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NOMIDAGI TATU FARG'ONA FILIALI

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REAL VAQT REJIMIDA NOQAT’IY MA’LUMOTLARNI QAYTA ISHLASHNING ANALITIK MODELLARINI ISHLAB CHIQISH

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Annotatsiya. Mazkur ilmiy-tadqiqot ishida boshqaruv va qaror qabul qilish tizimlarida hosil bo‘ladigan yuqori chastotali noaniq ma’lumotlarni qayta ishlash masalalari ko‘rib chiqilgan. Mazkur masalalarda noaniq to‘plamlar uchun gorizontal va vertikal analitik modellarning hisoblash kutubxonasini sintez qilishga alohida e'tibor qaratildi. Ishlab chiqilgan hisoblash kutubxonasidan foydalanish real vaqt rejimida noaniq ma’lumotlarni qayta ishlash tezligi va aniqligini oshirish imkonini beradi. Tadqiqotda hisoblash kutubxonasidan mos modelni avtomatik rejimda aniqlash imkonini beruvchi noaniq raqamlarning mos keluvchi parametrlari o‘rtasidagi munosabatlarni baholash uchun niqoblashni taqdim etadi.

Kalit so‘zlar: big data, noqat’iy to‘plam, vertikal va gorizontal modellar, maksimum, hisoblash kutubxonasi, real vaqtda ma’lumotlarni qayta ishlash.

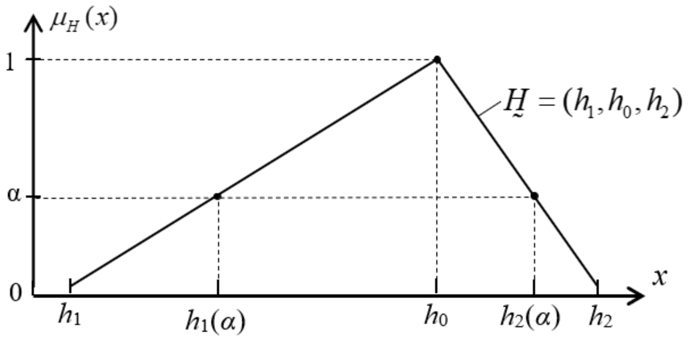
Kirish. Bugungi kunda real vaqt rejimida noravshan axborot muhitlarida qaror qabul qilish jarayonlarining samaradorligini oshirish muhim masalalardan biri hisoblanadi. Shu munosabat bilan ob’yekt ma’lumotlarining dinamik xususiyatlarini hisobga olgan holda, real vaqt rejimida katta hajmli ma’lumotlarni qayta ishlash, boshqarish va tahlil qilishning yangi usullarini yaratish dolzarbligicha qolmoqda [1-2]. Mazkur yo‘nalishda sun’iy intellekt va chuqur o`qitish texnologiyalari, mashinali o‘qitish, noqat’iy mantiq tizimlari, noqat’iy neyron tarmoqlari kabi bir qancha muvaffaqiyatli usul va yondashuvlar ishlab chiqilgan [2]. Shunga qaramay, ma’lumotlar hajmining eksponensial o‘sishi va ularning shakllanish tezligining ortib borishi mazkur usul va yondashuvlarni doimiy ravishda takomillashtirish va o‘zgartirishni taqozo qilmoqda. Noravshan axborot muhitlarida katta hajmli ma’lumotlarni qayta ishlash muammolarni yechishda samarali vosita sifatida noravshan to‘plamlar, noravshan mantiq va noravshan optimallashtirish nazariyasini qo‘llashga alohida e’tibor qaratish lozim bo‘ladi [2-3].

Adabiyotlar tahlili va metodologiya. Barchaga ma’lumki, noravshan to‘plamlar nazariyasi dastlab L. Zade [3,4] tomonidan taklif etilgan bo‘lib, ko‘plab olimlar tomonidan ma’lumotlarni qayta ishlash, muhandislik, iqtisodiyot va boshqa turli murakkab tizimlarni boshqarish sohalarida noravshan mantiq va uni nazorat qilish, qaror qabul qilishning usul va yondashuvlaridan foydalangan holda tadqiqotlar olib bordilar. [2,3,4,6].

So`nggi yillarda olib borilgan ilmiy ishlanmalarning tahlili shuni ko‘rsatadiki, noqat’iy yondashuvlar asosida ko‘plab qaror qabul qilish va boshqarish tizimlari ishlab chiqilgan. Jumladan, o‘rnatilgan boshqaruv tizimlarida ma’lum arxitekturaga ega bo‘lgan noqat'iy boshqaruv texnologiyasi (fuzzy control technology) va noqat'iy adaptiv PID algoritmlari (fuzzy adaptive PID algorithm) asosida Loyihalash metodologiyasi (Design methodology), Sanoat boshqaruvi (Industrial control), Boshqaruv tizimi (Control systems), Loyihalashni avtomatlashtirish (Design automation), Qurilmani loyihalash tillari (Hardware design languages), Sanoat elektronikasi (Industrial electronics) va Qayta ishlash (Refining) [5,6] kabi yirik loyihalar muvaffaqiyatli amalga oshirilishi mumkin.

Noravshan axborot muhitlarida real vaqt rejimida ma’lumotlarni tahlil qilish turli yirik loyihalarni amalga oshirish uchun yangi modellar va algoritmlarni ishlab chiqishga zamin yaratadi. Ushbu model va algoritmlar amaliy masalalarni yechishda hisoblash tezligi, aniqligi, ishonchliligi kabi samaradorlikni ko‘rsatuvchi parametrlarni oshirishga xizmat qiladi [5,7,8].

Tadqiqot ishi davomida noaniq $\underset{\sim}{H}$ to‘plamni $(x, \mu_{\underset{\sim}{H}}(x))$ juftliklar to‘plami sifatida ko‘rib chiqamiz (1-rasm). Bu yerda x universal to‘plamning F - elementi tegishlilik funksiyasining (*membership function* (*MF*)) $\mu_{\underset{\sim}{H}}(x) \in [0,1]$ oraliqdagi qiymati.



1-rasm. $\underset{\sim}{H}, \underset{\sim}{H} \in R$ uchburchak noqat’iy sonning α-kesimi.

Noaniqlik sharoitlarida erishilgan natijalarni samarali yechimlarini qo‘llashga turli texnologik jarayonlarni avtomatlashtirish, transport yo‘nalishlarini optimallashtirish va tadqiqot loyihalarini baholash sohalarida qaror qabul qilish va boshqalarni misol keltirish mumkin. Ma’lumotlarni tahlil qilishning ushbu usullarida parametrlashtirilmagan va parametrlangan operatorlarining moslashuvchan yumshoq hisoblash komponentlaridan foydalanishga tayanadi. Vektor kvantlash va turli noniq xulosa chiqarish mexanizmlari (Mamdani, Sugeno va boshqalar), shuningdek, noqat’iy raqamlar (*fuzzy numbers*(FN)) bilan noaniq arifmetik amallarni amalga oshirish uchun turli xil noaniq yondashuvlar, jumladan FNs-minimal, FNs-maksimal, FNs-ayirish, FNs-ko‘paytirish, FNs-bo‘linish va FNs-qo‘shishdan faol tarzda foydalanishga tayanadi [5-9].

Katta hajmdagi ma’lumotlarni qayta ishlashning aniqligi va tezligini oshirish qobiliyati tufayli noaniq arifmetika uchun olingan analitik modellarni shakllantirishga alohida e'tibor qaratish lozim [9]. Ba'zi amaliy holatlarda FN bilan mos keladigan arifmetik amallar uchun olingan MF larni keyinchalik amalga oshirish bilan katta hajmdagi axborotga mos keladigan noaniq raqamlarga aylantirish mumkin [10-12].

Olingan MF larning analitik modellarini sintez qilishning samarali usullaridan biri *α*-kesimlardan [11-14], xususan, hosil bo‘lgan a’zolik funksiyalarining gorizontal (teskari) va vertikal (to‘g‘ridan-to‘g‘ri) modellarini qurishda foydalanish hisoblanadi. Biroq, ba'zi hollarda, bunday natijaviy modellarni shakllantirish zarurati ko‘p vaqt talab qiladi va ma’lumotlarni qayta ishlash tezligining pasayishiga va real vaqt rejimida boshqaruv va qaror qabul qilish jarayonlari sifatining pasayishiga olib keladi [9-13].

Yana bir yondashuv Zadening kengaytma prinsipidan [11-14] yoki Maks-Min konvolyutsiyasi algoritmidan foydalanish bilan bog'liq bo‘lib, u har bir dastlabki noaniq to‘plamni (noaniq ma’lumotlarni qayta ishlashda ishtirok etgan) diskretlik bosqichi yordamida diskret shaklga o‘zgartirishni talab qiladi. $x_{i+1} = x_i + \Delta x$, (i = 0, 1, 2, . . . , K) ni aniqlash uchun, $\Delta x = \frac{x_{\max} - x_{\min}}{K} = const$. Bu natijada paydo bo‘lgan nonaiq to‘plamlarning sinteziga olib keladi, masalan, jadval uslubi yoki birlashgan singletonlar to‘plami $\underset{\sim}{P} = \sum_{i=0}^{K} \frac{\mu_{\underset{\sim}{P}}(x_i)}{x_i}$.

