Fuzzy Inference Engine Specification for PID Auto-Tuning Control

Supplementary Material to: "Deterministic Compliance Failures in Large Language Models: A Structural Analysis Using a Legacy Fuzzy Inference Benchmark"

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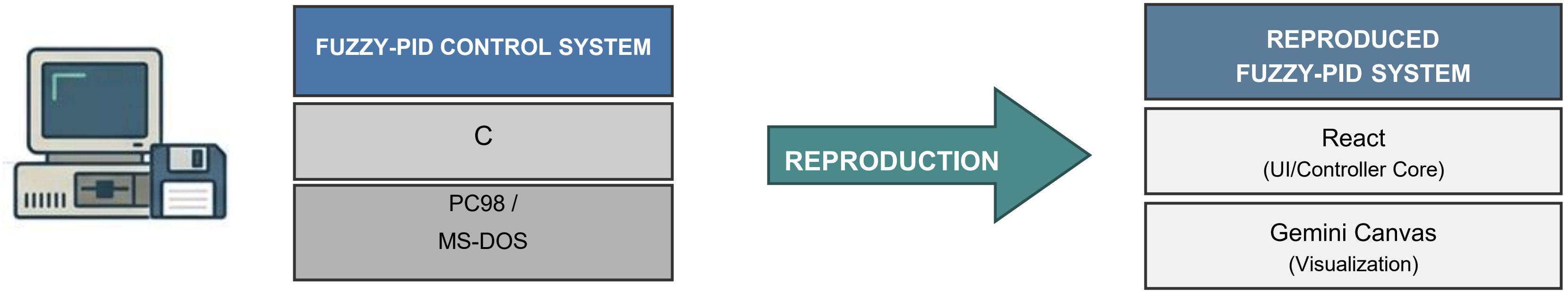
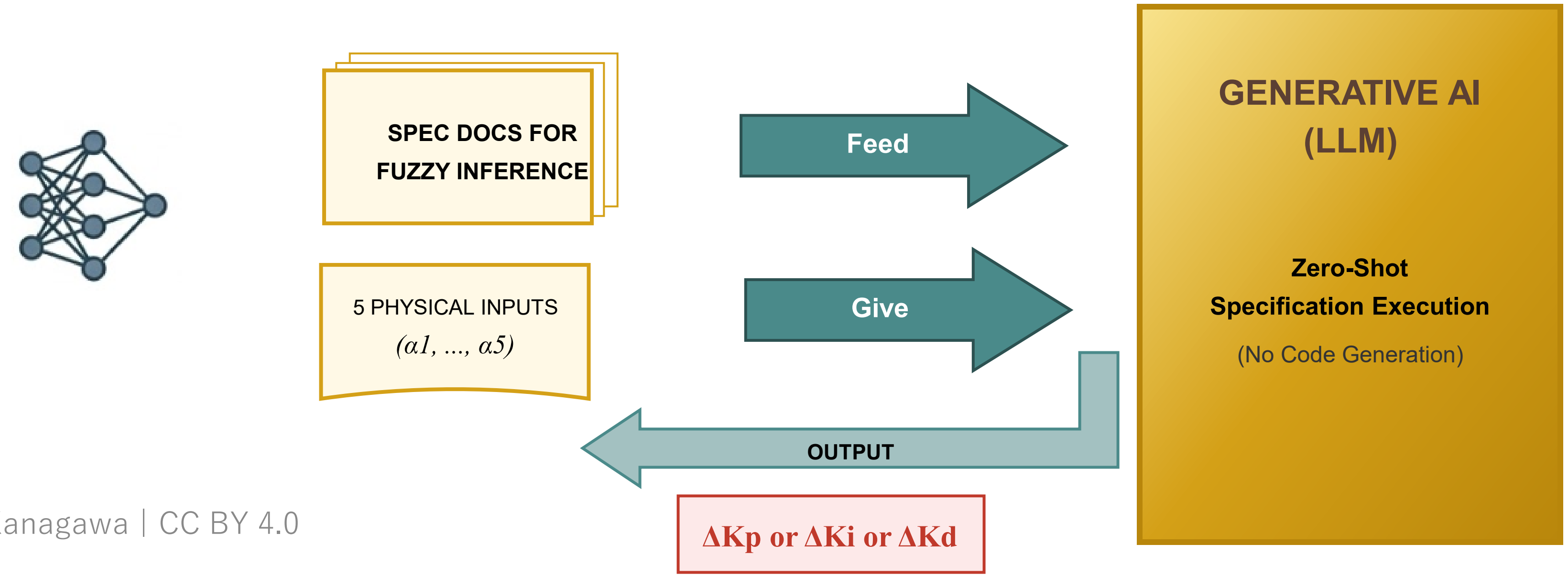
Fuzzy Inference System Evolution and Logical Validation Scheme

