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A Comparative Study of Fuzzy Aggregation Strategies in Modeling the Syntax Pragmatics Interface

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ABSTRACT

Traditional approaches to grammaticality often rely on binary judgments, overlooking the gradient and context sensitive nature of linguistic acceptability, particularly at the syntax pragmatics interface. Fuzzy grammar models attempt to capture this nuance by assigning degrees of membership; however, most employ a fixed aggregation strategy, typically the minimum operator, to combine syntactic and pragmatic evaluations. This study addresses the research question: How do different fuzzy aggregation operators influence grammatical acceptability judgments at the syntax pragmatics interface? We introduce a comparative framework that systematically evaluates four fuzzy aggregation operators, namely minimum, product, arithmetic mean, and weighted average. Using a pilot dataset of five English sentences rated on a 7-point Likert scale, we normalize the ratings into fuzzy membership values and apply each operator to compute integrated acceptability scores. The results reveal that operator choice significantly influences final judgments, especially in cases where one linguistic dimension is strong and the other weak. While the minimum and product operators enforce strict conjunction, the mean and weighted average provide more flexible and interpretable assessments. These findings highlight aggregation as a critical design factor in fuzzy grammar models, with practical

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implications for educational NLP systems, grammar assessment tools, and context aware language technologies. Overall, this work contributes a methodological extension to fuzzy grammar modeling and offers guidance for tailoring aggregation strategies to specific linguistic and computational applications.

Keywords: Fuzzy Grammar; Linguistic Acceptability; Fuzzy Logic; Graded Grammaticality; Natural Language Processing

1. Introduction

In the field of linguistics, the relationship between syntax and pragmatics has long been recognized as a complex interface that challenges traditional grammatical theories. Syntax governs the structural formation of sentences through formal, rule based systems, while pragmatics concerns the use of language in context, accounting for speaker intention, shared knowledge, and situational appropriateness [1]. Conventional grammatical frameworks often treat these two domains separately, with syntax forming the core computational engine of language and pragmatics serving as an interpretive filter applied after syntactic processing [2]. However, real world language use rarely conforms to such a rigid division. Instead, syntactic acceptability is frequently influenced, and sometimes determined, by pragmatic factors [3].

This complexity becomes especially apparent in linguistic phenomena that do not fit neatly into binary categories of grammatical versus ungrammatical. Sentences that are syntactically marginal may be deemed acceptable in certain contexts but unacceptable in others [4]. For example, constructions involving ellipsis, topicalization, or non-canonical word orders can appear more or less acceptable depending on discourse context, politeness conventions, or speaker listener relationships [5]. Such gradience challenges the binary assumptions of most generative grammatical models [6].

In response to these challenges, linguists and computational linguists have begun exploring fuzzy logic as a mathematical tool to model linguistic phenomena that exhibit uncertainty, vagueness, or partial membership [7]. Fuzzy logic, originally introduced by Lotfi Zadeh, offers a formal system in which variables can assume values on a continuous scale between zero and one, rather than being constrained to strict true or false dichotomies [8]. This makes it particularly suitable for modeling linguistic acceptability, where judgments are often scalar rather than categorical [9].

Recent work has proposed fuzzy grammar models that assign membership degrees to syntactic and pragmatic properties of utterances [10]. In such models, sentences are not simply labeled as grammatical or not, but are instead assigned values reflecting their degree of conformity to syntactic norms and pragmatic appropriateness [11]. These membership values are then aggregated to yield an overall acceptability score. However, the choice of aggregation strategy is critical, as it influences how the syntactic and pragmatic dimensions are combined. Most existing studies rely on the minimum operator, which effectively applies a weakest link principle, meaning the overall score is equal to the lower of the two input values [12]. While this has intuitive appeal, it may not always reflect how human language users integrate multiple linguistic cues when making acceptability judgments [13].

There is a growing need to explore alternative fuzzy aggregation strategies to better understand their interpretive implications and suitability across different linguistic contexts [14]. For instance, the product operator emphasizes mutual reinforcement between syntax and pragmatics but penalizes disparity. The arithmetic mean provides a more balanced compromise-based integration. The weighted average allows researchers to model scenarios where one linguistic dimension, such as syntactic correctness, is given more importance than the other [15]. Each of these strategies embodies a different theory of how language users resolve ambiguity and make grammaticality judgments [16].

Unlike prior models which assume a fixed aggregation scheme, typically the minimum operator, to combine syntactic and pragmatic acceptability scores [17], this study introduces a flexible, comparative framework that systematically evaluates multiple fuzzy aggregation strategies. By incorporating not only the minimum operator but also product, arithmetic mean, and weighted average formulations, we provide a more comprehensive view of how syntax and pragmatics interact in shaping graded grammaticality. This allows our model to better capture the nuanced nature of linguistic judgment and adapt to different application contexts, such as educational assessment or natural language understanding. Moreover, the framework is designed to be modular and extensible, supporting a broader theoretical and computational interpretation of the syntax pragmatics interface.

