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# Smart traffic AI: an artificial intelligence-based system for adaptive traffic signal control and road incident detection

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***Abstract.*** *Rapid motorisation of Uzbekistan's cities is outpacing the development of road infrastructure, while most intersections are still controlled by fixed-time traffic signals that do not take actual traffic conditions into account. The aim of this study is to substantiate the concept of Smart Traffic AI, a low-cost artificial intelligence system that analyses traffic flows from video cameras in real time and controls traffic lights automatically. The study draws on official road safety and vehicle fleet statistics and applies problem analysis, a modular system design approach and a criteria-based comparison of conventional and AI-controlled traffic signals. The proposed system forms a closed "observation – analysis – decision – control" loop built on the EfficientDet object detector and recognises 14 types of road events grouped into five categories. The comparison shows that the AI-controlled signal outperforms the conventional one on all functional criteria and is inferior only in installation cost, while the reuse of existing cameras and controllers makes it affordable for regional cities. A business-to-government (B2G) business model is outlined, and practical recommendations are given on pilot deployment, system reliability and protection of video data.*

***Keywords:*** *artificial intelligence, adaptive traffic signal control, computer vision, EfficientDet, road incident detection, intelligent transport systems, smart city.*

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# Smart traffic AI: система адаптивного управления светофорами и выявления дорожных инцидентов на основе искусственного интеллекта

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***Аннотация.*** *Рост автомобилизации городов Узбекистана опережает развитие дорожной инфраструктуры, тогда как большинство перекрёстков по-прежнему регулируется светофорами с фиксированным циклом, не учитывающим реальную дорожную обстановку. Цель исследования — обосновать концепцию Smart Traffic AI, недорогой системы на основе искусственного интеллекта, которая в реальном времени анализирует транспортные потоки по изображению с видеокамер и автоматически управляет светофорами. Исследование опирается на официальную статистику аварийности и численности автопарка; использованы методы проблемного анализа, модульного системного проектирования и сравнительного анализа традиционного и интеллектуального светофоров по набору критериев. Предложенная система реализует замкнутый цикл «наблюдение – анализ – решение – управление» на базе детектора объектов EfficientDet и распознаёт 14 типов дорожных событий, объединённых в пять групп. Сравнение показало, что интеллектуальный светофор превосходит традиционный по всем функциональным критериям и уступает лишь по*

*стоимости установки, а использование существующих камер и контроллеров делает систему доступной для региональных городов. Описана бизнес-модель B2G и даны практические рекомендации по пилотному внедрению, надёжности системы и защите видеоданных.*

***Ключевые слова:*** *искусственный интеллект, адаптивное управление светофорами, компьютерное зрение, EfficientDet, выявление дорожных инцидентов, интеллектуальные транспортные системы, умный город.*

# Smart traffic AI: sun’iy intellekt asosida svetoforlarni adaptiv boshqarish va yo‘l hodisalarini aniqlash tizimi

Musinov Shahruz Qudrat o‘g‘li

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***Annotatsiya.*** *O‘zbekiston shaharlarida avtomobillashuv sur’ati yo‘l infratuzilmasining rivojlanishidan oldinda bormoqda, ammo chorrahalarning aksariyati hamon real yo‘l vaziyatini hisobga olmaydigan, qat’iy belgilangan sikl bo‘yicha ishlaydigan svetoforlar bilan boshqarilmoqda. Tadqiqotning maqsadi — videokameralar tasviri asosida transport oqimini real vaqt rejimida tahlil qiladigan va svetoforlarni avtomatik boshqaradigan arzon sun’iy intellekt tizimi — Smart Traffic AI konsepsiyasini asoslashdan iborat. Tadqiqot yo‘l-transport hodisalari va avtopark soni bo‘yicha rasmiy statistikaga tayanadi; muammoli tahlil, modulli tizimli loyihalash hamda an’anaviy va intellektual svetoforlarni mezonlar bo‘yicha qiyosiy tahlil qilish usullari qo‘llanilgan. Taklif etilgan tizim EfficientDet obyektlarni aniqlash modeli asosida «kuzatish – tahlil – qaror – boshqaruv» yopiq siklini amalga oshiradi va besh guruhga birlashtirilgan 14 turdagi yo‘l hodisalarini aniqlaydi. Qiyosiy tahlil intellektual svetofor barcha funksional mezonlar bo‘yicha an’anaviysidan ustun ekanini, faqat o‘rnatish narxi bo‘yicha undan qolishishini ko‘rsatdi; mavjud kamera va kontrollerlardan foydalanish tizimni viloyat shaharlari uchun ham qulay qiladi. B2G biznes modeli tavsiflangan hamda pilot joriy etish, tizim ishonchliligi va videoma’lumotlarni himoya qilish bo‘yicha amaliy tavsiyalar berilgan.*