1. 1987 Legacy Reproduction Path

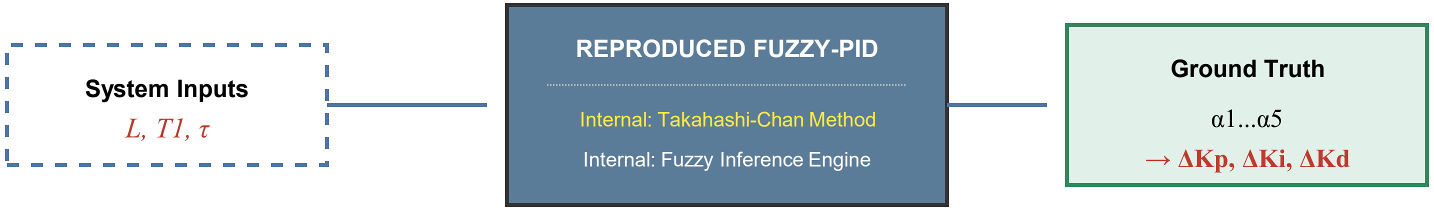


2. Current Experiment: LLM Logical Validation



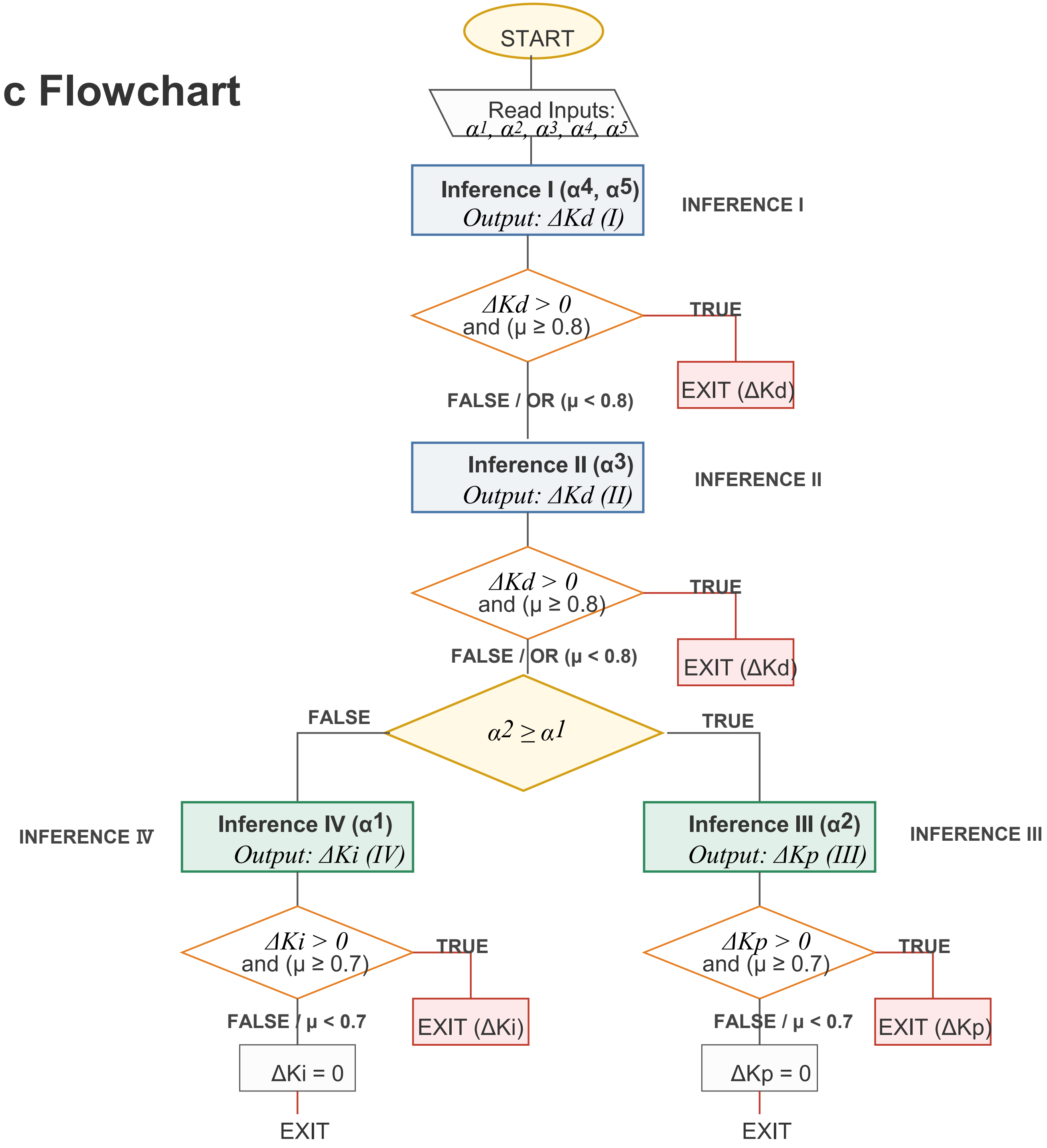
Preparation for Logical Validation Scheme

1. Input system parameters ($L, T1, \tau$) *to the reproduced system.*
2. The system automatically calculates initial PID via Takahashi-Chan's method.
3. Execute auto-tuning to derive final correction values ($\Delta Kp, \Delta Ki, \Delta Kd$).
4. Use ($\alpha 1$ - $\alpha 5$) *and* ($\Delta Kp,i,d$) *as ground truth for LLM logical validation.*
5. Logic is human-traceable via inference flowchart and fuzzy set tables