This study addresses this gap by conducting a comparative analysis of multiple fuzzy aggregation operators in the context of a syntax pragmatics interface model. Using a small experimental dataset consisting of sentences rated on both syntactic and pragmatic scales, we compute fuzzy membership values and apply four aggregation methods, namely minimum, product, average, and weighted average. We then analyze how each method influences the final grammar acceptability scores and discuss the linguistic interpretations that emerge.

By systematically comparing these strategies, this paper contributes to a more nuanced understanding of fuzzy grammar modeling and opens the door for its application in areas such as natural language processing, educational language assessment, and computational models of linguistic competence.

2. Related Work

Research on the syntax pragmatics interface has developed along multiple theoretical lines in both formal and functional linguistic traditions. Early generative grammar approaches, as discussed by Nefdt (2021) and Nefdt (2020), posited a modular view of linguistic architecture, where syntax operated as an autonomous computational system and pragmatics applied only after structural processing was complete [18,19]. However, empirical findings in psycholinguistics, discourse analysis, and sociolinguistics, such as those reported by Elshater and Abusaada (2025) and Siregar (2021), increasingly challenge this strict separation, suggesting that contextual interpretation interacts with structural processing in real time [20,21].

Recent models have emphasized the inherently graded nature of linguistic acceptability, especially in constructions where contextual factors modulate syntactic judgments. For example, studies by Yao (2024) and Kim et al. (2025) describe cases where optional word order variation, discourse marked ellipsis, and topic comment structures often yield acceptability that is context sensitive and not easily classified in binary terms [22,23]. These observations have motivated a range of alternative formalisms capable of modeling partial grammaticality, including probabilistic grammars, constraint based models, and fuzzy logic systems as outlined by Nefdt and Baggio (2024) and Moral et al. (2021) [24,25].

Within this landscape, fuzzy logic has emerged as a promising mathematical framework for representing linguistic uncertainty. Unlike traditional logic, which models truth in binary terms, fuzzy logic allows variables to take on degrees of membership within the range from zero to one. This has been successfully applied to a variety of linguistic subfields, including phonology, semantics, discourse analysis, and pragmatics as described by Vashishtha et al. (2023), Reyes García and Torres García (2022), and Kroeger (2023) [26–28]. Fuzzy set theory, in particular, has been instrumental in capturing vague category boundaries, such as in syntactic gradient acceptability or context dependent lexical meaning as shown by İskender (2023) and Trott and Bergen (2023) [29,30].

Several studies have proposed fuzzy grammar models that assign fuzzy membership functions to syntactic rules, allowing for continuous valued representations of well formedness. For instance, Wang (2025) and Torrens Urrutia et al. (2022) define fuzzy phrase structure grammars or fuzzy context free grammars to handle marginal constructions [31,32]. These models often rely on triangular, trapezoidal, or Gaussian membership functions to approximate linguistic intuitions, as discussed by Wang et al. (2025) [33]. On the pragmatics side, fuzzy logic has been used to model speaker intention, politeness, implicature strength, and discourse relevance, as demonstrated by Torrens Urrutia et al. (2022) and Nasser (2022) [34,35].

Aggregating syntactic and pragmatic evaluations into a unified judgment requires some form of combination strategy, and most existing models default to the minimum operator as noted by Michaelis (2024) and Klavan et al. (2025) [36,37]. While this makes sense under the weakest link assumption, namely that a sentence is only as acceptable as its most problematic aspect, it ignores possible compensatory effects where strong pragmatic fit may offset minor syntactic violations, as highlighted by Jennings (2023) and Zhang and Hinzen (2022) [38,39]. Alternative aggregation strategies have been suggested, including arithmetic averaging, weighted combinations, and even fuzzy inference systems like Mamdani or Sugeno style reasoning, as proposed by Shitsukane (2022), Amoura (2024), and Sredanović et al. (2021) [40–42]. However, comparative evaluations of these methods within linguistic frameworks remain scarce. Most previous work selects a single operator without justifying its psychological plausibility or empirical fitness, leaving a gap in the literature on the interpretive implications of different aggregation strategies, as discussed by Sommer et al. (2024) and Baggio et al. (2024) [43,44].