Yuqorida aytib o‘tilgan *α*-kesimlar va Maks-Min konvolyutsiya yondashuvlari [12] natijasida hosil bo‘lgan noaniq $\underset{\sim}{P}$ to‘plamining $\mu_P(x)$ a'zolik funksiyasining analitik modelini olish uchun qo‘shimcha matematik o‘zgarishlar kiritishni talab qiladi, bu esa hisoblash uchun ishlatilishi mumkin bo‘lgan (har qanday $y^*, y^* \in [y_{\min}, y_{\max}]$) y^* ning natijaviy noaniq $\underset{\sim}{P}$ to‘plamiga tegishliligini tavsiflovchi mos keluvchi a’zolik qiymati $\mu_{\underset{\sim}{P}}(x^*)$ [13] diskret noaniq to‘plami $\underset{\sim}{P} = \sum_{i=0}^{K} \frac{\mu_{\underset{\sim}{P}}(x_i)}{x_i}$ uchun o‘rinli hisoblanadi.

Agar $y*$ har qanday qo‘shni qiymatlar x_i va x_{i+1}o‘rtasida joylashgan bo‘lsa, ya'ni $x_i < x^* < x_{i+1}$ bo‘lsa, tegishli $\mu_{\underset{\sim}{P}}(x^*)$ qiymatini hisoblash uchun interpolyatsiya protsedurasidan foydalanish ham mumkin. Ko‘rib chiqilgan ikkala yondashuv ham "ko‘p bosqichli" hisoblash protseduralarini amalga oshirishga asoslangan. Dastlabki noqat’iy to‘plamlardagi har qanday o‘zgarishlar noaniq ma’lumotlarni qayta ishlash uchun ko‘p nomli yaqinlashish yoki interpolyatsiya protseduralarini amalga oshirishni talab qiladi, bu esa hisoblashning murakkabligi va hisoblash vaqtining oshishiga, shuningdek, hisob-kitoblarning aniqligini pasayishiga olib keladi. Shunday qilib, olingan analitik modellarni sintez qilish jarayonlarini avtomatlashtirishning yangi usullarini ishlab chiqish noqat’iy ma’lumotlarni qayta ishlashda “bir bosqichli” hisoblash jarayonlari sifatini sezilarli darajada oshirishi mumkin.

Ikki noqat’iy to‘plamlar uchun FN-maksimalni amalga oshirishda α-kesishdan foydalanish turli α-darajalar uchun mos keladigan arifmetik algoritmni bosqichma-bosqich amalga oshirish zaruriyatini yuzaga keltiradi [12-15] (1-rasm):

$$\alpha_i = \alpha_{i-1} + \delta\alpha, (i = 1, 2, ..., N) \quad (1)$$

Bu yerda $\delta\alpha$ diskretlik bosqichi bo‘lib, uni $\delta\alpha = \frac{1}{N}$ orqali ifodalash mumkin.

Ushbu takrorlanuvchi jarayon yuqori hisoblash murakkabligiga ega hamda N parametri va mos keladigan $\delta\alpha$ qiymatini tanlash natijasida olingan MF ning hisoblash tezligi va hisoblash aniqligiga yetarlicha ta’sir qiladi [13-15].

Umuman olganda, $\underset{\sim}{H} \in R$ noqat’iy sonining α-kesimi $H_\alpha = \{x \mid \mu_{\underset{\sim}{P}}(x) \geq \alpha\}$, $\alpha \in [0,1]$ aniq kichik to‘plam bo‘lib, u (1-rasm) faqat $\underset{\sim}{P}$ to‘plamiga a'zolik darajasidan kam bo‘lmagan $x \in R$ qiymatlarini o‘z ichiga oladi, bu yerda R - haqiqiy sonlar to‘plami [29,30]. $\underset{\sim}{H} \in R, \underset{\sim}{B} \in R$ noqat’iy to‘plamlar uchun ularning α-to‘plamlari H_α va B_α ni quyidagi uslubda tasvirlash mumkin:

$$H_\alpha = [h_1(\alpha), h_2(\alpha)], \quad (2)$$

$$B_\alpha = [b_1(\alpha), b_2(\alpha)],\ \alpha \in [0,1] \quad (3)$$

Dastlabki sintezlanishi mumkin bo‘lgan MF ning analitik modelida hisoblash tezligi va aniqligi nuqtai nazaridan FN-maksimalni hisoblash samaraliroq hisoblanadi [15]. Ushbu tadqiqotning asosiy maqsadi (a) hisoblash jarayonining murakkabligini kamaytirish, (b) hisoblash jarayonining tezligini oshirish uchun FNs-maksimalning arifmetik ishlashi uchun olingan gorizontal va vertikal analitik modellarning hisoblash kutubxonasini sintez qilish orqali, (c) rooting iterativ hisoblash protsedurasini istisno qilish va (d) noaniq ma’lumotlarni qayta ishlashning aniqligini oshirish hisoblanadi.

Parametrlari o‘rtasida turli xil R munosabatlarga ega bo‘lgan uchburchak noqat’iy sonlar (*triangular fuzzy numbers*(TrFN)) MF lari asosida yuqorida qayd etilgan hisoblash kutubxonasi [42,43] uchun sintez jarayonini keltiramiz (1-rasm).

$\underset{\sim}{H} = (h_1, h_0, h_2)$ va $\underset{\sim}{B} = (b_1, b_0, b_2)$ uchburchak noaniq raqamlari bo‘lgan MFs $\mu_{\underset{\sim}{H}}(x)$ va $\mu_{\underset{\sim}{B}}(x)$ mos keladigan parametrlari $\mu_{\underset{\sim}{H}}(h_0) = 1$, $\mu_{\underset{\sim}{B}}(b_0) = 1$, $\mu_{\underset{\sim}{H}}(h_1) = 0$, $\mu_{\underset{\sim}{H}}(h_2) = 0$, $\mu_{\underset{\sim}{B}}(b_1) = 0$ va $\mu_D(d_2) = 0$ bilan tavsiflanishi mumkin. Gorizontal H_α, B_α va vertikal $\mu_{\underset{\sim}{H}}(x)$, $\mu_{\underset{\sim}{B}}(x)$ $\underset{\sim}{H} \in R, \underset{\sim}{B} \in R$ uchburchak noqat’iy sonlarning modellari (4)-(7) [9,11,12,15,16] ifodalar bilan tavsiflanishi mumkin:

$$H_\alpha = [h_1(\alpha), h_2(\alpha)] = [h_1 + \alpha(h_0 - h_1), h_2 - \alpha(h_0 - h_1)], \quad (4)$$

$$\mu_{\underset{\sim}{H}}(x)=\begin{Bmatrix} 0, \forall(x\le h_1)\cup(x\ge h_2) \\ E_{H_L}(x,h_1,h_0), \forall(h_1<x\le h_0) \\ E_{H_R}(x,h_0,h_2), \forall(h_0<x<h_2) \end{Bmatrix} \quad (5)$$

$$B_\alpha=[b_1(\alpha),b_2(\alpha)]=[b_1+\alpha(b_0-b_1),b_2-\alpha(b_0-b_1)] \quad (6)$$

$$\mu_{\underset{\sim}{B}}(x)=\begin{Bmatrix} 0, \forall(x\le b_1)\cup(x\ge b_2) \\ E_{B_L}(x,b_1,b_0), \forall(b_1<x\le b_0) \\ E_{B_R}(x,b_0,b_2), \forall(b_0<x<b_2) \end{Bmatrix} \quad (7)$$

bu yerda $E_{H_L}(x,h_1,h_0)=(x-h_1)/(h_0-h_1)$ TrFN $\underset{\sim}{H}$ uchun MF $\mu_{\underset{\sim}{H}}(x)$ ning chap qismi;

$E_{B_L}(x,b_1,b_0)=(x-b_1)/(b_0-b_1)$ TrFN $\underset{\sim}{B}$ uchun MF $\mu_{\underset{\sim}{B}}(x)$ ning chap qismi;

$E_{H_R}(x,h_0,h_2)=(h_2-x)/(h_2-h_0)$ TrFN $\underset{\sim}{H}$ uchun MF $\mu_{\underset{\sim}{H}}(x)$ ning o‘ng qismi;

$E_{B_R}(x,b_0,b_2)=(b_2-x)/(b_2-b_0)$ TrFN $\underset{\sim}{B}$ uchun MF $\mu_{\underset{\sim}{B}}(x)$ ning o‘ng qismi;

FNs-maksimal hisoblashda, *α*-kesish algoritmiga nisbatan Max-Min yoki Min-Max konvolyutsiyalari [30,42] kabi algoritmlardan foydalanish ko‘p hollarda (a) xususiyatlarning buzilishiga olib keladi, xususan hosil bo‘lgan noqat’iy to‘plamning normalligi va qavariqligi $(\underset{\sim}{P}=\underset{\sim}{H}(\vee)\underset{\sim}{B})$, (b) noaniq ma’lumotlarni qayta ishlash uchun murakkablik va hisoblash vaqtining ortib borishi yuzaga keladi.