Calculations are fully deterministic and human-traceable

Fuzzy Inference Logic Flowchart



Inference Ⅰ (1/3)

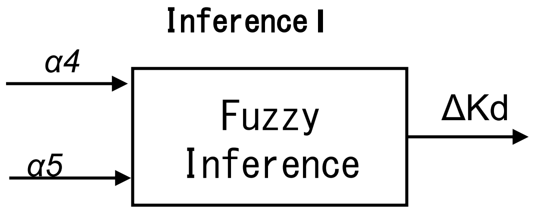


Table B-1-3. Universe of Discourse for ΔKd

Element	Range (V)	Output
0	0	0
1	0 < ΔKd ≤ 14	7
2	14 < ΔKd ≤ 26	20
3	26 < ΔKd ≤ 34	30
4	34 < ΔKd ≤ 40	37
5	40 < ΔKd ≤ 50	45
6	50 < ΔKd ≤ 60	55
7	60 < ΔKd	70

TableB-1-1. Universe of Discourse α4

Element	Range of Real values
0	0 ≦ α4 < 100
1	100 ≦ α4 < 300
2	300 ≦ α4 < 500
3	500 ≦ α4 < 1000
4	1000 ≦ α4 < 5000
5	5000 ≦ α4 < 10000
6	10000 ≦ α4 < 50000
7	50000 ≦ α4

TableB-1-2. Universe of Discourse α5

Element	Range of Real values
0	0 ≦ α5 < 0.1
1	0.1 ≦ α5 < 0.5
2	0.5 ≦ α5 < 1
3	1 ≦ α5 < 5
4	5 ≦ α5 < 10
5	10 ≦ α5

Inference Ⅰ (2/3)

Table B-1-4: Membership Values for α4

Label	0	1	2	3	4	5	6	7
EB	0	0	0	0	0	0	0.2	1
VB	0	0	0	0	0.2	0.8	1	0.5
B	0	0	0.2	0.8	1	0.8	0.2	0
M	0	0.2	1	0.8	0.2	0	0	0

Table B-1-6: Membership Values for ΔKd

Label	0	1	2	3	4	5	6	7
EB	0	0	0	0	0	0.1	0.5	1.0
VB	0	0	0	0.2	0.5	0.8	1.0	0.5
B	0	0	0.2	0.7	1.0	0.7	0.2	0
M	0	0.5	1.0	0.8	0.2	0	0	0

Table B-1-5: Membership Values for α5

Label	0	1	2	3	4	5
B	0	0	0.2	0.9	1	1

Inference Ⅰ (3/3)

Inference I: Rule Matrix ($\alpha4$, $\alpha5$ → ΔKd)

α4 / α5	B (Big)
EB	ΔKd is EB
VB	ΔKd is VB
B	ΔKd is B
M	ΔKd is M

※ Adjustment Rules:

IF α4 is [Label]
AND α5 is B
THEN ΔKd is [Result]

1. Fuzzification
Convert input real values into "Elements" based on the Universe of Discourse.
•**α4**: Select Element 0–7 based on its real value range.
•**α5**: Select Element 0–5 based on its real value range.

2. Membership Grade Extraction & Confidence Filter
Identify the membership grade (μ) for the selected Elements.
•**Exit Condition**: If the membership grade μ of the selected input is **less than 0.8**, set **ΔKd = 0** and **Exit** the process immediately and go to the Inference Ⅱ.
•**Multiple Labels**: If an input Element corresponds to multiple labels (e.g., both **VB** and **B** have μ >= 0.8):
1. Execute the Adjustment Rules for each label individually.
2. Identify the resulting ΔKd label elements.
3. Select the final output ΔKd Element by calculating the **average of these elements**.
4. Round up any decimal results to the nearest whole number.

3. Adjustment Rules (Rule Base)
Apply the following linguistic rules to determine the output label.
•**Rule 1**: IF α4 is EB and α5 is B THEN ΔKd=EB
•**Rule 2**: ELSE IF α4 is VB and α5 is B THEN ΔKd=VB
•**Rule 3**: ELSE IF α4 is B and α5 is B THEN ΔKd=B
•**Rule 4**: ELSE IF α4 is M and α5 is B THEN ΔKd=M

4. Defuzzification & Output Selection
Determine the final real output value from Table B-1-6.
•**Exit Condition**: If the membership grade μ of the selected output is **less than 0.8**, set **ΔKd = 0** and **Exit** the process immediately and go to the Inference Ⅱ.
•**Mean of Maxima (MoM)**: If multiple output Elements share the same maximum membership value, use the **Mean of Maxima** method to select the final output Element.
•**Final Conversion**: Map the selected Element to the "Output Value" (0–70) as defined in Table B-1-3.

