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Model upravljanja procesom obnavljanja cijevne vodovodne mreže primjenom fuzzy logike i fuzzy odlučivanja

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Ciljevi rada

Generalni cilj rada:

- Doprinos razvoju efikasne i operativne metodologije planiranja

Specifični ciljevi:

- Korištenje prednosti fuzzy logike i fuzzy teorije odlučivanja
- Razvoj modela upravljanja zasnovanog na temelju dostupnih znanja

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Upravljanje procesom obnavljanja cijevne vodovodne mreže

- Rangiranje prioriteta za obnavljanje, između pojedinih cijevnih dionica ili zona na osnovu odabranih kriterija

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Kriteriji

- Kriteriji procjene
- Finansijski kriteriji
- Kriteriji rizika

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Kriteriji procjene

Procjena stanja cijevi na osnovu:

- TV inspekcije
- Radar, ultrazvuk, laser...
- Uzorka stijenke cijevi
- OTKAZA
- GUBITAKA (skriveni kvarovi)

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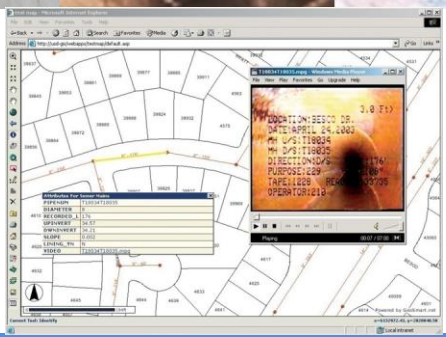
TV inspekcija



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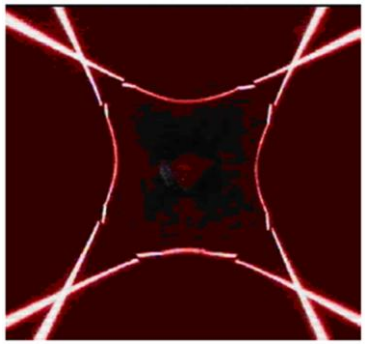
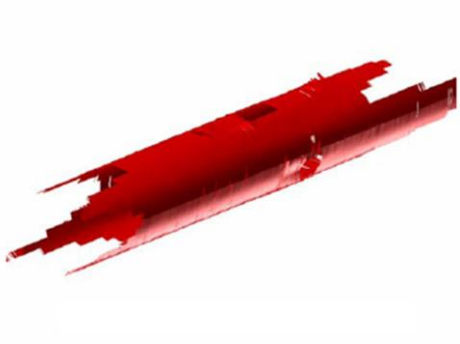
Laser





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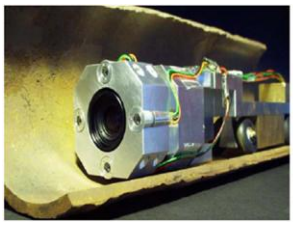
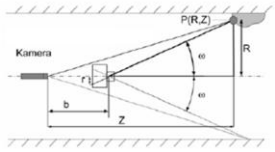
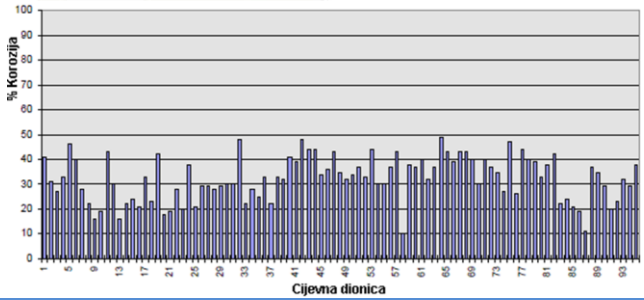
Radar







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Uzorak stijenke cijevi



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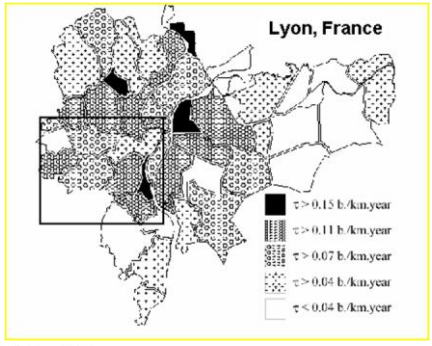
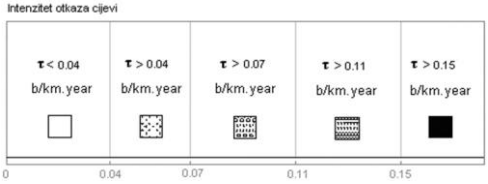
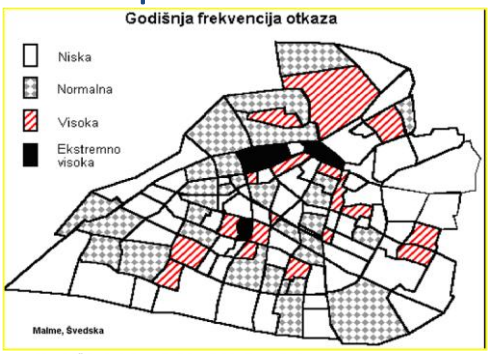
Broj otkaza po km dužine godišnje





Intenzitet otkaza cijevi po zonama



Lingvistički opis frekvencije (intenziteta) otkaza cijevi

Niska	Normalna	Visoka	Ekstremno visoka

Finansijski kriteriji

Minimiziranje cijene

Maksimiziranje efekta rekonstrukcije:

- alternativa sa što većim brojem priključaka ili
- što većim procentom zamjene ili
- sa što većom potrošnjom vode.. Itd.

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Kriteriji rizika

Rizik (Lawrence, 1976) je mjera vjerovatnoće da se neki događaj desi i jačine negativnog efekta koji proizvodi.