FNs-maksimal $(\underset{\sim}{P}=\underset{\sim}{H}(\vee)\underset{\sim}{B})$ ning ishlashi *α*-kesmalar yordamida shunday uslubda taqdim etilishi mumkin:

$$P_\alpha=H_\alpha(\vee)B_\alpha=[h_1(\alpha),h_2(\alpha)](\vee)[b_1(\alpha),b_2(\alpha)]= \\ =[h_1(\alpha)\vee b_1(\alpha),h_2(\alpha)\vee b_2(\alpha)], \quad (8)$$

bu yerda $P_\alpha=[p_1(\alpha),p_2(\alpha)]$ natijadan olingan noaniq $\underset{\sim}{P}$ to‘plamning gorizontal modelidir. *α* - kesishlar protsedurasi FNs-maksimal ishlov berish (8) natijasida olingan noaniq to‘plamning universal analitik modellarini sintez qilish uchun $(\underset{\sim}{P}=\underset{\sim}{H}(\vee)\underset{\sim}{B})$ hosil bo‘lgan bir bosqichli hisoblash protsedurasi uchun a'zolik funksiyasi qiymatlari $\mu_{\underset{\sim}{P}}(x)$.

Noaniq arifmetik amallar “TrFNs-Maximum” uchun gorizontal va vertikal natijaviy modellarni shakllantirish.

TrFNlarning $\underset{\sim}{H}\in R,\underset{\sim}{B}\in R$ ning chap novdalari $\underset{\sim}{H}_L\cap\underset{\sim}{B}_L$ va $\underset{\sim}{H}_R\cap\underset{\sim}{B}_R$ o‘ng shoxlari orasidagi kesishuvni alohida ko‘rib chiqamiz. Chap va o‘ng shoxlar uchun kesishish nuqtalari TrFNs-maksimalning natijaviy analitik modellari uchun kommutatsiya nuqtalari hisoblanadi.

Tenglamaning yechimlarini (x_L, x_R argumentlari) :

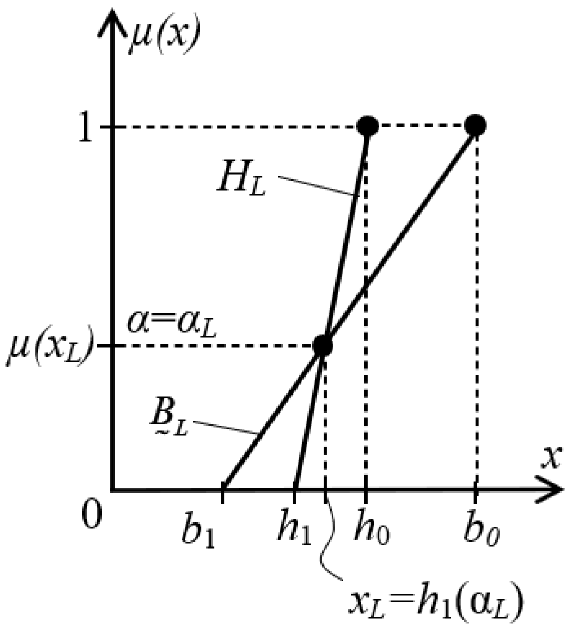
$$\mu_{\underset{\sim}{H}}(x)=\mu_{\underset{\sim}{B}}(x) \quad (9)$$

$\underset{\sim}{H}\in R,\underset{\sim}{B}\in R$ TrFN larning (a) chap shoxlari $\underset{\sim}{H}_L\cap\underset{\sim}{B}_L$ kesishishini tahlil qilish orqali (2-rasm).

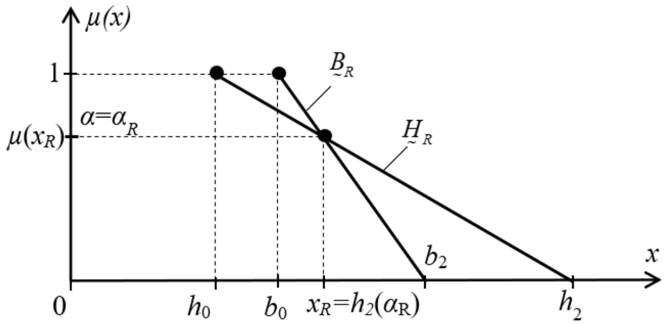
$$E_{H_L}(x,h_1,h_0)\cap E_{B_L}(x,b_1,b_0):\underset{\sim}{H}\in R,\underset{\sim}{B}\in R \quad (10)$$

va (b) $\underset{\sim}{H}\in R,\underset{\sim}{B}\in R$ TrFN larning o‘ng shoxlarini $\underset{\sim}{H}_R\cap\underset{\sim}{B}_R$ (3-rasm) hisoblash mumkin.

$$E_{H_R}(x,h_0,h_2)\cap E_{B_R}(x,b_0,b_2):\underset{\sim}{H}\in R,\underset{\sim}{B}\in R \quad (11)$$



2-rasm. Uchburchak noaniq sonlar (TrFNs) chap shoxlarining kesishishi.



3-rasm. TrFNlarning o‘ng shoxlarining kesishishi.

O‘ng shoxlarning kesishishini (3-rasm) batafsil ko‘rib chiqamiz.

$\alpha \in [0, 1]$ shartli o‘ng shoxlar orasidagi kesishish (11) uchun shunday tenglama hosil qilish mumkin:

$$h_2(\alpha) = b_2(\alpha) = p_2(\alpha) \quad (12)$$

boshqa uslubda qayta yozilishi mumkin:

$$h_2 - \alpha(h_2 - h_0) = b_2 - \alpha(b_2 - b_0) \quad (13)$$

Gorizontal $H_\alpha(2)$ va $B_\alpha(3)$ modellarining to‘g'ri komponentlari asosida:

$$h_2(\alpha) = h_2 - \alpha(h_2 - h_0) \quad (14)$$

va

$$b_2(\alpha) = b_2 - \alpha(b_2 - b_0) \quad (15)$$

(12) va (13) yordamida kesishish nuqtasining $\alpha = \alpha_R$ vertikal koordinatasini topish mumkin:

$$\alpha_R = \frac{b_2 - h_2}{b_2 - b_0 - h_2 + h_0} \quad (16)$$

Bunda ifodani quyidagicha yozish mumkin:

$$\alpha_R = \mu_{\underset{\sim}{H}}(x_R) = \mu_{\underset{\sim}{B}}(x_R) = \mu_{\underset{\sim}{P}}(x_R) \quad (17)$$

(11) shart uchun x_R gorizontal koordinatasidan foydalanish.

Shunday qilib, ikkita juftlik:

$$\left\{\left(h_2(\alpha_R), \alpha_R\right), \left(x_R, \mu_{\underset{\sim}{H}}(x_R)\right)\right\} \quad (18)$$

(11) uchun kesishish nuqtasining koordinatalari gorizontal $\left(h_2(\alpha_R), \alpha_R\right)$ va vertikal $\left(x_R, \mu_{\underset{\sim}{H}}(x_R)\right)$ modellarining to‘g'ri komponentlari uchun tuzilishi mumkin. Bunda $x_R = h_2(\alpha_R), \mu_{\underset{\sim}{H}}(x_R) = \alpha_R$ ega bo‘ladi.

$h_2(\alpha_R)$ parametrini (4) va (16) yordamida aniqlash mumkin:

$$h_2(\alpha_R) = h_2 - \alpha_R(h_2 - h_0) = h_2 - \frac{(b_2 - h_2)(h_2 - h_0)}{b_2 - b_0 - h_2 + h_0}$$

bu yerda $h_2(\alpha_R) \in [\max(h_0, b_0), \max(h_2, b_2)]$.

TrFN ning chap shoxlari orasidagi kesishuv (10) uchun $\alpha = \alpha_L \in [0, 1]$ni aniqlash mumkin va o‘ng shoxlar kesishishi uchun bir xil yondashuvdan foydalanib, ikkita juftlikni aniqlash mumkin:

$$\left\{\left(h_1(\alpha_L), \alpha_L\right), \left(x_L, \mu_{\underset{\sim}{H}}(x_L)\right)\right\} \quad (20)$$

kesishish nuqtasi (10) koordinatalarining gorizontal $\left(h_2(\alpha_L), \alpha_L\right)$ va vertikal $\left(x_L, \mu_{\underset{\sim}{H}}(x_L)\right)$ modellarning chap komponentlari.

Bu holda $x_L = h_2(\alpha_L)$ va $\mu_{\underset{\sim}{H}}(x_L) = \alpha_L$ uchun mos keluvchi α_L va $h_1(\alpha_L)$ parametrlarini quyidagicha ifodalash mumkin:

$$\alpha_L = \frac{b_1 - h_1}{h_0 - h_1 - b_0 + b_1} \quad (21)$$

$$h_1(\alpha_L) = h_1 + \alpha_L(h_0 - h_1) = h_1 + \frac{(b_1 - h_1)(h_0 - h_1)}{h_0 - h_1 - b_0 + b_1} \quad (22)$$

bu yerda $h_1(\alpha_L) \in [\max(h_1, b_1), \max(h_0, b_0)]$.

Ushbu holatda, ishlab chiqilgan analitik modellar (17), (19) yordamida kesishish nuqtalari (10) va (11) uchun $(h_1(\alpha_L), \alpha_L)$ va $(h_2(\alpha_R), \alpha_R)$ koordinatalarining qiymatlarini hisoblash mumkin, (21), (22) va ko‘rib chiqilgan tegishli ma’lumotlar (h_1, b_1, h_0, b_0, h_2, b_2) TrFNs uchun $\underset{\sim}{H} = (h_1, h_0, h_2)$ va $\underset{\sim}{B} = (b_1, b_0, b_2)$ holatda bo‘ladi.

