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Research Paper

Distribution of a Taxi Fleet: The Problem of Arranging Repair and Maintenance in the Absence of Centralized Management

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Abstract

The article presents a mathematical model for distributed taxi fleet operations. A technological approach based on mathematical models of transport systems using the Hungarian algorithm was used to model the arrangement of repair and maintenance in the absence of centralized management. The literature review on taxi fleet robotics has shown that central management is the cause of increasing transport service costs up to 30%. The results of approximating the cases of repairing and maintaining the taxi fleet in the absence of centralization to the lognormal and Gaussian distributions are provided based on 2019-2020 data. A blockchain scheme for work organization and maintenance of the taxi fleet within the decentralization framework is developed. The statistical analysis of repair and emergency maintenance cases in the distributed taxi fleets calculated per 1000 cars was 3.6 to 15%. Pearson's criterion $\chi 2$ was from 0.001 to 0.17. Statistical significance values of the results were $p \leq 0.005$. A multivariate cluster analysis of the accident or technical failure occurrence among the distributed taxi fleet vehicles was conducted in months, taking statistical data for the last two years. An algorithm that allows performing optimal assignments for a distributed taxi fleet is developed in this work. A sample calculation of the optimal allocation for taxi fleet vehicles distributed in the state of minimum vehicle repair cost based on the Hungarian algorithm was provided. The application of this algorithm also makes it possible to determine the optimal destinations for vehicles in the taxi fleet.

Keywords: Blockchain; Taxi fleet; Distributed register; "product-service" system

1. Introduction

Improving the efficiency of passenger transport services is a pressing problem for many countries worldwide. The use of distributed recording technologies in taxi operations is expected to improve the efficiency and availability of passenger transport [1]. Distributed register technologies used by Uber are an effective type for regulating the function of distributed vehicles in contrast to conventional taxis. It can instantly connect drivers and customers (passengers) of the taxi fleet. To determine the productivity of the cabs and to evaluate the efficiency of using a driver and taxi resources, the occupancy rate of the vehicles shall be measured [2]. The literature provides a methodology for comparing the efficiency of taxi operations in centralized and decentralized taxi parks on urban and suburban roads [3]. However, there are still shortcomings in measuring efficiency, comparing efficiency between the two modes of transport, and the difference in terms of effectiveness. For measurement, due to data limitations, it is still difficult to estimate the free time/distance of a vehicle if a GPS trajectory is not available. In comparison, the existing literature has shown that car trips are more efficient than taxi trips in the economy [4, 5]. The most famous taxi services include Uber, DiDi, Bolt, Uklon, Yandex Taxi, etc.

The results of monitoring the performance of distributed taxi fleets lead to discussions about the implications for commercial operations of attracting tourists and transport policy interventions [6]. Reliable analytical methods must be used to ensure that system implementation requirements are met. This can be achieved by maintaining a system delivery model resulting from events that result in changes in the space environment [7]. In the literature, there are regression mathematical models of taxi companies, models based on Markov chains. Undoubtedly, mathematical models based on neural networks will be promising and will allow the system to self-learn. But this system is quite complex and requires the participation of a coach for training. Forecasting of the distributed taxi fleet operation is also carried out using streaming data [8]. According to this model transition probabilities:

$$P_i = \begin{cases} L[i,j] & i \neq j \\ 1 + L[i,j] - \sum_j L[i,j] & i = j \end{cases} \quad (1)$$

where L[i; j] be the probability of having a passenger to pick up from cell i and deliver to cell j.

Regression models are often used to estimate arrays of information. But these models are not very informative because the regression coefficients can encode heterogeneous information. However, such models are easy to build and allow obtaining data on the correlation of parallel experiments [9].

This resource-intensive performance assurance method cannot be supported by resource-limited devices that fill the space and must be unloaded in the cloud [8]. However, resource allocation and cost issues, especially where the workload is unknown during system development. As a result, it may be difficult, if not impossible, to secure service level agreements for mobile applications, such as response times. To this end, spatial verification processes are implemented by integrating them to the service level of an Internet of Things cloud-based microservice architecture [9, 10]. Several cloud deployments for such an architecture have been proposed in this paper to meet space requirements based on virtual machines, containers, and the recent paradigm of the function as a service [11]. Return on investment, return, and the cost is then evaluated using a workload scenario using a known set of cab movement data [12]. This approach can be repeated in similar spatially distributed Internet of Things systems [13].

As a new distributed ledger technology, blockchain has attracted considerable academic and industrial attention [14]. Previous research has demonstrated that blockchain technology applies to data transfer, storage, and protection among stakeholders. It also provides a decentralized data management platform that allows multiple stakeholders to update, maintain and check data simultaneously. Distributed ledger (blockchain) technology is used to build and maintain mutual trust in the delivery of passenger transportation services. The ability to use blockchain for recording, sharing, and protecting the data generated over the lifetime of the vehicles is an essential prerequisite for the efficient operation of the taxi fleet. The authors [15, 16] review some earlier work on applying blockchain technology in taxi fleets [17]. But in many countries around the world, the success of this technology is compared to the confidence issues in blockchain technology. A blockchain-based product-service system (PSU) in the automotive industry is presented in [18], where blockchain provides an innovative approach to data management and transactional execution to build confidence among parties involved. A product-service system is defined as a system that integrates tangible products, intangible services, networks, and supporting infrastructure [19, 20]. The primary objective of PSU is to help manufacturers improve their competitive advantage by responding to consumer demands and reducing their environmental impact [21]. The auto industry is often associated with research on how taxi fleets operate. In the past, vehicle services were primarily classified as product-based services. Maintenance services are most prevalent in the automotive industry [22]. Because customers are forced to replace specific components, manufacturers are starting to offer service subscriptions to customers to reduce costs. To date, product-based services continue to play an important role in the automotive product-service system and grow through innovation. For example, Toyota and BMW are beginning to use information technology for vehicle data collection and remote diagnostic services [23]. By providing this service, manufacturers can effectively work through quality issues based on feedback and the most frequent breakdowns, which results in fewer defects, recalls of vehicles, and better prediction of potential risks during future operations.