- Otkazi
- Gubici

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Problemi kod klasifikacija

- Oskudni podaci
- Nepreciznost
- Subjektivnost
- Klasični skupovi uključuju čvrste granice među klasama

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Gubici vode DVGW

Nominalne vrijednosti vodosnabdijevanja	Struktura vodosnabdijevanja		
	Veliki gradovi	Mali gradovi	Naselja
Broj stanovnika koji se snabdijeva vodom	> 100000	10000 – 100000	< 10000

Kategorija gubitaka	Aproksimativni stvarni specifični gubitak vode q_{VR} (m^3/h po km)		
	Veliki gradovi	Mali gradovi	Naselja
Mali gubici	< 0,13	< 0,07	< 0,05
Srednji gubici	0,13 – 0,25	0,07 – 0,15	0,05 – 0,10
Veliki gubici	> 0,25	> 0,15	> 0,10

0,06

Stvarni specifični gubici q_{VR} (m^3 /h / km)	Kompletno ispitivanje cijele mreže
Veliki gubici vode	1 put u godini
Srednji gubici vode	Svake 3 godine
Mali gubici vode	Može izostati

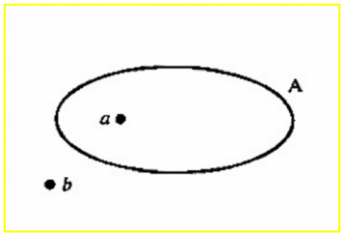
Fuzzy koncept

- Fuzzy engl. Nejasan, zamagljen, neizrazit, rasplinut;
- Fuzzy skupovi – skupovi sa rasplinutim granicama – pojam fuzzy skupa u metematiku je uveo Litfi A. Zadeh 1965.

Klasični (Cantorov) i Fuzzy skup

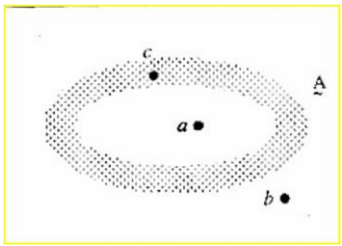
- Klasični (Cantorov) skup

$$\forall x \in A, \exists\, \chi(x) \in \{0,1\}$$



- Fuzzy skup

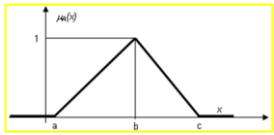
$$\forall x \in A, \exists\, \mu(x) \in (0,1)$$



Primjeri fuzzy skupova

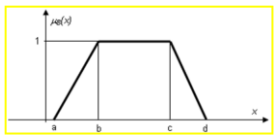
- Trougaona funkcija pripadnosti

$$A = \int_a^b \frac{\left(\frac{x-a}{b-a}\right)}{x} + \int_b^c \frac{\left(\frac{c-x}{c-b}\right)}{x}.$$



- Trapezoidna funkcija pripadnosti

$$B = \int_a^b \frac{\left(\frac{x-b}{b-a}\right)}{x} + \int_b^c \frac{1}{x} + \int_c^d \frac{\left(\frac{d-x}{d-c}\right)}{x}.$$



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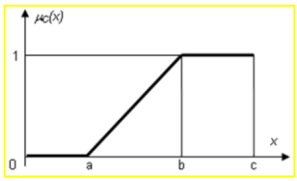
Primjeri fuzzy skupova

- Kontinualna funkcija pripadnosti

$$C = \int_0^a \frac{0}{x} + \int_a^b \frac{\left(\frac{x-b}{b-a}\right)}{x} + \int_b^c \frac{1}{x}.$$



- Zvonasta funkcija pripadnosti

$$D = \int_0^b \frac{e^{-0,5(x-a)^2}}{x}.$$

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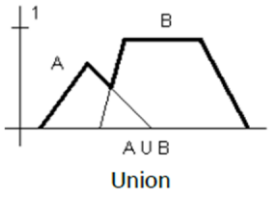
Osnovne operacije sa fuzzy skupovima

Unija

$\mu_{AUB}(x) = \mu_A(x) \vee \mu_B(x) = \max\{\mu_A(x), \mu_B(x)\}$



Union

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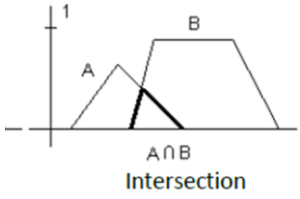
Osnovne operacije sa fuzzy skupovima

Presjek

$$\mu_{A\cap B}(x) = \mu_A(x) \wedge \mu_B(x) = \min\{\mu_A(x), \mu_B(x)\}$$



Intersection

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Fuzzy logika

- Aristotel – binarna , dvovrijednosna logika
- Lukasiewicz – trovrijednosna logika
- Zadeh – fuzzy logika

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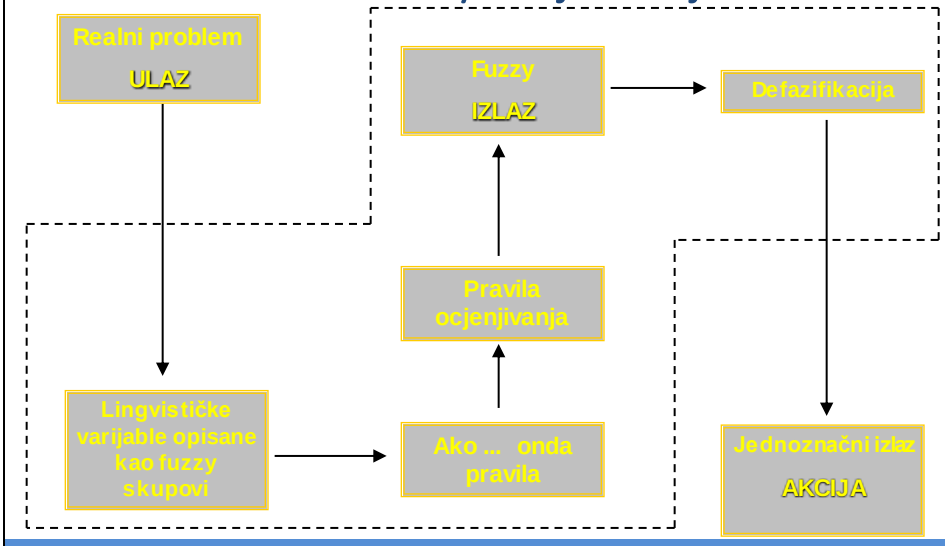
Model fuzzy zaključivanja