Ishlab chiqilgan modellar (17), (19), (21) va (22) har qanday TrFN juftlari uchun universal hisoblanadi. Masalan, $h_1 < b_1$, $h_0 > b_0$, $h_2 < b_2$ kabi TrFN parametrlari orasidagi munosabatlar uchun ishlab chiqilgan analitik modellar yordamida hosil bo‘lgan MF ning gorizontal $P_\alpha = H_\alpha(\vee)B_\alpha$ va vertikal $\mu_{\underset{\sim}{P}}(x)$ modellarini hosil qilish mumkin (17), (19), (21) va (22).

$$P_\alpha = H_\alpha(\vee)B_\alpha = [h_1(\alpha)\vee b_1(\alpha), h_2(\alpha)\vee b_2(\alpha)] = [p_1(\alpha), p_2(\alpha)] =$$
$$= \left[\begin{Bmatrix} b_1(\alpha), \forall\alpha \,|\, \alpha\in[0,\alpha_L] \\ h_1(\alpha), \forall\alpha \,|\, \alpha\in[\alpha,1] \end{Bmatrix}, \begin{Bmatrix} h_2(\alpha), \forall\alpha \,|\, \alpha\in[\alpha_R,1] \\ b_2(\alpha), \forall\alpha \,|\, \alpha\in[0,\alpha_R] \end{Bmatrix}\right] \quad (23)$$

$$\mu_P(x) = \begin{Bmatrix} 0, \forall(x\le b_1)\bigcup(x\ge b_2) \\ E_{B_L}(x,b,b_0), \forall(b_1 < x \le b_1(\alpha_L)) \\ E_{H_L}(x,h_1,h_0), \forall(h_1(\alpha_L) < x \le h_0) \\ E_{H_R}(x,h_0,h_2), \forall(h_1 < x \le h_2(\alpha_R)) \\ E_{B_R}(x,b_0,b_2), \forall(h_2(\alpha_R) < x \le b_2) \end{Bmatrix} \quad (24)$$

bu yerda $p_1(0) = b_1$; $p_2(0)=b_2$; $p_1(1) = p_2(1) = h_0$;

$$p_1(\alpha) = \begin{Bmatrix} b_1 + \alpha(b_0 - b_1), \forall\alpha \,|\, \alpha\in[0,\alpha_L] \\ h_1 + \alpha(h_0 - h_1), \forall\alpha \,|\, \alpha\in[\alpha_L,1] \end{Bmatrix},$$

$$p_2(\alpha) = \begin{Bmatrix} h_2 + \alpha(h_2 - h_0), \forall\alpha \,|\, \alpha\in[\alpha_R,1] \\ b_2 + \alpha(b_2 - b_0), \forall\alpha \,|\, \alpha\in[0,\alpha_R] \end{Bmatrix}.$$

Yuqorida asosiy komponentlar sifatida umumlashtirilgan hisoblash kutubxonasiga birlashtirilishi mumkin bo‘lgan P_α va $\mu_{\underset{\sim}{P}}(x)$ analitik modellari to‘plamini yaratish hamda $\underset{\sim}{H}\in R, \underset{\sim}{B}\in R$ boshlang'ich noaniq to‘plamlarining chap (21), (22) va o‘ng (16), (19) tarmoqlari orasidagi kesishish parametrlarini aniqlash uchun yondashuv taklif qilingan.

FNs-Maksimal operatsiya natijalari uchun gorizontal va vertikal analitik modellarning hisoblash kutubxonasining sintezi.

Hosil bo‘lgan noqat’iy to‘plam $(\underset{\sim}{P} = \underset{\sim}{H}(\vee)\underset{\sim}{B})$ uchun gorizontal P_α (23) va vertikal $\mu_{\underset{\sim}{P}}(x)$ (24) analitik modellari TrFNs parametrlari orasidagi quyidagi munosabatlarni hisobga olgan holda FNs-maksimal ishlash uchun sintez qilindi:

$$h_1 < b_1,\ h_0 > b_0,\ h_2 < b_2. \quad (25)$$

Shunday qilib, analitik modellar (23) va (24) faqat TrFN $\underset{\sim}{H} = (h_1, h_0, h_2)$ va $\underset{\sim}{B} = (b_1, b_0, b_2)$ holatlarida (25) munosabatlar uchun tasdiqlanadi.

Shu bilan birga, parametrlari o‘rtasidagi $\mathbb{R}$ munosabatlari turlicha bo‘lgan TrFNlar real tizimlar va jarayonlarda juda ko‘p kirish signallarini taqdim etishi mumkin [42]:

$$\{h_1 \mathbb{R} b_1, h_0 \mathbb{R} b_0, h_2 \mathbb{R} b_2\} \quad (26)$$

bu yerda $\mathbb{R}\in\{(<),(>)\}$.

TrFNs $(\underset{\sim}{H}, \underset{\sim}{B})$ parametrlari (h_1, b_1; h_0, b_0; h_2, b_2) orasidagi har xil kombinatsiya (25) uchun FNs-maksimal arifmetik operatsiyani amalga oshirishda olingan MF ning alohida gorizontal va vertikal analitik modellarini sintez qilish kerak.

Olingan noaniq $\underset{\sim}{P}$ to‘plamlarning hisoblash kutubxonasini $\mathbb{R}$ munosabatlari bilan turli kombinatsiyalar (26) uchun TrFNs $\underset{\sim}{H}$ va $\underset{\sim}{B}$ bilan FNs-maksimal arifmetik operatsiyani amalga oshirish uchun gorizontal va vertikal analitik modellarning mos keladigan to‘plamlari sifatida sintez qilaylik.

Maskani ko‘rib chiqamiz:

$$Mask(\underset{\sim}{H}, \underset{\sim}{B}) = \{q_1, q_2, q_3\}, \quad (27)$$

TrFN $\underset{\sim}{H}$ va $\underset{\sim}{B}$ parametrlari orasidagi munosabatlar sifatida mos keladigan $\mathbb{R}$ munosabatlarini tan olish uchun ishlatilishi mumkin [37,42].

Maskadagi (27) q_1, q_2, va q_3 ikkilik ko‘rsatkichlari quyidagicha ko‘rsatilishi mumkin:

$$q_1 = \begin{Bmatrix} 0, if\ h_1 > b_1 \\ 1, if\ h_1 < b_1 \end{Bmatrix};$$
$$q_2 = \begin{Bmatrix} 0, if\ h_0 > b_0 \\ 1, if\ h_0 < b_0 \end{Bmatrix}$$
$$q_3 = \begin{Bmatrix} 0, if\ h_2 > b_2 \\ 1, if\ h_2 < b_2 \end{Bmatrix}; \quad (28)$$

Maska (27) yordamida gorizontal (29)–(44) va vertikal (45)–(52) analitik modellarning $\{PQ_1 \ldots PQ_8\}$ FN-lar parametrlari orasidagi turli $\mathbb{R}$ munosabatlari (26) bilan maksimal operatsiya bajarilgan taqdirda olingan noqat’iy to‘plamlar uchun hisoblash kutubxonasini shakllantirish mumkin PQ_i, (i = 1 ... 8) i-analitik model. Maskalar (27) va mos keladigan modellar, PQ_i, i = 1 ... 8, hisoblash kutubxonasining komponentlari sifatida {PQ_1, PQ_2, ..., PQ_8}, 1-jadvalda keltirilgan.

1-jadval. TrFNs $\underset{\sim}{H}, \underset{\sim}{B} \in R$ ning turli kombinatsiyalari uchun modellar PQ_i, (i = 1 . . . 8) va maskalar { q_1, q_2, q_3 }.

PQ_i, i=1...8	PQ_1	PQ_2	PQ_3	PQ_4	PQ_5	PQ_6	PQ_7 PQ_8
{q_1, q_2, q_3}	{1, 1, 1}	{1, 1, 0} {0, 0, 0}	{1, 0, 1}	{1, 0, 0}	{0, 1, 1}	{0, 1, 0}	{0, 0, 1}

Turli maskalar (27) uchun hosil bo‘lgan noaniq to‘plamning gorizontal $P_\alpha = [p_1(\alpha), p_2(\alpha)]$ va vertikal $\mu_{\underset{\sim}{P}}(x)$ analitik modellarining hisoblash kutubxonasini tuzamiz. 1-jadval.

Gorizontal P_α modellari quyidagilar asosida sintezlanadi: (a) a-kesimlarning parametrlari $\{h_1(\alpha), h_2(\alpha), b_1(\alpha), b_2(\alpha)\}$, (b) a qiymati va (c) TrFN parametrlari $\{h_1, h_2, h_3, b_1, b_2, b_3\}$.

