Building a fuzzy expert system: case study

- A service centre keeps spare parts and repairs failed ones.
- A customer brings a failed item and receives a spare of the same type.
- Failed parts are repaired, placed on the shelf, and thus become spares.
- The objective here is to advise a manager of the service centre on certain decision policies to keep the customers satisfied.

Process of developing a fuzzy expert system

- 1. Specify the problem and define linguistic variables.
- 2. Determine fuzzy sets.
- 3. Elicit and construct fuzzy rules.
- 4. Encode the fuzzy sets, fuzzy rules and procedures to perform fuzzy inference into the expert system.
- 5. Evaluate and tune the system.

Step 1: Specify the problem and define linguistic variables

- There are four main linguistic variables:
  - average waiting time (mean delay) m,
  - repair utilization factor of the service centre ρ,
  - number of servers s,
  - initial number of spare parts n.

Linguistic variables and their ranges

Linguistic Variable: *Mean Delay*, *m*		
Linguistic Value	Notation	Numerical Range (normalised)
Very Short	VS	[0, 0.3]
Short	S	[0.1, 0.5]
Medium	M	[0.4, 0.7]
Linguistic Variable: *Number of Servers*, *s*		
Linguistic Value	Notation	Numerical Range (normalised)
Small	S	[0, 0.35]
Medium	M	[0.30, 0.70]
Large	L	[0.60, 1]
Linguistic Variable: *Repair Utilisation Factor*, ρ		
Linguistic Value	Notation	Numerical Range
Low	L	[0, 0.6]
Medium	M	[0.4, 0.8]
High	H	[0.6, 1]
Linguistic Variable: *Number of Spares*, *n*		
Linguistic Value	Notation	Numerical Range (normalised)
Very Small	VS	[0, 0.30]
Small	S	[0, 0.40]
Rather Small	RS	[0.25, 0.45]
Medium	M	[0.30, 0.70]
Rather Large	RL	[0.55, 0.75]
Large	L	[0.60, 1]
Very Large	VL	[0.70, 1]

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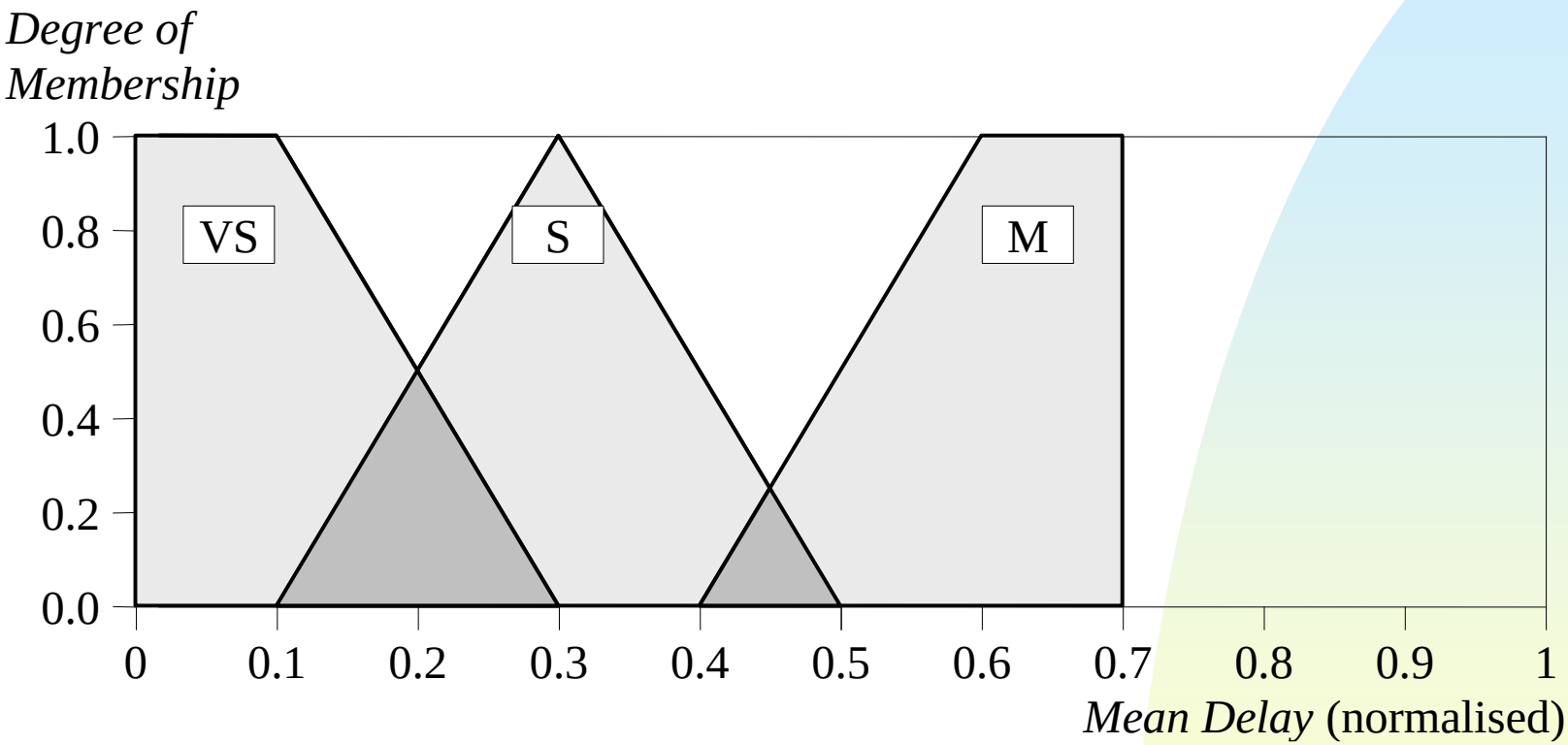
Step 2: Determine fuzzy sets

- Fuzzy sets can have a variety of shapes.
- A triangle or a trapezoid can often provide an adequate representation of the expert knowledge, and at the same time, significantly simplifies the process of computation.