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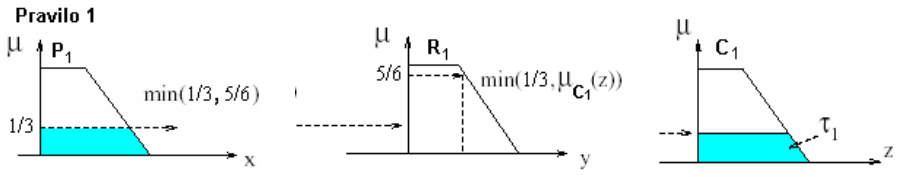
Fuzzy logičko zaključivanje – primjer upravljanja rezervoarom

Ako je potrošnja Mala (P_1) **I** ako je nivo u rezervoaru Visok (R1) **tada** je dotok Mali (C_1)



Izborom manje vrijednosti zadovoljen je logički uslov prema kojem istinitost zaključka ne može biti veća od istinitosti premise.

Mamdani model

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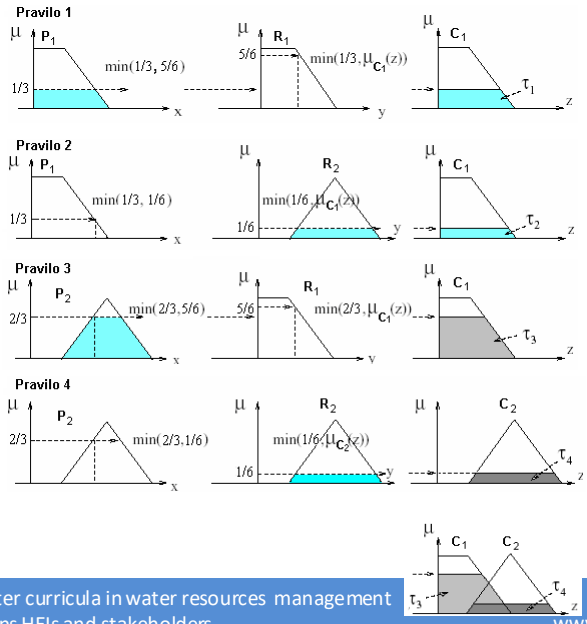
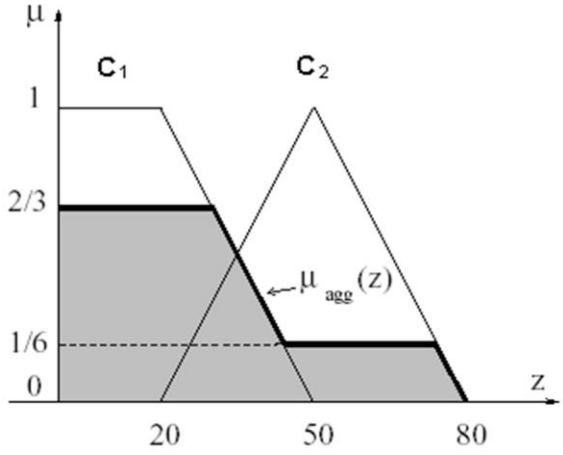
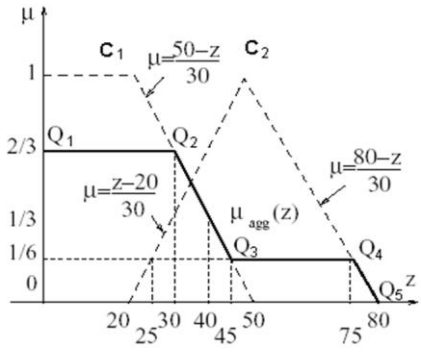


Fuzzy izlaz



Defazifikacije, metod težišta



$$Q_c = \frac{\sum_{k=1}^{Q_{k-1}} z_k \mu_{agg}(z_k)}{\sum_{k=1}^{Q_{k-1}} \mu_{agg}(z_k)} = 29{,}41$$

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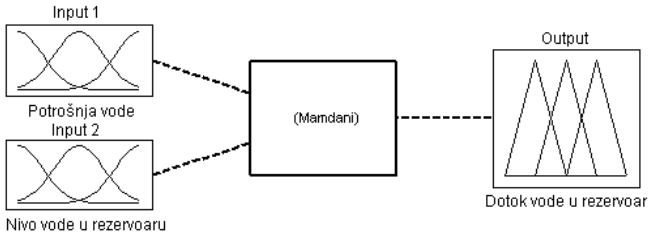
Šema zaključivanja - Mamdani



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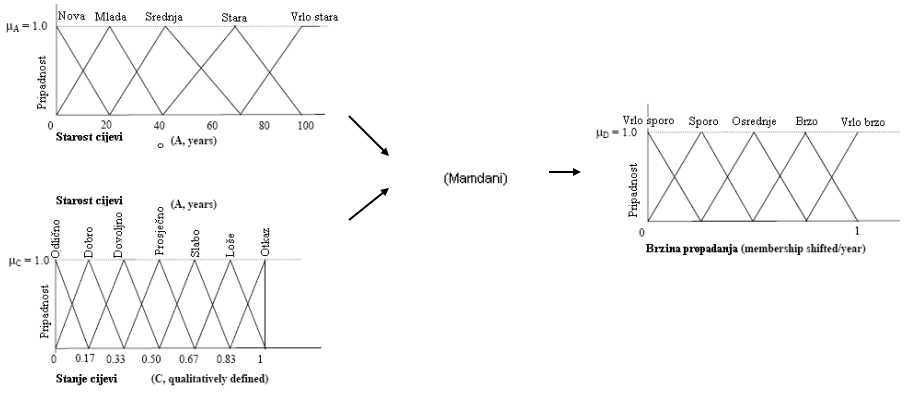
ZAKLJUČIVANJE:
(Starost , Stanje) →Brzina propadanja