Complementary to these linguistic efforts, studies in other domains have developed flexible fuzzy modeling approaches that emphasize interpretability and aggregation adaptability. For instance, weighted aggregation strategies have been applied in fuzzy clustering for metabolomics data by Rustam et al. (2022) [45], modified fuzzy clustering techniques have been proposed for handling incomplete datasets by Rustam et al. (2021) [46], and robust centroid estimation methods have been explored using Manhattan distance and weighted medians by Rustam and Usman (2025) [47]. These contributions demonstrate the broader applicability of tunable fuzzy systems, which this paper extends to the modeling of graded grammaticality at the syntax pragmatics interface.

In applied computational linguistics, fuzzy logic has also gained traction in areas such as machine translation, sentiment analysis, and essay grading, where linguistic judgments are inherently fuzzy, as reviewed by Alahmadi et al. (2025), Peralta et al. (2025), and Gandhi et al. (2023) [48–50]. For example, fuzzy scoring models in automated essay evaluation, as described by Ramesh and Sanampudi (2022), allow partial credit for structurally flawed but contextually appropriate expressions, while chatbots, as reported by Faraz et al. (2024), benefit from fuzzy intent matching when parsing non standard queries [51,52]. These applications highlight the broader utility of fuzzy linguistic modeling beyond theoretical syntax.

Despite growing interest, few studies have explicitly explored how different fuzzy aggregation operators affect the modeling of syntax pragmatics interfaces. A recent exception is the work of Katzir and Cummins (2025), which examined fuzzy modeling of scalar implicatures but did not compare aggregation methods systematically [53]. Another line of research integrates fuzzy systems into cognitive models of language processing, as in the work of Muralidaran (2022), yet often abstracts away from sentence level grammar [54].

This paper addresses these gaps by directly comparing four fuzzy aggregation strategies, namely minimum, product, average, and weighted average, using controlled experimental data. While prior work has explored individual aggregation strategies in fuzzy grammar modeling, direct comparative evaluations remain limited. This study addresses that gap by offering a systematic side by side analysis.

3. Theoretical Framework and Model Development

This study is grounded in fuzzy set theory, originally developed by Zadeh, which allows the representation of linguistic concepts with degrees of truth rather than binary values. In the context of linguistic acceptability, fuzzy logic enables us to model sentences that are not strictly acceptable or unacceptable, but may lie anywhere along a continuum. This is particularly relevant at the syntax pragmatics interface, where structural form and contextual appropriateness often interact in gradient ways.

3.1. Fuzzy Membership Functions

Let S = {s1, s2, ..., sn} be a set of sentences under evaluation. Each sentence s ∈ S is assigned two fuzzy membership values:

- $\mu_{\text{syntax}}(s)$: the degree to which sentence s conforms to syntactic rules;
- $\mu_{\text{pragmatics}}(s)$: the degree to which sentence s is contextually appropriate.

These values are derived from human ratings on a 7 point Likert scale, normalized using the linear transformation:

$$\mu(x) = \frac{x-1}{6} \tag{1}$$

so that a rating of 1 maps to 0 and a rating of 7 maps to 1.

3.2. Fuzzy Aggregation of Syntax and Pragmatics

To model overall grammatical acceptability, the two dimensions must be combined into a single fuzzy value $\mu_{\text{grammar}}(s)$. This is done through an aggregation operator Φ:

$$\mu_{\text{grammar}}(\mathrm{s}) = \Phi\left(\mu_{\text{syntax}}(\mathrm{s}), \mu_{\text{pragmatics}}(\mathrm{s})\right) \quad (2)$$

We explore four aggregation strategies commonly used in fuzzy logic systems:

(a) Minimum Operator

$$\mu_{\text{grammar}}(\mathrm{s}) = \min\left(\mu_{\text{syntax}}(\mathrm{s}), \mu_{\text{pragmatics}}(\mathrm{s})\right) \quad (3)$$

This operator models the weakest link principle, assuming that the least acceptable component determines the overall judgment.

(b) Product Operator

$$\mu_{\text{grammar}}(\mathrm{s}) = \mu_{\text{syntax}}(\mathrm{s}) \cdot \mu_{\text{pragmatics}}(\mathrm{s}) \quad (4)$$

This operator models mutual reinforcement and penalizes disparity between dimensions.

(c) Arithmetic Mean

$$\mu_{\text{grammar}}(\mathrm{s}) = \frac{\mu_{\text{syntax}}(\mathrm{s}) + \mu_{\text{pragmatics}}(\mathrm{s})}{2} \quad (5)$$

This operator treats both dimensions as equally important, modeling compromise.

(d) Weighted Average

$$\mu_{\text{grammar}}(\mathrm{s}) = \alpha \cdot \mu_{\text{syntax}}(\mathrm{s}) + (1-\alpha) \cdot \mu_{\text{pragmatics}}(\mathrm{s}) \quad (6)$$

This allows tuning the contribution of each dimension. In this study, we set $\alpha = 0.6$, giving slightly more weight to syntactic correctness. This reflects contexts such as formal writing, where grammatical form may outweigh discourse naturalness.

