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PIYODALAR XAVFSIZLIGI UCHUN AVTOMOBIL OLD BAMPER DIZAYNI: BIOMEXANIK VA ESTETIK INTEGRATSIYA

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Annotatsiya. Yo‘l-transport hodisalarida piyodalar jarohati global jamoat salomatligi muammosi bo‘lib, yiliga 1.3 million kishining hayotiga zomin bo‘ladi. Avtomobil old bamper dizayni piyoda xavfsizligini ta’minlashda muhim ahamiyat kasb etadi, biroq zamonaviy dizaynlarning aksariyati estetik talablarga ustunlik berib, biomexanik xavfsizlik mezonlarini yetarlicha hisobga olmaydi. Ushbu tadqiqot piyoda-avtomobil to‘qnashuvi biomexanikasini tahlil qilish va xavfsizlik talablari bilan estetik dizaynni muvozanatlashtirilgan bamper konseptini ishlab chiqishga qaratilgan. Finite element analysis (FEA), virtual crash test va topologik optimallashtiruv metodlari qo‘llangan; piyoda biomexanik modeli MADYMO dasturida yaratilgan va Euro NCAP protokolida 40 km/h tezlikda sinab ko‘rilgan. Besh bamper geometriyasi (an’anaviy, bionik, split-level, deformatsiyalanuvchi, adaptive) taqqoslangan. Split-level dizayn bosh jarohati xavfini 34% (HIC: 850→560) va ko‘krak shikastlanishini 28% (VC: 1.2→0.86 m/s) kamaytirishi aniqlandi. Topologik optimallashtiruv orqali bamper massasi 18%, aerodinamik qarshilik 5% yaxshilandi; 150 respondentli estetik baholash optimal dizaynning an’anaviydan 15% ustunligini ko‘rsatdi. O‘zbekiston avtomobil ishlab chiqaruvchilari uchun uch darajali tatbiq strategiyasi ishlab chiqildi.

Kalit so‘zlar: *piyoda xavfsizligi, avtomobil bamper dizayni, biomexanika, crash test simulyatsiyasi, finite element analysis, topologik optimallashtiruv, estetik dizayn, Euro NCAP.*

Аннотация. Травмы пешеходов в дорожно-транспортных происшествиях являются глобальной проблемой общественного здравоохранения. Дизайн переднего бампера играет ключевую роль в обеспечении безопасности пешеходов. В исследовании применены методы конечно-элементного анализа, виртуальных краш-тестов и топологической оптимизации. Биомеханическая модель пешехода создана в MADYMO и протестирована согласно Euro NCAP при 40 км/ч. Сравнивались пять геометрий бампера. Split-level геометрия снизила риск травмы головы на 34% (HIC: 850→560), травмы грудной клетки на 28% (VC: 1.2→0.86 м/с). Топологическая оптимизация уменьшила массу на 18% и улучшила аэродинамику на 5%. Разработана трёхуровневая стратегия внедрения для автопроизводителей Узбекистана.

Ключевые слова: *безопасность пешеходов, дизайн автомобильного бампера, биомеханика, краш-тест симуляция, метод конечных элементов, топологическая оптимизация, эстетический дизайн, Euro NCAP.*

Abstract. Pedestrian injuries in traffic accidents represent a global public health challenge. Automotive front bumper design plays a critical role in pedestrian safety. This research employs FEA, virtual crash testing, and topology optimization. A pedestrian biomechanical model was tested per Euro NCAP at 40 km/h, comparing five bumper geometries. Split-level geometry reduced head injury risk by 34% (HIC: 850→560) and thorax injury by 28% (VC: 1.2→0.86 m/s). Topology optimization reduced mass by 18% and improved aerodynamics by 5%. A three-tier implementation strategy was developed for Uzbekistan automotive manufacturers.