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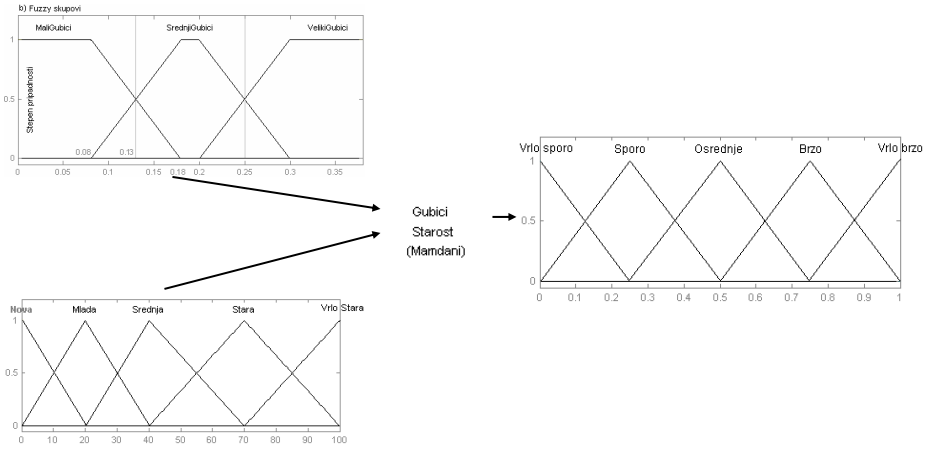
ZAKLJUČIVANJE:
(Gubici, Starost) → Brzina propadanja



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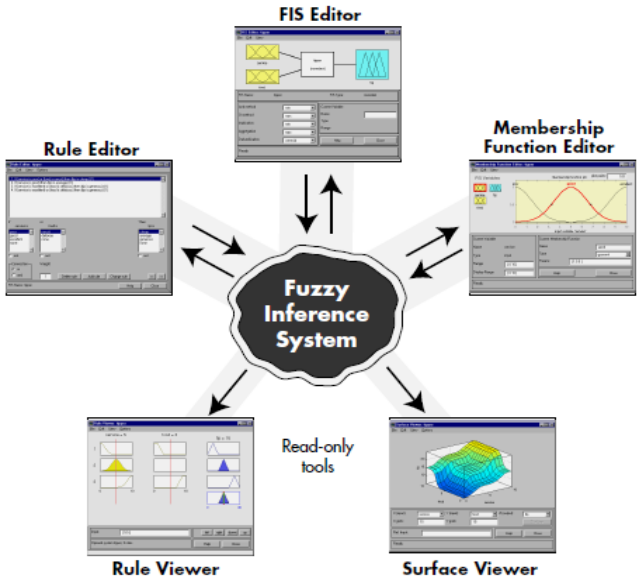
MatLab FLT



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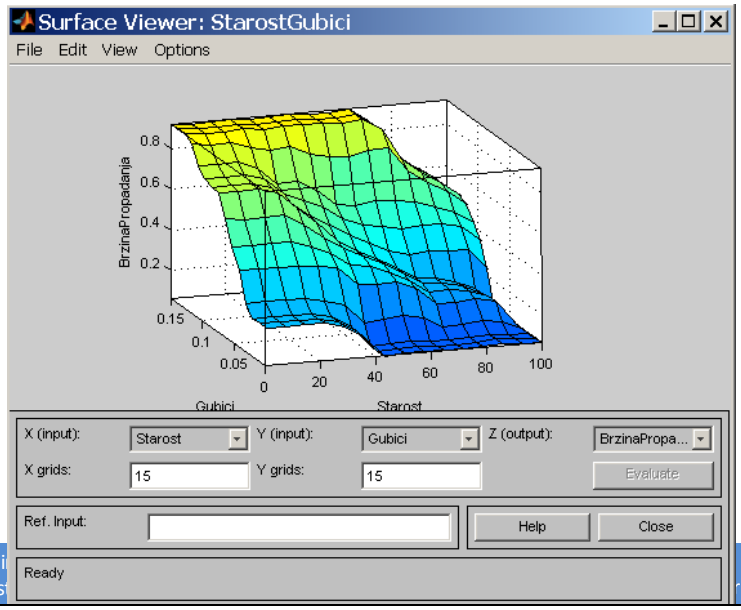
MatLab



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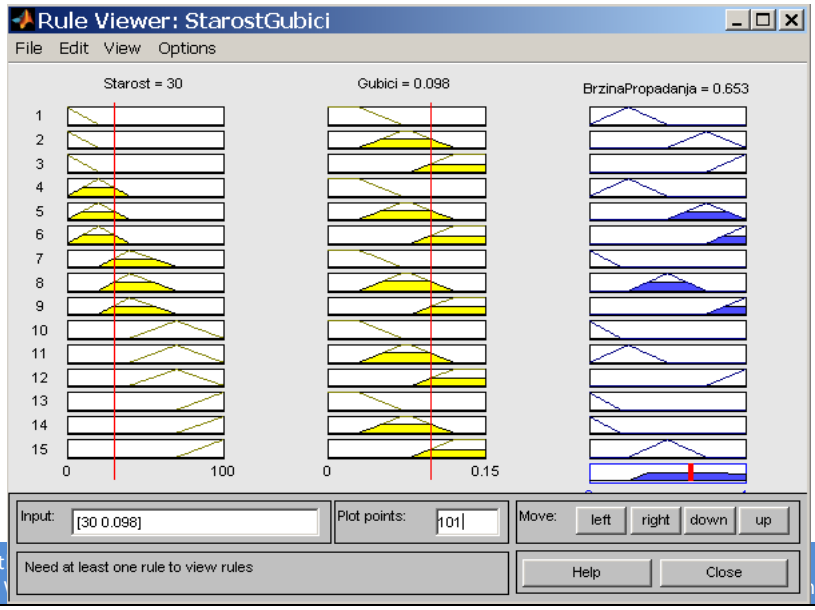
MatLab



