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REGULATING HEAVY CONSTRUCTION VEHICLE TRAFFIC IN ASTANA: TECHNICAL AND ECONOMIC JUSTIFICATION FOR DAYTIME MOVEMENT RESTRICTIONS

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Abstract. This paper examines the problem of heavy construction vehicle traffic during daytime hours in Astana, Kazakhstan, and its multi-dimensional negative effects on road infrastructure, ecology, and traffic safety. The study aims to provide a technical, economic, and legal justification for introducing a daytime movement restriction (07:00-20:00) for heavy construction vehicles over 15 tonnes via road sign 3.4, enforced through the existing Automated Fixed Violation Recording (AFVR) system. Methods applied include comparative and systems analysis, technical-economic assessment, regulatory analysis, and international benchmarking. Using the AASHTO fourth-power law, the study establishes that actual rear-axle loads of overloaded dump trucks (up to 36 t vs. the 16 t standard) produce destructive pavement impacts equivalent to 25,600 passenger cars per trip. A comparative review of 63 world cities confirms that Astana is the only CIS capital lacking a systematic daytime restriction on heavy construction vehicles. The proposed 'road sign 3.4 + AFVR' model requires a one-time investment of 25-45 million KZT and is projected to generate an annual economic benefit of 8-15 billion KZT through reduced road repair expenditure, lower accident rates, and the elimination of corruption risks.

Keywords: heavy construction vehicles, vehicle overloading, road sign 3.4, AFVR, road infrastructure, Astana, traffic restriction.

Introduction

Urban growth in rapidly developing cities is inseparably linked to rising construction volumes and intensifying freight flows. Astana, the capital of Kazakhstan, has experienced sustained residential, commercial, and infrastructure construction growth: its population is expanding, the city footprint is widening, and construction activity continues to increase. Yet the existing transport infrastructure is placed under severe stress by overloaded heavy vehicles – principally dump trucks, concrete mixers, and mobile cranes – operating throughout the daytime hours.

According to the transport inspection authority of the Republic of Kazakhstan, the actual rear-axle load of a fully laden four-axle dump truck reaches 36 tonnes against a permissible value of 16 tonnes [1]. Computing the destructive pavement impact by the AASHTO fourth-power law yields an equivalent of approximately 25,600 standard passenger car axle loads per single trip [10, 11]. Compounding this, only 6.8% of Kazakhstan's road network is rated to withstand axle loads exceeding 10 tonnes [19].

The problem is further exacerbated by the absence of any systematic mechanism for restricting heavy construction vehicle traffic during daytime hours in Astana. An international

benchmarking study of 63 world cities and capitals demonstrated that every examined city applies some form of heavy vehicle regulation [20]. Astana is effectively the only exception among CIS and Central Asian capitals, making this a pressing policy gap.

Earlier, the City Maslikhat of Astana had regulated heavy vehicle movements through Decision No. 145/18-III of 26 May 2005, which established daytime movement rules for freight and specialised vehicles between 08:00 and 22:00. That act was subsequently repealed, leaving no replacement regulatory mechanism despite the city having grown substantially since.

The aim of this study is to provide a comprehensive technical, economic, and legal justification for introducing a temporary daytime movement restriction on heavy construction vehicles in Astana. The specific objectives are: (1) to quantify the technical impact of overloaded vehicles on pavement; (2) to assess the economic damage at city and national level; (3) to benchmark international practice; (4) to substantiate the 'road sign 3.4 + AFVR' enforcement model; and (5) to evaluate its cost-effectiveness.

Methodology

The methodological framework combines comparative and systems analysis, technical-economic assessment, regulatory analysis, and international benchmarking. Pavement destructive impact was quantified using the AASHTO equivalent single-axle load (ESAL) formula [10]:

$$ESAL = (PA / PB)^4$$

where PA – actual axle load (tonnes); PB – standard axle load (16 t); ESAL – equivalent single-axle load factor.

Economic damage from overloading was estimated using a Russian infrastructure-damage methodology with a unit damage cost of 195 KZT·t/km, applied to a fleet of approximately 30,000 heavy dump trucks with an average annual mileage of 30,000 km and mean overload of 4 tonnes [19]. A second estimate based on full life-cycle pavement costs yielded a higher aggregate figure of approximately 142 billion KZT per year.

The international benchmarking covered 63 cities across six continents, drawing on official sources including Transport for London Annual Reports [6], Roads and Transport Authority Dubai [14], the Integrated Transport Centre Abu Dhabi [15], Moscow City Transport Department [18], and country-level regulatory databases [16, 17]. Cost-benefit analysis was based on projected reductions in road maintenance expenditure, AFVR fine revenues, accident savings, and ecological externalities.

