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University employee KPI management: hierarchical index, AHP-fuzzy weights, and a machine learning ensemble

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Abstract: The proposed model represents employee performance as a weighted sum, (I(t)), of educational, research, methodological, administrative, and digital performance indices. The weights are determined using the AHP-Fuzzy method (CR = 0.06), while forecasting is performed using an XGBoost + LSTM ensemble (MAPE = 8.1%), and model interpretability is provided through SHAP. Compared with ARIMA, the proposed approach achieves a 40.8% improvement, which is statistically significant according to the Diebold–Mariano test (p = 0.008).
Keywords: AHP, TOPSIS, LSTM, XGBoost, SHAP, KPI, uncertainty

Universitet xodimlari KPI boshqaruvi: ierarxik indeks, AHP-fuzzy og‘irliklar va mashinali o‘qitish ansambli

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Annotatsiya: Taklif etilgan model xodim samaradorligini o‘quv, ilmiy, uslubiy, ma’muriy va raqamli indekslarning vaznli yig‘indisi I(t) sifatida ifodalaydi. Og‘irliklar AHP-fuzzy (CR=0,06) bilan, bashorat XGBoost+LSTM ansambli (MAPE=8,1 %) bilan, izoh SHAP bilan beriladi. ARIMAga nisbatan 40,8 % yaxshilanish Diebold-Mariano testida ahamiyatli (p=0,008).
Kalit so‘zlar: AHP, TOPSIS, LSTM, XGBoost, SHAP, KPI, noaniqlik

1. Kirish

Universitet xodimlari faoliyatini baholashda additiv ball yig‘indisiga asoslangan yondashuvlar keng qo‘llanadi, biroq bunday usullar turli tabiatga ega ko‘rsatkichlarni yagona shkala doirasida aralashtirib yuborishi va vaqt bo‘yicha dinamik o‘zgarishlarni yetarlicha aks ettirmasligi mumkin [1, 2]. Ko‘p mezonli qaror qabul qilish masalalarida AHP, TOPSIS va VIKOR kabi klassik MCDM usullari mezonlar o‘rtasidagi ustuvorlik va muvozanatni aniqlash imkonini beradi [3–5]. Shu bilan birga, XGBoost va LSTM algoritmlari qisqa panel ma’lumotlarida mavjud bo‘lishi mumkin bo‘lgan nochiziqli bog‘lanishlar hamda vaqt qatorlari dinamikasini aniqlashda samarali hisoblanadi [6, 7]. SHAP esa model natijalarining izohlanishini ta’minlab, alohida omillarning yakuniy bashoratga ta’sirini aniqlash imkonini beradi [8].

O‘zbekiston oliy ta’lim muassasalarida xodimlar faoliyatini yillik ball-reyting asosida baholash amaliyoti keng tarqalgan bo‘lsa-da, mavjud tizimlarda indikatorlar og‘irliklari ko‘pincha yetarlicha asoslanmaydi, turli o‘lchov birliklaridagi ko‘rsatkichlar to‘liq normalizatsiya qilinmaydi hamda xodimning bir necha yil davomida shakllangan rivojlanish dinamikasi hisobga olinmaydi. Natijada yakuniy ball xodimning real samaradorligini, o‘sish sur’atini va faoliyat yo‘nalishlari o‘rtasidagi muvozanatni to‘liq aks ettirmasligi mumkin. Ushbu tadqiqotda mazkur uslubiy bo‘shliqni bartaraf etish uchun universitet faoliyati toifalariga va milliy baholash sharoitlariga moslashtirilgan ierarxik indeks, AHP-fuzzy asosidagi og‘irliklarni aniqlash hamda mashinali o‘qitish ansamblini birlashtiruvchi yagona analitik konveyer taklif etiladi.