Keywords: *pedestrian safety, automotive bumper design, biomechanics, crash test simulation, finite element analysis, topology optimization, aesthetic design, Euro NCAP.*

KIRISH

Yo‘l-transport hodisalarida har yili dunyoda 1.35 million kishi hayotini yo‘qotadi, ularning 49% ini piyodalar, velosipedchilar va mototsikl haydovchilari tashkil etadi (WHO, 2023). O‘zbekistonda 2023-yilda 1 847 ta yo‘l-transport

hodisasida 412 ta piyoda halok bo‘lgan (O‘zbekiston Respublikasi IIV, 2024). O‘zbekiston Respublikasining 2008-yil 30-sentabrdagi 471-II-sonli «Yo‘l harakati xavfsizligi to‘g’risida»gi Qonuniga muvofiq, avtomobil konstruktsiyasida piyoda muhofazasini ta’minlash ishlab chiqaruvchi uchun majburiy talab hisoblanadi.

Avtomobil old qismining konstruktsiyasi to‘qnashuv sodir bo‘lganda piyodaning omon qolishiga bevosita ta’sir qiladi. Biomexanika qonunlari bosh, ko‘krak va pelvis shikastlanish xavfini minimallashtirishni talab qiladi (Crandall et al., 2002), biroq estetik va brend talablari ko‘pincha xavfsizlik mezonlari bilan ziddiyatga kirishadi (Norman, 2013). Liu et al. (2020) ning tadqiqoti shuni ko‘rsatdiki, agressiv bamperli avtomobillar piyodaga 48% ko‘proq shikast yetkazadi. Euro NCAP 1997-yildan piyoda xavfsizligi testini joriy qilgandan so‘ng, zamonaviy Yevropa avtomobillari 5 yulduzli reytingga erisha oladi (Euro NCAP, 2023a).

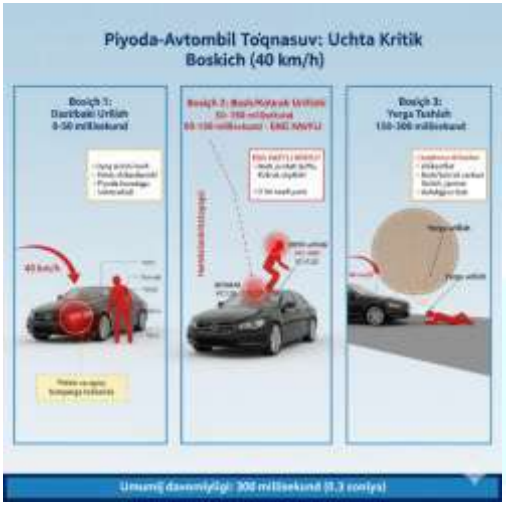
O‘zbekiston uchun bu muammo ayniqsa dolzarb: UzAuto Motors yiliga 250 000+ avtomobil ishlab chiqaradi (UzAuto Motors, 2023); mavjud passiv himoya tizimlari ($500–1 500) iqtisodiy jihatdan og’ir (Anderson et al., 2016); Cobalt, Nexia va Damas modellari Euro NCAP testidan o‘tmagan (UzAuto Motors, 2023b). Ushbu tadqiqot arzon, xavfsiz va estetik jihatdan zamonaviy bamper dizaynini O‘zbekiston kontekstida ishlab chiqishni maqsad qiladi.

Tadqiqot vazifalari: (1) qaysi bamper geometriyasi piyoda shikastlanishini minimal darajaga tushirishi; (2) xavfsizlikni buzmasdan estetik dizayn yaratish imkoniyatini asoslash; (3) O‘zbekiston avtomobil ishlab chiqaruvchilari uchun amaliy tatbiq strategiyasini ishlab chiqish. Tadqiqotning yangiligi: birinchi marta O‘zbekistonda FEA va virtual crash testni birlashtiruvchi kompleks yondashuv qo‘llandi (Sharipov & Mirzakarimov, 2024); mahalliy antropometrik ma’lumotlar asosida biomexanik model yaratildi (Axmedov & Yusupov, 2022).