A centralized dispatching strategy exists based on the TESLA algorithm [24]. The centrally distributed algorithm is considered in the time interval T. At each instant T for each taxi, the system calculates its priority and sorts all the cabins according to their priority. After that, it selects suitable cabs according to their importance. If the number Vt is less than the number Qt, all Vt are candidate taxis. Otherwise, the candidate taxi will be selected from Vt in lots depending on the size of the steps. Finally, the algorithm performs a bipartite graphical mapping and recommends a route segment for the taxi that could not be matched [25].

In the last few years, there has been a car-based approach to passenger transportation [26]. This new company requires a modernized transportation network that offers customers the necessary services on demand. Trust issues in the auto transportation industry have been the subject of many years of development, offering significant advantages in our daily lives. However, fraud can occur in almost all services in this industry [27]. Many of these types of scams are very hard to detect. Therefore, not all interested parties rely on information provided by other industry stakeholders.

In general, the risks related to confidence in PSU vehicles can be caused by the following factors. The risk associated with confidence in the functioning of distributed taxi fleets can be caused by inadequate documentation. For instance, property history, maintenance history, and accident records are missing for many vehicles attracted by distributed taxi fleets. Automama experts identify unauthorized changes in mileage readings in 55% of cars [28]. However, the decentralization of taxi fleets allows for a 30% reduction in travel costs [23]. In addition, improper documentation is often associated with insurance fraud. For example, due to the lack of documentation, many drivers take advantage of the resulting accident and claim past losses. However, customers and other parties involved may not obtain sufficient information on vehicles and drivers. For example, a third-party service may withhold information about the consumable components because they may be counterfeit, used, or imported [29]. The lack of transparency of access to crucial information in centrally managed taxi parks can pose significant risks to taxi safety fleet's customers (passengers) and even the entire automotive industry.

Consequently, it is challenging to build mutual trust among clients, service providers, or other stakeholders. In centrally managed taxi fleets, the integrity of vehicle data is not guaranteed due to the inability to prevent data modification. Research shows that one of the most common frauds is the misrepresentation of the actual state of the vehicle. With the development of modern methods of repair, a variety of modifications are possible. For example, mileage fraud is a common type of data change in car exchange and resale services [5]. Blockchain technology is a distributed register that provides a decentralized means of storing, sharing, and maintaining data and information by multiple stakeholders [4]. A typical blockchain system is composed of a network of nodes, a network protocol, and a data structure. This includes blockchain nodes that verify each signed transaction. The network protocol defines permissions, communication methods, verification, and consensus processes among blockchain network nodes.

Additionally, the network protocol is designed to propagate transactions to other network nodes until the transaction reaches all network nodes. The data structure of a blockchain is a list of linked blocks wherein each block records the corresponding transaction data [4]. Today, new blockchain systems, such as smart deals, allow transactions to happen automatically with conditions agreed upon by buyers and sellers. Several functionalities have transformed the blockchain into an innovative approach to data management, where accuracy and reliability are paramount. The most important benefits of blockchains are reflected in the following points. Blockchain has the potential to improve the transparency of information. The recorded data is visible to all authorized stakeholders, and identical copies are stored in multiple computer systems, increasing the capacity to verify and trust the stored information. The data stored on a blockchain platform remains constant. In a blockchain, the data structure can record events in a verifiable and persistent way using an encryption algorithm, making the blockchain resistant to changes or reconfigurations of data.

Given the above, the lack of transparency and stability of information makes centralized models for managing the taxi fleet inefficient. Especially concerning the maintenance of mutual trust between stakeholders [30]. For better financial and environmental outcomes, transport companies need to incorporate blockchain technology. The purpose of the study is a) to provide the results of distributing emergency maintenance and repair needs of taxi fleet vehicles under decentralized management conditions; b) to estimate the critical periods within the year for taxi fleet operations using cluster analysis methods; c) and to develop a mathematical model for determining the optimal assignments for available taxi fleet vehicles under distributed taxi fleet emergency maintenance and calculating the optimal assignment for the maintenance of vehicles.

2. Method

2.1. Description

Methodology for evaluating the quality of the taxi has been proposed, which is part of the structure of the distributed taxi company Yandex Taxi, Russian Federation. To determine the requirement for maintenance and repair of passenger cars, we used data on car repairs related to the car's technical condition and accidents. The analysis was completed using Yandex Taxi statistics for 2019 and 2020.

A cluster analysis was conducted to determine the highest and lowest civilian prevalence periods of taxi fleet repair and maintenance cases in the absence of centralization. The outcome was a matrix that included 2019-20 repair cases per month - 12 variables representing category and 2 variables representing the year. The STATISTICA 7.0 package was used to determine the periods of the year where the demand for vehicle repairs is highest and lowest. Segmentation of objects was done using the Ward method. The analysis of hierarchical clusters was used as well.

Mathematical model of maintaining a fleet of distributed taxis:

$$F(x)=\sum_{i=1}^{n}\sum_{j=1}^{n}C_{i,j}x_{i,j}\rightarrow \min \quad (2)$$

where *i* is quarter, *j* is a vehicle, *C* is vehicle repair cost, *x* is an optimal assignment, $x = 0$ shows that the car requires no maintenance or repair, $x = 1$ shows that the vehicle needs maintenance or repair.

The prerequisite of the taxi fleet operation is to minimize maintenance costs. Accepting the following constraints:

$$\sum_{i=1}^{n}x_{i,j}=1, \quad i=\overline{1,n} \quad (3)$$

$$\sum_{j=1}^{n}x_{i,j}=1, \quad j=\overline{1,n} \quad (4)$$

$$x_{i,j}\in\{0,1\} \quad (5)$$

Condition (2) implies that a given car has been repaired. Condition (4) assumes that the car service will maintain or repair the taxi.

