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ORIGINAL

Fuzzy Decision-Making Model for the inventory leveling under uncertainty condition

Modelo de toma de decisiones difusa para la nivelación del inventario en condiciones de incertidumbre

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ABSTRACT

The Option to create inventory is not always the optimal choice, due to the associated expenses and space requirements. Nevertheless, there are instances where a shortage of materials on customer lines can result in substantial financial penalties. This constant contradiction places supply chain managers in a perplexing predicament, especially when considering the amplification of inventory through the bullwhip effect as it moves across different stages. Moreover, the uncertain backdrop created by unforeseen events intensifies this already critical situation, compelling managers to seek new decision-making approaches. These approaches should enable the simulation of risks and the selection of suitable scenarios, particularly within the intricate domain of stochastic and dynamically evolving supply chains. The purpose of this study is to provide a new decision-making model rooted in the fuzzy logic concept introduced by Loutfi Zadeh in 1965. This model is applied to criteria assessed by experts, representing the most pertinent parameters for guiding inventory optimization. The chosen criteria encompass Lead Time, Equipment Production Reliability, and Warehousing Costs. This model exhibits the potential to unearth intricate patterns and associations among variables that conventional statistical methods struggle to reveal. Notably, the integration of fuzzy logic for inventory prediction yields promising outcomes, extendable to the realm of artificial intelligence, where comprehensive inference rules facilitate effective decision-making.

Keywords: Supply Chain Uncertainty; Inventory Management; Decision-making; Bullwhips Effects; Fuzzy Logic; Simulation.

RESUMEN

La opción de crear inventario no siempre es la opción óptima debido a los gastos asociados y las necesidades de espacio. Sin embargo, hay casos en los que la escasez de materiales en las líneas de clientes puede resultar en sanciones financieras sustanciales. Esta contradicción constante coloca a los gerentes de la cadena de suministro en una situación desconcertante, especialmente cuando se considera la ampliación del inventario a través del efecto látigo a medida que se mueve a través de diferentes etapas. Además, el telón de fondo incierto creado por acontecimientos imprevistos intensifica esta situación ya crítica, obligando a los directivos a buscar nuevos enfoques de toma de decisiones. Estos enfoques deberían permitir la simulación de riesgos y la selección de escenarios adecuados, en particular en el complejo ámbito de las cadenas de suministro estocásticas y en evolución dinámica. El objetivo de este estudio es proporcionar un nuevo modelo de toma de decisiones basado en el concepto de lógica difusa introducido por Loutfi Zadeh en 1965. Este modelo se aplica a criterios evaluados por expertos, que representan los parámetros más pertinentes para orientar la optimización del inventario. Los criterios elegidos abarcan el tiempo de entrega, la confiabilidad en la producción de equipos y los costos de almacenamiento. Este modelo exhibe el potencial de desenterrar patrones intrincados y asociaciones entre variables que los métodos estadísticos convencionales luchan por revelar. En particular, la integración de la lógica difusa para la predicción de inventarios produce resultados prometedores, ampliables al ámbito de la inteligencia artificial, donde las reglas de inferencia integral facilitan la toma de decisiones efectiva.

Palabras clave: Incertidumbre de la Cadena de Suministro; Gestión de Inventario; Toma de Decisiones; Bullwhips Effects; Lógica Difusa; Simulación.

INTRODUCTION

The management of the supply chain's performance has an important contribution margin on the profitability of companies, because it covers all the functions of transport, production, storage and handling. And companies always tend to expand their management fields from upstream suppliers to downstream in order to perform well in sales and distribution, nevertheless stock management remains the core of supply chain management, because it is strongly linked to the performance of manufacturing units as well as the reliability of production equipment, because the stock is always created to absorb and compensate all production hazards and unforeseen events (shutdown, non-quality, lack of forecast, etc.).[1] As shown in the figure 1, considering the water level of a river as the level of the stock, the passage of the boat will be conditioned by the fact of being far from the pebbles, which concretely represents all the hazards of production and the unforeseen events like the change of the production schedule, machine shutdown.

