of the defuzzification results using the surface viewer graphs to understand the relationship between the two input indicators, occurrence and detection, and the output indicator, complaint risk:

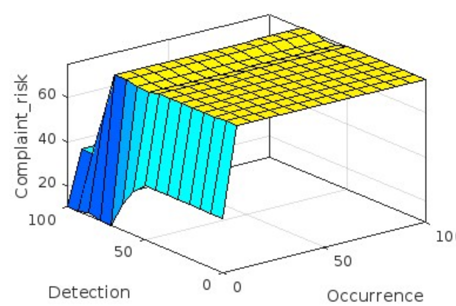

Figure 14: Surface View

On the basis of figure 14, we can see that when the occurrence of the defect is low, the risk of complaint is low, provided that the detection value is not low, and if the occurrence is medium or high, the detection indicator of the defect, if it is high, can considerably compensate for the high or medium occurrence and reduce the risk of receiving a complaint due to this defect. Inversely, if the detection is high, it means that the risk of complaint is low, whatever the value of occurrence, but if it is low, the risk of complaint is still present; that is to say, in the opposite direction, a low value of occurrence cannot compensate for the low detection. Thus, having a robust control system is a primary requirement for companies, yet a high or at least medium detection needs to be complemented by a low occurrence, or in other words, a strong problem solving and defect reduction system, to remain protected from any customer complaint.

Hence the importance of using primarily Poka Yoke and Jidoka to improve defect detection and root cause analysis tools to reduce their occurrence.

The results of the proposed model show that it is possible to prevent complaints by focusing not only on the occurrence but also on the detection using customer-defined defect data. We can also deduce that the root cause analysis tools must be used perfectly beforehand and not wait for the receipt of the complaints in order to remedy them; nevertheless, the deffuzification step has shown how important it is to complement the actions on the occurrence with a robust defect control system.

6. CONCLUSION

Quality management has become a strategic advantage for industrial companies in today's highly competitive world. This competition is focused on a specific objective, which is customer satisfaction, which means automatically manufacturing high-quality products and avoiding as much as possible sending non-conforming products to avoid receiving complaints and losing customers, which is negative word-of-mouth for companies without forgetting the financial losses that result from it.

In this paper, we have developed a fuzzy logic model that identifies defects that present serious risks of receiving a complaint by calculating the output indicator of complaint risk based on two input indicators, which are the occurrence and detection of each defect.

We then interpreted the results of the model and highlighted the importance of focusing on defect detection and then on their occurrence, and we proposed effective lean tools to reduce the occurrence of defects and to properly control the parts to detect defects and prevent their escape to the customers, thus preventing customer complaints.

7. LIMITATIONS

The fuzzy logic model that we have proposed is effective in identifying defects that may be subjects of customer complaints, and with the Lean tools presented, companies will be able to act on the occurrence or detection of these defects, or both, to prevent customer complaints.

However, the adoption of adequate part control systems, or poka-yoke, remains a major challenge for managers, especially in terms of efficiency in detecting some very specific defects, which requires more powerful capabilities, especially in image processing. Moreover, these systems can be significantly improved in the context of the connected factory and industry 4.0 to allow, in addition to the detection, to determine the causes that generated the defect and even to prevent them by highlighting the deviations in the process and the probable failures of the machines, which presents one of the objects of research in actuality within the framework of the digitalization.

On the other hand, the proposed methodology focuses on the type of customer complaints due to the reception of non-conforming parts and quality defects and does not take into account the other types of complaints, which are generally due to delays in deliveries and non-observance of deadlines, which in turn are due to problems of availability of production lines and productivity of manufacturing processes, which is why this problem will be the subject of the next research work.

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