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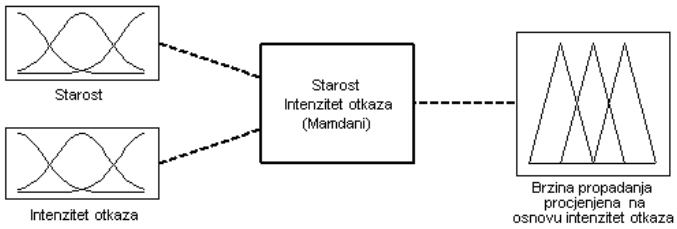
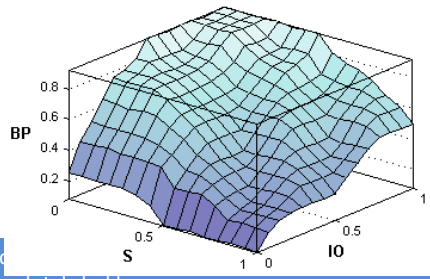
(Starost, Int. Otkaza) → Brzina propadanja





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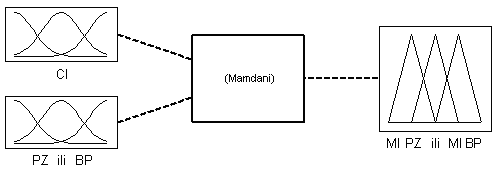
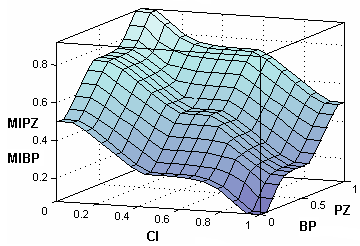
(Cijena, % zamjene ili Br priključaka) → Mjera isplativosti





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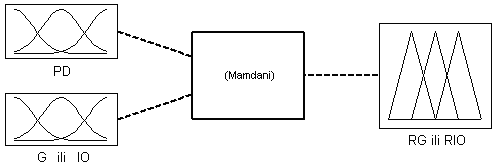
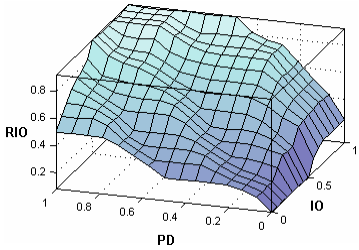
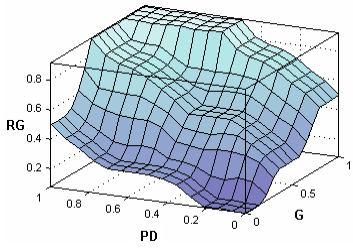
(Posljedice, Gubici ili Int. Otkaza) → Rizik







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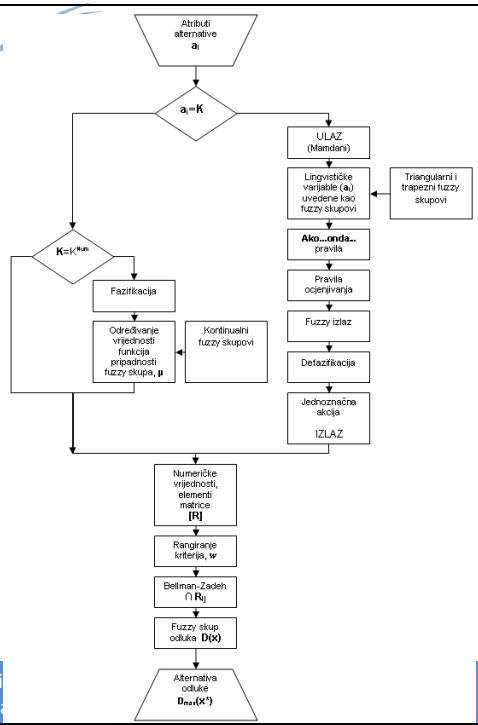

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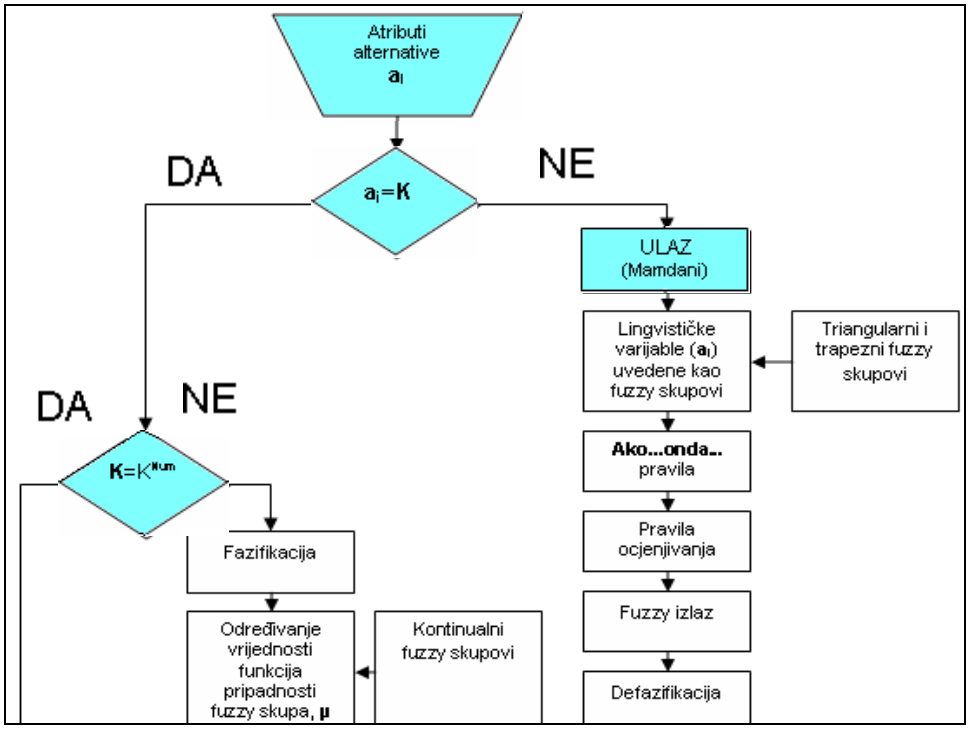
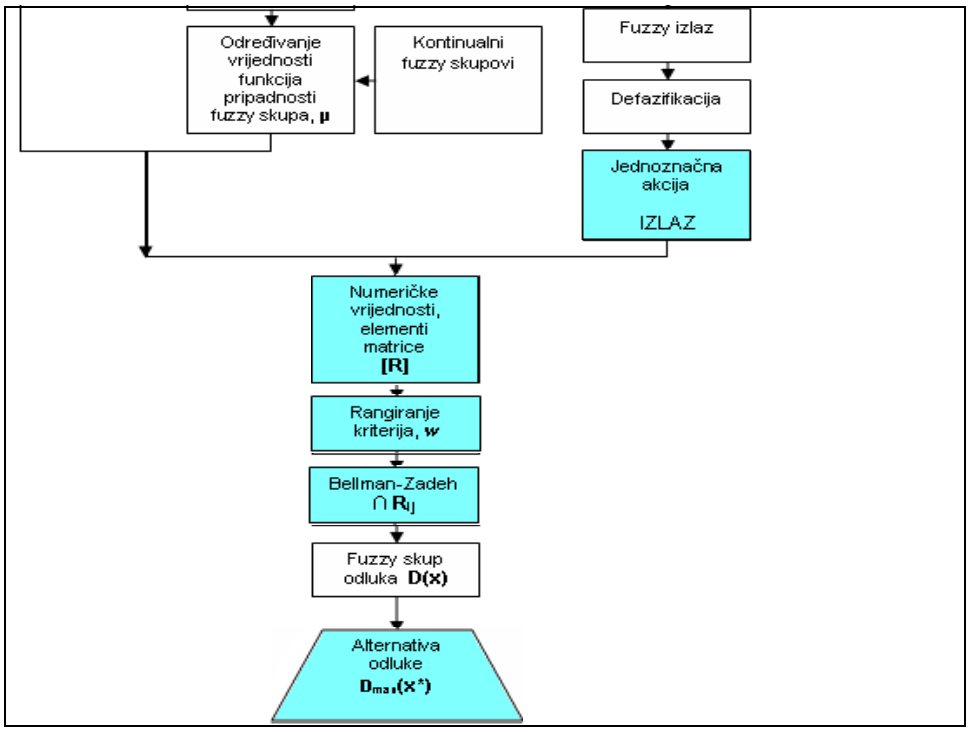