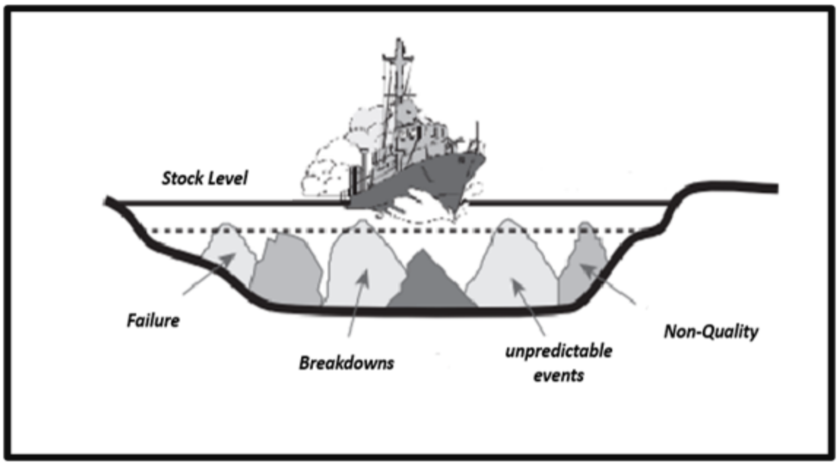

Figure 1. Just in Time concept

Thus to properly manage the stock it will be necessary to use a tool to simulate the impact of the stock level on the customer's line by taking into account all factors that can disturb any step on the supply chain, and it is in this context that we use a new type of artificial intelligence that is capable of handling inaccurate data and making decisions based on uncertain information approach that complements the Boolean logic (true/False, Black/white, Reliable/not reliable, etc.) which is the fuzzy logic initiated by LOUTFI ZADEH in 1965,[2,3] and which is traditionally applied in several issues such as the choice of suppliers for companies.[4,5]

Stock management is a universal paradigm,[6] it is not even specific to the industry or the supply chain management, there are in nature animals that make stock to survive from one season to another, even the human body is designed to stock up when needed. thus, there must be a purpose and an objective of the stock, which means that the stock must always be considered as the consequence of either a management rule resulting from a decision or an arbitration, either a mode of regulation between functions involved in the level of stocks.

There are those who define logistics as the science of flows,[7] and also the science of stocks, because there is always a tendency to reduce the level of stock through the implementation of just-in-time, Just-in-time means nothing other than the harmonization of flows to reduce stocks and achieve the ultimate goal of "zero stock". there is also a phenomenon of extreme importance in the functioning of the supply chain which means concretely that: the further away from the final customer, the more the variability of orders augment , this principle is called the Bullwhips Effect (figure 2) , also known as demand information amplification or the Forrester effect (1958, 1961), is a phenomenon whereby a small variation in end-customer demand leads to a significant fluctuation in orders that the upstream supplier receives in the supply chain system.[6] This phenomenon has a negative influence on supply chain performance, with associated costs, such as machine capacity, staff recruitment fluctuations and excessive inventory levels.