Fuzzy sets of Mean Delay m



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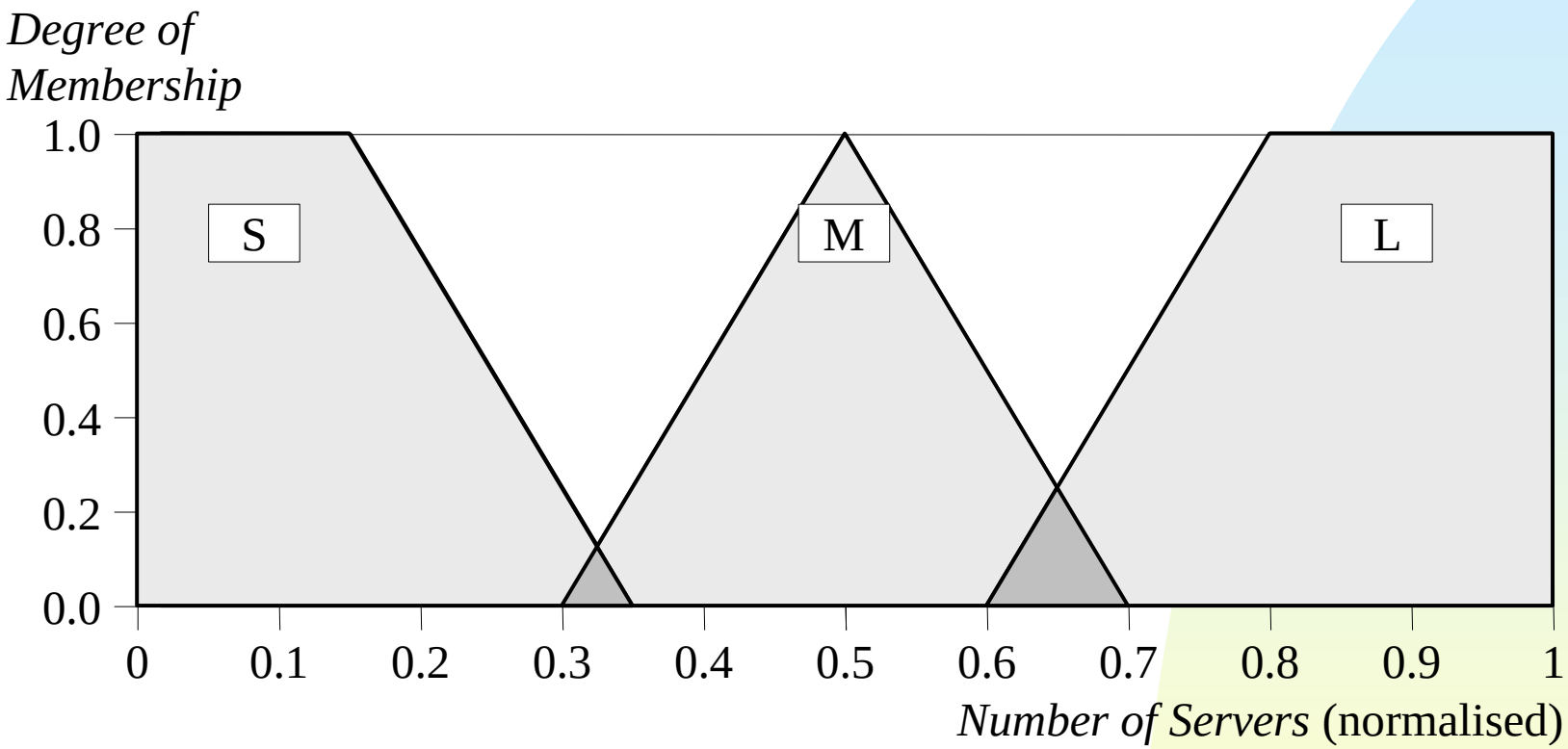
Fuzzy sets of Number of Servers s



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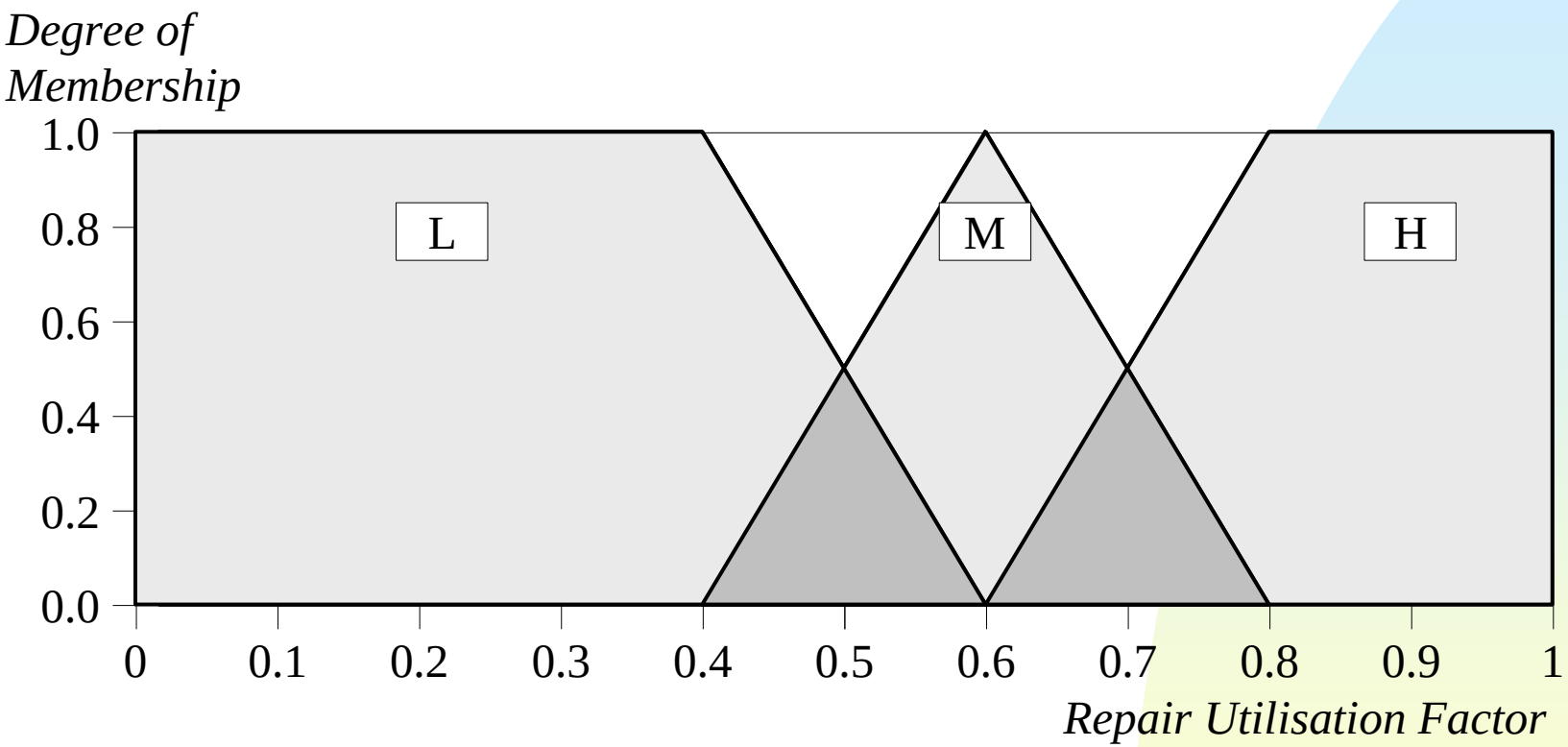
Fuzzy sets of Repair Utilisation Factor ρ