***Kalit so‘zlar:*** *sun’iy intellekt, svetoforlarni adaptiv boshqarish, kompyuter ko‘rishi, EfficientDet, yo‘l hodisalarini aniqlash, intellektual transport tizimlari, aqlli shahar.*

## 1. Introduction

The growth of motorisation in the cities of Uzbekistan is outpacing the development of road infrastructure. Between 2021 and 2025 the country’s vehicle fleet increased from 3.82 to 5.53 million vehicles, while the population grew from 35.27 to 38.23 million people [4]. Despite a steady decline in road accidents over the past five years, 2,188 people were killed and 8,901 were injured in road traffic collisions in 2025 [4]. According to an estimate voiced by the President of the country, the economic damage from road accidents amounts to about 0.4% of GDP [5]. Congestion is not only a local problem: according to INRIX, in 2024 a driver in Istanbul, the most congested city in the world, lost 105 hours in traffic jams [3].

A significant share of these losses is related to how intersections are controlled. A conventional traffic light switches signals according to a predetermined cycle and does not “see” the actual traffic situation: the green signal stays on for an empty street while a queue grows in the perpendicular direction. Research on intelligent traffic signal control, including methods based on machine learning and reinforcement learning, considers such approaches as an alternative to rigid, pre-timed switching plans [2]. At the same time, progress in deep-learning object detection, in particular the scalable EfficientDet family of detectors [1], makes real-time video analysis possible on relatively inexpensive hardware.

The state is already moving towards adaptive control: in Tashkent, 125 key intersections have been connected to an intelligent system, and by the end of 2026 their number is planned to reach 545 out of approximately one thousand signalised junctions in the city [6]. However, such solutions require substantial investment in new infrastructure, which hinders their extension to regional cities. Thus, there is a research gap between costly city-wide intelligent transport systems and fixed-time signals that remain in most of the country.

The aim of this article is to present and substantiate the concept of Smart Traffic AI, a low-cost artificial intelligence system that analyses traffic flow from video images in real time and controls traffic lights automatically. The objectives of the study are: (1) to identify the limitations of conventional traffic control; (2) to design the system architecture and define the list of recognised road events; (3) to compare the system with conventional and costly intelligent solutions; and (4) to substantiate the business model and assess the market potential.

## 2. Materials and methods

The study is conceptual and design-oriented. Its information base comprises official statistics of the Ministry of Internal Affairs of the Republic of Uzbekistan on road accidents and the vehicle fleet [4, 5], international congestion data [3], public information on the modernisation of the traffic signal network in Tashkent [6, 8], the provisions of the Strategy “Uzbekistan – 2030” [7], and scientific publications on object detection and intelligent traffic signal control [1, 2].

The following methods were used. Problem analysis was applied to the operation of urban signalised intersections in order to identify the key shortcomings of fixed-time control. A modular system design approach was used to develop the architecture of Smart Traffic AI as a closed control loop. The object detection model was selected on the basis of an analysis of the literature, with priority given to the ratio of accuracy to computational cost [1]. The taxonomy of road events was formed by grouping typical emergencies, traffic violations and flow states observable from an intersection camera. A comparative analysis of a conventional traffic light and an AI-controlled one was

carried out against eight criteria (operating principle, adaptability, congestion reduction, decision making, efficiency, handling of emergencies, installation cost and scalability) using qualitative expert assessment by the project authors. The market potential was assessed on the basis of the authors' estimates and state programme documents [7, 8].

## 3. Results

### *3.1. Problems of conventional intersection control*

The analysis of urban intersection operation revealed four main problems. First, conventional traffic lights operate in a fixed mode and do not take actual traffic intensity into account. Second, this leads to congestion, uneven traffic flow, lost time and excessive fuel consumption. Third, the passage of emergency vehicles – ambulances, fire engines and patrol cars – through busy intersections is difficult and slow to organise. Fourth, information about road accidents reaches patrol services with a delay, and an uncleared accident site itself becomes a source of new congestion.

### *3.2. System architecture*

Smart Traffic AI addresses these problems through a closed "observation – analysis – decision – control" loop, shown in Figure 1. A video camera at the intersection transmits an image stream; the computer vision module detects and counts vehicles and pedestrians; the analytical module estimates the load on each approach and detects abnormal events; the decision-making module selects the optimal duration of the signal phases or generates an alert for the relevant services.




**Figure 1. Operating scheme of the Smart Traffic AI system**

The EfficientDet architecture is used for object detection. Its authors proposed a weighted bi-directional feature pyramid network (BiFPN) and a compound scaling method, owing to which the family of models achieves high accuracy with substantially fewer parameters and lower computational cost than comparable detectors [1]. This is essential for the project: the scalability of EfficientDet makes it possible to choose a model to suit the available hardware and to process video in real time without expensive computing servers at every intersection.