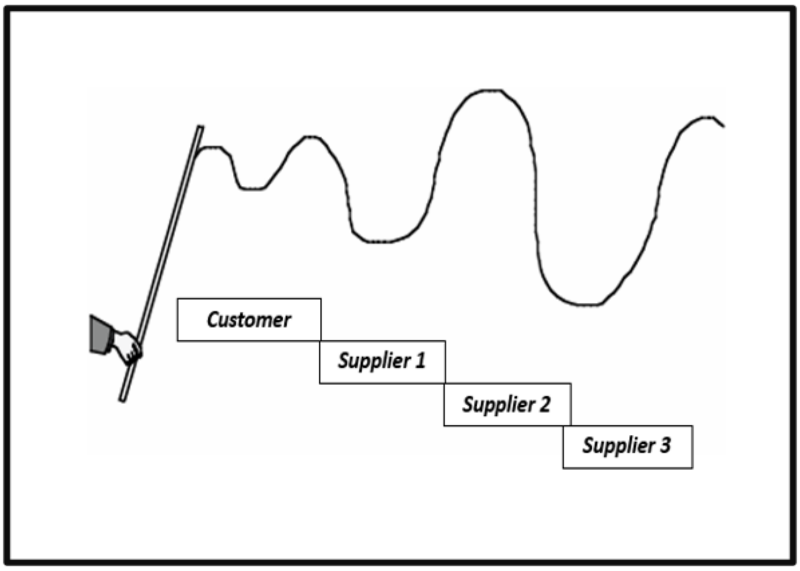

Figure 2. Bullwhips Effect

For example: if consumers order one day 120 instead of 100, wholesalers order 150 themselves to follow this trend, the supplier warehouse in turn orders 200 and the factory goes producing 300 to meet rising demand… to remedy this phenomenon, which promotes the generation of stock throughout the stages of the supply chain.

Supply chain stock management involves all the links in the chain by including all suppliers and all costumers,[8] managing these business relationships is crucial for the success of the supply chain. Emphasis should be placed on developing sustainable and profitable relationships between its entire links. In fact, the only question that remains is how find the right inventory management parameters (safety stocks, safety deadlines, batch-sizing rules …) at all levels in order to satisfy the end customer on the desired deadline at the lowest cost.

Most scientific publications have been focused on mathematical optimization models,[9] which aims to minimize storage costs, such as the theory of Economic Order Quantity,[8,10] this model is Developed by the American engineer Ford Whitman Harris in 1913, and R.H. Wilson in 1934 under the formula shown in the figure 3:

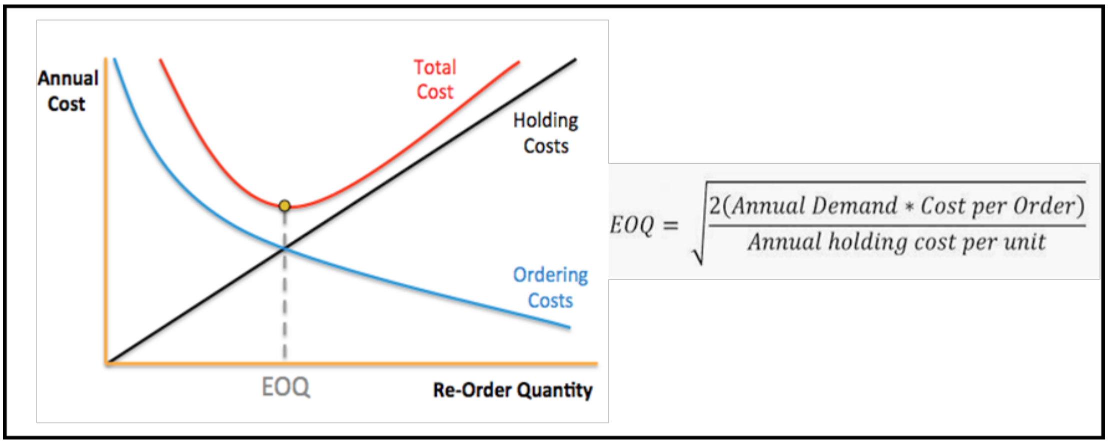

Figure 3. Economic Order Quantity

Stock management can also be done with the Newsboy model which takes into account the cost of holding h and the cost of breaking b. In this model, demand is considered a random variable with a known distribution (Porteus, 1990, Dupont 1998).

A reinforcement learning approach was recently applied to a coordination and integration problem of multinational corporations with emphasis on logistics and production management. The problem was formulated as a semi-Markov decision model and solved via a reinforcement learning technique called Q-learning.[8]

There are also manufacturers easily accept MRP planning methods that are the best-known methods in the context industrial, MRP systems, the majority industrial decision makers are familiar with it across all existing management systems production informatics.

However, MRP is based on the assumption that demand and lead times are known. However, in the industrial world, we very often see that supply times often vary randomly. Supply times for finished components are rarely reliably predictable. Indeed, there are some random factors such as machine failures, transport delay, etc. Therefore, deterministic assumptions embedded in MRP systems regarding supply time are often too limited.