Atributi alternative a_i
DA
a_i=K
NE
ULAZ (Mamdani)
Lingvističke varijable (a_i) uvedene kao fuzzy skupovi
Triangularni i trapezni fuzzy skupovi
Ako...onda... pravila
Pravila ocjenjivanja
Fuzzy izlaz
Defazifikacija
DA
NE
K=K^num
Fazifikacija
Određivanje vrijednosti funkcija pripadnosti fuzzy skupa, μ
Kontinualni fuzzy skupovi


Određivanje vrijednosti funkcija pripadnosti fuzzy skupa, μ
Kontinualni fuzzy skupovi
Fuzzy izlaz
Defazifikacija
Jednoznačna akcija
IZLAZ
Numeričke vrijednosti, elementi matrice [R]
Rangiranje kriterija, w
Bellman-Zadeh ∩ R_{ij}
Fuzzy skup odluka D(x)
Alternativa odluke
$D_{max}(x^*)$

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Primjer skupa odabranih atributa

a_1: Cijena koštanja (€).
a_2: Starost cijevi. (god)
a_3: Gubici vode. ($m^3/h/km$, q_{VR})
a_4: Intenzitet otkaza (broj otkaza/km/god).
a_5: Procenat obnavljanja mreže (%).
a_6: Posljedice oštećenja objekata od otkaza (lingvistička kvalifikacija).
a_7: Posljedice oštećenja objekata od gubitaka, curenja (lingvistička kvalifikacija).
a_8: Posljedice oštećenja druge podzemne infrastrukture od otkaza (lingvistička kvalifikacija).
a_9: Posljedice oštećenja druge podzemne infrastrukture od gubitaka, curenja (lingvistička kvalifikacija) .
a_{10}: Procjenjeni broj nelegalnih priključaka (%).
a_{11}: Broj pritužbi građana (lingvistička kvalifikacija).
a_{12}: Broj korisnika (#).

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	A_1	A_2	A_3	A_4	A_5	A_6	A_7
a_1	1.1 mln €	1.15 mln €	1.2 mln €	1.4 mln €	1.6 mln €	2.4 mln €	3.2 mln €
a_2	40	38	40	45	42	45	50
a_3	0,28	0,30	0,32	0,29	0,31	0,34	0,36
a_4	0,11	0,13	0,12	0,14	0,12	0,13	0,145
a_5	1,2%	0,85%	0,5%	0,8 %	0,9%	1,4 %	1,6%
a_6	Srednje	Velike	Srednje	Male	Velike	Male	Velike
a_7	Velike	Male	Srednje	Vrlo male	Srednje	Vrlo male	Male
a_8	Srednje	Male	Velike	Srednje	Velike	Srednje	Srednje
a_9	Velike	Srednje	Male	Vrlo velike	Male	Velike	Velike
a_{10}	5 %	7 %	6 %	8 %	6 %	9 %	10 %
a_{11}	Veliki	Srednji	Mali	Srednji	Veliki	Veliki	Vrlo veliki
a_{12}	1.500	1.320	1.600	2.100	2.450	3.200	3.800