Hisoblash kutubxonasining asosiy komponentlari (29)–(44) {PQ_1, PQ_2, . . . , PQ_8} gorizontal analitik modellarining $P_\alpha = [p_1(\alpha), p_2(\alpha)]$ lari:

- $Mask(\underset{\sim}{H}, \underset{\sim}{B}) = \{q_1, q_2, q_3\} = \{1,1,1\}$ uchun model PQ_1:

$$P_\alpha = [p_1(\alpha), p_2(\alpha)] = [\{b_1(\alpha), \forall\alpha \mid \alpha \in [0, 1]\}, \{b_2(\alpha), \forall\alpha \mid \alpha \in [0, 1]\}], \quad (29)$$

$$[p_1(\alpha), p_2(\alpha)] = [\{b_1 + \alpha(b_0 - b_1), \forall\alpha \mid \alpha \in [0, 1]\}, \{b_2 - \alpha(b_2 - b_0), \forall\alpha \mid \alpha \in [0, 1]\}]; \quad (30)$$

- $Mask(\underset{\sim}{H}, \underset{\sim}{B}) = \{q_1, q_2, q_3\} = \{1,1,0\}$ uchun model PQ_2:

$$P_\alpha = [p_1(\alpha), p_2(\alpha)] = \left[\{b_1(\alpha), \forall\alpha|\alpha \in [0,1]\}, \begin{Bmatrix} b_2(\alpha), \forall\alpha|\alpha \in [\alpha_R, 1] \\ h_2(\alpha), \forall\alpha|\alpha \in [0, \alpha_R] \end{Bmatrix} \right], \quad (31)$$

$$[p_1(\alpha), p_2(\alpha)] = \left[\{b_1 + \alpha(b_0 - b_1), \forall\alpha|\alpha \in [0,1]\}, \begin{Bmatrix} b_2 + \alpha(b_2 - b_0), \forall\alpha|\alpha \in [\alpha_R, 1] \\ h_1 + \alpha(h_2 - h_0), \forall\alpha|\alpha \in [0, \alpha_R] \end{Bmatrix} \right]; \quad (32)$$

- $Mask(\underset{\sim}{H}, \underset{\sim}{B}) = \{q_1, q_2, q_3\} = \{1,0,1\}$ uchun model PQ_3:

$$P_\alpha = [p_1(\alpha), p_2(\alpha)] = \left[\begin{Bmatrix} b_1(\alpha), \forall\alpha|\alpha \in [0, \alpha_L] \\ h_1(\alpha), \forall\alpha|\alpha \in [\alpha_L, 1] \end{Bmatrix}, \begin{Bmatrix} h_2(\alpha), \forall\alpha|\alpha \in [\alpha_R, 1] \\ b_2(\alpha), \forall\alpha|\alpha \in [0, \alpha_R] \end{Bmatrix} \right], \quad (33)$$

$$[p_1(\alpha), p_2(\alpha)] = \left[\begin{Bmatrix} b_1 + \alpha(b_0 - b_1), \forall\alpha|\alpha \in [0, \alpha_L] \\ h_1 + \alpha(h_0 - h_1), \forall\alpha|\alpha \in [\alpha_L, 1] \end{Bmatrix}, \begin{Bmatrix} h_2 - \alpha(h_2 - h_0), \forall\alpha|\alpha \in [\alpha_R, 1] \\ b_2 - \alpha(b_2 - b_0), \forall\alpha|\alpha \in [0, \alpha_R] \end{Bmatrix} \right]; \quad (34)$$

- $Mask(\underset{\sim}{H}, \underset{\sim}{B}) = \{q_1, q_2, q_3\} = \{1,0,0\}$ uchun model PQ_4:

$$P_\alpha = [p_1(\alpha), p_2(\alpha)] = \left[\begin{Bmatrix} b_1(\alpha), \forall\alpha|\alpha \in [0, \alpha_L] \\ h_1(\alpha), \forall\alpha|\alpha \in [\alpha_L, 1] \end{Bmatrix}, \{h_2(\alpha), \forall\alpha|\alpha \in [0,1]\} \right], \quad (35)$$

$$[p_1(\alpha), p_2(\alpha)] = \left[\begin{Bmatrix} b_1 + \alpha(b_0 - b_1), \forall\alpha|\alpha \in [0, \alpha_L] \\ h_1 + \alpha(h_0 - h_1), \forall\alpha|\alpha \in [\alpha_L, 1] \end{Bmatrix}, \{h_2 - \alpha(h_0 - h_1), \forall\alpha|\alpha \in [0,1]\} \right]; \quad (36)$$

- $Mask(\underset{\sim}{H}, \underset{\sim}{B}) = \{q_1, q_2, q_3\} = \{0,1,1\}$ uchun model PQ_5:

$$P_\alpha = [p_1(\alpha), p_2(\alpha)] = \left[\begin{Bmatrix} h_1(\alpha), \forall\alpha|\alpha \in [0, \alpha_L] \\ b_1(\alpha), \forall\alpha|\alpha \in [\alpha_L, 1] \end{Bmatrix}, \{b_2(\alpha), \forall\alpha|\alpha \in [0,1]\} \right], \quad (37)$$

$$[p_1(\alpha), p_2(\alpha)] = \left[\begin{Bmatrix} h_1 + \alpha(h_0 - h_1), \forall\alpha|\alpha \in [0, \alpha_L] \\ b_1 + \alpha(b_0 - b_1), \forall\alpha|\alpha \in [\alpha_L, 1] \end{Bmatrix}, \{b_2 - \alpha(b_0 - b_1), \forall\alpha|\alpha \in [0,1]\} \right]; \quad (38)$$

- $Mask(\underset{\sim}{H}, \underset{\sim}{B}) = \{q_1, q_2, q_3\} = \{0,1,0\}$ uchun model PQ_6:

$$P_\alpha = [p_1(\alpha), p_2(\alpha)] = \left[\begin{Bmatrix} h_1(\alpha), \forall\alpha|\alpha \in [0, \alpha_L] \\ b_1(\alpha), \forall\alpha|\alpha \in [\alpha_L, 1] \end{Bmatrix}, \begin{Bmatrix} b_2(\alpha), \forall\alpha|\alpha \in [\alpha_R, 1] \\ h_2(\alpha), \forall\alpha|\alpha \in [0, \alpha_R] \end{Bmatrix} \right], \quad (39)$$

$$[p_1(\alpha), p_2(\alpha)] = \left[\begin{Bmatrix} h_1 + \alpha(h_0 - h_1), \forall\alpha|\alpha \in [0, \alpha_L] \\ b_1 + \alpha(b_0 - b_1), \forall\alpha|\alpha \in [\alpha_L, 1] \end{Bmatrix}, \begin{Bmatrix} b_2 - \alpha(b_2 - b_0), \forall\alpha|\alpha \in [0, \alpha_R] \\ h_2 - \alpha(h_2 - h_0), \forall\alpha|\alpha \in [\alpha_R, 1] \end{Bmatrix} \right]; \quad (40)$$

- $Mask(\underset{\sim}{H}, \underset{\sim}{B}) = \{q_1, q_2, q_3\} = \{0,0,1\}$ uchun model PQ_7:

$$P_\alpha = [p_1(\alpha), p_2(\alpha)] = \left[\{h_1(\alpha), \forall\alpha|\alpha \in [0,1]\}, \begin{Bmatrix} h_2(\alpha), \forall\alpha|\alpha \in \\ b_2(\alpha), \forall\alpha|\alpha \in \end{Bmatrix} \right. \quad (41)$$

$$[p_1(\alpha), p_2(\alpha)] = \left[\{h_1+\alpha(h_0-h_1), \forall\alpha|\alpha\in[0,1]\}, \begin{cases} h_2+\alpha(h_2-h_0), \forall\alpha|\alpha\in[\alpha_R,1] \\ b_1+\alpha(b_2-b_0), \forall\alpha|\alpha\in[0,\alpha_R] \end{cases}\right];$$

(42)

- $Mask(\underset{\sim}{H},\underset{\sim}{B})=\{q_1,q_2,q_3\}=\{0,0,0\}$ uchun

model PQ_8:

$$P_\alpha = [p_1(\alpha), p_2(\alpha)] = [\{h_1(\alpha), \forall\alpha \mid \alpha\in[0,\ 1]\}, \{h_2(\alpha), \forall\alpha \mid \alpha\in[0,\ 1]\}],$$

(43)

$$[p_1(\alpha), p_2(\alpha)] = [\{h_1+\alpha(h_0-h_1), \forall\alpha \mid \alpha\in[0,\ 1]\}, \{h_2-\alpha(h_2-h_0), \forall\alpha \mid \alpha\in[0,\ 1]\}];$$

(44)

Olingan noaniq to‘plamlarning vertikal (45)–(52) $\mu_{\underset{\sim}{P}}(x)$ modellari $\underset{\sim}{P}=\underset{\sim}{H}(\vee)\underset{\sim}{B}$ quyidagilar asosida sintezlanadi: (a) chap va o‘ng funksiyalar $\{E_{H_L},E_{H_R},E_{B_L},E_{B_R}\}$ va (b) TrFN parametrlari $\{h_1,h_0,h_2,b_1,b_0,b_2\}$.