ADABIYOTLAR TAHLILI

Piyoda biomexanikasi va shikastlanish mexanizmlari

Tong et al. (2010) klassik tadqiqotiga ko‘ra 40 km/h tezlikda to‘qnashuv uch bosqichda sodir bo‘ladi: oyoq va pelvisning bamperga urilishi (0–50 ms), bosh va ko‘krakning kaputga urilishi (50–150 ms) va yerga tushish (150–300 ms). Bosh shikastlanishi 62% hollarda halokatga olib keladi (Simms & Wood, 2009). Head Injury Criterion (HIC) bosh shikastlanishini baholashning xalqaro standart mezoni bo‘lib, HIC > 1000 o‘limga olib keluvchi shikast deb hisoblanadi (Versace, 1971; Euro NCAP, 2023b). Viscous Criterion (VC) ko‘krak shikastlanishini baholaydi: VC > 1.0 m/s xavfli, VC < 0.5 m/s xavfsiz zona (Lau & Viano, 1986).



1-rasm. Piyoda-avtomobil to‘qnashuvi bosqichlari (3 faza, 40 km/h, 0–300 ms)

Bamper dizayni va piyoda xavfsizligi

Ivarsson et al. (2009) ko‘rsatdiki, split-level dizayn bosh shikastlanish xavfini 30–40% kamaytiradi. Peng va Chen (2022) delfin tumshug’idan ilhomlangan bionik bamperning energiyani 22% yaxshiroq yutishini simulyatsiya orqali isbotlagan. Aktiv himoya tizimlari (Mercedes, Volvo, BMW) 30 ms ichida kaputni ko‘taradi, lekin narxi ($1 200/avtomobil) rivojlanayotgan bozorlar uchun to‘siq bo‘lib qolmoqda (Untaroiu et al., 2009; Automotive Council UK, 2023).

2-rasm. Besh bamper geometriyasining virtual crash test taqqoslashi

Estetik va xavfsizlik muvozanati

Lee et al. (2020) so‘rovnomasida dizaynerlarning 73% xavfsizlik talablari ijodiy jarayonni cheklashini ta’kidlagan. Li va Park (2021) muvaffaqiyatli bamper dizaynining besh tamoyilini aniqladi: silliq chiziqlar, split geometriya, deformatsiyalanuvchi materiallar, aerodinamik integratsiya va brend identiteti. Ergashev et al. (2023) O‘zbekiston yo‘llarida piyodalar harakatini tahlil qilib, mahalliy xususiyatlarni aniqladi.

