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Design and development of an intelligent transportation management system using blockchain and smart contracts

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Abstract
The automated toll-tax collection system (ATCS) is advantageous to facilitate traffic management at the toll plaza and to save fuel for vehicles. The most advanced application of the electronic toll collection (ETC) system is to collect the toll-tax amount (TA) at toll plazas of the national highways. The few existing TA collection systems suffer from data security, transparency, privacy, and data immutability as these are centralized systems. As the Blockchain is a decentralized, transparent, secure, and low-cost technology. However, this paper presents an intelligent transportation management system (I-TMS) using Blockchain. The proposed I-TMS shows the way of implementation of blockchain technology for vehicle data management in various applications of I-TMS. Herein, a framework of blockchain-enabled ATCS (BATCS) is provided as a blockchain-based I-TMS application to collect TAs without stopping vehicles while they pass the toll plaza. Smart contracts are used to authenticate vehicles' data and to collect TAs automatically. An efficient algorithm is presented for data verification and TA collection in this paper. This research work provides a secure, transparent, and privacy-preserving framework in the field of the ETC system. The significant contributions of the BATCS compared with the RFID-based system are less fuel consumption and time-saving for a vehicle. The proposed framework can enhance data security and user privacy in the intelligent decentralized ETC system.

Keywords Blockchain · Smart contract · Decentralized electronic toll collection · Intelligent transportation management system · Blockchain-enabled ETC system

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1 Introduction

The number of vehicles on the road has grown day by day. Vehicles need to wait for a long time at toll plazas to pay the toll-tax amount (TA). Thus, traffic congestion of the toll plaza has been risen using the hand-operated TA collection system. So, there is a need for an automated toll collection system (ATCS) to avoid traffic congestion of the toll plaza and reduce waiting time and fuel consumption. However, the electronic toll collection (ETC) [1] is an ATCS, which can collect TAs automatically without slowing down the vehicle. TAs can be solicited directly from their registered bank accounts, which are associated with their vehicle number. The ETC system is composed of four subsystems [2], which are automated vehicle identification (AVI), automatic vehicle classification (AVC), violation enforcement system (VES), and transaction processing. The automatic number-plate recognition (ANPR) [3] method can recognize a vehicle plate number and identify the vehicle.

In the past two decades of successful ETC applications, several technical challenges have been resolved. Interoperability and software adoption contribute to the present problem with the deployment of ETC systems. The choice of technologies has a direct effect on interoperability. One of the existing ETC systems in India is Fastag [4], which is developed using the radio frequency identification (RFID) technology [1, 5]. But, using the RFID, a few disadvantages exist, such as data modification, data security, data privacy, and transparency of the transaction data. Other difficulties are manifested by using Fastag such as it can be stolen or lost, it faces glitch or failure, and the National Highways Authority of India (NHAI) cannot be involved itself at the time of payments. If a service company uses another RFID standard, clients from distant organizations may not read it. States, cities, and local tax officials will have to work together to establish a cohesive framework. So, there is a need for a decentralized system instead of the traditional centralized system. Thus, blockchain [6] can be incorporated with the ETC system to enhance the ATCS service.

This paper presents an intelligent transportation management system (I-TMS) using Blockchain. Herein, a framework of blockchain-enabled automated toll-tax collection system (BATCS) is shown as a blockchain-based I-TMS application to avoid the disadvantages of the existing ATCS system. Blockchain is a decentralized, secure, transparent, and low-cost technology. It has a table of records named blocks, which are linked by using cryptography [7]. So, transactions can be secured and visible to all associated organizations within the Blockchain network. Using the proposed BATCS, an appropriate TA can be collected for the passing vehicle securely and transparently without having the toll barrier system at the toll plaza of the national highways. In this proposed BATCS, blockchain can provide the transparency and security of the transacted and stored information of the blockchain.

The major contributions of this proposed research work are summarized in the following:

- This paper shows the way of implementation of blockchain technology for vehicle data management in various applications of I-TMS.
- This paper also provides a secure, transparent BATCS framework to collect the TA for a vehicle without stopping the vehicle at the toll plaza.
- An algorithm has been formulated and incorporated within the smart contract to verify the vehicle's data and collect TA automatically.
- An implementation flowchart of the proposed algorithm and the experimental results have been presented concisely.
- A comparative analysis based on the time and fuel consumption of the proposed BATCS framework with the RFID-based system has been provided.
- Key features and benefits of BATCS over the RFID-based system have been presented in this paper.

The remainder section is structured as follows. Section 2 describes the existing ATCS systems in the domain of the ETC system. Section 3 presents the overall system overview of the proposed I-TMS and depicts the implementation of an application of I-TMS. The performance evaluation of the BATCS is provided in Sect. 4. In Sect. 5, testing and desired result scenarios of the smart contract code are shown. Section 6 gives a clear comparative analysis of the BATCS with the RFID-based system. Finally, the conclusion and future direction are provided in Sect. 7.

2 Related works

ATCSs have made a significant contribution to minimizing the high traffic jams that have prompted the highways of crowded cities in the world. It is the easiest way to regulate congested traffic movements. The ETC system can find whether the vehicle has been registered or not and then inform the administrator's facility about the activity of violation, transaction, and reconfiguring account. After analyzing various types of challenges of the existing ATCS systems (see in Table 1), a transparent and secure solution is expected to overcome these challenges, where the BATCS can be a new proper solution in the domain of the ETC system.