The common point between all the methods already mentioned is the fact that it is based on stationary data, the thing that is impossible in an uncertain context where the data are very variable and always in fluctuations. there is also the lack of others parameters that can be taken into account in the leveling of the stock such as: reliability and availability of machines and production tools in the company, because if the machines are still available, we can minimize the stock since there will be no blockage if we want to produce at the time of demand, the thing we cannot do if the production tools are degraded or deteriorated, also the change of series, because to go from a product A to a product B it will take operations that take time which acts on the deadlines of delivery . therefore, we will try to broaden the field of criteria and parameters that impact the decision to create or not the stock to have the maximum of variables that can be simulated to guide the managers of the supply chain.

the approach that we will use is the fuzzy logic which has become a well-exploited alternative in a context of invisibility and uncertainty.[11]

METHODS

Fuzzy Logic model

The fuzzy logic is an extension of the Boolean logic (0 or 1), or the truth value of the variable instead of being true or false- is a real that varies between the value 0 and the value 1 (figure 4) , it is formalized by Mr. Lotfi ZADEH in 1965,[11,12] who has already given the right and complete definition of fuzzy logic: “Fuzzy 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”,[13] 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”.

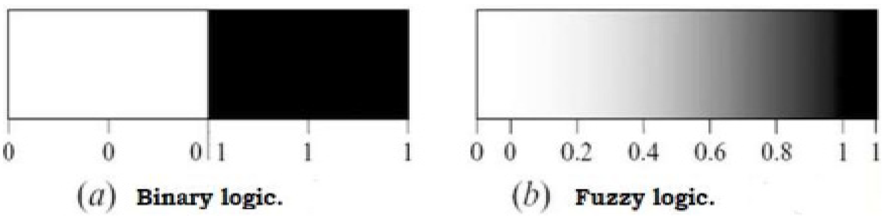

Figure 4. Fuzzy and Boolean Logic

As shown in the figure 5 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 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.

decision-maker through the fuzzy inference that is fed by rules, can estimate the level of the stock with linguistic terms (Low, Medium and High Risk) to be converted to one digit after defuzzification.

Fuzzy logic has been used in many fields, including stock analysis and prediction, one advantage of using fuzzy logic in stock behavior prediction is that it can handle the uncertainty and imprecision of the data. Fuzzy logic is capable of processing data that is not precise or accurate, and can make simulations based on the available information.

As already explained, the fuzzy Inventory Control model, contains three components: fuzzy inputs, fuzzy outputs and fuzzy rules. Fuzzy logic toolbox of MATLAB is used to construct the Fuzzy model for calculating the stock quantity. in our case there are 3 inputs: the lead time, the reliability of the equipment and the cost of storage the figure 6 shows the proposed model in MATLAB.

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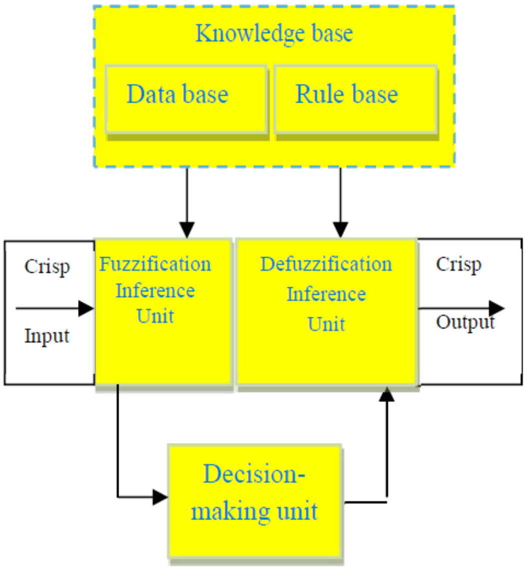