3.3. Model Structure

The proposed model can be represented as a multi-stage fuzzy system, where each stage corresponds to a specific step in the application of fuzzy aggregation strategies:

The diagram shows four main stages: input of human ratings for syntax and pragmatics, normalization to fuzzy membership values, aggregation via one of four operators (minimum, product, mean, weighted average), and output of a unified grammatical acceptability score. The decision step highlights the flexibility to choose an operator based on application needs.

1. **Input Layer**: Receives raw human ratings for syntactic acceptability and pragmatic appropriateness. These ratings are typically obtained on an ordinal scale, such as a 7-point Likert scale.
2. **Fuzzification Layer**: Converts the raw ordinal ratings into fuzzy membership values using a normalization function that maps the scale to the interval [0, 1]. This step allows the representation of graded acceptability rather than binary judgments.
3. **Aggregation Layer**: Combines the two membership values (μ_{syntax} and $\mu_{\text{pragmatics}}$) using the chosen fuzzy aggregation operator Φ. The operator can be one of the four strategies examined in this study: minimum, product, arithmetic mean, or weighted average.
4. **Output Layer**: Produces a single fuzzy value μ_{grammar} that represents the overall grammatical acceptability of the sentence. This score can then be interpreted in different application contexts, such as educational feedback, automated grammar checking, or dialogue system response evaluation.

To improve the clarity of the proposed approach and address the reviewer's suggestion, a detailed flowchart has been included to illustrate the step-by-step procedure for applying the fuzzy aggregation strategies in the grammaticality modeling process. The diagram outlines all key stages, from data collection to final output, and highlights the decision point where the aggregation operator is selected.

As shown in **Figure 1**, the model operates in a sequential manner. The process starts by receiving two separate ratings, one for syntax and one for pragmatics, which are then converted into fuzzy membership values through normalization. The decision step in the flowchart allows the user or system to select one of the four aggregation strategies based on the intended application context. Once the operator is selected, the aggregation layer integrates the two membership values into a single grammatical acceptability score. This design ensures flexibility, enabling the model to adapt to different linguistic tasks and evaluation criteria.

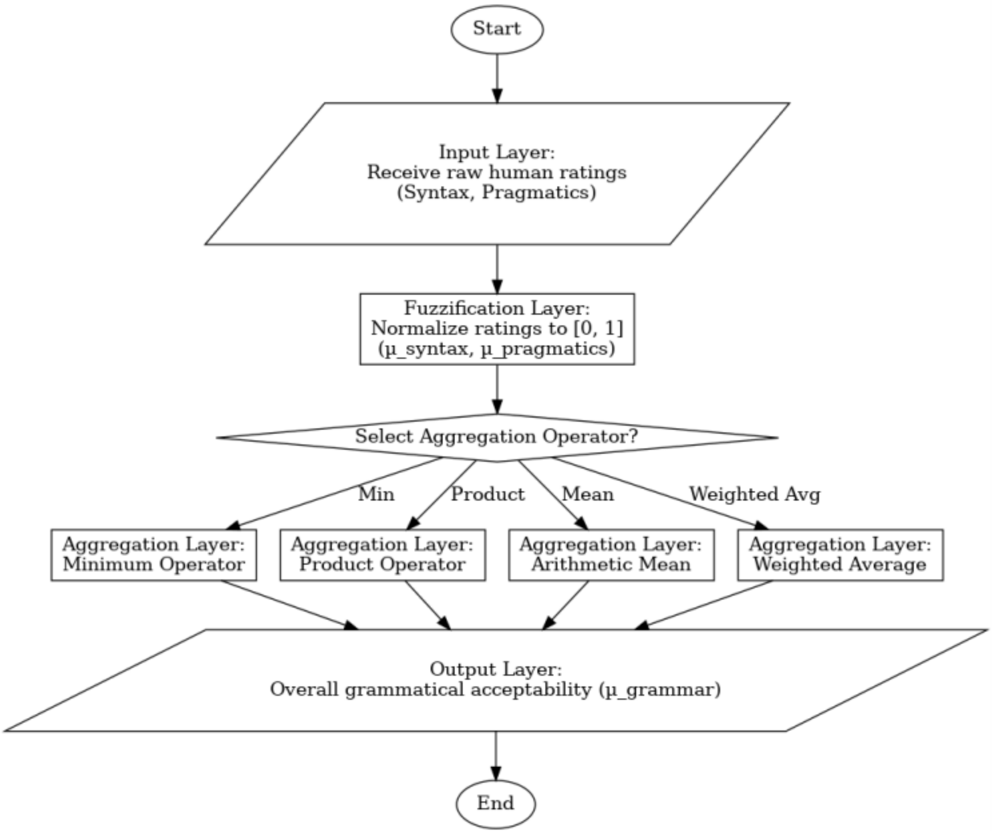

Figure 1. Flowchart of the proposed multi-operator fuzzy grammar model.