To resolve the problem of the fleet of taxis distributed in decentralized conditions on the example of Yandex Taxi, we used the Hungarian algorithm. It was implemented in several steps:

1. *Matrix transposition.* This step aims to maximize the number of nulls in the matrix. The result is achieved by subtracting the minimum values of the corresponding line from the corresponding values of the elements in that line and each item in the column, subtracting the minimum value from this column. Following this stage, a transposed matrix can be built.
2. Determination of vehicle assignments for maintenance or repair. This step uses the algorithm for determining "the greatest combination of data pairs with a bipartite graph matrix, c_{ij}=0 of $\overline{C}$ the matrix to be changed with '1', and c_{ij}>0 – with '0'.
   If it is not possible to find the allocation of the vehicles for maintenance or repair, a modification of the transposed matrix is used.

3. Matrix transposition modification. For a transposed maintenance or repair matrix for vehicles, it is required:
   a) to determine the number of nulls for each uncrossed row and each uncrossed column.
   b) cross out the row or column with the maximum number of null values.
   c) repeat points a) and b) until all null values will be crossed out in the matrix.
   d) subtract the values of the minimum elements from all the values that are not crossed out and add this value to each element of the matrix that is at the intersection of the two lines.

   Then follows point 2.

2.2. *Statistics*

Regression analysis was used to assess the significance of the results obtained. A procedure that allows evaluating the degree of consistency of the chosen lognormal or Gaussian law of distribution of sample data was developed. The criteria for such a check are the criteria of agreement. The most informative in the study was the Pearson χ^2 criterion (xy-square). Pearson criterion, statistical mean deviation, and standard errors were calculated in MS Excell and Statistica software. The values of $\chi 2 < 0.05$ were taken under experimental conditions. Also, values of statistical significance *p* were calculated, accepting that $p < 0.005$. The computed value of the $\chi2$ criterion is compared with its critical value, which is in the range $0 \leq \chi^2 < 0.05$

3. Result and Discussion

Figure 1 provides an approximation of the lognormal and Gaussian models of taxi fleet vehicle repair and maintenance occurrences in the absence of centralization for 2019-20. A threshold can be selected to reject the null hypothesis H0 that the interval is spare time. If the time interval exceeds the threshold, the percentage of the area below the lognormal distribution for 2019 (**Figure 1a**) and 2020 (**Figure 1b**).

To measure the performance of the distributed taxi fleet, we used statistics on emergency maintenance of Yandex taxi cars (Russia), on average per month for 2019-2020. The results of the statistical treatment of average monthly results over two years are presented in **Table 1.**

The statistical processing of data on emergency repairs and maintenance of Yandex taxi cars in Russia showed acceptable values. The results were highly divergent between the first and second quarters. **Table 2** indicates that Q2 suggests minimum maintenance costs. The convergence of the 2019 and 2020 results on insured events due to accidents or technical failure of the vehicle does not exceed 45 cases. In the first quarter, this figure reaches 85 cases.

To summarize the vehicle maintenance data for the taxi fleet, monthly averages were used for 2019-2020. Two clusters were obtained, indicating periods of increased and decreased demand for the repair and maintenance of taxi vehicles. The cluster analysis results (**Figure 2**) showed the minimum probability of repair and maintenance of taxi fleet vehicles between April and June. The most demanding conditions were encountered during the winter months.

In a distributed taxi fleet environment, the main emphasis is on the availability of Internet connection as the distribution of orders and data on the technical condition of vehicles are made using the Yandex Go application. In this work, the

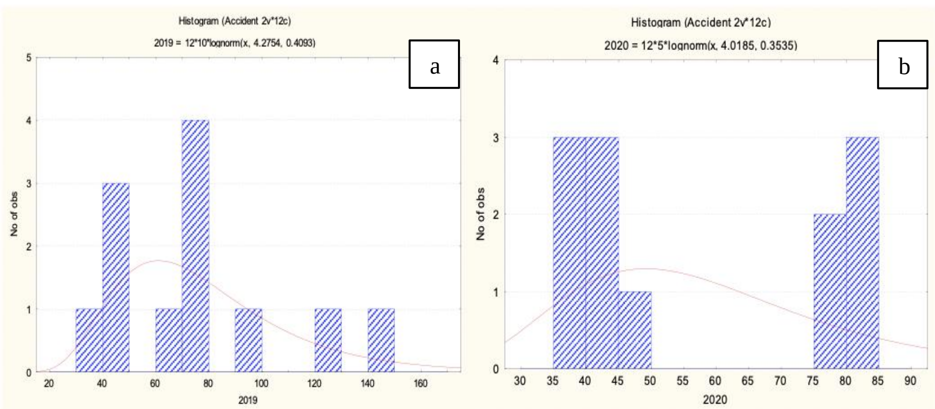

Figure 1. Distribution of taxi fleet vehicle repair and maintenance cases without centralization for 2019 (a) and 2020 (b)

Table 1. Data on cases of emergency repair and maintenance of taxi fleet vehicles in the absence of centralization per 1,000 cars

	Number of accidents in 2019, (pcs)	Percentage per 1,000 vehicles, (%)	Number of accidents in 2020, (pcs)	Percentage per 1,000 vehicles, (%)	χ2	p
January	125	12.5	85	8.5	0.05	0.0005
February	150	15	80	8	0.17	0.004
March	80	8	85	8.5	0.11	0.001
April	50	5	40	4	0.021	0.001
May	40	4	45	4.5	0.0003	0.0009
June	43	4.3	40	4	0.013	0.0001
July	80	8	42	4.2	0.053	0.0001
August	75	7.5	43	4.3	0.037	0.003
September	80	8	50	5	0.016	0.001
October	65	6.5	36	3.6	0.06	0.002
November	50	5	78	7.8	0.3	0.00015
December	95	9.5	83	8.3	0.069	0.001