Figure 5. Process of fuzzy logic

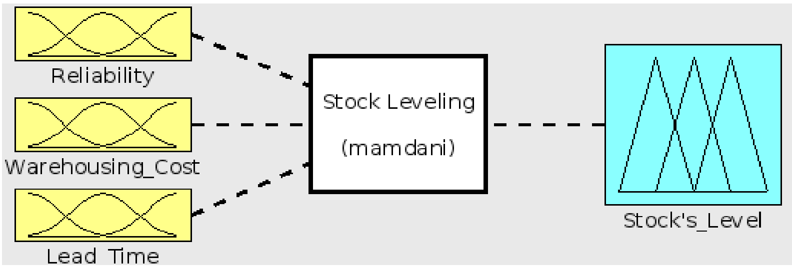


Figure 6. The Fuzzy Stock Leveling Model

Modelling of the Stock Level by Fuzzification

The location of the customer and the time distance take an important place in the decision to create or eliminate the stock, this index is measured by what is called: Lead Time [14]. This parameter has an overseas importance in decision-making because it measures the margin of reaction we have in front of the customer, there is also the concept of the reliability of the equipment which indicates the probability that a factory will be able to carry out its production operation at a given time, and in the end the cost of storage which remains the great burden of the logistics managers, especially when it comes to parts with large size and that require handling machines. In this context, we introduce a model based on fuzzy logic, which will allow us to simulate the stock level by taking into account all the criteria already mentioned:

Reliability of Equipment: Reliability is defined as the probability that a product, system, or service will perform its intended function adequately for a specified period of time, or will operate in a defined environment without failure.

In an industrial context, experts consider that a process is stable if its reliability exceeds 75 %, however it is not reliable if the reliability index does not exceed 30 %, the table below summarizes these quotes:

Table 1. Reliability Cotation

Reliable	**Reliable more than 75 %**
Average Reliability	Between 40 % and 75 %
Unreliable	Less than 30 %

Lead Time [8]: In general, lead time in inventory management is the amount of time between when a purchase order is placed to replenish products and when the order is received in the warehouse. Order lead times can vary between suppliers, the more suppliers involved in the chain, the longer the lead time is likely to be.

Generally experts always tend to reduce lead time, because for them 8 days of waiting impacts the responsiveness of suppliers.

Table 2. Lead Time Cotation	
Long term	**More than 8 days**
Average Term	Between 1 and 6 days
Short Term	Less than day

Warehousing Cost: stock is always considered a waste of money (Muda), it often takes up space that can be used in manufacturing operations, and to allocate storage space with specific ranks will require a cost in addition to the cost degradation and obsolescence of stored parts.

The table below indicates the storage cost levels judged by experts in the field:

Table 3. Warhousing Cost Cotation	
Expensive	**More than 80£ per week per pieces**
Moderate	Between 20£ and 80£
Cheap	Less than 20£ per day per pieces

In order to visualize the degree of truth of each variable, we will make use of the membership functions, traced by the supply chain managers, as illustrated in figures 7, 8, 9 and 10, the indicators are modeled by a trapezoidal membership functions using linguistic terms appropriate to each indicator [12]:

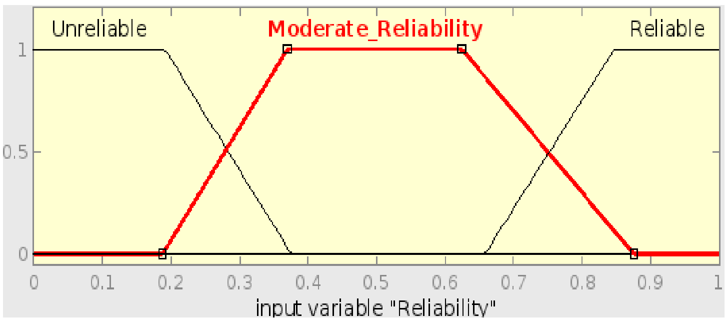


Figure 7. Membership Function of Lead Time

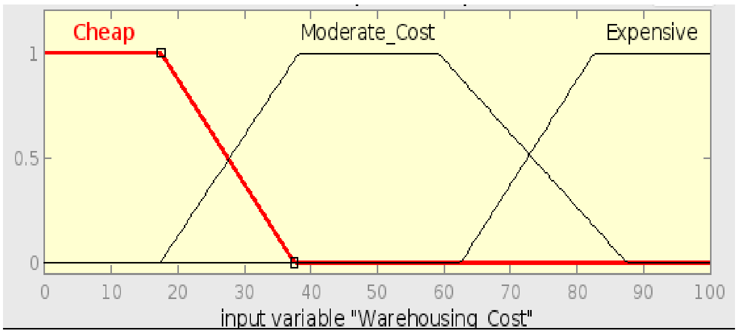


Figure 8. Membership Function of Warehousing Cost

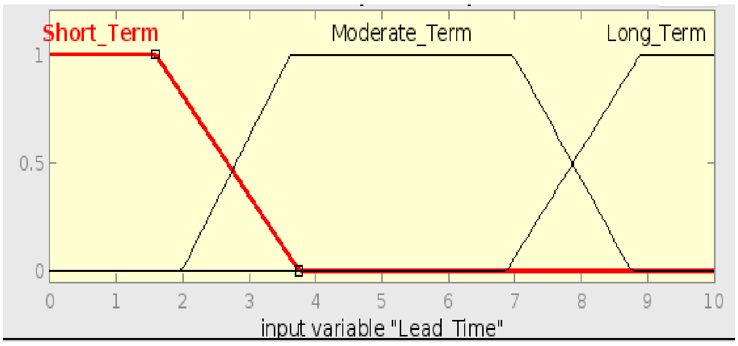


Figure 9. Membership Function of Reliability

As already initiated in the paragraphs above, the objective of the model will be the prediction of the level of the stock, in this sense the levels of the stock have been set using the membership function.

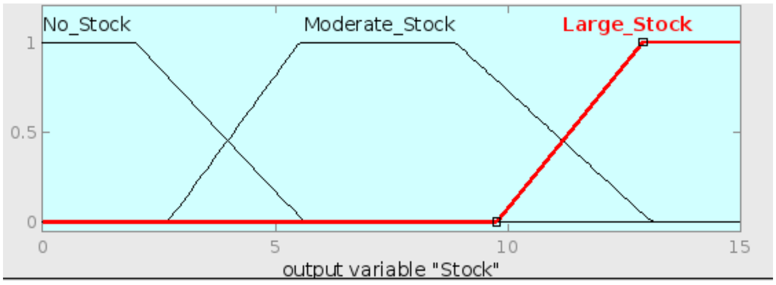


Figure 10. Membership Function of Stock Level

Fuzzy Inference

The "linguistic variables are linked together by rules and allow us to draw inferences". 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.[13]

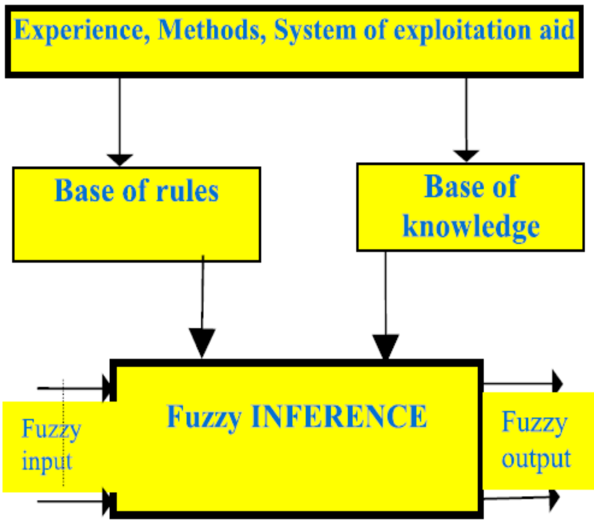
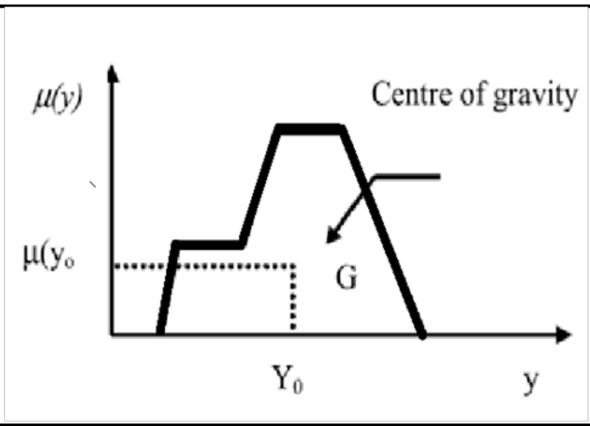