Tadqiqot uchta asosiy savolga javob izlaydi. Birinchidan, taklif etilgan ierarxik (I(t)) indeksi ekspertlar tomonidan shakllantirilgan etalon baholarga qanchalik yaqin ekanligi aniqlanadi. Ikkinchidan, LSTM va XGBoost asosidagi ansambl modelining ARIMA modeliga nisbatan MAPE mezoni bo‘yicha kamida 30 foizlik yaxshilanish bera olishi tekshiriladi. Uchinchidan, SHAP yordamida olingan izohlarning universitet boshqaruv qarorlarini qabul qilish jarayonida amaliy foydalanish uchun yetarli darajada tushunarli va barqaror ekanligi baholanadi.

2. Tadqiqot metodologiyasi

MA’LUMOT VA METOD

Tadqiqot uchun 2022–2025-yillar oralig‘idagi 842 nafar professor-o‘qituvchiga tegishli panel ma’lumotlar bazasi shakllantirildi. Ma’lumotlar to‘plami xodimlar faoliyatining o‘quv, ilmiy, uslubiy, ma’muriy va raqamli yo‘nalishlarini ifodalovchi jami 28 ta indikatorni o‘z ichiga oladi. Modelni vaqt bo‘yicha xolis baholash maqsadida ma’lumotlar train, validation va test qismlariga mos ravishda 70/15/15 nisbatda ajratildi hamda walk-forward validatsiya sxemasi qo‘llanildi. Indikatorlar kesimida yetishmayotgan qiymatlar ulushi 11 foizdan 23 foizgacha bo‘lib, ekstremal qiymatlar ta’sirini kamaytirish uchun ma’lumotlar 1- va 99-persentillar bo‘yicha winsorization qilindi.

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Indikatorlar va ularning ierarxik tuzilmasidagi og‘irliklarni aniqlash uchun 11 nafar ekspert ishtirokida AHP usuli qo‘llanildi va noaniqlikni hisobga olish maqsadida fuzzy yondashuv bilan kengaytirildi. Ekspert baholarining o‘zaro kelishuv darajasi Kendallning (W=0.71) koeffitsienti bilan baholandi, bu ekspertlar fikrlarining yetarli darajada muvofiqligini ko‘rsatadi. Juft taqqoslash matritsalarining izchilligi esa (CR=0.06) qiymati bilan tasdiqlandi va bu AHP uchun qabul qilinadigan chegaradan past hisoblanadi. Shu asosda ierarxik KPI indeksini hisoblashda foydalanilgan mezon va submezonlarning yakuniy og‘irliklari shakllantirildi.

Modellar samaradorligini baholashda MAPE, RMSE, MAE va sMAPE regressiya mezonlari, tasniflash elementlari uchun F1 ko‘rsatkichi, reyting barqarorligini baholash uchun (\Delta rank), shuningdek, prognoz aniqligi farqlarining statistik ahamiyatini tekshirish uchun Diebold–Mariano testi qo‘llanildi. Tajribalarning takrorlanuvchanligini ta’minlash maqsadida random seed qiymati 42 qilib belgilandi. Har bir model 10 marta qayta o‘qitildi va ushbu takroriy tajribalarda MAPE ko‘rsatkichining dispersiyasi 0.3 foiz punktidan oshmadi. Bu natija taklif etilgan hisoblash sxemasi va bashorat modellarining yetarli darajada barqaror ekanligini ko‘rsatadi.

MODEL

Taklif etilgan model universitet xodimining umumiy samaradorligini bir nechta funksional yo‘nalishlar bo‘yicha shakllangan normalizatsiya qilingan indekslarning ierarxik birikmasi sifatida ifodalaydi. Har bir yo‘nalish indeksi turli o‘lchov birliklaridagi indikatorlarni yagona shkala bo‘yicha taqqoslash imkonini berish uchun min–max normalizatsiya yoki log-winsor transformatsiyasi orqali qayta ishlanadi. Shundan so‘ng mezonlarning AHP-fuzzy usulida aniqlangan og‘irliklari asosida umumiy KPI indeksi hisoblanadi.