Inference Ⅱ(1/3)

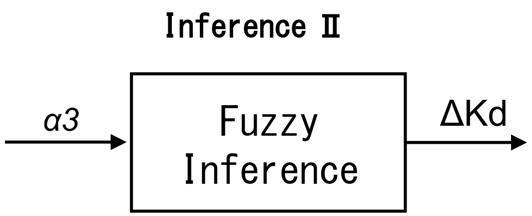


Table B-2-1: Universe of Discourse for α3

Element	Range of Real Values (α3)
0	$0 \le \alpha3 < 100$
1	$100 \le \alpha3 < 200$
2	$200 \le \alpha3 < 400$
3	$400 \le \alpha3 < 600$
4	$600 \le \alpha3 < 1000$
5	$1000 \le \alpha3 < 10000$
6	$10000 \le \alpha3$

Table B-2-2: Universe of Discourse for ΔKd (Inference II)

Element	Range of Real Values (ΔKd)	Output
0	0	0
1	$0 \le \Delta Kd < 8$	4
2	$8 \le \Delta Kd < 12$	10
3	$12 \le \Delta Kd < 18$	15
4	$18 \le \Delta Kd < 22$	20
5	$22 \le \Delta Kd < 28$	25
6	$28 \le \Delta Kd < 32$	30
7	$32 \le \Delta Kd < 68$	50
8	$68 \le \Delta Kd$	80

Inference Ⅱ (2/3)

Table B-2-3: Membership Values for α3

Label / Element	0	1	2	3	4	5	6
VB	0	0	0	0	0.2	0.8	1.0
B	0	0.1	0.5	0.7	1.0	0.8	0.2
RB	0	0.2	0.8	1.0	0.8	0.2	0
SB	0.2	0.7	1.0	0.8	0.2	0	0

Table B-2-4: Membership Values for ΔKd (Inference II)

Label / Element	0	1	2	3	4	5	6	7	8
VB	0	0	0	0	0.2	0.8	1	0.7	0.2
B	0	0	0.2	0.7	1	0.8	0.2	0	0
RB	0	0.2	0.8	1	0.8	0.2	0	0	0
SB	0.2	0.7	1	0.8	0.2	0	0	0	0

Inference Ⅱ (3/3)

Inference Ⅱ: Rule Matrix (α3 → ΔKd)

α3	ΔKd
VB	VB
B	B
RB	RB
SB	SB

※ Adjustment Rules:

IF α3 is [Label]

THEN ΔKd is [Result]

1. Fuzzification

Convert input real values into "Elements" based on the Universe of Discourse.

•**α3**: Select Element 0–6 based on its real value range.

2. Membership Grade Extraction & Confidence Filter

Identify the membership grade (μ) for the selected Elements.

•**Exit Condition**: If the membership grade μ of the selected input is **less than 0.8**, set **ΔKd = 0** and **Exit** the process immediately and go to the condition α2>= α1.

•**Multiple Labels**: If an input Element corresponds to multiple labels (e.g., both **VB** and **B** have μ >= 0.8):

1.Execute the Adjustment Rules for each label individually.
2.Identify the resulting ΔKd label elements.
3.Select the final output ΔKd Element by calculating the **average of these elements**.
4.Round up any decimal results to the nearest whole number.

3. Adjustment Rules (Rule Base)

Apply the following linguistic rules to determine the output label.

•**Rule 1**: IF α3 is VB THEN ΔKd=VB
•**Rule 2**: ELSE IF α3 is B THEN ΔKd=B
•**Rule 3**: ELSE IF α3 is RB THEN ΔKd=RB
•**Rule 4**: ELSE IF α3 is SB THEN ΔKd=SB

4. Defuzzification & Output Selection

Determine the final real output value from Table B-2-4.

•**Exit Condition**: If the membership grade μ of the selected output is **less than 0.8**, set **ΔKd = 0** and **Exit** the process immediately and go to the condition α2>=α1.

•**Mean of Maxima (MoM)**: If multiple output Elements share the same maximum membership value, use the **Mean of Maxima** method to select the final output Element.

•**Final Conversion**: Map the selected Element to the "Output Value" (0–80) as defined in Table B-2-2.

Conditional Branching: If the **inferred** value Δ Kd is greater than 0, the inference engine must terminate the current tuning cycle immediately. In this case, do not proceed to Inference III or Inference IV. This ensures that derivative compensation is applied first to suppress oscillation before adjusting proportional or integral gains.

Inference Ⅲ(1/4)