Table 2. The statistical data processing results on the repair and maintenance of taxi fleet vehicles in the absence of centralization per 1,000 cars

Mounth 2019 and 2020	Observed Value (pcs)	Predicted Value (pcs)	Residual	Standard Pred. v.	Standard Residual	Std.Err. Pred.Val	Mahalanobis Distance	Deleted Residual	Deleted Residual	Cook's Distance
January	85	77	7.8	1.42	0.45101	8.94630	2.028	10.65	10.65	0.05
February	80	86	-6.9	2.17	-0.39771	12.4016	4.74	-14.162	-14.16	0.17
March	85	59	25.21	0.068	1.45818	5.00382	0.0046	27.5172	27.52	0.106
April	40	48	-8.18	-0.83	-0.47296	6.62770	0.7	-9.5863	-9.5863	0.023
May	45	44	0.69	-1.138	0.04003	7.75234	1.29	0.8663	0.8663	0.0003
June	40	45	-5.47	-1.047	-0.31629	7.39787	1.097	-6.6943	-6.6943	0.014
July	42	59	-17.78	0.06782	-1.02874	5.00382	0.0046	-19.41	-19.413	0.053
August	43	57	-14.85	-0.08	-0.85900	5.00998	0.0069	-16.21	-16.21	0.04
September	50	59	-9.79	0.067	-0.56606	5.00382	0.0046	-10.68	-10.68	0.02
October	36	53	-17.98	-0.3840	-1.04003	5.37838	0.147683	-19.909	-19.909	0.06414
November	78	48	29.8223	-0.8361	1.72479	6.62770	0.699580	34.9588	34.9588	0.30032
December	83	65	17.4078	0.51993	1.00679	5.67981	0.270327	19.5135	19.5135	0.06872
Minimum	36	44	-17.9826	-1.1372	-1.04003	5.00382	0.004599	-19.909	-19.909	0.00025
Maximum	85	86	29.8223	2.17768	1.72479	12.4015	4.742278	34.9588	34.9588	0.30032
Mean	58	58	0.0000	0.00000	0.00000	6.73609	0.916667	-0.2630	-0.2630	0.0754
Median	47	58	-6.1727	-0.0074	-0.35700	6.15375	0.484954	-8.1403	-8.1403	0.05173

vehicle product-service system (PSU) structure based on confidence, which is combined using blockchain technology, has been provided. This technology is the basis for the distribution of taxi fleets of Yandex Taxi, DiDi, Uber, Bolt, etc. Concerning the scope of blockchain technology, the primary objective is to maintain mutual confidence among PSU parties, reduce the risks associated with passenger transport and vehicle depreciation, and increase the transparency of driver, vehicle, and passenger information.

The structure consists of five main components:

1. *data,*
2. *interested parties,*
3. *blockchain platform,*
4. *link*
5. *and the Yandex Go app.*

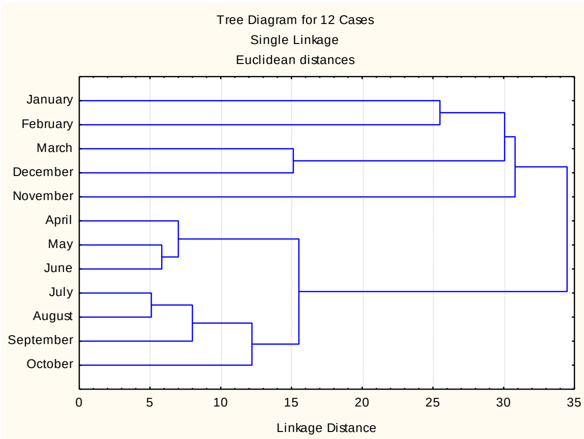

Figure 2. Cluster analysis of year-to-year accident trend for 2019-2020 per 1,000 vehicles

Each person involved in the structure is responsible for a specific service section and thorough data maintenance. Blockchain functions for storing, verifying, translating data, and protecting transactions. Communication is the flow of documents, information, and transactions amongst stakeholders. The Yandex Go app governs the functioning of the taxi fleet.

In the proposed blockchain structure, required data can be divided into five categories: component identification data, event data, vehicle condition data, component life cycle data, and customer (passenger) data from the taxi service (**Figure 3**).

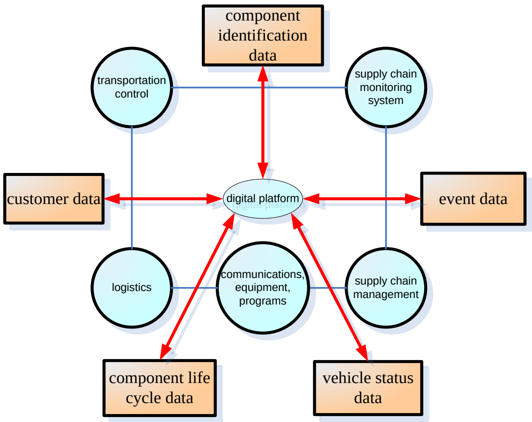

Figure 3. Blockchain structure of a taxi fleet

Component identification data originates primarily from manufacturers and suppliers. This type of data serves to check the authenticity of the vehicle components. By forwarding identification data to the blockchain platform, parties involved can track and check the manufacturer, serial number, and batch number of the components. Occurrence data provide parties with a reliable record of vehicle-related occurrences, such as maintenance, accidents, and damages. Blockchain allows all parties involved (e.g., traffic police, insurance company, service provider) to record vehicle events in a register and broadcast them to others. Vehicle condition data is generated through intelligent equipped resources. They can continuously monitor and estimate the remaining lifetime of the components and update these data in the blockchain database. Component lifecycle data records the history of each component throughout its lifecycle. This kind of data makes it possible to monitor vehicles.