### *3.3. Functional capabilities*

The product combines four functions: AI-based object detection, real-time video monitoring of traffic, an intelligent automatic decision-making system, and optimisation of traffic flow to reduce congestion. In addition to controlling the traffic

light, the system recognises 14 types of road events, grouped in Table 1.

**Table 1. Types of road events recognised by the system**

| Category | Events |
|---|---|
| Emergencies | road traffic collision; near miss (dangerous approach without contact); loss of control with impact on an obstacle; obstacle on the road and fire |
| Intersection violations | running a red light; crossing the stop line; prohibited U-turn; turning from the wrong lane |
| Traffic violations | driving in the oncoming lane; crossing a solid line; vehicle stopped on the carriageway for more than 10 seconds |
| Pedestrian safety | pedestrian on the carriageway outside a crossing; failure to yield to a pedestrian |
| Traffic flow | congestion (very slow movement or standstill of the flow) |

This set of events extends the purpose of the system: it not only regulates traffic flow but also shortens the response time of services to accidents and records violations that pose a threat to safety. Summary information on incidents is sent to the patrol service immediately, which directly addresses the fourth of the problems described above.

### *3.4. Comparative assessment*

Table 2 compares a conventional traffic light with a traffic light controlled by Smart Traffic AI against eight criteria.

**Table 2. Comparison of conventional and AI-controlled traffic lights**

| Criterion | Conventional traffic light | Smart Traffic AI |
|---|---|---|
| Operating principle | time-based | real-time, AI-based |
| Adaptability | none | yes |
| Congestion reduction | low | high |
| Decision making | pre-set plan | automatic, intelligent |
| Efficiency | medium | high |
| Emergency situations | not supported | adapts |
| Installation cost | low | medium |
| Scalability | difficult | easy |

As can be seen from Table 2, the AI-controlled traffic light outperforms the conventional one on all functional criteria and is inferior only in installation cost.

### *3.5. Business model and market*

The main monetisation channel is business-to-government (B2G) sales: to city khokimiyats and the relevant Ministry of Transport, including within “smart city” projects and the construction of new urban infrastructure. An additional channel is integration with existing traffic management systems. For the public, a mobile application with a paid subscription providing data on road conditions is envisaged. According to the authors’ estimate, the market for smart city technologies in Uzbekistan amounts to USD 1–3 billion with annual growth of about 20%, and by 2030

intelligent transport systems may be in demand in at least 15 cities. The go-to-market strategy involves starting in selected regional cities, followed by expansion to the national and then to foreign markets.

## 4. Discussion

The results indicate that the main value of Smart Traffic AI lies not in the novelty of individual components but in their combination into an inexpensive, closed control loop. Compared with existing comprehensive intelligent transport systems, which offer broad capabilities but are expensive and require new infrastructure [6], Smart Traffic AI is positioned as a cost-effective solution: it uses AI technologies, integrates easily with already installed cameras and controllers, and scales from a single intersection to an entire city. The key advantages of the project are real-time operation, adaptation to current traffic, low cost, simple integration and scalability.

The demand for such solutions is confirmed by the country's course towards the digitalisation of the urban environment enshrined in the Strategy "Uzbekistan – 2030" [7] and by the large-scale modernisation of the Tashkent traffic signal network, which provides for the installation of 7,880 traffic signal facilities [8]. While the capital is being equipped through large infrastructure programmes, regional cities need lighter solutions, and this is the niche the proposed system targets.

The study has several limitations. The comparison in Table 2 is qualitative and reflects the expert assessment of the project authors; the market figures are also the authors' estimates. The effect of the system on travel time, queue length and accident rates has not yet been measured in field conditions. The accuracy of video-based detection may decrease under poor lighting and adverse weather, and processing video of public roads raises issues of personal data protection and cybersecurity. In addition, the current version relies on rule-based phase selection; reinforcement learning methods reviewed in [2] represent a promising direction for further optimisation of signal timing.

## 5. Conclusion

The analysis shows that fixed-time traffic signal control does not correspond to the rapidly growing traffic load in the cities of Uzbekistan. The Smart Traffic AI project offers a low-cost computer vision-based solution that assesses traffic flow in real time, automatically selects the operating mode of the traffic light, gives priority to emergency vehicles and recognises 14 types of road events. The use of existing infrastructure makes the system affordable not only for the capital but also for regional cities.

Based on the results, the following practical recommendations can be formulated. Khokimiyats of regional cities should begin implementation with a pilot

project at one or two of the most congested intersections and compare travel times and queue lengths before and after launch. System developers need to ensure stable model performance under different lighting and weather conditions, a fall-back fixed-time mode in case of failure, protection of video data and compliance with legislation on personal data and cybersecurity. Integration with existing traffic management systems should be designed on the basis of open data exchange protocols. Further research should focus on the quantitative evaluation of the effect based on the results of pilot deployment.

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