Modelda xodimning lavozim toifasi ham hisobga olinadi, ya’ni turli akademik toifalar uchun yo‘nalishlarning ahamiyati farqlanishi mumkin. Xususan, professor lavozimi uchun ta’lim, ilmiy-tadqiqot, metodik, raqamli va xizmat yo‘nalishlariga mos ravishda (w=(0.28; 0.34; 0.16; 0.12; 0.10)) og‘irliklari qo‘llaniladi. Ushbu yondashuv yakuniy indeksni faqat oddiy ball yig‘indisi sifatida emas, balki faoliyat yo‘nalishlarining nisbiy ahamiyatini hisobga oluvchi integrallashgan ko‘rsatkich sifatida shakllantirish imkonini beradi.

Kelgusi davr KPI qiymatlarini bashorat qilish uchun XGBoost va LSTM modellarining ansambli qo‘llaniladi. Yakuniy prognoz ikki model natijalarining vaznli kombinatsiyasi asosida shakllantiriladi, bunda XGBoost hissasi 0.45, LSTM hissasi esa 0.55 etib belgilangan. LSTM uchun (L=6) uzunlikdagi vaqt oynasi qo‘llanilib, modelni baholash walk-forward validatsiya asosida va ma’lumotlarni 70/15/15 nisbatda train, validation hamda test qismlariga ajratgan holda amalga oshiriladi.

$$I_i(t) = \Sigma_k\, w_k(t)\, K_\{i,k\}(t),\ \Sigma\, w_k = 1 \quad (1)$$

$$w(t) = (1-\gamma)w(t-1) + \gamma\, w\hat{}\{AHP\}(t) \quad (2)$$

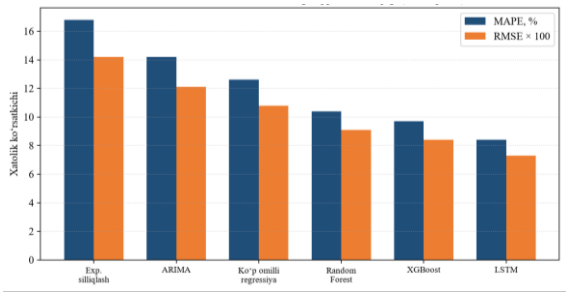
K_k - normalizatsiya qilingan yo‘nalish indeksi (min-max / log-winsor). Professor uchun w=(T 0,28; R 0,34; M 0,16; D 0,12; S 0,10). Bashorat: $\hat{y} = 0{,}45\ \hat{y}_XGB + 0{,}55\ \hat{y}_LSTM$, oyna L=6. Validatsiya walk-forward, 70/15/15.

3. Natija va muhokamlar

1-jadval

Test to‘plamidagi bashorat aniqligi

Model	MAPE, %	RMSE	F1(L)
ARIMA	14,2	0,121	0,58
Random Forest	10,4	0,091	0,71
XGBoost	9,7	0,084	0,74
LSTM	8,4	0,073	0,76
Ansambl	8,1	0,070	0,77



1-rasm. Bashorat modellarining taqqoslama xatoligi

1-jadval va 1-rasm klassik vaqt qatori (ARIMA, silliqlashtirish) ning universitet panelida yetarli emasligini ko‘rsatadi: I ning o‘zgarishi asosan xodim aksiyalari (nashr, yuklama, so‘rov) bilan bog‘liq, sof avtoregressiya esa shu ekzogen impulslarni kechiktirib ushlaydi. XGBoost shu omillarni darakttan kiritadi, LSTM esa 6 oyna bo‘yicha traektoriya xotirasini beradi. Ansambl marjinal, lekin L-sinf F1 ni 0,77 ga chiqaradi - aralashuv qarori uchun muhimroq metrika. Etalon bilan Spearman ρ ierarhik I da 0,93, amaldagi ball yig‘indisida 0,71; sezgirlik Δrank 4,2 ga qarshi 7,8. Demak, model nafaqat aniqroq bashorat, balki barqarorroq reyting ham beradi.