The client's data records the vehicle's ownership history and identity to determine the vehicle's last objective efficiently. The value of the vehicle to interested parties will also be generated based on this data. The PSU system includes dealers, third-party service providers, component suppliers, manufacturers, customers, vehicle financing services, and insurance companies. Dealers primarily offer services for the sale of new or pre-owned vehicles. Some licensed dealers also provide certain after-sales services, such as repairs, maintenance, etc. Licensed dealers are generally permitted to sell and maintain a single specific brand. By contrast, third-party service providers offer services without being affiliated with any brand. They can sell and maintain any vehicle, whoever manufactured it. Likewise, component suppliers can be classified as registered and third-party suppliers. Only registered suppliers produce and sell genuine components certified by the manufacturer.

However, third-party suppliers produce similar components but without approval and warranty from vehicle manufacturers. Customers are the end-users of the cars, whether they are owners or not. Insurance companies sell custom insurance based on the history of the car and the identity of the client. Financial services offer credit and assessment services to customers, helping them with a car purchase or mortgage. The blockchain platform delivers computing infrastructure for smart contracts in various sectors of the automotive industry. The data of the relevant parties and vehicles can be transferred to the intelligent contract for verification. In terms of information transparency, the data generated can be disseminated on the blockchain, allowing authorized parties involved to read and check it independently.

Within the proposed structure, the blockchain platform comprises two modules: the blockchain and smart deals. The blockchain network works to access, store, and disseminate data from all PSU areas, including vehicles, interested parties, and other events. Through the blockchain network, authorized parties involved have access to the most up-to-date information on the vehicle's condition, such as property history, mileage, maintenance history, etc. The smart deal functions to determine the service requirements of the taxi fleet's customers (passengers). Once the vehicles have completed service, the updated data will be uploaded to the smart contract. A predefined consensus protocol in the smart deal is used to verify the level of fulfillment of the requirements.

And the transaction will be initiated if the customer's requirements are met.

During service delivery, parties involved are connected through information flows, material flows, and transactions. For example, when ordering a service, the system will first request a customer ID to access the vehicle ledger. The request is sent to all interested parties on the blockchain network. Each party can broadcast its data and verify data from other sources. Once the data has been verified by all parties involved, the service provider will receive historical information about the vehicle and then upload the customized contract to the blockchain network and share it with other parties. The service contract must inform each party with proof of service, and the vehicle data must be updated after the service. All interested parties validate authentication of the vehicle data and the service contract.

Consequently, service within the system is maintained in a decentralized manner. If the customer receives the service and satisfies the condition of the smart deal, the transaction will be initiated. Several applications are needed in the proposed system to ensure mutual trust between all parties involved. These applications will help them properly document vehicle data and ensure its transparency and integrity. Each application includes a set of parties involved and is directly connected to the blockchain network. As soon as a customer requests new service, the platform automatically includes the responsible stakeholders and empowers each stakeholder to access the relevant data. Analyzing the vehicle data, the desired service, potential risks, and associated verification methods will be identified and recorded in a smart deal.

Blockchain allows vehicle records to be kept in a decentralized manner. Given that many services can significantly change vehicle information and prevent other service providers from further analyzing the vehicle's condition, each party should take responsibility for recording changes in detail. **Table 3** summarizes the set of data that should be updated by parties involved in the vehicle register.

Following the mathematical model above, a test calculation was made on the example of four Yandex Taxi units: online taxi ordering, carsharing, food ordering, express food delivery (rows) for four quarters of 2019 (columns).

To determine the demand for maintenance or repair of vehicles, the data are provided in the form of the following matrix:

$$C = (c_{ij}) = \begin{pmatrix} 2 & 10 & 9 & 7 \\ 15 & 4 & 14 & 8 \\ 13 & 14 & 16 & 11 \\ 4 & 15 & 13 & 19 \end{pmatrix} \quad (6)$$

Iteration 1

1. Transforming rows and columns of equation 6. The values of the minimal elements in rows of the given matrix are 1, 2, 3, and 4 are 2, 4, 11, and 4, respectively. Subtracting the corresponding minimum value from the elements of each row, the following matrix can be obtained:

$$\overline{C} = \begin{pmatrix} 0 & 8 & 2 & 5 \\ 11 & 0 & 5 & 4 \\ 2 & 3 & 0 & 0 \\ 0 & 11 & 4 & 15 \end{pmatrix} \quad (7)$$

2. Step 2. Finding an acceptable solution for all vehicle assignments for maintenance or repair is zero, i.e., vehicles that do not need repair. An algorithm to find the most effective combination of pairs was applied. Converting the matrix (7) into a bipartite graph matrix we

Table 3. Summary of vehicle record data

Data category	Description	Parties involved
Component Identity	Component name, supplier name, production date, lot number, serial number, material, brand, price, etc.	Manufacturer, supplier, dealer, third party service provider
Records of the vehicle's	Accidents, wear and tear, replaced components, service provider name, maintenance records, change records, meter data, operating data, etc.	Customer, third-party service provider, government, manufacturer, finance department, insurance provider
Customer Identification	Ownership history, customer profile, customer credits, driving style, accident records, etc.	Customer, dealer, car financing department, insurance agent

obtained a combination of pairs:

$$\begin{pmatrix} 1 & X & X & X \\ X & 1 & X & X \\ X & X & 1 & \\ & X & X & X \end{pmatrix} \quad (8)$$

This combination of pairs is not perfect, indicating no complete assignment of vehicles for maintenance or repair. Then Step 3 follows.