If α2>=α1 is TRUE

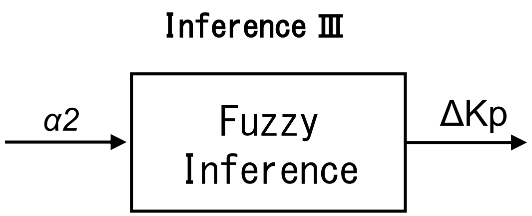


Table B-3-1. Complete Universe of Discourse for α2

Element	Range (%)	Element	Range (%)
0	$0 \le \alpha < 2$	13	$8 \le \alpha < 8.5$
1	$2 \le \alpha < 2.5$	14	$8.5 \le \alpha < 9$
2	$2.5 \le \alpha < 3$	15	$9 \le \alpha < 9.5$
3	$3 \le \alpha < 3.5$	16	$9.5 \le \alpha < 10$
4	$3.5 \le \alpha < 4$	17	$10 \le \alpha < 12$
5	$4 \le \alpha < 4.5$	18	$12 \le \alpha < 15$
6	$4.5 \le \alpha < 5$	19	$15 \le \alpha < 18$
7	$5 \le \alpha < 5.5$	20	$18 \le \alpha < 20$
8	$5.5 \le \alpha < 6$	21	$20 \le \alpha < 25$
9	$6 \le \alpha < 6.5$	22	$25 \le \alpha < 30$
10	$6.5 \le \alpha < 7$	23	$30 \le \alpha < 35$
11	$7 \le \alpha < 7.5$	24	$35 \le \alpha < 50$
12	$7.5 \le \alpha < 8$	25	$50 \le \alpha$

Table B-3-2. Universe of Discourse for ΔKp

Idx	Range	Out	Idx	Range	Out
0	$0 \le \Delta K < 2$	0	13	$8 \le \Delta K < 8.5$	8
1	$2 \le \Delta K < 2.5$	2	14	$8.5 \le \Delta K < 9$	8.5
2	$2.5 \le \Delta K < 3$	2.5	15	$9 \le \Delta K < 9.5$	9
3	$3 \le \Delta K < 3.5$	3	16	$9.5 \le \Delta K < 10$	9.5
4	$3.5 \le \Delta K < 4$	3.5	17	$10 \le \Delta K < 11$	10
5	$4 \le \Delta K < 4.5$	4	18	$11 \le \Delta K < 13$	12
6	$4.5 \le \Delta K < 5$	4.5	19	$13 \le \Delta K < 17$	15
7	$5 \le \Delta K < 5.5$	5	20	$17 \le \Delta K < 19$	18
8	$5.5 \le \Delta K < 6$	5.5	21	$19 \le \Delta K < 21$	20
9	$6 \le \Delta K < 6.5$	6	22	$21 \le \Delta K < 29$	25
10	$6.5 \le \Delta K < 7$	6.5	23	$29 \le \Delta K < 31$	30
11	$7 \le \Delta K < 7.5$	7	24	$31 \le \Delta K$	35
12	$7.5 \le \Delta K < 8$	7.5			

Inference Ⅲ(2/4)

Table B-3-3: Membership Values for α2

Element/ Label	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.5	0.9	1	1	1
VB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.7	0.9	1	0.9	0.7	0.2	0
B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.7	0.9	1	0.9	0.7	0.5	0.2	0	0
SB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.7	0.9	1	0.9	0.7	0.2	0	0	0	0	0
RAM	0	0	0	0	0	0	0	0	0	0	0.2	0.5	0.7	0.8	0.9	1	0.9	0.5	0.2	0	0	0	0	0	0	0
M	0	0	0	0	0	0	0	0	0.2	0.5	0.7	0.8	0.9	1	0.9	0.7	0.5	0	0	0	0	0	0	0	0	0
RBM	0	0	0	0	0	0	0.2	0.5	0.7	0.8	0.9	1	0.9	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0	0
SS	0	0	0	0.2	0.5	0.7	0.8	0.9	1	0.9	0.8	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0	0	0	0
S	0	0	0.2	0.5	0.7	0.9	1	0.9	0.8	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VS	0	0.5	0.7	0.8	1	0.9	0.9	0.8	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ES	0.7	1	0.9	0.8	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Inference Ⅲ(3/4)

Table B-3-4: Membership Values for ΔKp

Element/ Label	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
EB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.7	0.9	1
VB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.5	0.7	0.8	1	0.9	0.7
B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.5	0.7	0.9	1	0.9	0.7	0.2	0
SB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.5	0.7	0.9	1	0.9	0.7	0.2	0	0	0
RAM	0	0	0	0	0	0	0	0	0	0	0	0.2	0.5	0.7	0.8	0.9	1	0.9	0.5	0	0	0	0	0	0
M	0	0	0	0	0	0	0	0	0.2	0.5	0.7	0.8	0.8	0.9	1	0.9	0.9	0.7	0.2	0	0	0	0	0	0
RBM	0	0	0	0	0	0	0.2	0.5	0.7	0.8	0.8	0.9	1	0.8	0.7	0.5	0.2	0	0	0	0	0	0	0	0
SS	0	0	0	0	0.2	0.5	0.7	0.8	0.8	1	0.9	0.9	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0	0
S	0	0	0.2	0.5	0.7	0.9	0.9	1	0.9	0.8	0.8	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0	0	0
VS	0	0.5	0.7	0.8	0.9	1	0.8	0.8	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ES	0.5	0.8	1	0.9	0.9	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

InferenceⅢ (4/4)

Inference Ⅲ: Rule Matrix (α2 → ΔKp)

α2 (Input)	ΔKp (Output)
EB	EB
VB	VB
B	B
SB	SB
RAM	RAM
M	M
RBM	RBM
SS	SS
S	S
VS	VS
ES	ES

※ **Adjustment Rules:**

IF α2 is [Label] THEN ΔKp is [Result]

Fuzzification
Convert the input real values into "Elements" based on the Universe of Discourse (Table B-3-1).
•**α2**: Select Element **0–25** based on its real value range.