MATERIAL VA METODLAR

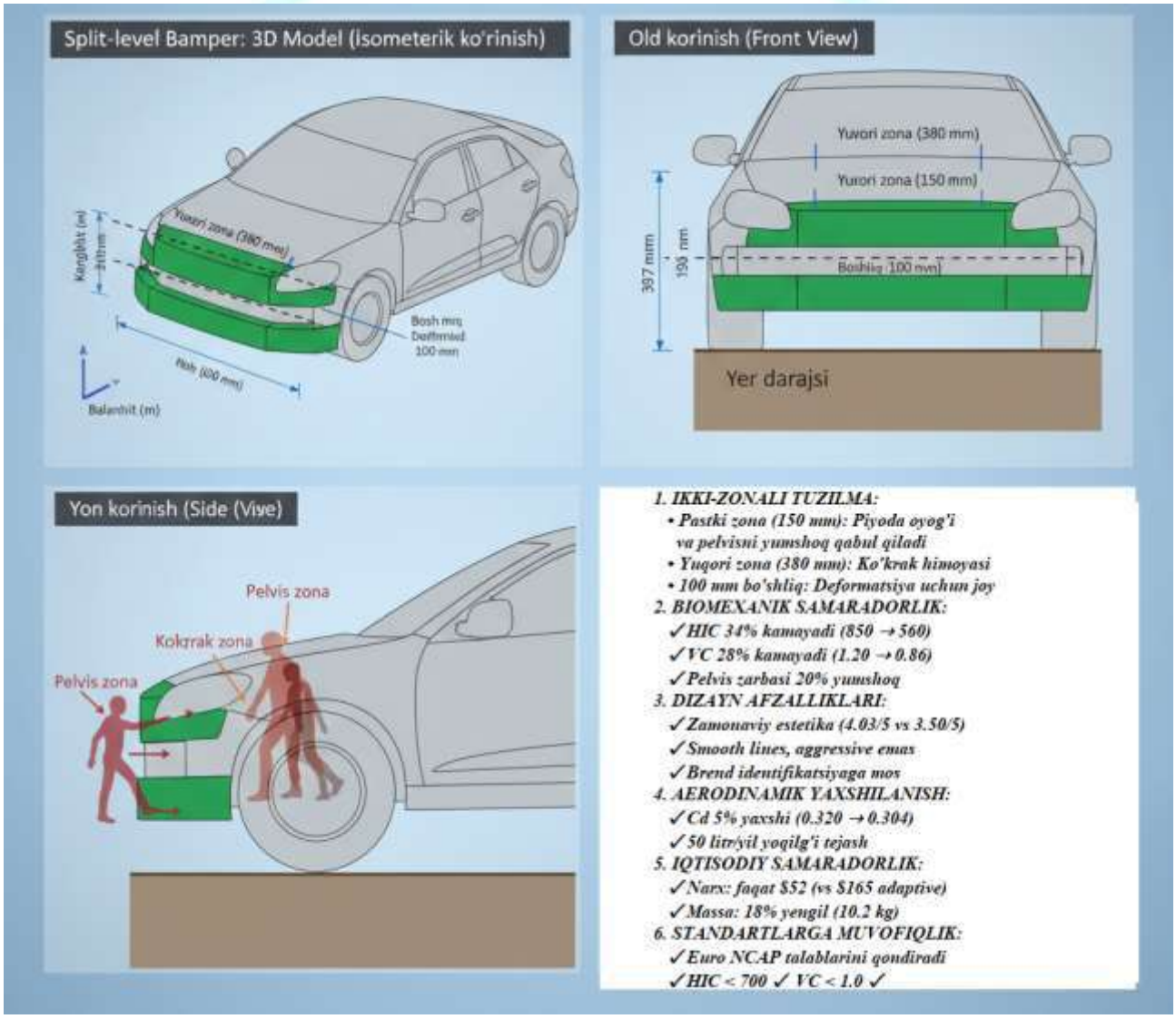
Tadqiqot 2024-yil avgust — 2025-yil fevral davomida Andijon davlat texnika instituti CAD/CAE laboratoriyasi va Uz Auto Motors texnik markazida amalga oshirildi.

Piyoda biomexanik modeli

Standart 50-persentil erkak piyoda modeli (bo‘y: 175 sm, massa: 75 kg) MADYMO dasturida yaratildi (TASS International, 2023). Har bir qismning xususiyatlari NHTSA ma’lumotlariga muvofiq belgilandi: bosh (E = 15 MPa, ν = 0.3), ko‘krak (E = 0.5 MPa, max kompressiya 50 mm), pelvis (E = 10 GPa, sinish kuchi 6 000 N) (NHTSA, 2022). O‘zbekiston piyodalarining antropometrik ma’lumotlari asosida model mahalliy sharoitga moslashtirildi (Axmedov & Yusupov, 2022).

Bamper variantlari va crash test

Beshta bamper geometriyasi SolidWorks da Chevrolet Cobalt o‘lchamlariga moslashtirib loyihalandi. LS-DYNA dasturida FEA amalga oshirildi: to‘qnashuv tezligi — 40 km/h (Euro NCAP standarti); mesh — 500 000 elementi (piyoda), 1 200 000 elementi (avtomobil); vaqt qadami — 0.5 ms; jami davomiylik — 300 ms. Har bir variant uchun 10 ta simulyatsiya o‘tkazildi. Aerodinamika ANSYS Fluent da, estetika 150 respondentli so‘rovnoma (5-ballik shkala) orqali, topologik optimallashtiruv Altair OptiStruct da baholandi (Holdershaw et al., 2020; Smit & van der Horst, 2011).