3. Step 3. Modifying the transposed matrix (7).
   a) The number of nulls in rows 1, 2, 3, and 4 is 1, 1, 2, and 1, respectively. For the columns, the corresponding values are 2, 1, 1, and 1.
   b) The maximum number of nulls, two each,are in row 3 and column 1. Selecting row 3 and crossing out all its elements with a horizontal line.
   c) The number of non-dashed nulls in rows 1, 2, and 4 is 1, 1, and 1, respectively. For the columns, the corresponding values are 2, 1, 0, and 0. Thus, column 1 is chosen to cross out with a vertical line. After that, there will be only one unsubtracted null: the element (2,2), and either row 2 or column 2 can be crossed out. Crossing out row 2 with a horizontal line, the following matrix can be obtained:

$$\begin{pmatrix} 0 & 8 & 2 & 5 \\ 11 & 0 & 5 & 4 \\ 2 & 3 & 0 & 0 \\ 0 & 11 & 4 & 15 \end{pmatrix} \quad (9)$$

   d) The value of the minimal non-dashed element is 2. By subtracting it from all the non-dashed elements and adding it to all the elements located at the intersection of the two lines, a new maintenance demand matrix can be obtained:

$$\begin{pmatrix} 0 & 6 & 0 & 3 \\ 13 & 0 & 5 & 4 \\ 4 & 3 & 0 & 0 \\ 0 & 9 & 2 & 13 \end{pmatrix} \quad (10)$$

Iteration 2.

Step 2. Performing the procedure of constructing an admissible minimum maintenance cost solution again, the following optimal solution is obtained:

$$\begin{pmatrix} 0 & 6 & (0) & 3 \\ 13 & (0) & 5 & 4 \\ 4 & 3 & 0 & (0) \\ (0) & 9 & 2 & 13 \end{pmatrix} \quad (11)$$

Optimal assignment for vehicle repair is following Equation 12.

This article presents a template for the management of a fleet of distributed taxis using blockchain technology. Because taxi fleets operate without dispatch control, there are numerous problems and problems associated with the maintenance of taxi fleet vehicles. This paper proposes concepts for changing the functioning of the communication system in this field to improve its quality. Emphasis was placed on strengthening the role of public transport in satisfying travel-related needs in a decentralized environment. This can only be achieved if communications are arranged on a blockchain-based Internet platform. It is also intended to be compulsory insurance for employees and movable assets in the taxi fleet. However, the spatial and temporal heterogeneity of taxi fleet labor remains unknown.

It should be noted that many authors' studies looked at the reasons for differences in vehicle occupancy rates [31, 32]. However, these statements are not supported empirically or analytically. To fill these gaps, this paper develops an efficiency estimation method based on origin-destination route data and measures and compares the efficiency of shuttle and taxi journeys. We also examine three hypothetical reasons that influence the difference in efficiency between carsharing and taxis: the efficiency of route matching, scale effects, and the number of cab trips.

The recent evolution towards an increasingly integrated world is based on new types of pervasive systems obtained through new technologies and new paradigms like the Internet of Things (IoT). These include both physically distributed devices and cloud-based infrastructure. This emergence is accompanied by new types of requirements and the need for

$$x_{13}^{*}=1,\ x_{22}^{*}=1,\ x_{34}^{*}=1,\ x_{41}^{*}=1,\ \text{the rest is } x_{ij}^{*}=0,\ F(X^{*})=9+4+11+4=28. \quad (12)$$

increased assurance regarding the behavior of physically distributed systems in general [33], as they permeate increasingly important aspects of human activity. IoT systems operate in dynamic spatial environments: a taxi fleet in a smart city that optimizes spatial distribution based on passenger flow or production media where humans and robots live together. They represent an important class of cyber-physical systems [34, 35] facing numerous problems associated with the dynamic-spatial environment. They require operational management to observe, evaluate and respond to a rapidly changing space.

In support of the blockchain and the fact that taxi fleets in a decentralized environment are 30% more competitive in centralized taxi fleets [16]. When the system is in operation, run-time analysis techniques are an important precondition for ensuring possible changes in space. For example, actions carried out by active agents or the environment itself do not cause violations of requirements. Typically, this can be achieved using the MAPE approach [36]; by (M) monitoring the spatial environment for changes, (A) analyzing possible requirements violations, (P) taking necessary countermeasures (e.g., moving a device from one point in the space to another), and then (E) performing such actions and updating the overall space model [37]. Component identification is initially documented by manufacturers and vendors. The identification data are marked on the components upon leaving the plant. The availability of this data enables purchasers (resellers, third-party service providers, customers) to monitor the origin of parts throughout the supply chain. Component identification enables all stakeholders to monitor the authenticity of automotive parts in a vehicle.

As the blockchain can record data in chronological order, records from previous owners will prevent non-certified components from being used. It also provides evidence in the event of a conflict, warranty, etc. The vehicle register shall also record data relating to all vehicle accidents, occurrences, and conditions. All authorized parties must update vehicle condition and maintenance records on the blockchain platform and notify others, such as replaced components, repaired components, and maintenance records. Other parties constantly check the updated data, and the connected sensors can monitor the vehicle's state in real-time. Data collected by sensors and data collected by stakeholders are cross-referenced to ensure data integrity. For example, sensors will record vehicle mileage data and update it on a blockchain platform, which can be applied to cross-check used car dealer reports to prevent mileage fraud. Thanks to the blockchain, the previous owner's information are related to car accidents and the taxi fleet's personal information (passengers). Customer data will be collected, verified, and stored on the platform before providing services to customers.

The property history is also entered in the vehicle register. Access to the vehicle registry will expand the variety of data, providing service providers with more reliable information to accurately evaluate a vehicle. Since the finance department can continue to monitor the condition and registration of vehicles, the system can automatically estimate the price of the vehicle until disposition becomes necessary. The analytical model is designed to access, validate and present data to interpret vehicle quality. Many indicators can affect the real value of a car in the real world: mileage, modification, etc. These metrics are described using logic and consensus, predetermined by finance departments, and written into a smart contract. The car evaluation process begins with a readout of the data from the blockchain network. The access to the car in the database allows comparing the car's condition to the appraisal metrics, and the system will calculate a value based on the wear and tear level of the car. The result produced by the blockchain platform is more reliable because the data are generated autonomously by sensors connected in the car, effectively preventing unauthorized tampering with the data.