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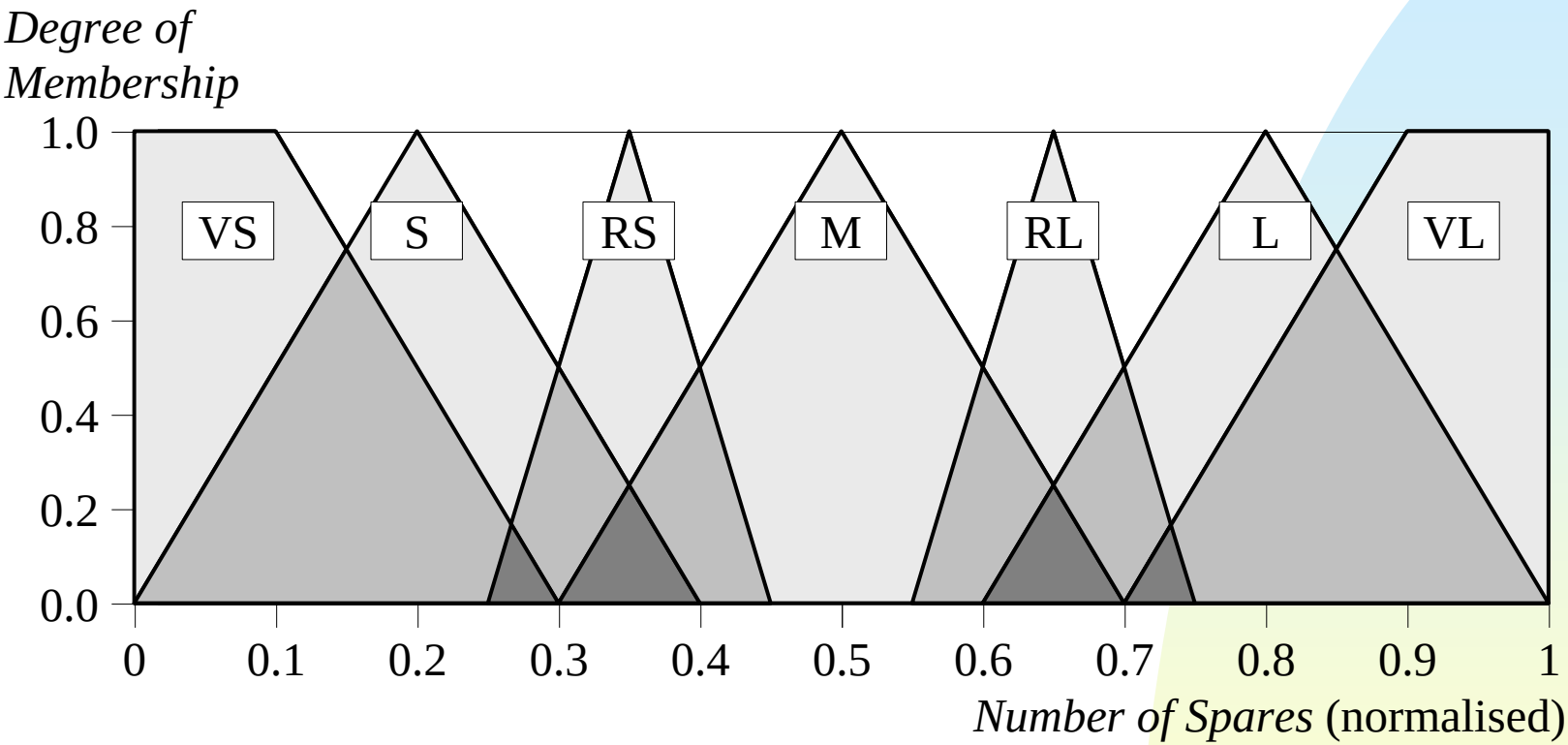
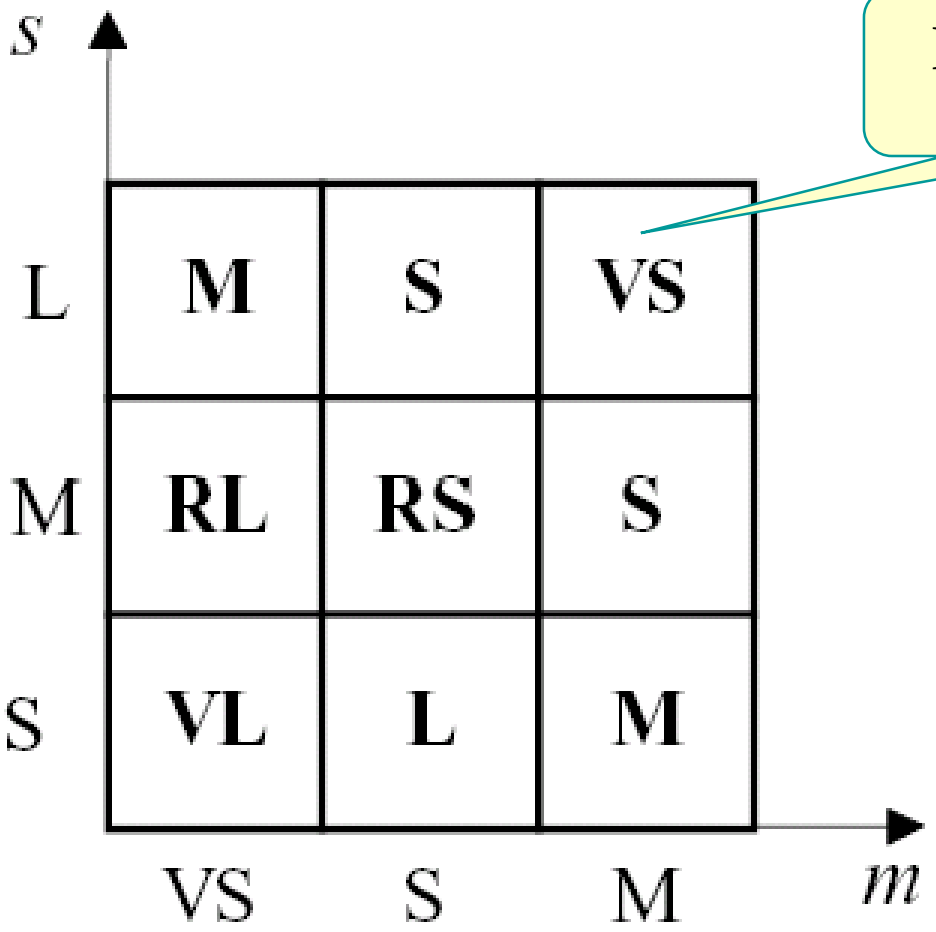
Fuzzy sets of Number of Spares n



Step 3: Elicit and construct fuzzy rules

- To accomplish this task, we might ask the expert to describe how the problem can be solved using the fuzzy linguistic variables defined previously.
- Required knowledge also can be collected from other sources such as books, computer databases, flow diagrams and observed human behaviour.