3.4. Model Flexibility

By incorporating multiple aggregation operators, our framework supports comparative analysis and can adapt to different linguistic applications. For instance, high stakes assessments may prioritize conservative operators like min, while applications such as dialogue systems may benefit from average based strategies. This multi operator fuzzy framework thus provides a generalizable and interpretable model for integrating syntactic and pragmatic dimensions into unified acceptability judgments.

4. Materials and Methods

This study aims to investigate how different fuzzy aggregation strategies influence the overall grammatical acceptability of sentences when syntactic and pragmatic evaluations vary. We adopt an experimental simulation approach based on an existing dataset of rated sentences. The methodology involves four main stages: (1) dataset adoption and description, (2) fuzzy membership value normalization, (3) implementation of multiple aggregation strategies, and (4) comparative analysis of results across strategies.

4.1. Dataset and Sentence Ratings

To enable direct comparison with prior work and to replicate existing results under different fuzzy logic operations, we reuse a dataset originally introduced in a previous study on fuzzy grammar modeling [17]. The dataset consists of five English sentences selected to reflect a range of syntactic constructions and varying degrees of pragmatic contextuality.

- **S1**: *"The cat sat on the mat."*
- **S2**: *"On the mat sat the cat?"*
- **S3**: *"The dog chased the ball in the park."*
- **S4**: *"In the park, the ball was chased by the dog."*
- **S5**: *"Despite the rain, she managed to complete the run."*

Each sentence was previously rated by human evaluators for syntactic acceptability and pragmatic appropriateness using a 7-point Likert scale (1 = completely unacceptable, 7 = fully acceptable). As the dataset was drawn from prior work and not collected anew, no human participants were recruited for this study and no new ethical approval was required.

This dataset was deliberately chosen to replicate prior work and enable a controlled, side-by-side comparison of different aggregation operators under clearly defined syntactic and pragmatic profiles. However, the small size of the dataset inevitably limits the generalizability of the findings. While sufficient for the pilot and comparative purposes of the present study, larger and more diverse datasets are needed in future work to confirm the robustness of the observed patterns across different sentence types, genres, and speaker populations.

4.2. Normalization to Fuzzy Membership Values

To convert ordinal ratings into fuzzy membership values within the range [0, 1], we using Equation (1), where x ∈ {1,2,…,7} is the raw Likert score. This ensures that the minimum score (1) maps to 0, the maximum score (7) maps to 1, and all intermediate values fall proportionally in between. This process was applied independently to each sentence's syntax and pragmatics score, resulting in two membership values per sentence: $\mu_{\text{syntax}}(s)$ and $\mu_{\text{pragmatics}}(s)$. These normalized membership values serve as the foundational inputs for the aggregation phase, where both syntactic and pragmatic evaluations are integrated to compute overall grammatical acceptability.

4.3. Aggregation Strategies

In this study, we applied the four fuzzy aggregation operators previously defined in Section 3.2, namely minimum, product, arithmetic mean, and weighted average, to compute an integrated grammatical acceptability score for each sentence. These operators combine the normalized syntactic and pragmatic membership values to yield a single fuzzy score representing overall sentence acceptability. The weighted average operator was configured with a syntactic weight of $\alpha = 0.6$, reflecting a moderate bias toward syntactic accuracy. This weighting scheme was selected to simulate contexts such as formal writing, where structural conformity is often prioritized over contextual fluency. By applying these different operators systematically to the same input values, we aimed to observe and compare how each strategy responds to syntactic pragmatic asymmetries and how its output aligns with intuitive grammaticality judgments.

4.4. Implementation

All calculations were implemented in Python using the pandas and numpy libraries for data manipulation, and matplotlib for visual output. For each sentence, we computed the four aggregated acceptability scores and visualized them side-by-side to allow interpretative comparison.

The code was designed to be modular and extensible, allowing future experiments to incorporate larger datasets, alternative normalization functions (e.g., sigmoidal), or other aggregation operators (e.g., max, fuzzy inference systems).

4.5. Evaluation Approach

Given the pilot nature of this study and the small dataset, the evaluation was conducted through qualitative comparison. We focused on:

- **Sensitivity to asymmetry:** how each operator handles cases where one dimension is high and the other is low.
- **Preservation of linguistic intuition:** whether the output matches expected acceptability.
- **Borderline discrimination:** the ability to distinguish subtly different acceptability profiles.

