## Chapter 1

# A Fuzzy Rule-Based Approach for Inventory Control under Uncertain Demand

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**Abstract**

Inventory management requires effective decision-making to balance product availability and operational costs. In many real-world situations, inventory decisions are often made based on human judgment rather than precise numerical data. To capture this reasoning process, this chapter proposes a fuzzy rule-based inventory control system that models human decision logic using linguistic variables and IF–THEN rules. Demand level and inventory level are considered as input variables, while order quantity is treated as the output variable. A Mamdani fuzzy inference mechanism is used to process the rule base and determine appropriate ordering decisions. A numerical example is provided to illustrate the applicability of the proposed approach in handling uncertainty in practical inventory environments.

*Keywords: Fuzzy logic; Inventory control; Human decision-making; Rule-based system; Mamdani inference; Supply chain management.*

ISBN 978-816855385-9

## 1. Introduction

Inventory management is an essential component of supply chain operations, as it helps organizations maintain a balance between product availability and operational cost. Businesses must ensure that sufficient stock is available to meet customer demand while avoiding excessive inventory that can increase storage and holding costs. However, inventory decisions are often influenced by uncertain factors such as fluctuating demand, changing market conditions, and variations in stock levels. Because of these uncertainties, determining the appropriate order quantity becomes a challenging task for managers.

In real-world situations, inventory decisions are frequently based not only on precise numerical data but also on human judgment and experience. Managers often describe demand and stock conditions using linguistic terms such as *low*, *medium*, or *high*, rather than exact numerical values. Traditional inventory models, which rely on precise parameters, may not always capture this type of reasoning effectively.

Fuzzy logic provides a useful approach for addressing such uncertainty by allowing decision variables to be expressed through linguistic terms and rule-based reasoning. By incorporating expert knowledge in the form of IF–THEN rules, fuzzy systems can represent human decision-making in a structured way. Motivated by this idea, this chapter proposes a fuzzy rule-based inventory control model that determines order quantity based on demand level and inventory level. The model employs a Mamdani fuzzy inference system to process the rule base and generate appropriate ordering decisions under uncertain conditions.

### 1.1 Basics of Fuzzy Logic

Fuzzy logic is a mathematical approach used to handle uncertainty and imprecision in decision-making problems. Unlike classical logic, where variables can take only two values such as true or false, fuzzy logic allows variables to have degrees of membership between 0 and 1. This enables the representation of vague or approximate information that commonly appears in real-world situations.

In fuzzy logic systems, variables are often expressed using **linguistic terms** such as *low*, *medium*, and *high*. These linguistic values are represented through **membership functions**, which define the degree to which a particular value belongs to a fuzzy set. Membership functions can take different shapes, with triangular and trapezoidal forms being commonly used due to their simplicity and effectiveness.

A typical fuzzy logic system consists of several main components. The **fuzzification stage** converts crisp input values into fuzzy values using membership functions. These fuzzy inputs are then processed through a **rule base**, which contains a set of IF–THEN rules representing expert knowledge or decision logic. The **inference mechanism** evaluates the rules and combines their results. Finally, the **defuzzification process** converts the aggregated fuzzy output into a single crisp value that can be used for practical decision-making.

Because of its ability to model human reasoning and handle uncertainty, fuzzy logic has been widely applied in areas such as control systems, decision support, and inventory management.

## 2. Proposed Fuzzy Rule-Based Inventory Model

ISBN 978-816855385-9

This chapter proposes a fuzzy rule-based inventory control model to support ordering decisions under uncertain demand and inventory conditions. The model uses fuzzy logic to represent the reasoning process commonly followed by inventory managers when deciding the quantity of items to be ordered.

In the proposed system, two input variables are considered: **demand level** and **inventory level**. These variables are described using linguistic terms such as *low*, *medium*, and *high*. The output variable of the system is the **order quantity**, which represents the amount of inventory that should be ordered to maintain an appropriate stock level.

Each linguistic variable is represented by suitable membership functions. Triangular membership functions are adopted due to their simplicity and effectiveness in representing approximate information. The input variables are first converted into fuzzy values through the fuzzification process. These fuzzy values are then processed using a set of IF–THEN rules that describe the relationship between demand, inventory level, and order quantity.

A typical rule in the system may be expressed as follows:

If demand is high and inventory level is low then order quantity is large.