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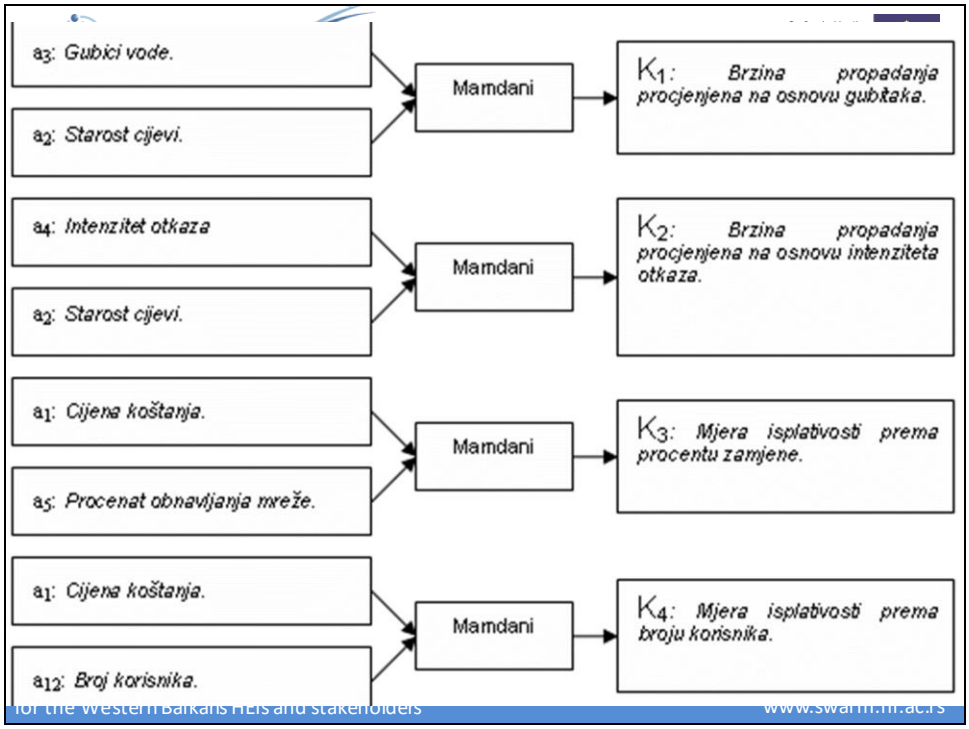
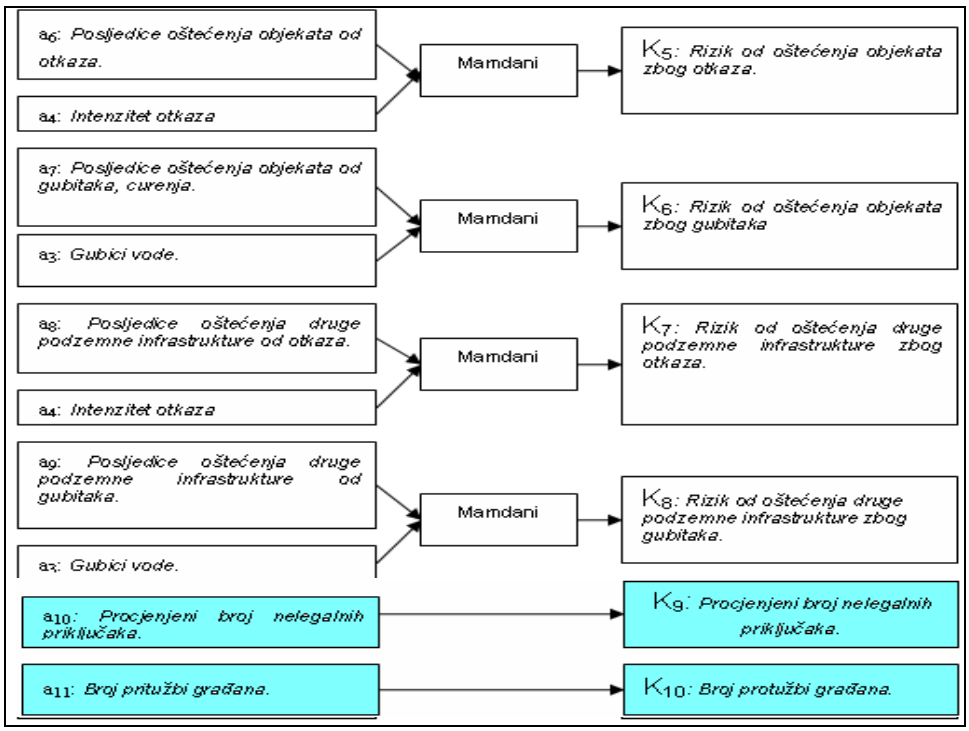

a3: Gubici vode.
a2: Starost cijevi.
Mamdani
K1: Brzina propadanja procjenjena na osnovu gubitaka.
a4: Intenzitet otkaza
a2: Starost cijevi.
Mamdani
K2: Brzina propadanja procjenjena na osnovu intenziteta otkaza.
a1: Cijena koštanja.
a5: Procenat obnavljanja mreže.
Mamdani
K3: Mjera isplativosti prema procentu zamjene.
a1: Cijena koštanja.
a12: Broj korisnika.
Mamdani
K4: Mjera isplativosti prema broju korisnika.


a6: Posljedice oštećenja objekata od otkaza.
a4: Intenzitet otkaza
Mamdani
K5: Rizik od oštećenja objekata zbog otkaza.
a7: Posljedice oštećenja objekata od gubitaka, curenja.
a3: Gubici vode.
Mamdani
K6: Rizik od oštećenja objekata zbog gubitaka
a8: Posljedice oštećenja druge podzemne infrastrukture od otkaza.
a4: Intenzitet otkaza
Mamdani
K7: Rizik od oštećenja druge podzemne infrastrukture zbog otkaza.
a9: Posljedice oštećenja druge podzemne infrastrukture od gubitaka.
a3: Gubici vode.
Mamdani
K8: Rizik od oštećenja druge podzemne infrastrukture zbog gubitaka.
a10: Procjenjeni broj nelegalnih priključaka.
K9: Procjenjeni broj nelegalnih priključaka.
a11: Broj pritužbi građana.
K10: Broj protužbi građana.