Fuzzy Associative Memeory (FAM) square



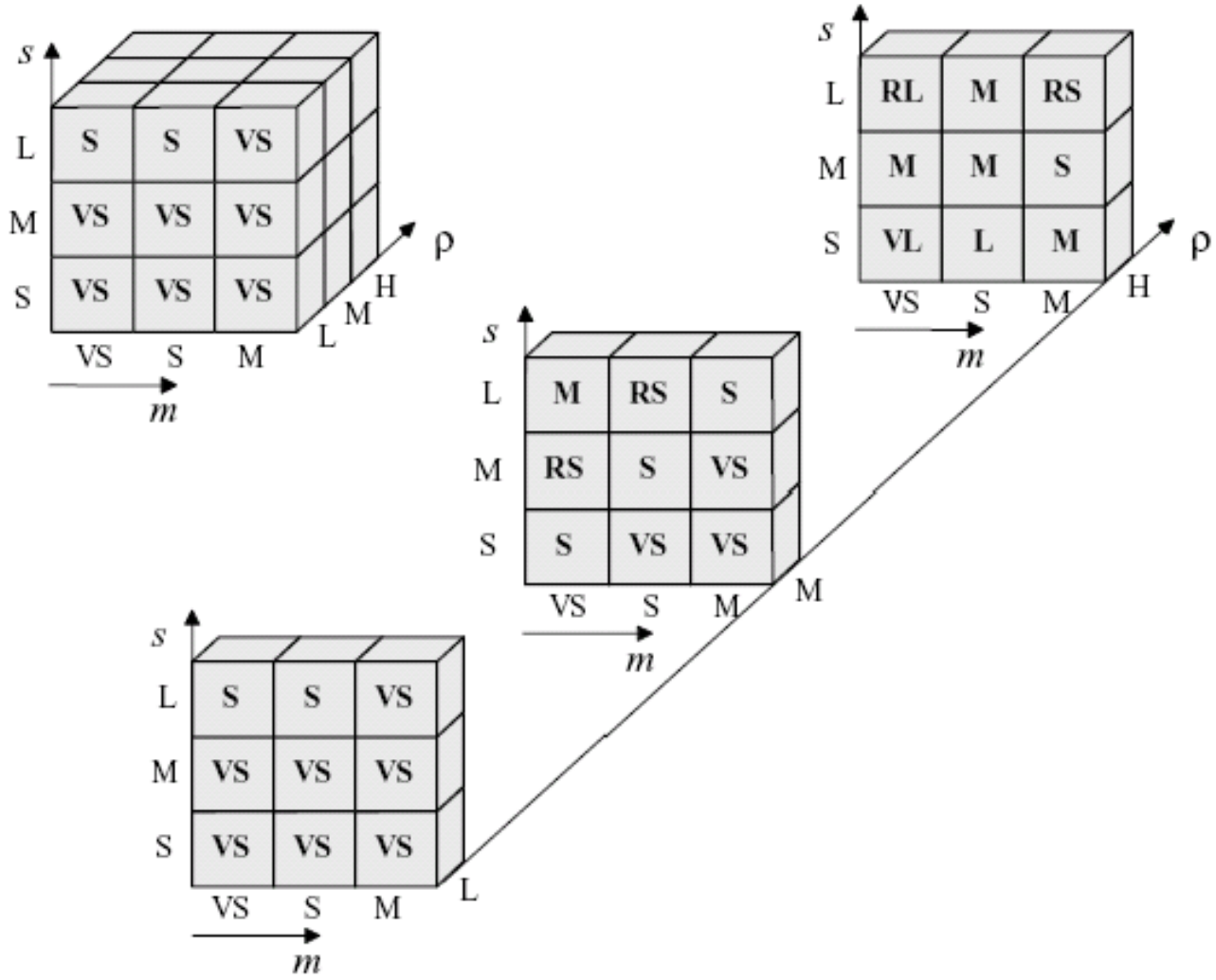
Rule Base 1

1. If (utilisation_factor is L) then (number_of_spares is S)
2. If (utilisation_factor is M) then (number_of_spares is M)
3. If (utilisation_factor is H) then (number_of_spares is L)
4. If (mean_delay is VS) and (number_of_servers is S) then (number_of_spares is VL)
5. If (mean_delay is S) and (number_of_servers is S) then (number_of_spares is L)
6. If (mean_delay is M) and (number_of_servers is S) then (number_of_spares is M)
7. If (mean_delay is VS) and (number_of_servers is M) then (number_of_spares is RL)
8. If (mean_delay is S) and (number_of_servers is M) then (number_of_spares is RS)
9. If (mean_delay is M) and (number_of_servers is M) then (number_of_spares is S)
10. If (mean_delay is VS) and (number_of_servers is L) then (number_of_spares is M)
11. If (mean_delay is S) and (number_of_servers is L) then (number_of_spares is S)
12. If (mean_delay is M) and (number_of_servers is L) then (number_of_spares is VS)

The rule table

Rule	*m*	*s*	ρ	*n*	Rule	*m*	*s*	ρ	*n*	Rule	*m*	*s*	ρ	*n*
1	VS	S	L	VS	10	VS	S	M	S	19	VS	S	H	VL
2	S	S	L	VS	11	S	S	M	VS	20	S	S	H	L
3	M	S	L	VS	12	M	S	M	VS	21	M	S	H	M
4	VS	M	L	VS	13	VS	M	M	RS	22	VS	M	H	M
5	S	M	L	VS	14	S	M	M	S	23	S	M	H	M
6	M	M	L	VS	15	M	M	M	VS	24	M	M	H	S
7	VS	L	L	S	16	VS	L	M	M	25	VS	L	H	RL
8	S	L	L	S	17	S	L	M	RS	26	S	L	H	M
9	M	L	L	VS	18	M	L	M	S	27	M	L	H	RS

Cube FAM of Rule Base 2



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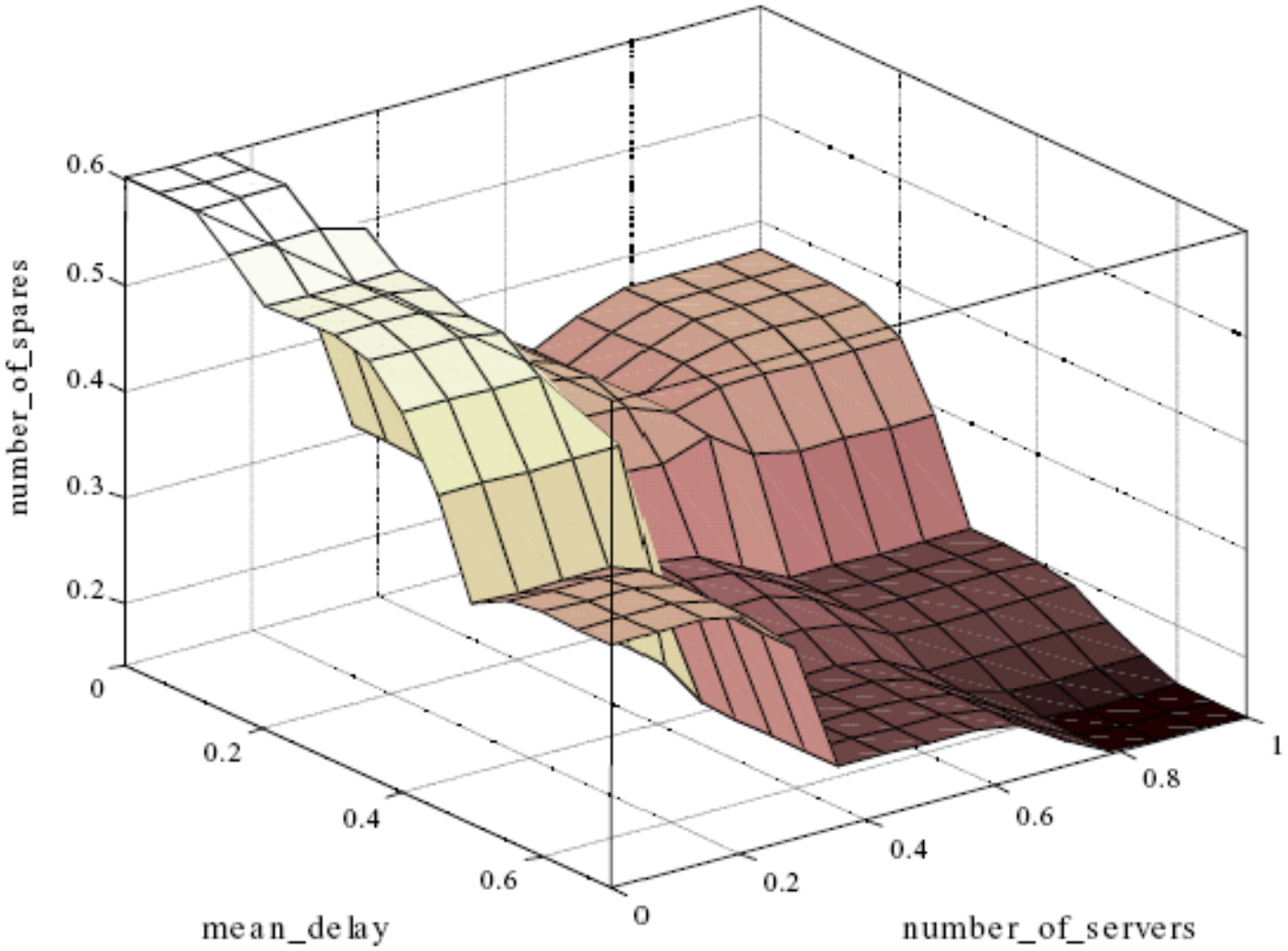
Step 4

- Encode the fuzzy sets, fuzzy rules and procedures to perform fuzzy inference into the expert system
- two options:
  - build our system using a programming language such as C/C++ or Pascal,
  - apply a fuzzy logic development tool such as MATLAB Fuzzy Logic Toolbox or Fuzzy Knowledge Builder.