Vertikal analitik modellar $\mu_{\underset{\sim}{P}}(x)$ hisoblash kutubxonasining {PQ_1, PQ_2, . . . , PQ_8} asosiy komponentlari (45)–(52):

- $Mask(\underset{\sim}{H},\underset{\sim}{B})=\{q_1,q_2,q_3\}=\{1,1,1\}$ uchun

model PQ_1:

$$\mu_{\underset{\sim}{P}}(x)=\begin{cases} 0, \forall(x\le b_1)\bigcup(x\ge b_2) \\ E_{B_L}(x,b_1,b_0), \forall(b_1<x\le b_0) \\ E_{B_R}(x,b_0,b_2), \forall(b_0<x<b_2) \end{cases} = \begin{cases} 0, \forall(x\le b_1)\bigcup(x\ge b_2) \\ (x-b_1)/(b_0-b_1), \forall(b_1<x\le b_0) \\ (b_2-x)/(b_2-b_0), \forall(b_0<x<b_2) \end{cases}$$

(45)

- $Mask(\underset{\sim}{H},\underset{\sim}{B})=\{q_1,q_2,q_3\}=\{1,1,0\}$ uchun

model PQ_2:

$$\mu_{\underset{\sim}{P}}(x)=\begin{cases} 0, \forall(x\le d_1)\bigcup(x\ge h_2) \\ E_{B_L}(x,b_1,b_0), \forall(b_1<x\le b_0) \\ E_{B_L}(x,b_0,b_2), \forall(b_0<x<h_2(\alpha_R)) \\ E_{H_R}(x,h_0,h_2), \forall(h_2(\alpha_R)\le x<h_2) \end{cases} = \begin{cases} 0, \forall(x\le b_1)\bigcup(x\ge b_2) \\ (x-b_1)/(b_0-b_1), \forall(b_1<x\le b_0) \\ (b_2-x)/(b_2-b_0), \forall(b_0<x<h_2(\alpha_R)) \\ (h_2-x)/(h_2-b_0), \forall(h_2(\alpha_R)\le x<h_2) \end{cases}$$

(46)

- $Mask(\underset{\sim}{H},\underset{\sim}{B})=\{q_1,q_2,q_3\}=\{1,0,1\}$ uchun

model PQ_3:

$$\mu_{\underset{\sim}{P}}(x)=\begin{cases} 0, \forall(x\le b_1)\bigcup(x\ge b_2) \\ E_{B_L}(x,b_1,b_0), \forall(b_1<x\le h_1(\alpha_L)) \\ E_{H_L}(x,h_1,h_0), \forall(h_1(\alpha_L)<x<h_0) \\ E_{H_R}(x,h_0,h_2), \forall(h_0<x<h_2(\alpha_R)) \\ E_{B_L}(x,b_0,b_2), \forall(h_2(\alpha_R)\le x<b_2) \end{cases} = \begin{cases} 0, \forall(x\le b_1)\bigcup(x\ge b_2) \\ (x-b_1)/(b_0-b_1), \forall(b_1<x\le h_1(\alpha_L)) \\ (x-h_1)/(h_0-h_1), \forall(c_1(\alpha_L)<x\le c_0) \\ (h_2-x)/(h_2-h_0), \forall(h_0<x<h_2(\alpha_R)) \\ (b_2-x)/(b_2-b_0), \forall(h_2(\alpha_R)\le x<b_2) \end{cases}$$

(47)

- $Mask(\underset{\sim}{H},\underset{\sim}{B})=\{q_1,q_2,q_3\}=\{1,0,0\}$ uchun

model PQ_4:

$$\mu_{\underset{\sim}{P}}(x)=\begin{cases} 0, \forall(x\le b_1)\bigcup(x\ge h_2) \\ E_{B_L}(x,b_1,b_0), \forall(b_1<x\le h_1(\alpha_L)) \\ E_{H_L}(x,h_1,h_0), \forall(h_1(\alpha_L)<x\le h_0) \\ E_{H_R}(x,h_0,h_2), \forall(h_0<x<h_2) \end{cases} = \begin{cases} 0, \forall(x\le b_1)\bigcup(x\ge h_2) \\ (x-b_1)/(b_0-b_1), \forall(b_1<x\le h_1(\alpha_L)) \\ (x-h_1)/(h_0-b_1), \forall(h_1(\alpha_L)<x\le h_0) \\ (h_2-x)/(h_2-h_0), \forall(h_0<x<h_2) \end{cases}$$

(48)

- $Mask(\underset{\sim}{H},\underset{\sim}{B})=\{q_1,q_2,q_3\}=\{0,1,1\}$ uchun

model PQ_5:

$$\mu_{\underset{\sim}{P}}(x)=\begin{cases} 0, \forall(x\le h_1)\bigcup(x\ge b_2) \\ E_{H_L}(x,h_1,h_0), \forall(h_1<x\le h_1(\alpha_L)) \\ E_{B_L}(x,b_1,b_0), \forall(h_1(\alpha_L)<x\le b_0) \\ E_{B_R}(x,b_0,b_2), \forall(b_0<x<b_2) \end{cases} = \begin{cases} 0, \forall(x\le h_1)\bigcup(x\ge b_2) \\ (x-h_1)/(h_0-h_1), \forall(h_1<x\le h_1(\alpha_L)) \\ (x-b_1)/(b_0-b_1), \forall(h_1(\alpha_L)<x\le b_0) \\ (b_2-x)/(b_2-b_0), \forall(b_0<x<b_2) \end{cases}$$

(49)

- $Mask(\underset{\sim}{H},\underset{\sim}{B})=\{q_1,q_2,q_3\}=\{0,1,0\}$ uchun

model PQ_6:

$$\mu_{\underset{\sim}{P}}(x)=\begin{cases} 0, \forall(x\le h_1)\bigcup(x\ge h_2) \\ E_{H_L}(x,h_1,h_0), \forall(h_1<x\le h_1(\alpha_L)) \\ E_{B_L}(x,h_1,h_0), \forall(h_1(\alpha_L)<x\le b_0) \\ E_{B_R}(x,b_0,b_2), \forall(b_0<x<h_2(\alpha_R)) \\ E_{H_L}(x,h_0,h_2), \forall(h_2(\alpha_R)\le x<h_2) \end{cases} = \begin{cases} 0, \forall(x\le h_1)\bigcup(x\ge h_2) \\ (x-h_1)/(h_0-h_1), \forall(h_1<x\le h_1(\alpha_L)) \\ (x-b_1)/(b_0-b_1), \forall(h_1(\alpha_L)<x\le b_0) \\ (b_2-x)/(b_2-h_0), \forall(b_0<x<h_2(\alpha_R)) \\ (h_2-x)/(h_2-h_0), \forall(h_2(\alpha_R)\le x<h_2) \end{cases}$$

(50)

- $Mask(\underset{\sim}{H},\underset{\sim}{B})=\{q_1,q_2,q_3\}=\{0,0,1\}$ uchun

model PQ_7:

$$\mu_{\underset{\sim}{P}}(x)=\begin{cases} 0, \forall(x\le h_1)\bigcup(x\ge b_2) \\ E_{H_L}(x,h_1,h_0), \forall(h_1<x\le h_0) \\ E_{H_L}(x,h_0,h_2), \forall(h_0<x<h_2(\alpha_R)) \\ E_{B_R}(x,b_0,b_2), \forall(h_2(\alpha_R)\le x<b_2) \end{cases} = \begin{cases} 0, \forall(x \\ (x-h_1 \\ (h_2-x \\ (b_2-x \end{cases}$$

(51)

- $Mask(\underset{\sim}{H},\underset{\sim}{B})=\{q_1,q_2,q_3\}=\{0,0,0\}$ uchun

model PQ_8:

$$\mu_{\underset{\sim}{P}}(x)=\begin{cases} 0, \forall(x\le h_1)\bigcup(y\ge h_2) \\ E_{H_L}(x,h_1,h_0), \forall(h_1<x\le h_0) \\ E_{H_R}(x,h_0,h_2), \forall(h_0<x<h_2) \end{cases} = \begin{cases} 0, \forall(x\le h_1)\bigcup(x\ge h_2) \\ (x-h_1)/(h_0-h_1), \forall(h_1<x\le h_0) \\ (h_2-x)/(h_2-h_0), \forall(h_0<x<h_2) \end{cases}$$

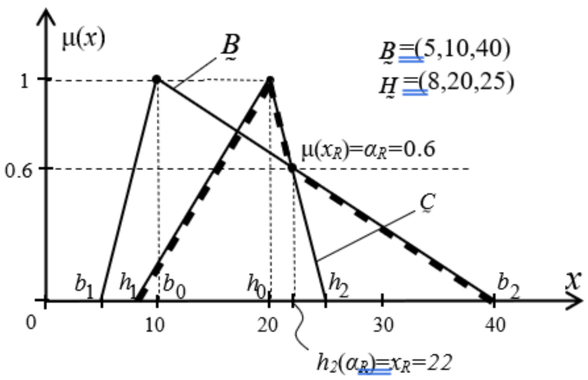
(52)

Shunday qilib, har qanday noqat’iy sonlar juftligi uchun ularning $\{h_1,h_0,h_2,b_1,b_0,b_2\}$ parametrlari orasidagi turli munosabatlar (26) uchun maskani (27) hosil qilish quyidagilarga imkon beradi: (a) mos keladigan sonlarni (avtomatik ravishda) aniqlashga imkon beradi. ishlab chiqilgan hisoblash kutubxonasi (29)–(52) asosida hosil bo‘lgan noqat'iy to‘plamning gorizontal va vertikal analitik modellari va (b) x o‘zgaruvchining turli qiymatlari uchun ushbu analitik modellardan $\mu_{\tilde{P}}(x)$ a’zolik funksiyasi qiymatlarini bir bosqichli hisoblash uchun foydalanish. Keyingi bo‘limda hisoblash kutubxonasi (29)-(52) qo‘llanilishiga asoslangan noqat’iy ma’lumotlarni qayta ishlashning raqamli misolini ko‘rib chiqamiz.