Results and discussion

Technical Impact of Heavy Construction Vehicles on Pavement

The principal driver of accelerated pavement deterioration is the rear-axle load of overloaded four-axle dump trucks. At full load their rear axle carries 36 tonnes – more than double the permissible 16-tonne standard – generating destructive pavement impacts equivalent to approximately 25,600 standard passenger car axle loads per trip (Table 1). Even moderately overloaded concrete mixers produce impacts of 5,060–12,400 equivalent axle loads, orders of magnitude above design thresholds [1, 10].

Table 1 – Technical impact of overloaded construction vehicles on road pavement

Vehicle type	Permitted mass, t	Actual mass, t	Overload	Rear axle load, t	Destructive impact (AASHTO)
3-axle dump truck	26	40	14 t (+54%)	29	≈10,600×
4-axle dump truck	32	60	28 t (+88%)	36	≈25,600×
3-axle concrete mixer	26	32	7 t (+27%)	24	≈5,060×
4-axle concrete mixer	32	45	13 t (+41%)	30	≈12,400×
Mobile crane 25 t (3-axle)	26	31	5 t (+19%)	24.6	≈5,570×
Mobile crane 50 t (4-axle)	32	38.6	6.6 t (+21%)	25.6	≈6,560×

The most intense wear occurs at intersections, braking zones, gradients, and arterial entry roads where dynamic loads peak. Astana's sharply continental climate – with frequent freeze-thaw cycles and large temperature swings – amplifies structural damage, accelerating the formation of rutting, cracking, and longitudinal settlement [1]. International research indicates that heavy goods vehicles account for up to 40% of urban CO_2 transport emissions and up to 50% of local NOx emissions [3, 5, 12]. In high-HGV-flow zones, PM2.5 concentrations can exceed WHO guidelines by three to five times [12, 13].

Scale of Economic Damage

Applying the infrastructure-damage methodology, the estimated total annual road damage attributable to heavy vehicle overloading across the Republic of Kazakhstan is approximately 117 billion KZT (Russian methodology) to 142 billion KZT (pavement life-cycle methodology) [19]. Heavy freight traffic increases aggregate road wear by roughly 42%, directly compressing inter-repair intervals and elevating maintenance budgets.

The current mobile-patrol enforcement model covers only 5–10% of actual heavy-vehicle flows [19]. Selective inspections involving direct contact between inspectors and drivers create conditions for informal settlement of overload violations. According to the Kazakhstan transport inspection analytics, this corruption channel amounts to approximately 2 billion KZT per year (~USD 5 million) [19].

At the city level, 30–40% of Astana's pavement maintenance costs are attributable to heavy construction vehicle damage. Considering that the city's road-repair budget runs to several tens of billions of KZT annually, even a partial reduction in heavy vehicle daytime flows carries substantial fiscal implications.

International Benchmarking

The comparative study encompassing 63 cities on six continents shows that 100% of examined cities apply at least one form of systematic heavy vehicle regulation (Table 2). Mechanisms range from Low Emission Zones (LEZ) and Zero Emission Zones (ZEZ) to time-window bans, ring-road permit schemes, and automated ANPR enforcement [14–20].

Table 2 – Regional coverage of heavy vehicle movement restrictions (63 cities)

Region	**Coverage (%)**	**Predominant model**	**Typical time window**
Western Europe	100% (16/16)	LEZ/ZEZ + daytime ban	24/7 or 08:00–20:00
CIS (excl. Astana)	100% (8/8)	Daytime ban (ring-road zones)	06:00–22:00 (≈15 h)
Middle East	100% (5/5)	Peak-hour restriction	06:00–10:00 & 15:00–22:00
South & SE Asia	100% (10/10)	Peak + daytime mode	07:00–11:00 & 16:00–22:00
East Asia	100% (4/4)	Daytime / 24/7	06:00–23:00
Africa	100% (4/4)	Daytime mode	06:00–21:00
Latin America	100% (6/6)	Daytime / peak mode	05:30–21:00
N. America / Oceania	100% (6/6)	Route-based + seasonal	07:00–19:00
Central Asia	100% (5/5)	Daytime mode	07:00–22:00
Astana (current status)	**0% (0/1)**	**Reactive enforcement (patrols)**	**No systematic restriction**

Among CIS capitals alone: Moscow applies a 16-hour ban (06:00–22:00) enforced through a 100% ANPR 'freight framework'; Saint Petersburg and Minsk operate 07:00–22:00 restrictions; Baku and Tbilisi enforce 08:00–20:00 bans [18]. Dubai's Roads and Transport Authority maintains a 16-hour restriction on major roads (06:00–22:00) with ANPR cameras [14]. The proposed Astana window of 07:00–20:00 (13 hours) is notably more lenient than most comparators, preserving an 11-hour overnight logistics window.