Step 5: Evaluate and tune the system

- We want to see whether our fuzzy system meets the requirements specified at the beginning.
- Several test situations depend on the mean delay, number of servers and repair utilisation factor.
- The Fuzzy Logic Toolbox can generate surface to help us analyze the system's performance.

Three-dimensional plots for Rule Base 1



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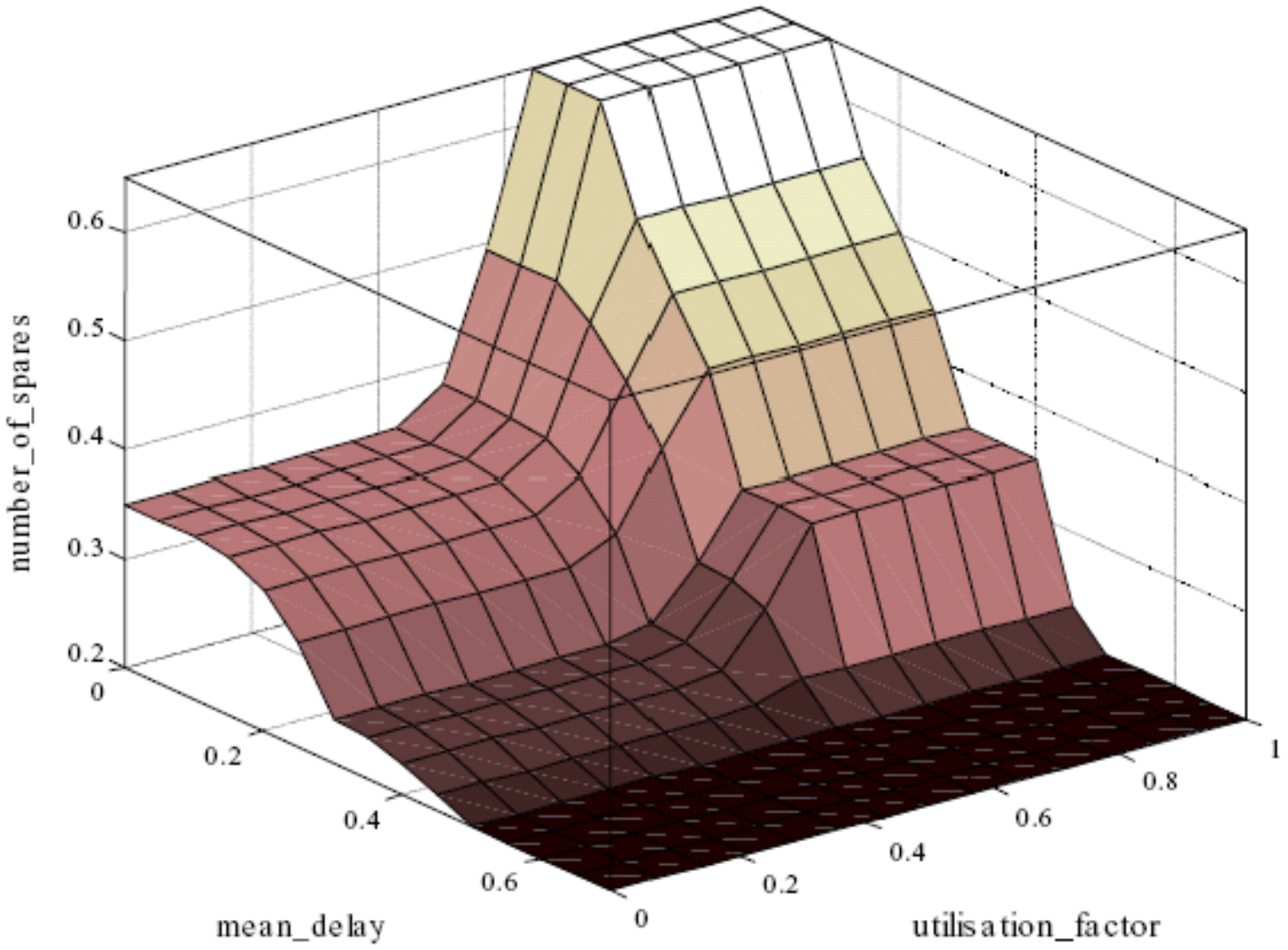
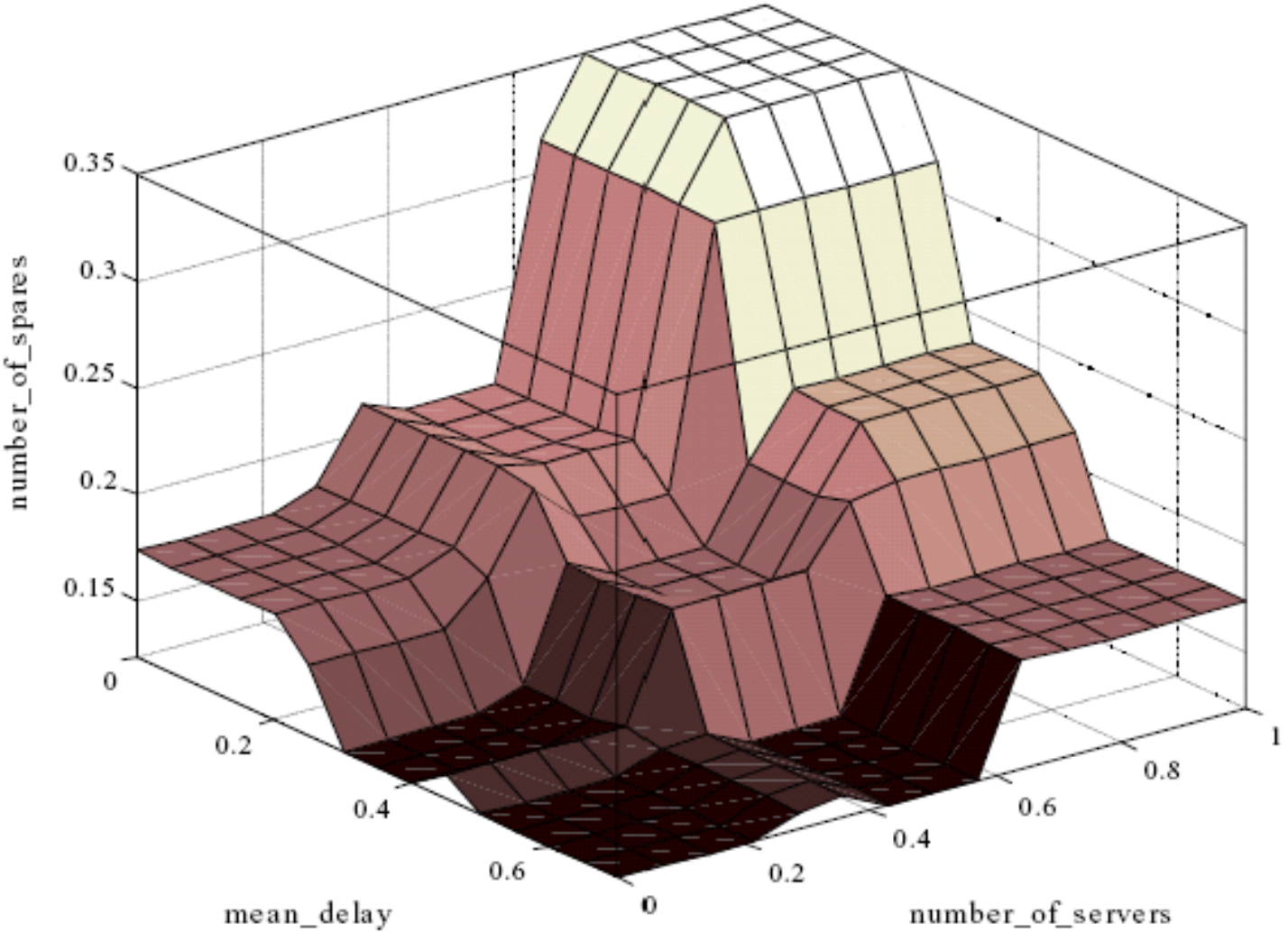
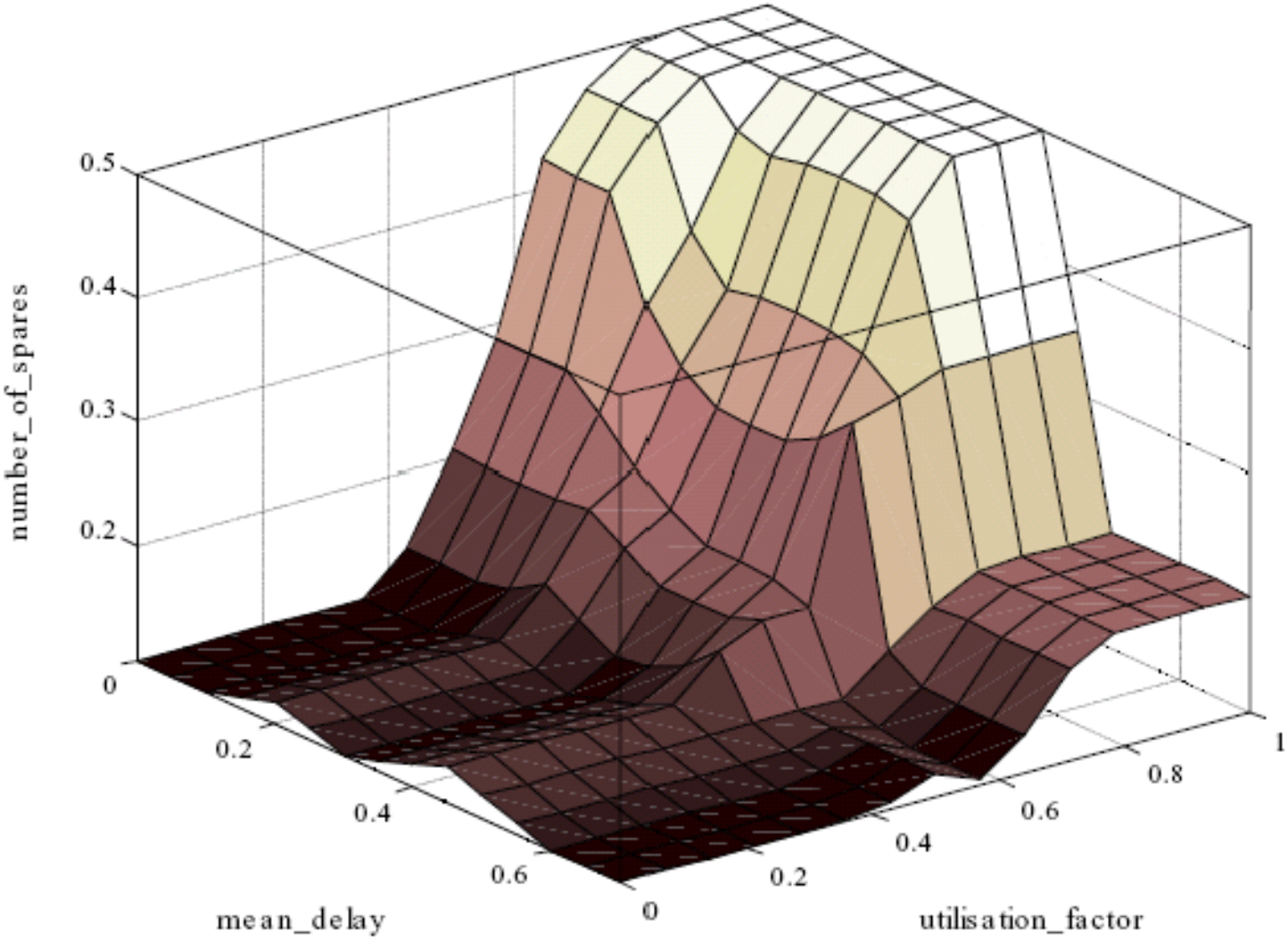
Three-dimensional plots for Rule Base 1