Natija. TrFN uchun FN-maksimal operatsiyani amalga oshirish misolini ko‘rib chiqaylik (4-rasm):

$$\tilde{H} = (8, 20, 25), \tilde{B} = (5, 10, 40) \quad (53)$$

TrFN parametrlari bu yerda: $h_1 = 8$; $b_1 = 5$; $h_0 = 20$; $b_0 = 10$; $h_2 = 25$; $b_2 = 40$.



4-rasm. TrFNs $\tilde{H} \in R$ va $\tilde{B} \in R$ ning FNs-maksimal $\tilde{P} = \tilde{H}(\vee)\tilde{B}$.

Bunda (21) munosabatlarni quyidagicha aniqlash mumkin

$$h_1 > b_1;\ h_0 > b_0;\ h_2 < b_2. \quad (54)$$

(27), (28) va (54) yordamida biz avtomatik ravishda quyidagilarni aniqlashimiz mumkin:

(a) tegishli $Mask(\tilde{H}, \tilde{B}) = \{q_1, q_2, q_3\} = \{0, 0, 1\}$

(b) modellarning hisoblash kutubxonasidan mos keladigan PQ_7 modeli $\{PQ_1, PQ_2, \ldots, PQ_8\}$ (Table 1).

Berilgan (53) noaniq sonlarning $(\tilde{H}, \tilde{B})$ kesishish nuqtasi (11) uchun koordinatalarini ($h_2(\alpha_R)$, α_R) (19) va (16) hisoblaymiz:

$$h_2(\alpha_R) = h_2 - \frac{(b_2 - h_2)(h_2 - h_0)}{b_2 - b_0 - h_2 + h_0} = 25 - \frac{(40-25)(25-20)}{40-10-25+20} = 22.0 \quad (55)$$

$$\alpha_R = \frac{b_2 - h_2}{b_2 - b_0 - h_2 + h_0} = \frac{40-25}{40-10-25+20} = 0.6 \quad (56)$$

Keyingi bosqichda biz (taniqlangan PQ_7 uchun) olingan analitik modellarning hisoblash kutubxonasidan (29)–(52) mos gorizontal P_α (41)–(42) va vertikal $\mu_{\tilde{P}}(x)$ (51) modellarini tanlashimiz mumkin.

Keyinchalik FNs-maksimal $\tilde{P} = \tilde{H}(\vee)\tilde{B}$ uchun olingan gorizontal $P_\alpha = H_\alpha(\vee)B_\alpha$ (57) va vertikal $\mu_{\tilde{P}}(x)$ (58) modellarini (4-rasm) taqdim etamiz:

$$P_\alpha = H_\alpha(\vee)B_\alpha = \begin{bmatrix} \{h_1 + \alpha(h_0 - h_1), \forall\alpha \mid \alpha \in [0,1]\}, \\ \begin{Bmatrix} h_2 + \alpha(h_2 - h_0), \forall\alpha \mid \alpha \in [\alpha_R, 1] \\ b_2 + \alpha(b_2 - b_0), \forall\alpha \mid \alpha \in [0, \alpha_R] \end{Bmatrix} \end{bmatrix} = \begin{bmatrix} \{8 + 12\alpha, \forall\alpha \mid \alpha \in [0,1]\}, \\ \begin{Bmatrix} 25 + 5\alpha, \forall\alpha \mid \alpha \in [0.6, 1] \\ 40 + 30\alpha, \forall\alpha \mid \alpha \in [0, 0.6] \end{Bmatrix} \end{bmatrix}, \quad (57)$$

$$\mu_{\tilde{P}}(x) = \begin{Bmatrix} 0, \forall(x \le h_1) \cup (x \ge b_2) \\ \frac{(x-h_1)}{(h_0-h_1)}, \forall(h_1 < x \le h_0) \\ \frac{(h_2-x)}{(h_2-h_0)}, \forall(h_0 < x \le h_2(\alpha_R)) \\ \frac{(b_2-x)}{(b_2-b_0)}, \forall(h_2(\alpha_R) \le x < b_2) \end{Bmatrix} = \begin{Bmatrix} 0, \forall(x \le 8) \cup (x \ge 40) \\ \frac{(x-8)}{12}, \forall(8 < x \le 20) \\ \frac{(20-x)}{5}, \forall(20 < x \le 22) \\ \frac{(40-x)}{30}, \forall(22 \le x < 40) \end{Bmatrix}. \quad (58)$$

Modellar (57) va (58) aniq analitik modellar bo‘lib, aniq hisoblash natijalarini olishga yordam beradi.

Gorizontal analitik model (57) har qanday $\alpha|\alpha\in[0,1]$ uchun $\tilde{P} = \tilde{H}(\vee)\tilde{B}$ natijaviy noaniq to‘plamning P_α ni hisoblash imkoniyatiga ega. Masalan, α=0,35 uchun P_α natija $P_\alpha = [8 + 12\alpha,\ 40 - 30\alpha] = [8 + 12 \cdot 0.35,\ 40 - 30 \cdot 0.35] = [12.2,\ 29.5]$ kabi hisoblanadi.

Vertikal modeldan (58) foydalanib, $x=x^*$ ning istalgan talab qilinadigan qiymati uchun natijada olingan a'zolik funksiyasi $\mu_{\tilde{P}}(x)$ ning $\mu_{\tilde{P}}(x^*)$ qiymatini hisoblash oson. Masalan, x^* = 21,1 uchun

$\mu_{\underset{\sim}{P}}(21.1)=0.78$, x^* = 23,05 $\mu_{\underset{\sim}{P}}(23.05)=0.565$ ning aniq natijasiga egamiz.

Analitik modellarning ishlab chiqilgan hisoblash kutubxonasi (45)–(52) yordamida olingan aniq natijalarning $(x^*=21.1;\mu_{\underset{\sim}{P}}(21.1)=0.78)$ va $(x^*=23.05;\mu_{\underset{\sim}{P}}(23.05)=0.565)$ bo‘linmalarini an’anaviy α-kesish usuli [29,30,43] yordamida olingan natijalar bilan solishtiramiz. (1) $\alpha_i=\alpha_{i-1}+\delta\alpha,(i=1,\ 2,\ ...,N)$.

Masalan, N = 4 ni tanlaymiz. Bu holda, $\delta\alpha=0.25$ va FNs-maksimal $\underset{\sim}{P}=\underset{\sim}{H}(\vee)\underset{\sim}{B}$ uchun gorizontal modellar P_α FNs-maksimal algoritm (8), dastlabki ma’lumotlar yordamida hisoblanishi mumkin. α = 0 uchun $P_{\alpha=0}=[8,40]$ va iterativ protsedura $\alpha_i=\alpha_{i-1}+0.25,(i=1,2,3,4),$ quyidagicha: $S_{\alpha=0.25}=[11,\ 32.5];S_{\alpha=0.5}=[14,\ 25];S_{\alpha=0.75}=[17,\ 21.25];\ and\ S_{\alpha=1}=[20,\ 20].$

Tegishli gorizontal modelning $P_{\alpha=\alpha_i}$ ning har bir komponentini aniqlash uchun turli formulalar yordamida ko‘p bosqichli hisoblash protsedurasini amalga oshirish kerak:

(a) TrFN $\underset{\sim}{H}$ ning chap filiali uchun gorizontal model (4-1) yordamida $h_1(\alpha_i)$ ni hisoblash;

(b) TrFN $\underset{\sim}{H}$ ning o‘ng filiali uchun gorizontal model (4-1) yordamida $h_2(\alpha_i)$ ni hisoblash;

(c) TrFN $\underset{\sim}{B}$ ning chap filiali uchun gorizontal model (6) yordamida $d_1(\alpha_i)$ ni hisoblash;

(d) TrFN $\underset{\sim}{B}$ ning o‘ng filiali uchun gorizontal model (6) yordamida $d_2(\alpha_i)$ ni hisoblash;

(e) hosil bo‘lgan noaniq to‘plamning $\underset{\sim}{H}$ chap tarmog‘i uchun gorizontal model (8) asosida va Max-operator yordamida $h_1(\alpha_i)$ ni aniqlash kerak: $h_1(\alpha_i)=\ h_1(\alpha_i)\vee b_1(\alpha_i)\ =max.\ \{h_1(\alpha_i),\ b_1(\alpha_i)\};$

(f) hosil bo‘lgan noaniq to‘plamning $\underset{\sim}{H}$ o‘ng tarmog‘i uchun gorizontal model (8) asosida va Max-operator yordamida $h_2(\alpha_i)$ ni aniqlash: $h_2(\alpha_i)=\ h_2(\alpha_i)\vee b_2(\alpha_i)\ =max.\ \{h_2(\alpha_i),\ b_2(\alpha_i)\};$

Tegishli natijaviy noaniq to‘plam

$$\underset{\sim}{P}=\sum_{i=0}^{2N}\frac{\mu_{\underset{\sim}{P}}(x_i)}{x_i}=\frac{0}{8}+\frac{0.25}{11}+\frac{0.5}{14}+\frac{0.75}{17}+\frac{1}{20}+\frac{0.75}{21.25}+\frac{0.5}{25}+\frac{0.25}{32.5}+\frac{0}{40} \quad (59)$$