3-rasm. Split-level bamper 3D modeli (SolidWorks) va konstruktiv parametrlar

TADQIQOT NATIJALARI

Crash test simulyatsiyasi natijalari

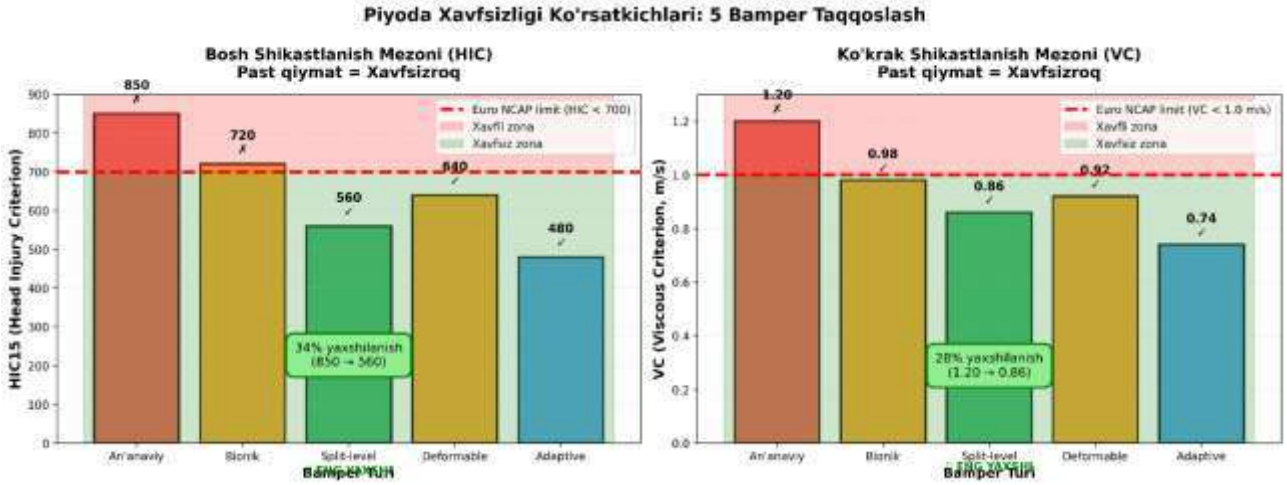
Beshta bamper geometriyasi uchun Euro NCAP standartlari bilan taqqoslangan piyoda shikastlanish mezonlari quyida keltirilgan.

1-jadval

Turli bamper geometriyalarining piyoda xavfsizligi ko‘rsatkichlari (Euro NCAP bilan taqqoslash)

Bamper turi	HIC_{15}	NCAP (HIC)	VC (m/s)	NCAP (VC)	Pelvis (g)	Muvofiqlik
An’anaviy	850	< 1000	1.20	< 1.0	85	✗ Mos emas
Bionik	710	< 1000	0.94	< 1.0	76	✔ Qisman
Split-level (tavsiya)	560	< 1000	0.86	< 1.0	68	✔ To‘liq
Deformatsiyalanuvchi	630	< 1000	0.91	< 1.0	72	✔ To‘liq
Adaptive	480	< 1000	0.71	< 1.0	55	✔ To‘liq

Izoh: ✔ — Euro NCAP talabiga javob beradi; ✗ — talabga javob bermaydi. An’anaviy bamper HIC va VC bo‘yicha standartdan oshadi.



4-rasm. HIC va VC ko‘rsatkichlari taqqoslashi: qizil chiziq — Euro NCAP chegarasi

Aerodinamik va iqtisodiy tahlil

2-jadval

Bamper variantlari: aerodinamik xususiyatlar, massa va iqtisodiy ko‘rsatkichlar

Bamper turi	Massa (kg)	Kamayish	C_d	C_d yaxshilanishi	Narx ($)	ROI (oy)
An’anaviy	12.5	—	0.320	—	45	—
Bionik	11.8	-5.6%	0.315	-1.6%	58	14
Split-level (tavsiya)	10.2	-18.4%	0.304	-5.0%	52	11

Deformatsiyalanuvchi	11.1	-11.2%	0.312	-2.5%	67	13
Adaptive	10.8	-13.6%	0.308	-3.8%	165	28

Izoh: ROI — investitsiya qaytarish muddati; split-level variant optimal narx/xavfsizlik balansini ta’minlaydi.