Figure 11. Fuzzy Inference

The defuzzification

As explained before, the defuzzification 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 :MAMDANI technique which is shown in the figure 12:[2,3]



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

Figure 12. MAMDANI Method

RESULTS

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,[15] 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 :Lead Time , Reliability or Warehousing Cost (that we will choose in different cases below) with the Stock level , and then we will interpret them to understand the experts' opinions and justify their choices[9]:

<u>Case N°1: [Input1 = Warehousing cost; Input2 = Reliability]</u>
The index of Lead Time is fixed in advance in Medium

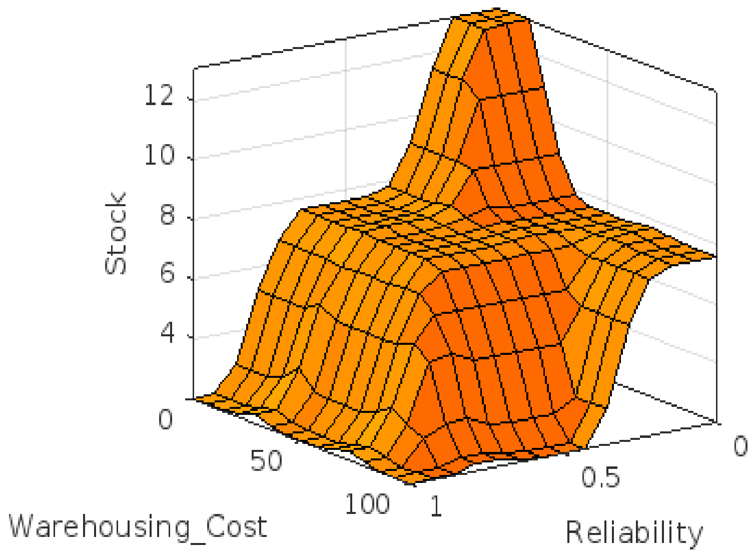


Figure 13. The curve of the case N°1

<u>Case N°2: [Input1 = Lead Time; Input3 = Reliability]</u>
The index of Warehousing cost is fixed in advance in Medium

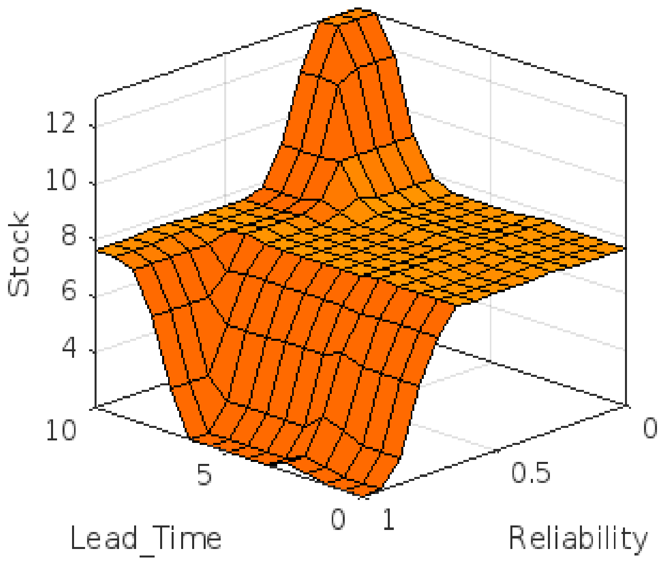


Figure 14. The curve of the case N°2

<u>Case N°3: [Input2 = Lead Time ; Input3 = Warehousing-Cost]</u>
The index of Reliability is fixed in advance in Medium_