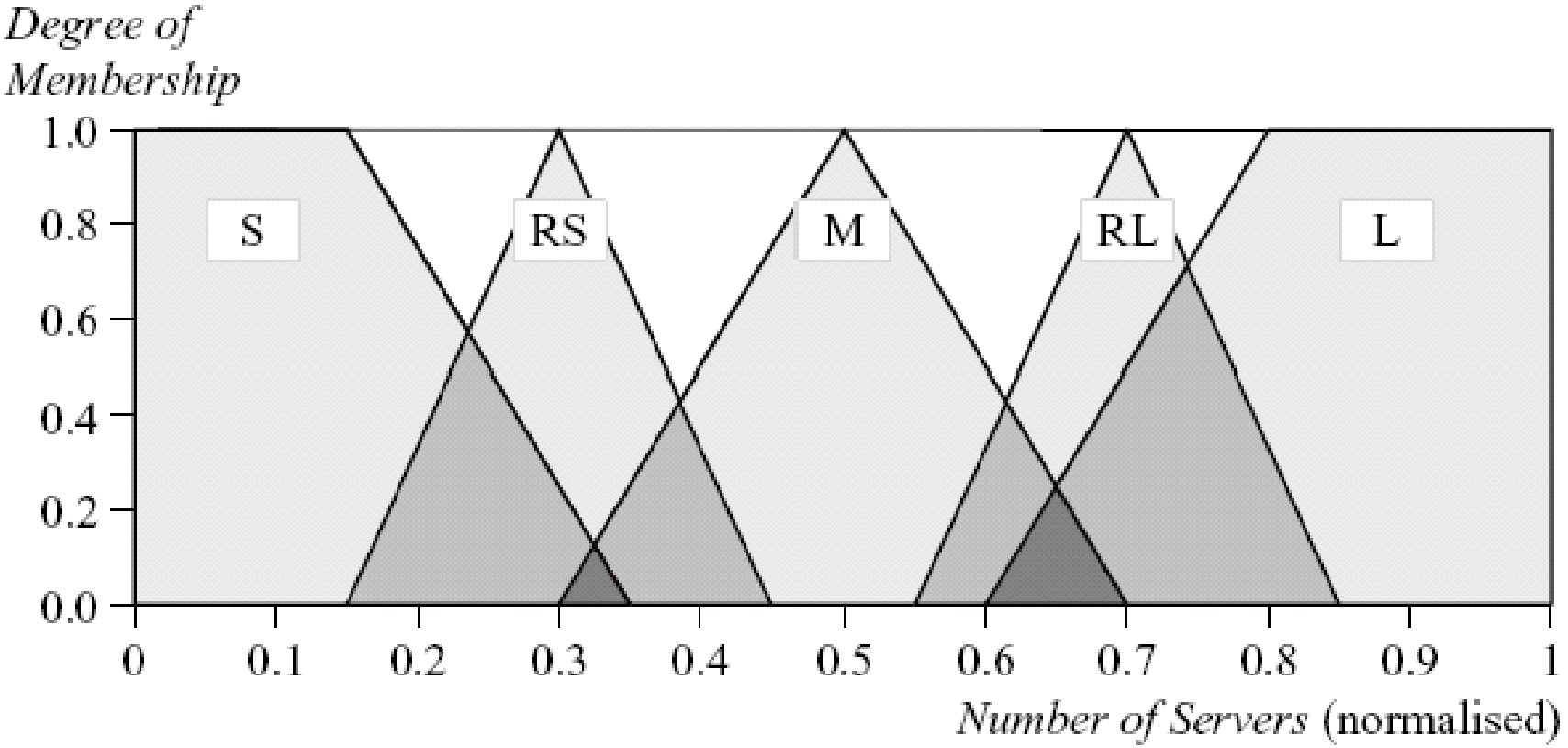
Three-dimensional plots for Rule Base 2



Three-dimensional plots for Rule Base 2



Modified fuzzy sets of Number of Servers s



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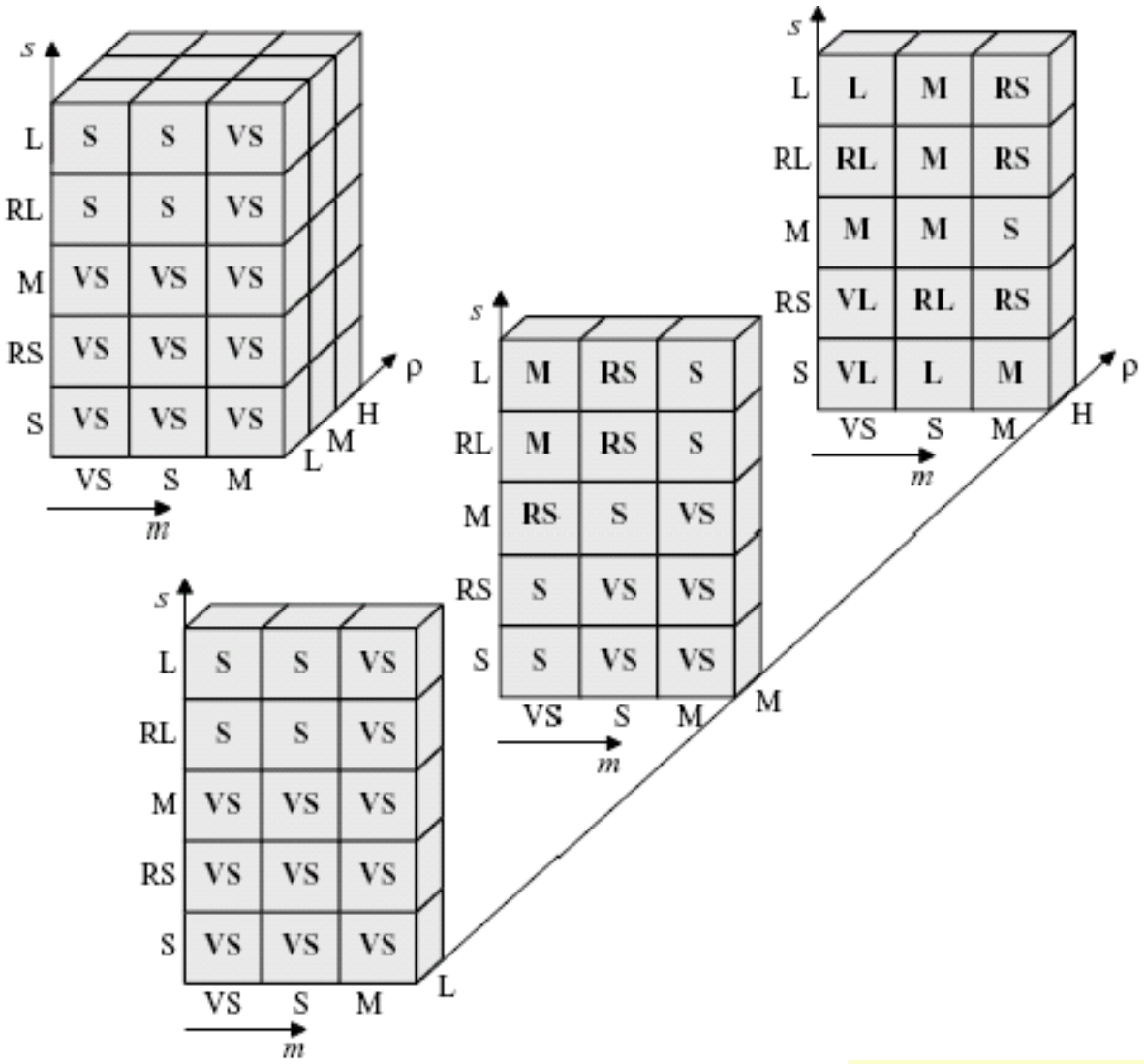
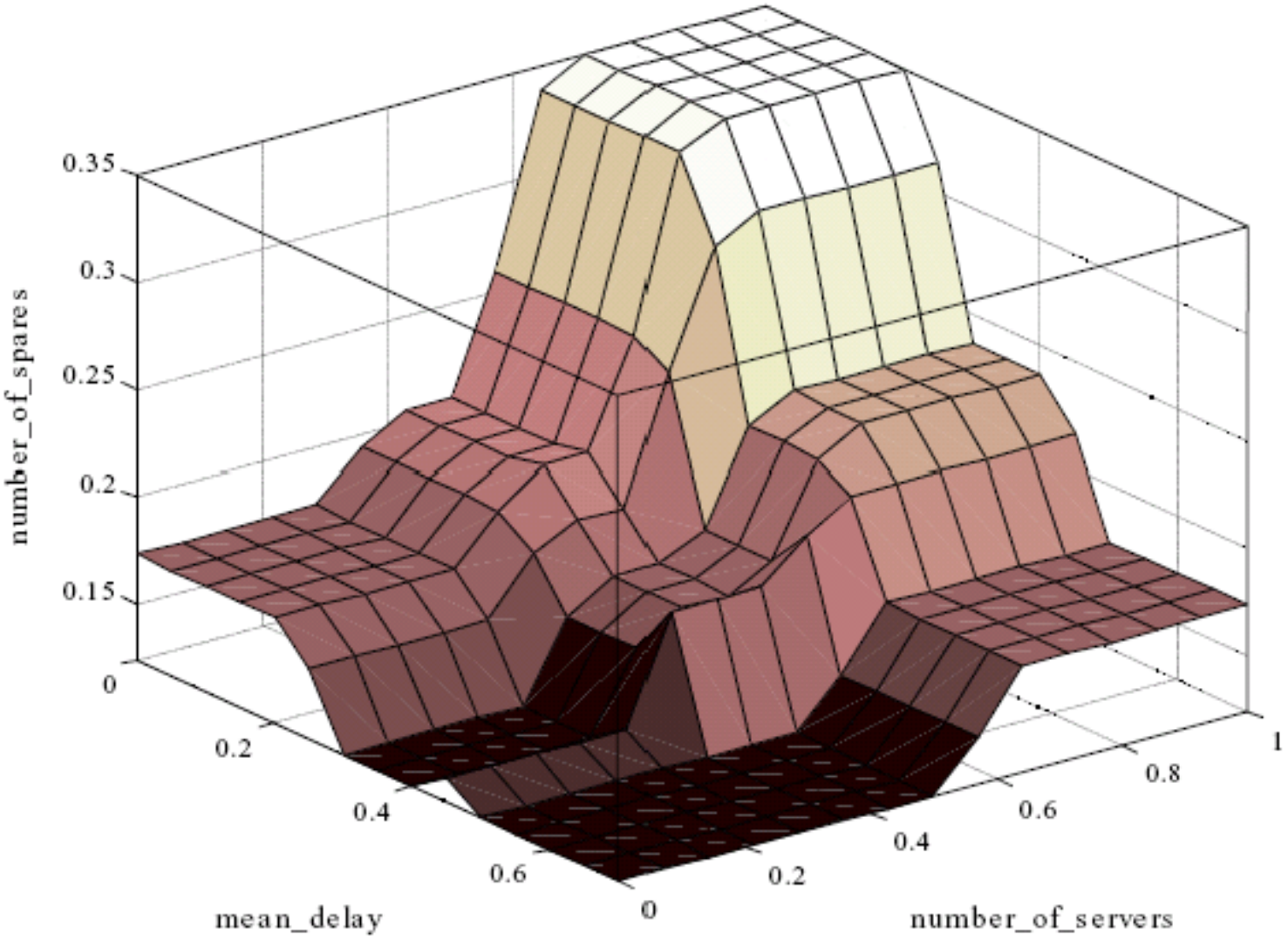
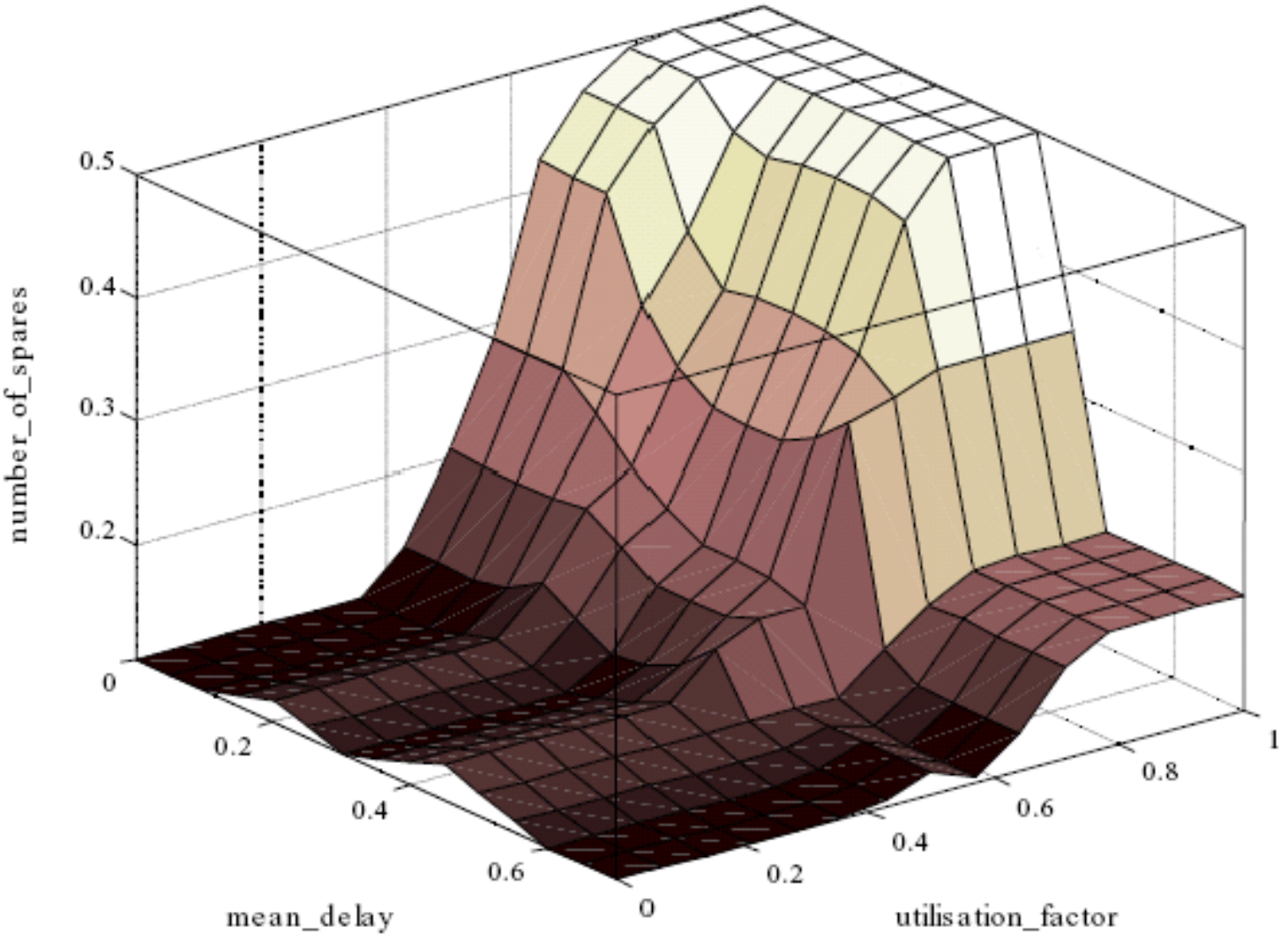
Cube FAM of Rule Base 3



Three-dimensional plots for Rule Base 3



Three-dimensional plots for Rule Base 3



Tuning fuzzy systems

- 1. Review model input and output variables, and if required redefine their ranges.
- 2. Review the fuzzy sets, and if required define additional sets on the universe of discourse. The use of wide fuzzy sets may cause the fuzzy system to perform roughly.
- 3. Provide sufficient overlap between neighbouring sets. It is suggested that triangle-to-triangle and trapezoid-to-triangle fuzzy sets should overlap between 25% to 50% of their bases.

Tuning fuzzy systems

- 4. Review the existing rules, and if required add new rules to the rule base.
- 5. Examine the rule base for opportunities to write hedge rules to capture the pathological behaviour of the system.
- 6. Adjust the rule execution weights. Most fuzzy logic tools allow control of the importance of rules by changing a weight multiplier.
- 7. Revise shapes of the fuzzy sets. In most cases, fuzzy systems are highly tolerant of a shape approximation.