2. Membership Grade Extraction & Safety Exit
Identify the membership grade (μ) for the selected Element using Table B-3-3.
•**CRITICAL EXIT**: If the membership grade μ of the selected input is **LESS THAN 0.7**:
  •Set **ΔKp = 0**.
  •**TERMINATE** the entire inference loop immediately. No further processes or inferences are executed.
•**PROCEED**: If the membership grade μ is **0.7 or higher**, proceed to the Adjustment Rules.

•**Crucial Rule for Output Determination (Aggregation & Defuzzification):**
If multiple α2 labels (e.g., “B” and “VB”) share the same maximum membership grade , the system must not pick only one. Instead, you must follow these exact steps : (1) Independent Evaluation: Identify the target Element Number of ΔKp for each applicable label independently based on the rules.(2) Mean of Indices with Roundup: Calculate the arithmetic mean of all identified Element Numbers. If the result has a decimal, you must round it up (ceil) to the next integer. (3) retrieve the final gain value ΔKp from Tbale B- 3-2 using this unified Element Number. (4) TERMINATE the entire inference loop immediately. No further processes or inferences are executed
For instance, If Label "B" points to Element 16 and Label "VB" points to Element 20:Calculation: (16 + 20) / 2 = 18: The value at Element 18 (which is ΔKp=15), not Element 16 or 20. Note that “B” and “VB” share the same maximum membership grade in this case.

3. Adjustment Rules (Complete Rule Base)
Apply the following linguistic rules to determine the output label. In Inference III, α2 labels map directly to ΔKp labels.
•**Rule 1**: IF α2 is **EB** THEN ΔKp = **EB**
•**Rule 2**: ELSE IF α2 is **VB** THEN ΔKp = **VB**
•**Rule 3**: ELSE IF α2 is **B** THEN ΔKp = **B**
•**Rule 4**: ELSE IF α2 is **SB** THEN ΔKp = **SB**
•**Rule 5**: ELSE IF α2 is **RAM** THEN ΔKp = **RAM**
•**Rule 6**: ELSE IF α2 is **M** THEN ΔKp = **M**
•**Rule 7**: ELSE IF α2 is **RBM** THEN ΔKp = **RBM**
•**Rule 8**: ELSE IF α2 is **SS** THEN ΔKp = **SS**
•**Rule 9**: ELSE IF α2 is **S** THEN ΔKp = **S**
•**Rule 10**: ELSE IF α2 is **VS** THEN ΔKp = **VS**
•**Rule 11**: ELSE IF α2 is **ES** THEN ΔKp = **ES**

4. Defuzzification & Loop Termination
4-1. Identify the resulting ΔKp Element based on the selected label and its membership grade from Table B-3-4.
4-2. Mean of Maxima (MoM): If multiple output Elements share the same maximum membership value, use the **Mean of Maxima** method to select the final output Element.
4-3. Final Conversion: Map the selected Element to the "Output Value" (0–70) as defined in Table B-3-2.
4-4. EXIT CONDITION: If the membership grade μ of the selected output is **LESS THAN 0.7**, set **ΔKp = 0**.
4-5. SYSTEM TERMINATION: After completing these steps, the entire inference loop ends. There are no subsequent inference stages after Inference III.

Inference Ⅳ(1/4)

If $\alpha 2 >= \alpha 1$ is FALSE

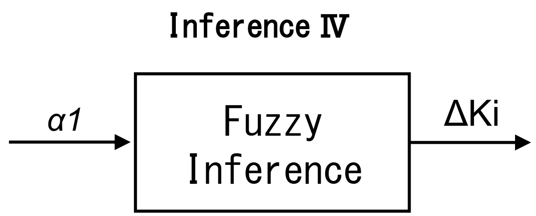


Table B-4-1. Complete Universe of Discourse for α1

Element	Range (%)	Element	Range (%)
0	$0 \le \alpha < 2$	13	$8 \le \alpha < 8.5$
1	$2 \le \alpha < 2.5$	14	$8.5 \le \alpha < 9$
2	$2.5 \le \alpha < 3$	15	$9 \le \alpha < 9.5$
3	$3 \le \alpha < 3.5$	16	$9.5 \le \alpha < 10$
4	$3.5 \le \alpha < 4$	17	$10 \le \alpha < 12$
5	$4 \le \alpha < 4.5$	18	$12 \le \alpha < 15$
6	$3.5 \le \alpha < 5$	19	$15 \le \alpha < 18$
7	$5 \le \alpha < 5.5$	20	$18 \le \alpha < 20$
8	$5.5 \le \alpha < 6$	21	$20 \le \alpha < 25$
9	$6 \le \alpha < 6.5$	22	$25 \le \alpha < 30$
10	$6.5 \le \alpha < 7$	23	$30 \le \alpha < 35$
11	$7 \le \alpha < 7.5$	24	$35 \le \alpha < 50$
12	$7.5 \le \alpha < 8$	25	$50 \le \alpha$