5. Results and Discussion

This section provides a comprehensive analysis of how different fuzzy aggregation operators influence grammaticality judgments at the syntax pragmatics interface. Our goal is not only to compare numerical outputs, but also to interpret how each operator encodes theoretical assumptions, aligns with linguistic intuitions, and responds to ambiguous or context sensitive constructions. The discussion is structured into five subsections: numerical results, operator behavior, theoretical implications, comparison with existing literature, and interpretive insights.

5.1. Aggregated Outputs and Interpretive Profiles

Table 1 reports the normalized syntactic and pragmatic membership scores for each sentence, along with the resulting aggregated acceptability values under four operators. The table highlights operator-induced differences across canonical, inverted, passive, and pragmatically enriched constructions. These results provide insight into how different types of sentence constructions, including canonical, inverted, passive, and pragmatically enriched forms, are interpreted through distinct computational lenses.

5.2. Cross-Operator Behavior and Sensitivity Analysis

Figure 2 visualizes how each operator modulates the interaction between syntactic and pragmatic components. The minimum operator exhibits threshold based behavior, acting as a bottleneck where the weakest dimension dominates. The product operator accentuates disparity, especially when either input is low, leading to steep drops in acceptability. In contrast, the arithmetic mean demonstrates stability and smoother integration, while the weighted average allows task specific prioritization.

Table 1. Normalized syntactic and pragmatic membership values for five sentences and their aggregated acceptability scores under four fuzzy operators (minimum, product, mean, weighted average).

Sentence	μ_{syntax}	$\mu_{pragmatics}$	Min	Product	Mean	Weighted Avg
S1	0.833	0.667	0.667	0.556	0.750	0.767
S2	0.333	0.500	0.333	0.167	0.417	0.400
S3	0.667	0.833	0.667	0.556	0.750	0.733
S4	1.000	1.000	1.000	1.000	1.000	1.000
S5	0.500	0.333	0.333	0.167	0.417	0.433

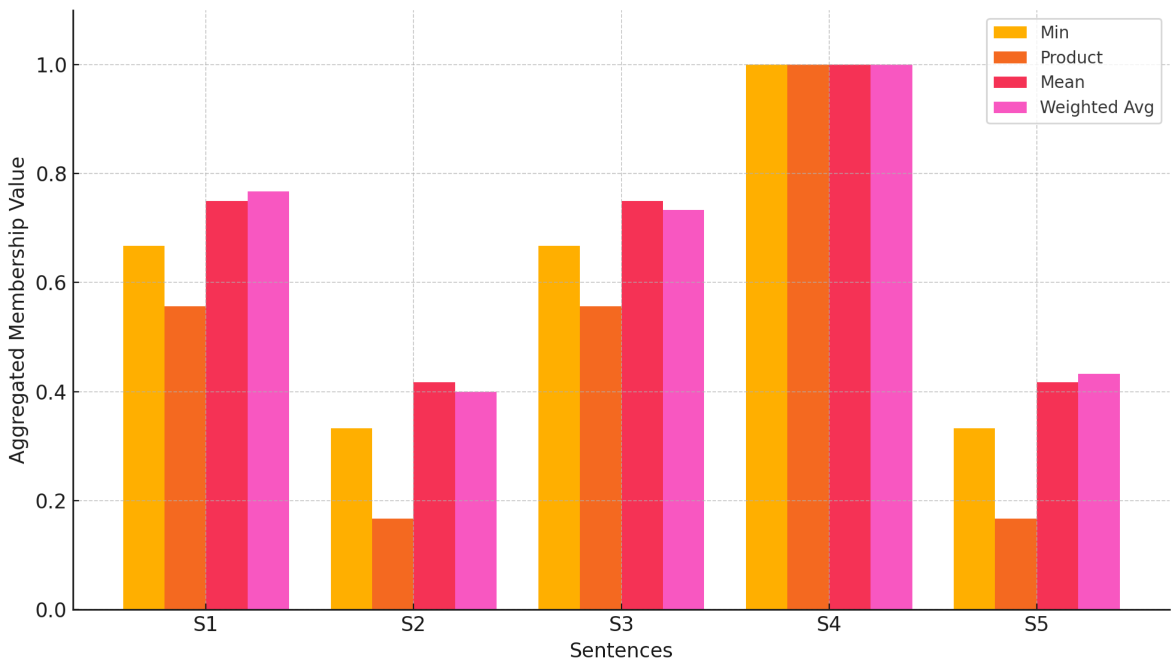

Figure 2. Comparison of aggregated acceptability scores for each sentence under four fuzzy aggregation operators.

Notably, sentences with balanced scores show minimal operator divergence. However, asymmetric sentences such as S2 and S5 exhibit wide variation, confirming that operator behavior is particularly consequential near decision boundaries, which are cases that linguists and educators often find the most challenging to evaluate.