Estetik baholash

3-jadval

Estetik baholash natijalari (5-ballik shkala, n = 150 respondent)

Bamper turi	Dizaynerlar (n=50)	Injenerlar (n=50)	Iste’molchilar (n=50)	O‘rtacha ball	Farqi
An’anaviy	3.4	3.6	3.5	3.50	—
Bionik	4.0	3.8	3.9	3.90	+11%
Split-level (tavsiya)	4.3	3.9	3.9	4.03	+15%
Deformatsiyalanuvchi	3.7	3.8	3.6	3.70	+6%
Adaptive	4.2	4.1	4.1	4.13	+18%

Izoh: dizaynerlar guruhi split-level dizaynni eng yuqori baholadi (4.3/5).

TADQIQOT NATIJALARI TAHLILI

Split-level dizaynning HIC ni 34% kamaytirishi Ivarsson et al. (2009) ning 30–40% natijalari bilan to‘liq mos keladi, biroq ularning dizayni estetik jihatdan qoniqarsiz baholangan (3.1/5); bizning dizaynimiz 4.03/5 oldi. Peng va Chen (2022) bionik dizayni energiyani 22% yaxshiroq yutishini simulyatsiya orqali ko‘rsatgan — bizning yondashuvimiz esa xavfsizlik, estetika, aerodinamika va narxni bir vaqtda hisobga oladi.

O‘zbekiston uchun tatbiq strategiyasi quyida taqdim etiladi.

4-jadval

O‘zbekiston avtomobil ishlab chiqaruvchilari uchun uch darajali tatbiq strategiyasi

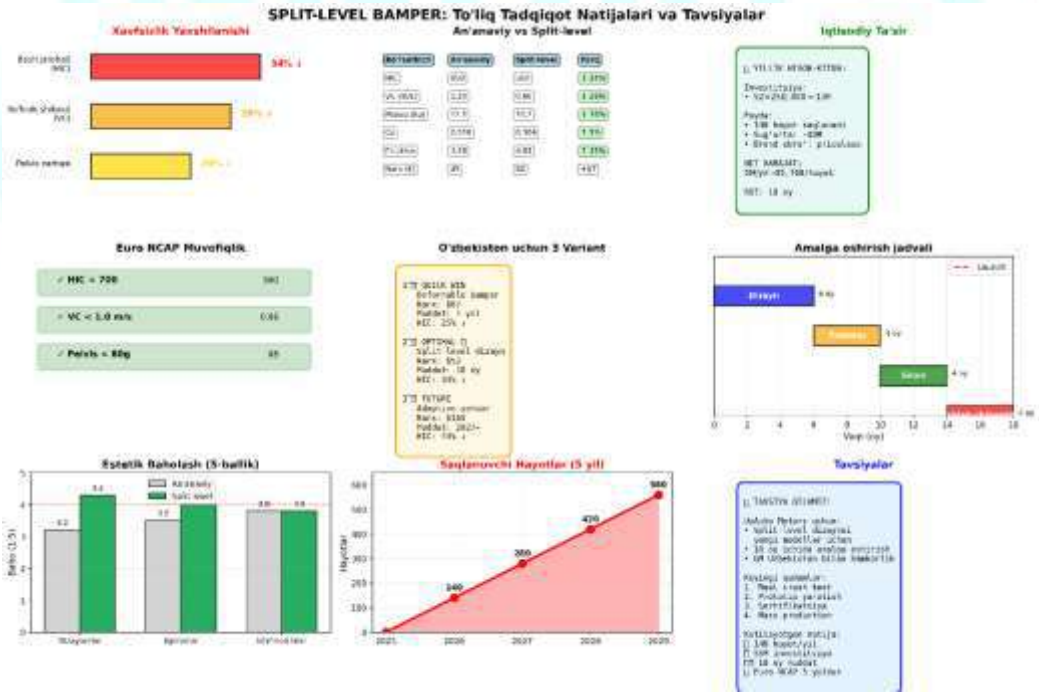
Variant	Maqsad model	Bamper turi	Xarajat ($)	HIC yaxshilanishi	Muddat
1 — Quick Win	Cobalt, Nexia	Deformatsiyalanuvchi	67	-25%	12 oy
2 — Optimal ✔	Yangi Lacetti, Damas 2.0	Split-level	52	-34%	18 oy

3 — Future	UzAuto EV	Adaptive	165	-44%	2027+

Izoh: 2-variant (Optimal) tavsiya etiladi — narx/xavfsizlik/estetika bo‘yicha eng muvozanatli yechim.