Agar $x^*\notin\text{supp}(\underset{\sim}{P})$, bu yerda (59) ga ko‘ra $\text{supp}(\underset{\sim}{P})=\{x:\mu_{\underset{\sim}{P}}(x)>0\}=\{(8),11,14,17,20,21.25,25,32.5,(40)\}$ bo‘lsa, u holda, keyingi bosqich sifatida, polinomga yaqinlashish yoki chiziqli interpolyatsiya protseduralarini amalga oshirish kerak. Noqat’iy to‘plam (59) va chiziqli interpolyatsiya usuli asosida $x_i<x^*<x_{i+1}$ uchun $\mu_{\underset{\sim}{P}}(x^*)$ ni topamiz:

$$\mu_{\underset{\sim}{P}}(x^*)=\mu_{\underset{\sim}{P}}(x_i)+\frac{\mu_{\underset{\sim}{P}}(x_{i+1})-\mu_{\underset{\sim}{P}}(x_i)}{x_{i+1}-x_i}(x^*-x_i) \quad (60)$$

Masalan, (a) $x^*=22,x_5<x^*<x_6$ uchun $\mu_{\underset{\sim}{P}}$ (22) ni (60) yordamida quyidagicha hisoblashimiz mumkin:

$$\mu_{\underset{\sim}{P}}(x^*)=\mu_{\underset{\sim}{P}}(x_5)+\frac{\mu_{\underset{\sim}{P}}(x_6)-\mu_{\underset{\sim}{P}}(x_5)}{x_6-x_5}(22-x_5)=0.75+\frac{0.5-0.75}{25-21.25}(22-21.25)=0.6786 \quad (61)$$

(b) $x^*=21.1,x_4<x^*<x_5$ uchun:

$$\mu_{\underset{\sim}{P}}(21.1)=1+\frac{0.75-1}{21.25-20}(21.25-20)=0.78 \quad (62)$$

(c) $x^*=23.05,x_5<x^*<x_6$ uchun:

$$\mu_{\underset{\sim}{P}}(23.05)=0.75+\frac{0.5-0.75}{25-21.25}(23.05-21.25)=0.622 \quad (63)$$

Ishlab chiqilgan hisoblash kutubxonasidan olingan analitik modelga asoslangan hisob-kitoblar bilan solishtirganda tegishli interpolyatsiya xatolari taqdim etiladi(58):

$x^*=22$ uchun, $\Delta_a=|0.6-0.6786|=0.0786$;

$x^*=21.1$ uchun, $\Delta_b=|0.78-0.78|=0$;

$x^*=23.05$ uchun ,$\Delta_c=|0.565-0.622|=0.057$;

bu 13,10%, 0,00% va 10,08% nisbiy qiymatlariga (foizda) mos keladi.

Bu misollar interpolyatsiya xatolarining $x_5<x^*<x_6$ sharti uchun mavjudligini ko‘rsatadi.

Umumiy holatda bu xatolar $[x_k, x_{k+1}]$ va $[x_j, x_{j+1}]$ oraliqlariga tegishli bo‘lgan $x*$ qiymatlari uchun mavjud bo‘lib, ular tegishli shartlarga ega: $h_1(\alpha_L) \in [x_k, x_{k+1}]$ va $h_2(\alpha_R) \in [x_j, x_{j+1}]$. α-kesimlarning N sonini oshirish orqali interpolyatsiya xatolarini kamaytirish mumkin, ammo bu holda hosil bo‘lgan noaniq to‘plam (59) ko‘proq komponentlarga ega bo‘ladi va ko‘p bosqichli hisoblar tufayli hisoblash vaqti sezilarli darajada oshadi.

Xulosa. Ushbu ishning asosiy hissasi metodologik yondashuv va noqat’iy ma’lumotlarni qayta ishlash uchun "bir bosqichli" hisoblash algoritmini ishlab chiqish bilan bog'liq: (a) taklif qilingan uch komponentli maska yordamida FN parametrlari o‘rtasidagi munosabatlarni baholash; (b) noqat’iy ma’lumotlarni qayta ishlashning yuqori aniqligini ta'minlaydigan noaniq to‘plamlar uchun universal gorizontal va vertikal analitik modellarni ishlab chiqish; va (c) FN parametrlari o‘rtasidagi turli kombinatsiyalar uchun "bir bosqichli" hisoblashni amalga oshirish imkonini beruvchi natijaviy analitik modellarning umumlashtirilgan hisoblash kutubxonasini yaratish.

Gorizontal va vertikal analitik modellarning tavsiya etilgan hisoblash kutubxonasi (29)–(52) real vaqt rejimida ma’lumotlarni yanada samarali qayta ishlash imkonini beradi. Uchburchak noqat’iy raqamlar parametrlari bilan FN-maksimal operatsiyalarni qo‘llash va amalga oshirish haqida gap ketganda, TrFNs parametrlari asosida hisoblash kutubxonasidan dastlabki sintezlangan analitik modellarni tanlash kerak. Ushbu yondashuv ma’lumotlarni qayta ishlashning hisoblash tezligini sezilarli darajada oshirishga olib keladi, chunki gorizontal va vertikal modellarning tavsiya etilgan kutubxonadan foydalanish noqat’iy ma’lumotlarni qayta ishlashda faqat bir bosqichli hisoblashni avtomatlashtirish rejimini amalga oshirishga imkon beradi, xususan, FNs-maksimal arifmetik operatsiya $\underset{\sim}{P} = \underset{\sim}{H}(\vee)\underset{\sim}{B}$ ni hisoblash uchun.

Ba'zi amaliy qo‘llanmalarda turli ma’lumotlar oqimlari uchun yig'ish algoritmlari yordamida katta ma’lumotlarni (tasodifiy vaqt seriyalari, tasodifiy oqibatlar va boshqalar) siqilgan noqat’iy to‘plamlar (noqat’iy raqamlar) sifatida ko‘rsatish kerak [15-17]. Taklif etilgan hisoblash kutubxonasidan foydalanib, bunday tasodifiy oqimlarni yoki "Katta ma’lumotlar-noqat’iy ma’lumotlar" ni qayta ishlash uchun to‘rt bosqichli algoritmdan foydalanish mumkin:

(a) Katta ma’lumotlarning har bir tasodifiy oqimi yoki natijasi siqilgan noqat’iy to‘plamga (noqat’iy son) aylantirilishi mumkin [14-18]. Shuningdek tartiblangan noqat’iy raqamlar va tartiblangan noqat’iy to‘plamlar [15] ishlatiladi;

(b) siqilgan noqat’iy to‘plamni uchburchak noqat’iy son bilan yaqinlashtirish va TrFNs parametrlarini aniqlash;

(c) har qanday TrFN juftligi uchun ularning parametrlari o‘rtasidagi munosabatlarga asoslangan maskani (21) aniqlash;

(d) TrFN $\{\underset{\sim}{H}(+)\underset{\sim}{B}, \underset{\sim}{H}(-)\underset{\sim}{B}, \underset{\sim}{H}(\times)\underset{\sim}{B}, \underset{\sim}{H}(\div)\underset{\sim}{B}, \underset{\sim}{H}(\wedge)\underset{\sim}{B}, \underset{\sim}{H}(\vee)\underset{\sim}{B}\}$ bilan noqat’iy arifmetikaning istalgan amalini bajarish uchun hosil bo‘lgan noqat’iy to‘plamning mos gorizontal va vertikal modellarini tanlash (tegishli hisoblash kutubxonasidan) . FN-maksimalni amalga oshirish uchun 4-bo‘limda taklif qilingan hisoblash kutubxonasidan foydalanish mumkin.

TrFN ning noqat’iy maksimallari uchun olingan analitik modellarning hisoblash kutubxonasini sintez qilishning ushbu yondashuvi TRFN ning chap va o‘ng tarmoqlari uchun kesishish nuqtalarini tahlil qilishga asoslangan va turli xil noaniq to‘plamlarning ma’lumotlarini qayta ishlash tegishli hisoblash kutubxonalarini qurish orqali a'zolik funktsiyalarining shakllari (gauss, qo‘ng'iroq shakli, eksponensial, trapezoidal va boshqalar). uchun muvaffaqiyatli qo‘llanilishi mumkin.

Simulyatsiya natijalari turli xil amaliy ilovalar uchun gorizontal va vertikal analitik modellarning tavsiya etilgan hisoblash kutubxonasining universalligi va samaradorligini tasdiqlaydi. Hisoblash kutubxonasi ilovasi turli boshqaruv va qarorlar qabul qilish muammolarini hal qilishda, masalan, “universitet-sanoat” hamkorligining optimal modelini tanlashda [16], biznes, ta’lim, sportda hamkorlarni tanlashda noqat’iy ma’lumotlarni qayta ishlash uchun tavsiya etilishi mumkin. yoki madaniyat almashinuvi [17-18], noaniqlik sharoitida marshrutni rejalashtirish va optimallashtirish [18-19], portfel tanlash [20], mutaxassislarning malaka darajasini baholash, dinamik muhitda robotlarni boshqarish [18-20], ko‘p sensorli ma’lumotlarni qayta ishlash bilan sanoat jarayonlari [21] va boshqalar. Ishlab chiqilgan hisoblash kutubxonasini qo‘llash (29) - (52) FN ning uchburchak shaklidan foydalanish bilan cheklangan. Kelgusi tadqiqotlarda kutubxonaning noqat’iy raqamlarning turli shakllari uchun kengayishi, shuningdek, turli amaliy va real muammolarni hal qilish uchun qo‘llanilishi ko‘rib chiqilishi kerak.

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