Blockchain technology enables insurance companies to provide more customized insurance contracts based on actual vehicle and owner data. By accessing the vehicle register, the system can assess the reliability and status of a customer's vehicle. Because data becomes transparent to insurance companies, companies can identify client risks in advance and organize appropriate services. Accordingly, a customized insurance contract with flexible prices will be proposed. The integration of blockchain technology, the Internet of Things, and data analytics will facilitate real-time monitoring of vehicle conditions and automatic prediction of implied claims. Internet of things devices is equipped for the collection and downloading of data into the register. A 4-step data analysis process is designed to predict quality problems ahead of time.

According to the diagnostic information, maintenance recommendations may be more precise. Authorized by customers, certain non-standard results will trigger a smart contract and automatically order customized services such as maintenance, repairs, and component replacement. The service provider will also use it to make decisions. For example, several data types, such as oil level, cylinder activity, fuel injection, pedal position, and air pressure, will provide all parties involved with evidence and guidance on what needs to be fixed. Because all components in a vehicle have a unique identification number, dealers can quickly identify vehicles that contain defective components and issue a special recall or service bulletins for such vehicles. At the end of a vehicle's life, identifying components will also help manufacturers disassemble and classify parts. Through blockchain technology, the origin of each component will be known, stored, and updated, enabling manufacturers to track the origin of components throughout the supply chain.

4. Conclusion

This article describes a blockchain structure for PSU vehicles in which various parties involved collaborate to maintain mutual trust in the industry. The proposed framework is a blockchain-based data collection platform that allows all stakeholders to update and verify vehicle information precisely. By increasing the immutability and transparency of data with blockchain technology, vehicles' conditions become easier to check. This will undoubtedly reduce the time required to determine the state of the cars and the operational risks. The present time means faster and faster progress in many fields of science, offering new solutions. It is therefore important to follow closely developments related to the improvement of communication. In addition, an important fact is the simplification of forecasts for companies and the general reduction in the cost of many processes and consequently the price of the final product. The statistical analysis and cluster results indicated higher risks of requiring emergency car service in Q_1 and Q_4. The maximum value of Pearson criterion χ^2 was 0.17. The value of the statistical significance of the results was $p \leq 0.005$. The presented mathematical model allows calculating the need for repair and maintenance of vehicles and can also be used to distribute orders, taking into account the minimum cost of travel and determining the minimum distance between destinations.

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Author's Declaration

Authors' contributions and responsibilities

MB, TS, IA	The authors made substantial contributions to the conception and design of the study.
EC, MG	The authors took responsibility for data analysis, interpretation and discussion of results.
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References

[1] S. Rajendran and S. Srinivas, "Air taxi service for urban mobility: A critical review of recent developments, future challenges, and opportunities," *Transportation Research Part E: Logistics and Transportation Review*, vol. 143, p. 102090, 2020.

[2] D. O. Rodrigues, A. Boukerche, T. H. Silva, A. A. Loureiro, and L. A. Villas, "Combining taxi and social media data to explore urban mobility issues," *Computer Communications*, vol. 132, pp. 111–125, 2018.

[3] S. Jiang, L. Chen, A. Mislove, and C. Wilson, "On ridesharing competition and accessibility: Evidence from Uber, Lyft, and taxi," in *Proceedings of the 2018 World Wide*

Web Conference, pp. 863–872, 2018.

[4] J. Dobroszek, M. Biernacki, and M. Macuda, "Management accounting in logistics and supply chain management: Evidence from Poland," *Zeszyty Teoretyczne Rachunkowości*, vol. 106, no. 162, pp. 153–175, 2020.

[5] S. Ma, Y. Zheng, and O. Wolfson, "T-share: A large-scale dynamic taxi ridesharing service", in *2013 IEEE 29th International Conference on Data Engineering (ICDE)*, IEEE, pp. 410–421, 2013.

[6] Y. Ge, C. Liu, H. Xiong, and J. Chen, "A taxi business intelligence system," in *Proceedings of the 17th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, pp. 735–738, 2011.

[7] J. Cramer and A. B. Krueger, "Disruptive change in the taxi business: The case of Uber," *American Economic Review*, vol. 106, no. 5, pp. 177–182, 2016.

[8] L. Moreira-Matias, J. Gama, M. Ferreira, J. Mendes-Moreira, and L. Damas, "Predicting taxi-passenger demand using streaming data," *IEEE Transactions on Intelligent Transportation Systems*, vol. 14, no. 3, pp. 1393–1402, 2013.

[9] H. Billhardt, A. Fernández, S. Ossowski, J. Palanca, and J. Bajo, "Taxi dispatching strategies with compensations," *Expert Systems with Applications*, vol. 122, pp. 173–182, 2019.

[10] H. R. Sayarshad and V. Mahmoodian, "An intelligent method for dynamic distribution of electric taxi batteries between charging and swapping stations," *Sustainable Cities and Society*, p. 102605, 2020.

[11] S. Silwal, M. O. Gani, and V. Raychoudhury, "A survey of taxi ride sharing system architectures," in *2019 IEEE International Conference on Smart Computing (SMARTCOMP)*, IEEE, pp. 144–149, 2019.

[12] Y. Zhang, H. Guo, C. Li, W. Wang, X. Jiang, and Y. Liu, "Which one is more attractive to traveler, taxi or tailored taxi? An empirical study in China," *Procedia Engineering*, vol. 137, pp. 867–875, 2016.

[13] Y. M. Nie, "How can the taxi industry survive the tide of ridesourcing? Evidence from Shenzhen, China," *Transportation Research Part C: Emerging Technologies*, vol. 79, pp. 242–256, 2017.