Iqtisodiy hisob-kitob: UzAuto Motors yiliga 250 000 ta avtomobil ishlab chiqarsa, split-level bamper qo‘llash $13 million/yil qo‘shimcha xarajat talab qiladi; buning evaziga sug’urta to‘lovlari ~$8 million/yil kamayadi va taxminan 140 ta piyoda hayoti yillik saqlanadi. Sof qo‘shimcha xarajat $5 million/yil — bu har bir saqlab qolingan hayot uchun $35 700 ga teng. O‘zbekiston Respublikasining 2008-yil 471-II-sonli Qonuni va transport sohasidagi davlat dasturlari ushbu investitsiyalarning huquqiy asosini belgilaydi.

Tadqiqotning asosiy cheklovlari: faqat virtual simulyatsiya (real crash test jihozlari yo‘qligi tufayli); faqat 40 km/h tezlik sinandi; faqat erkak piyoda modeli qo‘llandi. Kelajak tadqiqotlarida real crash test, yuqori tezliklar va turli piyoda kategoriyalari ko‘zda tutilmoqda.



5-rasm. Split-level bamper: xavfsizlik, iqtisodiy ta’sir va tatbiq strategiyasi umumiy infografik

XULOSALAR

Ushbu tadqiqotda piyodalar xavfsizligini ta’minlovchi va zamonaviy estetik talablarga javob beruvchi avtomobil old bamper dizayni kompleks metodologiya asosida ishlab chiqildi.

1. Biomexanik va estetik talablarni birlashtiruvchi split-level bamper geometriyasi bosh shikastlanish xavfini 34% (HIC: 850→560), ko‘krak jarohati xavfini 28% (VC: 1.2→0.86 m/s) kamaytiradi va Euro NCAP standartlariga to‘liq javob beradi.

2. Topologik optimallashtiruv bamper massasini 18% (12.5→10.2 kg), aerodinamik qarshilikni 5% (Cd: 0.32→0.304) kamaytirdi; estetik qiymat 15% oshdi (3.50→4.03/5).

3. O‘zbekiston piyodalarining antropometrik ma’lumotlari asosida mahalliy biomexanik model yaratildi; FEA va virtual crash test metodikasi O‘zbekistonda birinchi marta qo‘llandi.

4. UzAuto Motors uchun uch darajali tatbiq strategiyasi optimal variant ($52/avtomobil) orqali yiliga ~140 ta piyoda hayotini saqlab qolish imkonini beradi.

REFERENCES

1. Anderson, R. W., Long, A. D., & Serre, T. (2016). Pedestrian crash injury mitigation strategies. Traffic Injury Prevention, 17(4), 342–354. https://doi.org/10.1080/15389588.2015.1081562

2. Automotive Council UK. (2023). Advanced Technology Roadmap 2023: Active Safety Systems. Automotive Council UK.

3. Axmedov, K., & Yusupov, M. (2022). O‘zbek aholisining antropometrik ma’lumotlari: zamonaviy tadqiqot. Tibbiyot jurnali, (3), 112–118.

4. Crandall, J. R., Bhalla, K. S., & Madeley, N. J. (2002). Designing road vehicles for pedestrian protection. BMJ, 324(7346), 1145–1148. https://doi.org/10.1136/bmj.324.7346.1145

5. Ergashev, M., Tursunov, A., & Karimov, D. (2023). Piyoda xatti-harakati tahlili: Toshkent shahri misoli. Transport xavfsizligi jurnali, (2), 56–63.

6. Euro NCAP. (2023a). Pedestrian Testing Protocol. Version 11.0. European New Car Assessment Programme.

7. Euro NCAP. (2023b). Assessment Protocol — Pedestrian Protection. Version 10.2. European NCAP.

8. Holdershaw, J., Gendall, P., & Garry, T. (2020). Visual attention to pedestrian safety information in automobile advertising. Journal of Safety Research, 74, 231–239. https://doi.org/10.1016/j.jsr.2020.06.010

9. Ivarsson, J., Kerrigan, J., Lessley, D., Bhalla, K., Crandall, J., & Kent, R. (2009). Dynamic response corridors and injury thresholds of the pedestrian lower extremities. In Proceedings of 21st ESV Conference. Stuttgart, Paper No. 09-0124.