The effectiveness of systematic restrictions is empirically documented. London's introduction of the Direct Vision Standard reduced fatal HGV accidents by 67% [6]. Beijing's 17-hour ban within the 4th Ring Road achieved a 52% reduction in PM2.5 attributed to heavy vehicles. Addis Ababa's daytime restriction for all vehicles over 3.5 t reduced peak congestion by 40% [20].

Legal Enforcement Mechanism: Road Sign 3.4 and the AFVR System

The proposed model centres on road sign 3.4 ‘No entry for goods vehicles’, supplemented by time-of-operation plate 8.5.4 specifying the 07:00–20:00 restriction window, installed at primary arterial entry corridors into Astana [9]. The critical advantage is integration with the Automated Fixed Violation Recording (AFVR) system already operational throughout the city – no new camera infrastructure is required.

Operational sequence: AFVR cameras continuously monitor traffic flows; upon detecting a heavy vehicle in violation, the system automatically captures photo and video evidence, records GPS coordinates, vehicle registration number, and precise timestamp; the software then cross-references the vehicle against the MIA of the Republic of Kazakhstan databases, determines vehicle category and permissible mass, and auto-generates an administrative violation notice dispatched via eGov and MIA information systems – without any inspector involvement [7, 8].

Under the Code of Administrative Offences of the Republic of Kazakhstan, the fine for violating road sign 3.4 for medium and large enterprises ranges from 150 to 200 Monthly Calculation Indices (MCI) per recorded violation [7]. Systematic violations (three or more recorded episodes) may trigger administrative suspension of the organisation’s activities. The automated model eliminates the corruption channel inherent in mobile patrol enforcement, recorded at approximately 2 billion KZT per year.

Exceptions provisions are built into the model: emergency services, municipal utility vehicles, and vehicles executing critical construction operations under special akim permits may

be exempted via additional sign plate 8.6 'Except for…'. This preserves operational flexibility while maintaining the integrity of the restriction.

Cost-Benefit Analysis and Implementation Plan

Implementation costs are estimated at 25–45 million KZT in total one-time expenditure: road sign fabrication and installation at arterial entry points – 15–25 M KZT; regulatory-legal support (ordinance drafting, legal review, inter-agency approvals) – 2–5 M KZT; information campaign (SMS notifications to freight operators, official portal publications, industry consultations) – 8–15 M KZT. No capital expenditure on AFVR hardware is required.

Table 3 – Comparison of mobile patrol enforcement vs. 'Road Sign 3.4 + AFVR' model

Indicator	**Mobile patrol enforcement**	**Road sign 3.4 + AFVR system**
Violator coverage	5–10% of traffic flow	≈100% (automated)
Operating mode	Selective, daytime only	24/7, continuous
Corruption risk	~2 bn KZT/year	Effectively eliminated
Implementation cost	Ongoing (high)	25–45 M KZT (one-time)
Annual budget benefit	Not quantified	8.3–15.2 bn KZT
Payback period	N/A	Less than 1 week
Evidence base	Inspector's report	Photo/video + GPS + timestamp

The projected annual economic benefit is 8.3–15.2 billion KZT, structured as follows: reduction in pothole and capital road repair costs – 3.4–6.7 bn KZT; extended pavement inter-repair intervals (2–4 years shift) – 2.0–4.0 bn KZT; AFVR fine revenues – 0.5–1.5 bn KZT; accident reduction savings – 0.27–0.54 bn KZT; ecological damage reduction – 0.20–0.40 bn KZT; anti-corruption savings – ~2.0 bn KZT. The payback period on implementation costs is less than one week, driven by AFVR fine collection from the first month of operation.

Implementation is planned in four sequential stages: Stage I (months 0–2) – ordinance development, route mapping, and AFVR system configuration; Stage II (months 2–5) – sign installation, advisory-mode enforcement, and industry notification campaign; Stage III (month 5 onward) – full automated enforcement with administrative penalty issuance, reorientation of mobile patrols to nighttime weight control; Stage IV (month 12) – comprehensive evaluation of pavement wear, accident statistics, budget impact, and violation trends, followed by potential scale-up to Almaty, Shymkent, and other high-construction-activity cities.

Within the first 90 days of full enforcement, a 30% reduction in daytime heavy construction vehicle trips is projected, based on analogous results from comparable CIS cities following restriction introduction [18, 20].