[14] O. Zeira and S. Lee, *U.S. Patent Application No. 16/279,899*, 2019.

[15] S. Zhang, H. Wang, Y. F. Zhang, and Y. Z. Li, "A novel two-stage location model of charging station considering dynamic distribution of electric taxis," *Sustainable Cities and Society*, vol. 51, p. 101752, 2019.

[16] R. Qi, C. Feng, Z. Liu, and N. Mrad, "Blockchain-powered internet of things, e-governance and e-democracy," in *E-democracy for smart cities*, Springer, Singapore, pp. 509–520, 2017.

[17] T. Alladi, V. Chamola, R. M. Parizi, and K. K. R. Choo, "Blockchain applications for industry 4.0 and industrial IoT: A review," *IEEE Access*, vol. 7, pp. 176935–176951, 2019.

[18] E. B. Belhadji, G. Dionne, and F. Tarkhani, "A model for the detection of insurance fraud," *The Geneva Papers on Risk and Insurance-Issues and Practice*, vol. 25, no. 4, pp. 517–538, 2000.

[19] E. E. Ilina, T. E. Ilina, and B. P. Viktorovich, "Analysis of the application of turbulence models in the calculation of supersonic gas jet," *American Journal of Applied Sciences*, vol. 11, no. 11, pp. 1914–1920, 2014.

[20] K. P. O'Keeffe, A. Anjomshoaa, S. H. Strogatz, P. Santi, and C. Ratti, "Quantifying the sensing power of vehicle fleets," *Proceedings of the National Academy of Sciences*, vol. 116, n. 26, pp. 12752–12757, 2019.

[21] V. Sabadash, J. Gumnitsky, O. Lyuta, and I. Pochapska, "Thermodynamics of (NH4+) cation adsorption under static conditions," *Chemistry Chemical Technology*, vol. 12, no. 2, pp. 143–146, 2018.

[22] F. Y. Wang, Y. Yuan, C. Rong, and J. J. Zhang, "Parallel blockchain: An architecture for CPSS-based smart societies," *IEEE Transactions on Computational Social Systems*, vol. 5, no. 2, pp. 303–310, 2018.

[23] J. Sun, J. Yan, and K. Z. Zhang, "Blockchain-based sharing services: What blockchain technology can contribute to smart cities," *Financial Innovation*, vol. 2, no. 1, pp. 1–9, 2016.

[24] S. Kim, J. J. E. Chang, H. H. Park, S. U. Song, C. B. Cha, J. W. Kim, and N. Kang, "Autonomous taxi service design and user experience," *International Journal of Human-Computer Interaction*, vol. 36, no. 5, pp. 429–448, 2020.

[25] E. Nowińska, "Use and application of the internet of things in the digital transformation of enterprises," *Acta Universitatis Nicolai Copernici. Zarządzanie*, vol. 47, no. 2, pp. 21–35, 2020.
[26] D. H. Kaplan, "Growing sustainable transportation in an autocentric community: Current trends and applications," in *Urban and regional planning and development*, Springer, Cham, pp. 503–514, 2020.
[27] M. V. Smuk, "Product-service system based on blockchain technology in the automotive industry," *Financial Markets and Banks*, vol. 5, pp. 102–107, 2020.
[28] W. Zhang, T. V. Le, S. V. Ukkusuri, and R. Li, "Influencing factors and heterogeneity in ridership of traditional and app-based taxi systems." *Transportation*, vol. 47, no. 2, pp. 971–996, 2020.
[29] V. Sabadash, J. Gumnitsky, and O. Lyuta, "Combined adsorption of the copper and chromium cations by clinoptilolite of the sokyrnytsya deposit," *Journal of Ecological Engineering*, vol. 21, no. 5, pp. 42–46, 2020.
[30] W. Tu, Q. Li, Z. Fang, S. L. Shaw, B. Zhou, and X. Chang, "Optimizing the locations of electric taxi charging stations: A spatial-temporal demand coverage approach," *Transportation Research Part C: Emerging Technologies*, vol. 65, pp. 172–189, 2016.
[31] C. Sullivan and C. O'Fallon, "Vehicle occupancy in New Zealand's three largest urban areas," in *Working Paper presented at the 26th Australian Transport Research Forum (ATRF),' Leading Transport Research in the 21st Century'*, Wellington, New Zealand, pp. 1–3, 2003.
[32] P. V. Bulat, O. N. Zasuhin, and V. N. Uskov, "On classification of flow regimes in a channel with sudden expansion," *Thermophysics and Aeromechanics*, vol. 19, no. 2, pp. 233–246, 2012.
[33] S. Rahili, B. Riviere, S. Olivier, and S. J. Chung, "Optimal routing for autonomous taxis using distributed reinforcement learning," in *2018 IEEE International Conference on Data Mining Workshops (ICDMW)*, IEEE, pp. 556–563, 2018.
[34] W. T. Chai, B. Y. Ooi, S. Y. Liew, and S. Shirmohammadi, "Taxi-sharing: A wireless IoT-gateway selection scheme for delay-tolerant data," in *2018 IEEE International Instrumentation and Measurement Technology Conference (I2MTC)*, IEEE, pp. 1–6, 2018.
[35] I. Indrianto, M. N. I. Susanti, R. R. A. Siregar, and Y. Purwanto, "Smart taxi security system design with internet of things (IoT)," *Telkomnika*, vol. 17, no. 3, 2019.
[36] N. Davis, G. Raina, and K. Jagannathan, "A multi-level clustering approach for forecasting taxi travel demand," in *2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC)*, IEEE, pp. 223–228, 2016.
[37] C. Tsigkanos, M. Garriga, L. Baresi, and C. Ghezzi, "Cloud deployment tradeoffs for the analysis of spatially-distributed systems of internet-of-things," 2020, arXiv preprint arXiv:2004.11428.