Table B-4-2. Universe of Discourse for ΔKi

Idx	Range	Out	Idx	Range	Out
0	$0 \le \Delta K < 2$	0	13	$8 \le \Delta K < 8.5$	8
1	$2 \le \Delta K < 2.5$	2	14	$8.5 \le \Delta K < 9$	8.5
2	$2.5 \le \Delta K < 3$	2.5	15	$9 \le \Delta K < 9.5$	9
3	$3 \le \Delta K < 3.5$	3	16	$9.5 \le \Delta K < 10$	9.5
4	$3.5 \le \Delta K < 4$	3.5	17	$10 \le \Delta K < 11$	10
5	$4 \le \Delta K < 4.5$	4	18	$11 \le \Delta K < 13$	12
6	$4.5 \le \Delta K < 5$	4.5	19	$13 \le \Delta K < 17$	15
7	$5 \le \Delta K < 5.5$	5	20	$17 \le \Delta K < 19$	18
8	$5.5 \le \Delta K < 6$	5.5	21	$19 \le \Delta K < 21$	20
9	$6 \le \Delta K < 6.5$	6	22	$21 \le \Delta K < 29$	25
10	$6.5 \le \Delta K < 7$	6.5	23	$29 \le \Delta K < 31$	30
11	$7 \le \Delta K < 7.5$	7	24	$31 \le \Delta K$	35
12	$7.5 \le \Delta K < 8$	7.5			

Inference Ⅳ(2/4)

Table B-4-3: Membership Values for α1

Element/ Label	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
EB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.5	0.9	0.9	1	1
VB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.7	0.9	1	0.9	0.7	0.2	0
B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.7	0.9	1	0.9	0.7	0.5	0.2	0	0
SB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.7	0.9	1	0.9	0.7	0.2	0	0	0	0	0
RAM	0	0	0	0	0	0	0	0	0	0	0.2	0.5	0.7	0.8	0.9	1	0.9	0.5	0.2	0	0	0	0	0	0	0
M	0	0	0	0	0	0	0	0.2	0.5	0.7	0.8	0.9	1	0.9	0.9	0.8	0.7	0.2	0	0	0	0	0	0	0	0
RBM	0	0	0	0	0	0.2	0.5	0.7	0.8	0.9	1	0.9	0.8	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0	0
SS	0	0	0.2	0.5	0.7	0.8	0.9	0.9	1	0.9	0.9	0.8	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0	0	0
S	0	0.2	0.5	0.8	0.9	0.9	1	0.9	0.9	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VS	0.2	0.7	0.9	1	0.9	0.8	0.8	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ES	0.7	1	0.9	0.8	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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Table B-4-4: Membership Values for ΔKi

Element/ Label	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
EB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.5	0.9	0.9
VB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.7	0.9	1	0.9	0.7	0.2
B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.7	0.9	1	0.9	0.7	0.5	0.2	0
SB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.7	0.9	1	0.9	0.7	0.2	0	0	0	0
RAM	0	0	0	0	0	0	0	0	0	0	0.2	0.5	0.7	0.8	0.9	1	0.9	0.5	0.2	0	0	0	0	0	0
M	0	0	0	0	0	0	0	0	0.2	0.5	0.7	0.8	1	0.9	0.9	0.7	0.5	0	0	0	0	0	0	0	0
RBM	0	0	0	0	0	0.2	0.5	0.7	0.9	0.9	1	0.9	0.8	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0
SS	0	0	0	0.2	0.5	0.7	0.8	0.9	1	0.9	0.9	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0	0	0
S	0	0.2	0.5	0.7	0.9	0.9	1	0.8	0.8	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
VS	0.5	0.7	0.9	1	0.8	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ES	0.7	1	0.9	0.8	0.7	0.5	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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Inference Ⅳ: Rule Matrix (α1 → ΔKi)

α1 (Input)	ΔKi (Output)
EB	EB
VB	VB
B	B
SB	SB
RAM	RAM
M	M
RBM	RBM
SS	SS
S	S
VS	VS
ES	ES

※ Adjustment Rules:

IF α1 is [Label] THEN ΔKi is [Result]

Fuzzification

Convert the input real values into "Elements" based on the Universe of Discourse (Table B-4-1).

•**α1**: Select Element **0–25** based on its real value range.

2. Membership Grade Extraction & Safety Exit

Identify the membership grade (μ) for the selected Element using Table B-4-3.

•**CRITICAL EXIT**: If the membership grade μ of the selected input is **LESS THAN 0.7**:

- •Set **ΔKi = 0**.
- •**TERMINATE** the entire inference loop immediately. No further processes or inferences are executed.

•**PROCEED**: If the membership grade μ is **0.7 or higher**, proceed to the Adjustment Rules.