	W	A_1	A_2	A_3	A_4	A_5	A_6	A_7
K_1	0.09	0,741	0,919	0,92	0,715	0,887	0,85	0,809
K_2	0.09	0,75	0,782	0,759	0,747	0,735	0,721	0,712
K_3	0.12	0,75	0,681	0,5	0,586	0,585	0,597	0,48
K_4	0.08	0,547	0,5	0,572	0,619	0,633	0,559	0,473
K_5	0.12	0,75	0,905	0,759	0,678	0,915	0,625	0,919
K_6	0.12	0,84	0,75	0,92	0,467	0,92	0,5	0,75
K_7	0.09	0,75	0,625	0,915	0,827	0,915	0,782	0,864
K_8	0.09	0,84	0,92	0,75	0,919	0,75	0,92	0,92
K_9	0.10	5 %	7 %	6 %	8 %	6 %	9 %	10 %
K_{10}	0.10	Veliki	Srednji	Mali	Srednji	Veliki	Veliki	Vrlo veliki

	w	A_1	A_2	A_3	A_4	A_5	A_6	A_7
		$\mu_1(x)$	$\mu_2(x)$	$\mu_3(x)$	$\mu_4(x)$	$\mu_5(x)$	$\mu_6(x)$	$\mu_7(x)$
K_1	0,09	0,741	0,919	0,920	0,715	0,887	0,850	0,809
K_2	0,09	0,750	0,782	0,759	0,747	0,735	0,721	0,712
K_3	0,12	0,750	0,681	0,500	0,586	0,585	0,597	0,480
K_4	0,08	0,547	0,500	0,572	0,619	0,633	0,559	0,473
K_5	0,12	0,750	0,905	0,759	0,678	0,915	0,625	0,919
K_6	0,12	0,840	0,750	0,920	0,467	0,920	0,500	0,750
K_7	0,09	0,750	0,625	0,915	0,827	0,915	0,782	0,864
K_8	0,09	0,840	0,920	0,750	0,919	0,750	0,920	0,920
K_9	0,10	0,143	0,429	0,286	0,571	0,286	0,714	0,857
K_{10}	0,10	0,666	0,500	0,333	0,500	0,666	0,666	0,833

Belman – Zadeh model odlučivanja

$$D = \bigcap_{k=1}^{10} K_k^{(w_k)} = \left(\min_{k=1,10} \left(\mu_{K_k}^{w_k}(x_{k,i}) \right) \right)_{i=1}^{i=7}$$

$$D = \frac{\mu_{D_1}(\tilde{x}_1)}{A_1} + \frac{\mu_{D_2}(\tilde{x}_2)}{A_2} + \frac{\mu_{D_3}(\tilde{x}_3)}{A_3} + \frac{\mu_{D_4}(\tilde{x}_4)}{A_4} + \frac{\mu_{D_5}(\tilde{x}_5)}{A_5} + \frac{\mu_{D_6}(\tilde{x}_6)}{A_6} + \frac{\mu_{D_7}(\tilde{x}_7)}{A_7}$$

$$D = \frac{0,0143}{A_1} + \frac{0,0400}{A_2} + \frac{0,0286}{A_3} + \frac{0,0495}{A_4} + \frac{0,0286}{A_5} + \frac{0,0447}{A_6} + \frac{0,0378}{A_7}$$

$$D(X^*) = \max\left(D_1(A_1), D_2(A_2), \ldots, D_7(A_7)\right)$$
$$\mu_D(x^*) = \max\left(\mu_{D_1}(\tilde{x}_1), \mu_{D_2}(\tilde{x}_2), \ldots, \mu_{D_7}(\tilde{x}_7)\right)$$
$$\mu_D(x^*) = \mu_{D_4}(\tilde{x}_4) = 0,0495$$

Belman – Zadeh model odlučivanja

		A_1	A_2	A_3	A_4	A_5	A_6	A_7
	W_k	w_1 $\mu_1(X)$	w_1 $\mu_2(X)$	w_1 $\mu_3(X)$	w_1 $\mu_4(X)$	w_1 $\mu_5(X)$	w_1 $\mu_6(X)$	w_1 $\mu_7(X)$
$K_1^{(w_1)}$	0,09	0,0667	0,0827	0,0828	0,0644	0,0798	0,0765	0,0728
$K_2^{(w_2)}$	0,09	0,0675	0,0704	0,0683	0,0672	0,0662	0,0649	0,0641
$K_3^{(w_3)}$	0,12	0,0900	0,0817	0,0600	0,0703	0,0702	0,0716	0,0576
$K_4^{(w_4)}$	0,08	0,0438	0,0400	0,0458	**0,0495**	0,0506	0,0447	0,0378
$K_5^{(w_5)}$	0,12	0,0900	0,1086	0,0911	0,0814	0,1098	0,0750	0,1103
$K_6^{(w_6)}$	0,12	0,1008	0,0900	0,1104	0,0560	0,1104	0,0600	0,0900
$K_7^{(w_7)}$	0,09	0,0675	0,0563	0,0824	0,0744	0,0824	0,0704	0,0778
$K_8^{(w_8)}$	0,09	0,0756	0,0828	0,0675	0,0827	0,0675	0,0828	0,0828
$K_9^{(w_9)}$	0,10	0,0143	0,0429	0,0286	0,0571	0,0286	0,0714	0,0857
$K_{10}^{(w_{10})}$	0,10	0,0666	0,0500	0,0333	0,0500	0,0666	0,0666	0,0833

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ZAKLJUČCI

- Na ovom stepenu opservabilnosti i degradacije cijevne mreže informacije o kvarovima i gubicima mogu se smatrati dovoljnim skupom informacija o stanju sistema
- Za procjenu stanja mreže - brzine propadanja i rizika, na osnovu podataka o kvarovima i gubicima, kao i mjere isplativosti, primjena fuzzy logike (Mamdani metod) omogućava da se neprecizne i/ili subjektivne kvalifikacije koriste u modelu zaključivanja
- Povezivanje fuzzy logičkog zaključivanje (Mamdani) sa fuzzy teorijom odlučivanja (Bellman-Zadeh) kod donošenja odluka o prioritetima za obnavljanje, egzaktno uvodi u model iskustvena znanja umjesto oskudnih podataka

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Prednosti i slabosti

PREDNOSTI:

- Vrijeme potrebno za razumjevanje veoma kratko
- Jednostavnost primjene rezultira uspostavljanjem boljeg odnosa model-korisnik

SLABOSTI

- Nedovoljno teorijski obrazložen način formiranja pravila

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