To provide a concise reference for both researchers and practitioners, **Table 2** summarizes the key characteristics of the four aggregation operators examined in this study, including their main advantages, limitations, and potential application contexts. This comparative view complements the preceding numerical and interpretive analysis by highlighting practical considerations in selecting an operator for specific linguistic or computational tasks.

Table 2. Summary of the advantages, limitations, and potential applications of the four fuzzy aggregation operators examined in this study.

Operator	Advantages	Limitations	Potential Applications
Minimum	Easy to implement, clear in interpretation, consistent with conservative evaluation principles.	Too strict, ignores the contribution of strong dimensions, inflexible for more tolerant contexts.	Rule-based grammar checkers, formal evaluation systems requiring full accuracy.
Product	Captures synergistic interaction between dimensions, penalizes imbalance proportionally.	Highly sensitive to low values, may produce excessively low scores in asymmetric cases.	Applications with low tolerance for error such as legal or technical language processing.
Mean	Balances both dimensions equally, preserves partial contributions from each.	May be overly forgiving of weaknesses in one dimension, reducing evaluation strictness.	Language tutoring systems, essay grading that considers creativity and context.
Weighted Average	Allows adjustment of weights to suit needs, flexible across application contexts.	Requires accurate weight determination, may be biased if weights are not contextually tuned.	Adaptive assessment systems, domain-specific automated grammar checkers.

5.3. Linguistic and Computational Implications

Aggregation operators in fuzzy grammar models are not neutral mechanisms. Each encodes a theory of how humans reconcile form and context:

- **Minimum:** Operationalizes conservative grammar, suitable for applications requiring binary well-formedness such as syntax checkers or rule-based grading systems.
- **Product:** Emphasizes synergistic integration, reflecting strict standards valuable for systems demanding robustness across dimensions.
- **Mean:** Embodies egalitarian integration, simulating human judgment when form and context are jointly considered.
- **Weighted Average:** Supports calibrated judgment, ideal for domain-specific systems where the relative weight of syntax and pragmatics varies (e.g., formal essays vs. dialogue systems).

From a design standpoint, this shows that fuzzy grammar models can be reconfigured to reflect pedagogical intent or communicative context. For instance, a language tutor system may favor the mean, while an AI legal assistant may implement weighted averages biased toward syntactic correctness.

From a psycholinguistic perspective, the naturalness of each aggregation strategy may be linked to how humans integrate multiple linguistic cues during real time sentence processing. Empirical studies in language comprehension suggest that people often adopt compromise based strategies when faced with conflicting information, weighing different sources of evidence rather than relying solely on the weakest cue. This tendency aligns more closely with operators such as the arithmetic mean and weighted average, which preserve partial contributions from both syntax and pragmatics. In contrast, strategies such as the minimum or product operator may feel less natural in everyday language processing because they impose a strict penalty when one dimension is weak, resembling high stakes evaluative contexts where failure in one domain overrides strengths in another. These patterns reflect cognitive principles of cue integration, where humans balance efficiency and accuracy by flexibly combining structural and contextual signals instead of applying rigid all or nothing rules.

In our pilot dataset, which consists of only five sentences spanning canonical, inverted, passive, and pragmatically enriched structures, this plausibility pattern is particularly visible. Sentences such as S2 and S5, which are characterized by marked syntactic and pragmatic asymmetry, trigger sharper operator divergence, revealing how certain aggregation strategies (for example, mean and weighted average) better preserve partial acceptability than strict ones (minimum and product). This link between operator behavior and dataset characteristics illustrates the practical importance of matching aggregation choice to the linguistic profiles under study.

5.4. Comparison with Prior Work

Most previous studies, such as the work by Mohammad et al. (2025), relied on a single aggregation operator, typically the minimum, as a simplifying assumption [17]. While this approach provided initial insights, it fails to capture the graded and context sensitive nature of linguistic acceptability. In contrast, our study offers one of the first systematic side by side comparisons of multiple fuzzy aggregation strategies within a unified framework. This methodological expansion reveals how operator choice influences not only numerical outputs but also interpretive outcomes, particularly in borderline cases where syntax and pragmatics diverge. By treating aggregation as a configurable modeling decision rather than a fixed post processing step, our work contributes to more adaptive, transparent, and linguistically grounded fuzzy grammar models.

5.5. Concluding Insights

The comparative experiment yields several important takeaways:

- Aggregation strategy matters: operator choice influences interpretation even when base scores are fixed.
- Strict operators (minimum, product) encode low tolerance for imbalance and are appropriate for rigid linguistic contexts.
- Flexible operators (mean, weighted) provide nuanced evaluations for recoverable or pragmatic constructions.
- Weighted averaging emerges as a promising approach, enabling adaptive emphasis based on application needs.
- Operator behavior reflects and reinforces linguistic theory: aggregation is both mathematical and interpretive.