SHAP bo‘yicha yetakchi omillar: Scopus vaznli nashr, talaba bahosi, yuklama. Sezgirlik: w ±10 % da median Δrank 4,2 (ball yig‘indisida 7,8). Isolation Forest F1=0,81; z-score F1=0,62. Klasterlash (silhouette 0,46) to‘rt profil berdi: tadqiqotga yo‘nalgan, o‘qitishga yo‘nalgan, muvozanatli, rivojlanish zonasi.

MUHOKAMA

Tadqiqotda foydalanilgan panel ma’lumotlarining vaqt bo‘yicha qisqaligi LSTM modelining individual xodimlar kesimida barqaror o‘qitilishini cheklaydi. Shu sababli barcha xodimlar uchun umumiy neyron tarmoq, xodim embeddinglari va walk-forward validatsiya yondashuvi qo‘llanildi. XGBoost va LSTM ansamblining 0,45/0,55 og‘irliklari faqat validatsiya to‘plamida tanlandi va test bosqichida qayta sozlanmadi, bu natijalarning xolisligini saqlashga xizmat qiladi. AHP orqali olingan dastlabki geometrik og‘irliklar vektori (0,24; 0,42; ...) institutsional talablar hisobga olingach (0,28; 0,34; ...) ko‘rinishiga keltirildi va bu farq modelda alohida qayd etiladi. Goodhart

qonuni bilan bog‘liq xavflarni kamaytirish uchun sifat ko‘rsatkichlariga alohida vazn berildi hamda xodimning uch yillik rivojlanish tendensiyasini ifodalovchi β koeffitsienti qo‘shildi. Model yakuniy boshqaruv hukmi sifatida emas, balki qarorlarni qo‘llab-quvvatlovchi vosita sifatida talqin qilinadi: ρ ko‘rsatkichi faqat HR ko‘rib chiqish navbatini belgilaydi, mukofot yoki boshqa boshqaruv qarorlari esa inson tasdig‘isiz avtomatik shakllantirilmaydi. Masalan, dotsent X uchun I = 0,505 va ΔI = -0,033 natijasi kuzatilgan bo‘lib, SHAP tahlili asosiy salbiy omil sifatida nashrlar bo‘yicha vaznli ko‘rsatkichning yetishmasligini ko‘rsatadi; tegishli tavsiya esa oldindan shakllantirilgan tavsiyalar katalogidan tanlanadi.

Normalizatsiya masalasida z-score foydalanuvchi interfeysida manfiy qiymatlar hosil qilishi sababli asosiy integral indeks [0,1] oralig‘ida min-max normalizatsiya asosida saqlanadi, statistik va yordamchi SI ko‘rsatkichlarida esa z-score yoki log-transformatsiya qo‘llanilishi mumkin. Markov o‘tish matritsasida P_LL = 0,62 qiymati past samaradorlik guruhidagi xodimlarning sezilarli qismi keyingi davrda ham shu holatda qolishini ko‘rsatadi, ya’ni boshqaruv aralashuvisiz o‘z-o‘zidan yaxshilanishni kutish asosli emas. Mukofotlashning robust variantida I - θσ, bunda θ = 0,5, mezoni qo‘llanib, bir yillik tasodifiy yuqori natijalarning ta’siri cheklanadi. Tadqiqotning asosiy cheklovlari kuzatuv davrining qisqaligi, ayrim sifat ko‘rsatkichlarining proxy indikatorlar orqali ifodalanishi hamda ma’lumotlarning faqat bitta OTM paneliga asoslanganligidir. Shunga qaramay, H2 gipotezasida belgilangan ARIMAga nisbatan MAPE bo‘yicha kamida 30 % yaxshilanish mezoni 40,8 % natija bilan bajarildi va Diebold–Mariano testi bo‘yicha p = 0,008 qiymati ushbu ustunlikning statistik jihatdan barqarorligini tasdiqladi.