•Crucial Rule for Output Determination (Aggregation & Defuzzification):
If multiple α1 labels (e.g., "B" and "VB") share the same maximum membership grade , the system must not pick only one. Instead, you must follow these exact steps : (1) Independent Evaluation: Identify the target Element Number of ΔKi for each applicable label independently based on the rules.(2) Mean of Indices with Roundup: Calculate the arithmetic mean of all identified Element Numbers. If the result has a decimal, you must round it up (ceil) to the next integer. (3) retrieve the final gain value ΔKi from Table B-4-2 using this unified Element Number. (4) TERMINATE the entire inference loop immediately. No further processes or inferences are executed
For instance, If Label "B" points to Element 16 and Label "VB" points to Element 20:Calculation: (18 + 20) / 2 = 19: The value at Element 19 (which is ΔKi=15), not Element 18 or 20. Note that "B" and "VB" share the same maximum membership grade in this case.

3. Adjustment Rules (Complete Rule Base)

Apply the following linguistic rules to determine the output label. In Inference III, α1 labels map directly to ΔKi labels.

•**Rule 1**: α1 is EB THEN ΔKi = **EB**
•**Rule 2**: ELSE IF α1 is **VB** THEN ΔKi = **VB**
•**Rule 3**: ELSE IF α1 is **B** THEN ΔKi = **B**
•**Rule 4**: ELSE IF α1 is **SB** THEN ΔKi = **SB**
•**Rule 5**: ELSE IF α1 is **RAM** THEN ΔKi = **RAM**
•**Rule 6**: ELSE IF α1 is **M** THEN ΔKi = **M**
•**Rule 7**: ELSE IF α1 is **RBM** THEN ΔKi = **RBM**
•**Rule 8**: ELSE IF α1 is **SS** THEN ΔKi = **SS**
•**Rule 9**: ELSE IF α1 is **S** THEN ΔKi = **S**
•**Rule 10**: ELSE IF α1 is **VS** THEN ΔKi = **VS**
•**Rule 11**: ELSE IF α1 is **ES** THEN ΔKi = **ES**

4. Defuzzification & Loop Termination

4-1. Identify the resulting ΔKi Element based on the selected label and its membership grade from Table B-4-4.

4-2. Mean of Maxima (MoM): If multiple output Elements share the same maximum membership value, use the **Mean of Maxima** method to select the final output Element.

4-3. Final Conversion: Map the selected Element to the "Output Value" (0–70) as defined in Table B-4-2.

4-4. EXIT CONDITION: If the membership grade μ of the selected output is **LESS THAN 0.7**, set **ΔKi = 0**.

4-5. SYSTEM TERMINATION: After completing these steps, the entire inference loop ends. There are no subsequent inference stages after Inference Ⅳ.

Definition of Area Damping (Decay) Ratios (α1,…,α5)

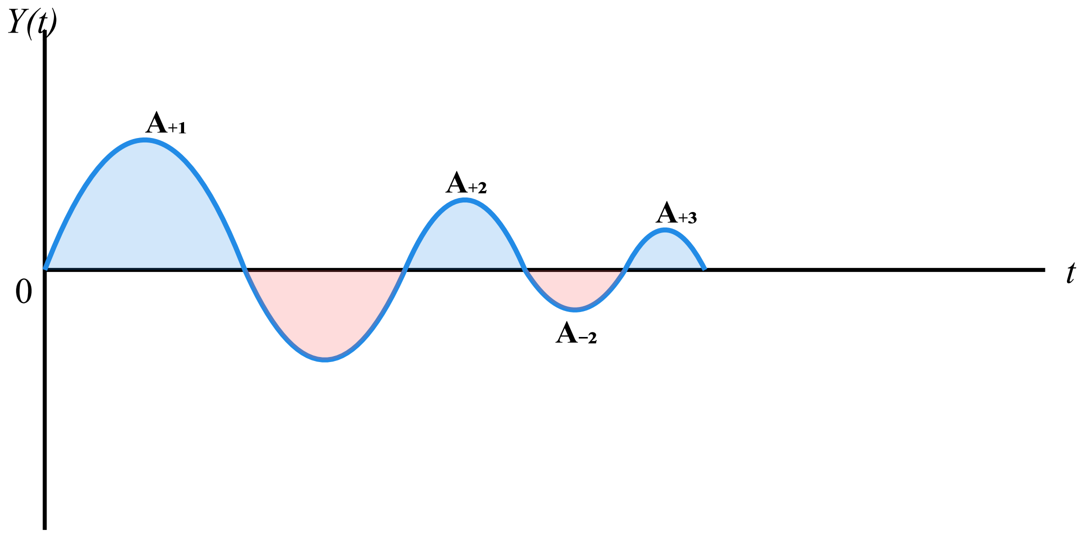

Fig. A-2: Definition of Deviation Areas

Calculation Formulas for Area Damping（Decay）Ratios

.The input variables α1 through α5 are defined by the following ratios (expressed as percentages):

$$\alpha_1 = (|A_{-1}| / |A_{+1}|) \times 100 \ [\%]$$

$$\alpha_2 = (|A_{+2}| / |A_{+1}|) \times 100 \ [\%]$$

$$\alpha_3 = (|A_{-2}| / |A_{-1}|) \times 100 \ [\%]$$

$$\alpha_4 = (|A_{+2}| / |A_{-1}|) \times 100 \ [\%]$$

$$\alpha_5 = (|A_{+3}| / |A_{+1}|) \times 100 \ [\%]$$