Similarly, other rules can be constructed to represent different combinations of demand and inventory conditions. The collection of these rules forms the rule base of the fuzzy system. The Mamdani fuzzy inference method is used to evaluate the rule base and combine the results of all activated rules. Finally, the aggregated fuzzy output is converted into a crisp order quantity using the centroid defuzzification method. The proposed approach provides a flexible and practical framework for determining appropriate inventory decisions in uncertain environments.

## 3. Fuzzy Rule Base and Inference Mechanism

The effectiveness of a fuzzy logic system largely depends on the design of its rule base and inference process. In the proposed inventory model, the rule base consists of a set of IF–THEN rules that describe the relationship between demand level, inventory level, and the required order quantity. These rules are formulated based on common inventory management practices and intuitive decision-making.

In this model, both input variables, demand level and inventory level, are represented using three linguistic terms: *low*, *medium*, and *high*. Similarly, the output variable, order quantity, is expressed using linguistic terms such as *small*, *medium*, and *large*. By combining the possible conditions of the input variables, a set of rules can be constructed to guide the ordering decision.

A simple rule base used in the proposed system is presented in Table 1.

ISBN 978-816855385-9

| Demand Level | Inventory Level | Order Quantity |
|---|---|---|
| Low | High | Small |
| Low | Medium | Small |
| Low | Low | Medium |
| Medium | High | Small |
| Medium | Medium | Medium |
| Medium | Low | Large |
| High | High | Medium |
| High | Medium | Large |
| High | Low | Large |

These rules are evaluated using the **Mamdani fuzzy inference method**. During the inference process, the fuzzified input values activate the relevant rules in the rule base. The outputs from all activated rules are then aggregated to form a combined fuzzy output. Finally, the centroid defuzzification technique is applied to convert the fuzzy result into a single crisp value representing the recommended order quantity.

This rule-based approach enables the inventory system to mimic human reasoning and provide flexible decision support under uncertain conditions.

### 3.1 Illustration

To illustrate the proposed fuzzy inventory model, consider demand level $D$and inventory level $I$as the input variables, while order quantity $Q$is the output variable.

Let the crisp input values be:

$$D = 90, I = 30$$

**Fuzzification**

Assume triangular membership functions are used for the linguistic variables *low*, *medium*, and *high*. The membership values for the given inputs are determined as follows:

For demand:

$$\mu_{Medium}(D) = 0.4, \mu_{High}(D) = 0.6$$

For inventory:

$$\mu_{Low}(I) = 0.7, \mu_{Medium}(I) = 0.3$$

**Rule Evaluation**

Using the rule base, the following rules are activated:

1. IF demand is **high** AND inventory is **low** THEN order quantity is **large**
2. $\alpha_1 = min\ (0.6, 0.7) = 0.6$
   IF demand is **medium** AND inventory is **low** THEN order

ISBN 978-816855385-9

quantity is **large**

3. $\alpha_2 = min\ (0.4,0.7) = 0.4$

   IF demand is **high** AND inventory is **medium** THEN order quantity is **large**

$$\alpha_3 = min\ (0.6,0.3) = 0.3$$

**Aggregation**

The aggregated membership value for the output set **large** is

$$\mu_{Large} = max\ (0.6,0.4,0.3) = 0.6$$

**Defuzzification**

Using the centroid method, the crisp order quantity is computed as

$$Q = \frac{\int x\mu(x)dx}{\int \mu(x)dx}$$

which yields approximately

$$Q \approx 120$$

Thus, when the demand level is relatively high and the inventory level is low, the fuzzy system recommends ordering approximately **120 units** to maintain an adequate stock level.

**4. Conclusion**

This chapter presented a fuzzy rule-based approach for supporting inventory control decisions under uncertain demand and stock conditions. Unlike traditional inventory models that rely on precise numerical parameters, the proposed method incorporates linguistic variables and rule-based reasoning to represent the intuitive decision process commonly used by inventory managers. Demand level and inventory level were considered as input variables, while order quantity was determined as the output through a set of fuzzy IF–THEN rules.

The Mamdani fuzzy inference mechanism was employed to evaluate the rule base, and the centroid defuzzification method was used to obtain a crisp ordering decision. A numerical illustration demonstrated how the model processes uncertain information and generates an appropriate order quantity. The results indicate that the fuzzy rule-based system can effectively capture human reasoning and provide flexible decision support in situations where precise data may not be available.

Overall, the proposed framework offers a simple yet practical approach for improving inventory decision-making in uncertain environments. The model can be further extended by incorporating additional factors such as lead time, shortage cost, or demand variability, making it a useful tool for more advanced inventory management applications.

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ISBN 978-816855385-9
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