In sum, this study repositions fuzzy aggregation as a core design component of grammar modeling, one that can be tuned, compared, and interpreted in service of both linguistic theory and computational utility.

In the context of language education, the findings of this study can inform the design of instructional materials and assessment tools that better reflect the graded nature of grammaticality. For example, an instructor could adopt aggregation strategies such as the arithmetic mean or weighted average to provide more nuanced feedback to students, acknowledging partial correctness in cases where syntactic accuracy and pragmatic appropriateness are not perfectly aligned. In automated grammar checking systems, selecting an appropriate aggregation operator could help avoid overly strict judgments that mark sentences as unacceptable based solely on one weak aspect, thereby improving user experience and promoting learning. Such applications illustrate how a theoretically informed choice of aggregation strategy can bridge the gap between computational modeling and pedagogical practice, ultimately supporting more effective and context sensitive language learning and evaluation.

The practical relevance of these findings extends to three key application domains. In educational NLP systems, selecting an aggregation operator that accommodates partial correctness can improve automated feedback for learners, encouraging progress without overlooking specific areas for improvement. In grammar assessment tools, a carefully chosen strategy such as weighted averaging can reflect both syntactic precision and pragmatic appropriateness, producing scores that align more closely with human evaluators. In context aware language technologies, including dialogue systems and adaptive translation tools, flexible aggregation methods can adjust the balance between form and meaning according to situational demands, thereby enhancing both linguistic accuracy and communicative effectiveness. These domain specific considerations illustrate that aggregation is not only a theoretical modeling choice but also a configurable design parameter that can be tuned to meet the needs of diverse real world language processing applications.

6. Conclusion

This study proposed a novel comparative framework for fuzzy aggregation in grammaticality modeling, addressing a key limitation in prior work that relied on fixed aggregation schemes. By incorporating four distinct fuzzy operators, namely minimum, product, arithmetic mean, and weighted average, we systematically evaluated how different strategies affect sentence-level acceptability across varying syntactic and pragmatic profiles. The findings demonstrate that aggregation is not a trivial post-processing step but a foundational modeling decision that shapes interpretability. Sentences with balanced linguistic signals exhibit robustness across operators, whereas asymmetrical inputs expose critical differences in operator behavior. Conservative strategies such as minimum and product reflect strict grammatical constraints, making them suitable for formal evaluation contexts, while arithmetic mean and weighted average accommodate partial acceptability and offer greater alignment with human linguistic judgment. Our contributions span theoretical, methodological, and practical domains, supporting a gradient and context-sensitive view of grammaticality, introducing an operato—flexible fuzzy framework for comparative exploration and domain-specific customization, and identifying weighted averaging as a versatile tool for real-world applications where interpretive flexibility is essential. As summarized in **Table 2**, each aggregation operator embodies distinct advantages and limitations: the minimum operator is conservative and suitable for strict evaluation contexts, the product operator captures synergy but penalizes imbalance, the arithmetic mean balances both dimensions equally for more tolerant assessments, and the weighted average offers adjustable emphasis for context-specific needs. This concise comparison underscores the importance of selecting an operator that aligns with the intended linguistic or computational application. The practical relevance of these findings extends to multiple domains. In educational NLP systems, operators that accommodate partial correctness, such as the arithmetic mean or weighted average, can enhance automated feedback and encourage learner progress. In grammar assessment tools, weighted averaging can integrate syntactic precision with pragmatic appropriateness, producing scores that align more closely with human evaluators. For context-aware language technologies, including dialogue systems and adaptive translation tools, flexible aggregation allows dynamic adjustment between form and meaning according to situational demands. Across these domains, aggregation becomes not merely a computational step but a configurable design parameter that bridges computational precision with linguistic nuance. It is important to note that the present study is limited by the small size of the experimental dataset, which consisted of only five sentences. Although this controlled dataset was deliberately selected to replicate prior work and ensure a clear comparison across operators, it inevitably constrains the generalizability of the findings. Future research should validate these results with larger and more diverse datasets, incorporate empirical validation with large-scale linguistic corpora, and conduct human evaluation studies to align fuzzy outputs with perceived acceptability, while also exploring integration with fuzzy rule-based reasoning or adaptive learning mechanisms to enhance the model's capacity to capture dynamic language use. Ultimately, this research advocates for a shift from rigid and uniform approaches toward interpretable and context-aware fuzzy grammar models, bridging the gap between computational precision and linguistic nuance.

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Conflict of Interest

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