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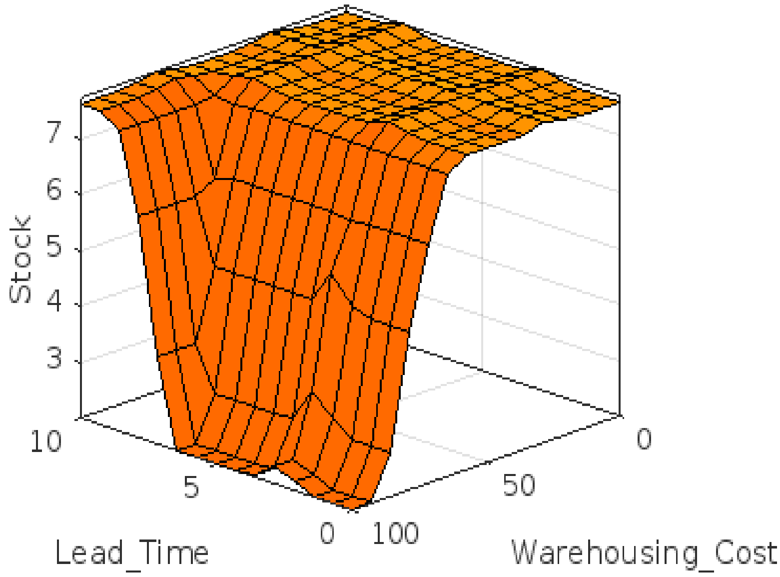

Figure 15. The Curve of the case N°3

We can see in the surface view that as long as the Warehousing Cost and Reliability are close to zero, the stock level tends to exceed 12 days of stock, and when we increase either the Warehousing Cost or Reliability or both at the same time, the stock level follows the reverse direction.

The same thing if we integrate the Lead Time in the graph, we can notice that once we exceed 5 days of the lead time, the model begins to constitute the stock to avoid any kind of disturbances caused by the uncertainties that it is transport, production or component failure.[16-20]

On the other hand, we can notice that the graph is not symmetrical, since for experts, unreliability exposes the company to customer shutdown risks, this is why as soon as the reliability decreases, we start creating stock.

DISCUSSION

The phenomenon of bullwhips is irritating for supply chain managers, especially with fluctuations that constantly disrupt the smooth running of work from suppliers to end customers, the proposed work will mitigate the difficulties because it takes into consideration the most relevant parameters to properly manage the creation of the stock (Reliability of machines, storage cost and delivery times) and to properly simulate the trend of the stock, we chose fuzzy reasoning, which has become the best approach to adopt in an increasingly uncertain world.[21,22,23]

Traditional methods of stock management remain limited because they do not take into account external factors and they are based on accurate data, so all the results developed will be logical theoretically but not applicable on the real plane.[24,25] And if we are looking to improve the resilience of our logistics chain, it is imperative to work on stock regulation to keep a good level of security stock without having additional costs that will penalize the competitiveness of the company.[26,27]

This decision support model will surely contribute to improving the resilience of the supply chain as a new concept that indicates the speed of finding the initial state before applying a constraint (whether internal or external).[28,29,30]

CONCLUSION

Since creating the inventory or disposing of it is costly for businesses, we must always return to decision-making tools that can help and guide decision-makers ,in this context the usefulness of this paper lies in the support of 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, with the model proposed, the stock level can be estimated based on the three criteria already presented Lead Time, Warehousing Cost and Reliability of the equipment.

Thus, we started with linguistic data through fuzzification, that were schematized by membership functions, and then we inserted the inference rules judged by the experts of the supply chain and finally we returned to the real data via defuzzification to come out with measurable and quantified data that support decision making at all levels and stages of the supply chain.

Despite its potential benefits, there are also some limitations to fuzzy logic implementation for stock leveling prediction. One limitation is that the model may not capture all of the complex relationships and interactions that exist in the stock market. Additionally, the accuracy of the model can be affected by the quality and availability of the input data.

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Formal analysis: Hatim LAKHOUIL.
Acquisition of funds: Hatim LAKHOUIL.
Research: Hatim LAKHOUIL.
Methodology: Aziz SOULHI.
Project management: Hatim LAKHOUIL.
Resources: Hatim LAKHOUIL.
Software: Hatim LAKHOUIL.
Supervision: Hatim LAKHOUIL.
Validation: Aziz SOULHI.
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