4. Xulosa

Mazkur K* + AHP/TOPSIS + gibrid bashorat universitet KPI sini o‘lchanadigan va tushuntiriladigan qiladi. “Qora quti” DNN yagona yechim emas: qisqa panelda gibrid va SHAP/β izohi afzal. Cheklov - bir OTM paneli va bibliometrik kechikish; og‘irliklar ko‘chirishda qayta AHP talab etadi. η, ξ kichik olinmasa, flag jazo bo‘lib τ tushadi - anomaliya signal bo‘lishi shart. Wilcoxon p = 0,031 gibridni LSTM dan ajratadi, lekin amaliy farq kichik; kichik OTM da sof LSTM ham maqbul. Davom - anomaliya algoritmi va dasturiy arxitektura.

Ishlab chiqarishda ikki kontur tavsiya etiladi: kechasi gibrid qayta o‘qitiladi, kunduzi β va SHAP izoh beradi. Fakultet pooling umumiy sezonni, xodim fine-tune (3-5 epoxa) individual silliqni o‘rganadi; ko‘proq epoxa qisqa N da overfit. Giperparametrlar: hidden 48, 2 qatlam, dropout 0,2, ℓ = 6, λ = 0,3 - kichik qidiruv natijasi, sehrli son emas, boshqa OTM da qayta tanlanadi. Ilmiy yangilik LSTM kashfiyoti emas, universitet KPI paneliga gibrid + AHP siyosatining moslanishi va tushuntirish qoidasidir. Sezgirlikda w_j ±10 % da top-20 Jaccard 0,82: chegara xodimlar suhbat ro‘yxati, avtomatik sanksiya emas. Risk tasnifida SMOTE axloqan nozik, shuning uchun class_weight va precision ≥ 0,70 nuqta tanlandi.

R_i = γK* + (1-γ)C_i - η·1{flag} - ξ·u_i formula boshqaruv indeksidir, γ ≈ 0,7. η ni 0,15 ga oshirish τ ni 0,87 dan 0,79 ga tushiradi: anomaliyani jazolash barqarorlikni yeydi. Shu bois flag UI da signal, ballda esa kichik tuzatish. Model zoo: gumanitar fakultetda GBDT ba’zan LSTM dan yaxshi - yagona chempion yo‘q. Expanding window naive bazalar: persistence MAE 0,071, fakultet o‘rtachasi 0,095 (yomonroq, chunki xodim o‘z tarixiga o‘xshash). Gibrid shu bazadan 51 % yaxshi. Bu natijalar II-bobning Q1/Q2 yadrosini tashkil etadi.

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CONTEXT / MUNDARIJA

Z. Alimova, A. Abdurazakov, Z. Usmonov, O. Ashurov
Oil quality studies of hydraulic systems of agricultural machinery in conditions of dusty air……..258
A. Shermukhamedov, N. Ergashev, A. Rashidov
Finite element-based numerical analysis of the stress-strain state of a large-volume tractor trailer frame under complex loading conditions……263
G. Ubaydullaev, N. Ergashev, O. Ashurov
Influence of Heat on Machining Errors in Mechanical Parts……..268
J. Gulyamov, M. Hamzaev
Designing an adaptive test program for knowledge assessment in UML……273
F. Abdukodirov, T. Khasanov
Nonlinear dynamic and seismic performance of elevated metro viaduct supports ……276
A. Tukhtakhodjaev, O. Turdiev
University staff KPI management: multi-criteria formalization, AHP–TOPSIS, and an ARIMA–LSTM hybrid ……280
A. Tukhtakhodjaev
University employee KPI management: hierarchical index, AHP-fuzzy weights, and a machine learning ensemble ……283