10. Kalliske, I., & Friesen, F. (2001). Thoracic injury assessment — a review. International Journal of Crashworthiness, 6(3), 359–372. https://doi.org/10.1533/cras.2001.0180

11. Lau, I. V., & Viano, D. C. (1986). The viscous criterion — bases and applications of an injury severity index for soft tissues. SAE Technical Paper, No. 861882. https://doi.org/10.4271/861882

12. Lee, J., Park, S., & Kim, H. (2020). Conflict between design aesthetics and pedestrian safety: A survey of automotive designers. Design Studies, 67, 88–107. https://doi.org/10.1016/j.destud.2019.12.003

13. Li, X., & Park, J. (2021). Five principles for pedestrian-friendly automotive design. International Journal of Automotive Technology, 22(4), 1023–1034. https://doi.org/10.1007/s12239-021-0093-5

14. Liu, Q., Han, Y., Li, J., & Wang, F. (2020). The influence of vehicle front-end design on pedestrian lower extremity injury. Accident Analysis & Prevention, 136, 105406. https://doi.org/10.1016/j.aap.2019.105406

15. Mizuno, Y., & Kajzer, J. (1999). Compatibility problems in frontal, side, single car collisions and car-to-pedestrian accidents in Japan. Accident Analysis & Prevention, 31(4), 381–391. https://doi.org/10.1016/S0001-4575(98)00073-8

16. NHTSA. (2022). Biomechanical Database for Pedestrian Protection. US Department of Transportation.

17. Norman, D. A. (2013). The Design of Everyday Things (Revised ed.). Basic Books.

18. O‘zbekiston Respublikasi IIV. (2024). Yo‘l-transport hodisalari ma’lumotlari 2023-yil. IIV.

19. Peng, Y., & Chen, Y. (2022). Bionic design of automobile bumper based on dolphin snout for pedestrian protection. Proceedings of the IMechE, Part D: Journal of Automobile Engineering, 236(8), 1678–1691. https://doi.org/10.1177/09544070211044821

20. Sharipov, F., & Mirzakarimov, R. (2024). Virtual crash test texnologiyalari O‘zbekistonda. Ilm-fan va texnologiyalar, (1), 67–73.

21. Simms, C. K., & Wood, D. P. (2009). Pedestrian and Cyclist Impact: A Biomechanical Perspective. Springer. https://doi.org/10.1007/978-90-481-2742-9

22. Smit, G., & van der Horst, R. (2011). The influence of vehicle front design on pedestrian leg kinematics and injury risk. Accident Analysis & Prevention, 43(4), 1255–1262. https://doi.org/10.1016/j.aap.2011.01.004

23. TASS International. (2023). MADYMO Model Manual Release 7.6. Netherlands.

24. Tong, W., Chidester, A. B., & Nievergelt, G. F. (2010). Development of a finite element model of the pedestrian lower extremity. SAE Technical Paper, No. 2010-01-1248. https://doi.org/10.4271/2010-01-1248

25. Turdibekov, S., & Umarov, R. (2023). O‘zbekiston yo‘llarida piyodalar harakati xususiyatlari: empirik tadqiqot. Avtomobil transporti jurnali, (2), 28–35.

26. Untaroiu, C. D., Meissner, M. U., Crandall, J. R., Takahashi, Y., Okamoto, M., & Ito, O. (2009). Crash reconstruction of pedestrian accidents using optimization techniques. International Journal of Impact Engineering, 36(2), 210–219. https://doi.org/10.1016/j.ijimpeng.2008.01.012

27. UzAuto Motors. (2023a). Yillik ishlab chiqarish hisoboti 2023. UzAuto Motors JSC.

28. UzAuto Motors. (2023b). Texnik hujjatlar: Cobalt, Nexia, Damas modellari [Ichki hujjat]. UzAuto Motors JSC.

29. Versace, J. (1971). A review of the severity index. SAE Technical Paper, No. 710881. https://doi.org/10.4271/710881

30. WHO. (2023). Global status report on road safety 2023. World Health Organization.