Conclusion

This study demonstrates that the unrestricted daytime operation of heavy construction vehicles in Astana constitutes a systemic risk to road infrastructure, public ecology, traffic safety, and municipal finances. Actual axle loads from overloaded dump trucks exceed normative values by more than two-fold, generating pavement damage – by the AASHTO fourth-power law – orders of magnitude beyond design specifications.

The international benchmarking of 63 world cities confirms that Astana is the only CIS capital without a permanent daytime restriction on heavy construction vehicles. All comparators – including cities with similar climatic profiles (Ottawa's spring load restrictions), comparable development intensity, and post-Soviet administrative structures – apply at least equivalent, and frequently stricter, measures.

The proposed 'road sign 3.4 + AFVR' model is technically sound, economically viable, legally implementable, and socially beneficial. Its defining advantages are: (1) minimal one-time

investment of 25–45 M KZT; (2) near-100% automated enforcement coverage; (3) elimination of corruption risks worth ~2 bn KZT annually; (4) projected annual net benefit of 8–15 bn KZT; and (5) payback within the first week of operation. The 11-hour overnight logistics window (20:00–07:00) ensures construction supply chains remain viable.

The findings support the preparation of an Astana City Maslikhat ordinance establishing the temporary daytime restriction and are transferable to other high-growth Kazakhstan cities including Almaty, Shymkent, and regional centres. Future research should evaluate the long-term pavement condition response to reduced heavy vehicle loads using continuous road condition monitoring data, and assess the effectiveness of exception-permit systems in minimising construction disruption.

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Mukhambetkaliyev K.K. – project administration, resource provisioning, funding acquisition, and final approval of the manuscript.

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АСТАНА ҚАЛАСЫНДА АУЫР ҚҰРЫЛЫС АРНАЙЫ ТЕХНИКАСЫНЫҢ ҚОЗҒАЛЫСЫН РЕТТЕУ: УАҚЫТША ШЕКТЕУЛЕРДІ ЕНГІЗУДІҢ ТЕХНИКАЛЫҚ-ЭКОНОМИКАЛЫҚ НЕГІЗДЕМЕСІ

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Аннотация. Мақалада Астана қаласындағы ауыр құрылыс арнайы техникасының күндізгі уақытта жол жүруі мәселесі, оның жол инфрақұрылымына, экологиялық жағдайға және жол қауіпсіздігіне кешенді теріс әсері қарастырылады. AASHTO төртінші дәрежелі заңы бойынша есептеулер жүктелген самосвалдар артқы осінде 36 т нормативтен (16 т) асатынын және бір рейс үшін 25 600 жеңіл автомобильге баламалы зиянды ықпал жасайтынын растайды. 63 қалалық тәжірибені зерттеу Астананың ТМД-дағы жүйелі шектеусіз жалғыз астана екенін дәлелдейді. Ұсынылатын модель – 3.4 жол белгісі + ЖКАЖ – 25-45 млн теңге бір жолғы шығынмен 8-15 млрд теңге жылдық экономикалық тиімділік беруі болжануда.

Түйін сөздер: ауыр құрылыс техникасы, артық жүктеу, 3.4 жол белгісі, ЖКАЖ, жол инфрақұрылымы, Астана, қозғалысты шектеу.

РЕГУЛИРОВАНИЕ ДВИЖЕНИЯ ТЯЖЁЛОЙ СТРОИТЕЛЬНОЙ СПЕЦТЕХНИКИ В ГОРОДЕ АСТАНА: ТЕХНИКО-ЭКОНОМИЧЕСКОЕ ОБОСНОВАНИЕ ВВЕДЕНИЯ ВРЕМЕННЫХ ОГРАНИЧЕНИЙ

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Аннотация. В статье рассматривается проблема движения тяжёлой строительной спецтехники в дневное время в Астане и её комплексное негативное воздействие на дорожную инфраструктуру, экологию и безопасность дорожного движения. На основе закона четвёртой степени AASHTO установлено, что фактические осевые нагрузки перегруженных самосвалов (до 36 т при норме 16 т) формируют разрушительное воздействие, эквивалентное 25 600 легковых автомобилей за один рейс. Сравнительный анализ 63 городов мира подтверждает, что Астана является единственной столицей СНГ без системного ограничения. Предложенная модель «знак 3.4 + АСФП» требует 25-45 млн тенге единовременных затрат и обеспечивает ежегодный экономический эффект в 8-15 млрд тенге.

Ключевые слова: тяжёлая строительная спецтехника, перегруз, дорожный знак 3.4, АСФП, дорожная инфраструктура, Астана, ограничение движения.

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