Table 1 Comparison table of existing ETC systems

Method	Description	Pros	Cons	Reference
RFID-based ATCS	The RFID-based system can detect RFID tags and collect toll amount	Solve traffic problems Maintain a little bit of transparency Reduces human error rates and manual labors	Inadequate detection of tags Security and privacy Equipment costs	[8]
RFID-based ETC	A new advanced security feature that can counter the occurrence of possible crimes	the concerned authority can block a specific vehicle Detect RFID tags and collect TAs	Data security, and inefficient features	[9]
GPS-based ATCS	An ATCS system using the GPS and SIM of the GPRS by using the longitude and latitude of the toll plaza's corner	Can able to find vehicles' accurate positions	Inefficiency and weakness of the network's connectivity	[10]
ETC system using the OCR technology	Using RFID sense to get the passing vehicle number and make a digital transaction using the unique identification	Reduce the over-collection of TAs and manage vehicle theft issues	Data security, adoption of qualities	[11]
Simulation-based ETC system	A solution to explain the traffic barrier	Reliable gate management and reconstructing a new design for toll plazas	The quality of the proposed model and irrelevant simulation time	[12]

Blockchain is a new cut-edging technology, where it provides different trusty solutions for several applications such as smart contracts, supply chains [13], home appliances [14], and healthcare management [15]. A Blockchain is also a decentralized architecture that allows users to form a collective agreement without involving a middleman or intermediaries such as a government and a company. Data privacy of Blockchain can provide confidentiality and transparency for all the sensitive data stored on it. Griggs et al. proposed Blockchain-based smart contracts to aid the secure management of pharmaceutical sensors using a private Blockchain based on Ethereum protocol [16]. Here, sensors interact with smart contracts, which write data on the Blockchain. The smart contract can verify and trigger an event automatically using a set of specified requirements. Blockchain can store the tracking information of communication between vehicles [17]. It can also be applied for vehicle registration and traffic violator tracking [18].

3 Blockchain-based intelligent transportation management system

Figure 1 describes the system overview of the Intelligent Transportation Management System (I-TMS). The proposed system is transparent and secure for various vehicle data management issues. In this system, vehicles data will be collected using specific technology in which that data will be stored in specific local storage. Herein, it is assumed that vehicles data can be collected using sensor devices, cameras, and GPS. Therefore, data will be processed for further implementations as per the application requirements. The implementation process is discussed using the electronic toll collection scenario in Sect. 3.1. However, this system can be applied for many purposes such as intelligent parking management, emergency vehicle notification systems, automated road speed enforcement, speed alerts, collision avoidance systems, etc. The connected authorities of the Blockchain network in the proposed I-TMS can collect real-time information like travel route, travel time, road accidents, vehicle speed, speed limit, work zone areas, etc.

In this study, the toll tax collection framework has been considered for the implementation and performance evaluation of the proposed I-TMS. The proposed methodology and implementation process of the Blockchain-based toll-tax collection framework has been discussed in Sect.3.1.

3.1 Blockchain-enabled automated toll-tax collection

This section describes the proposed framework of a Blockchain-enabled automated toll-tax collection system (BATCS). The BATCS is intended to collect the TA automatically for a vehicle, without stopping the vehicle and without using the barrier system at the toll plaza. In this framework, The optical character recognition (OCR) method [19] and image processing [20] are used to collect the vehicle number and to detect the vehicle speed in this proposed work. OCR reader is the electronic transformation of images into machine-encoded text. So, digitized text

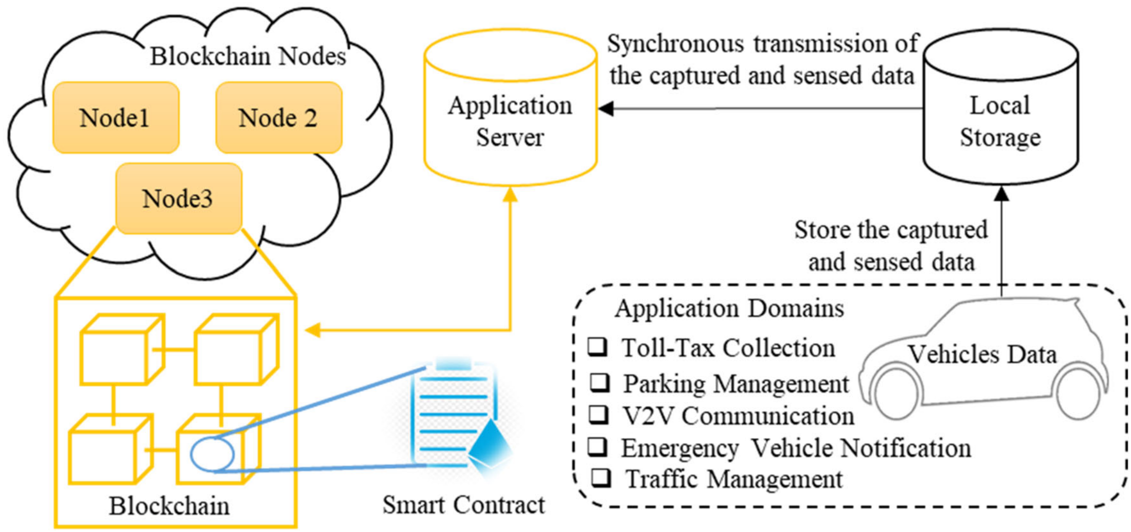
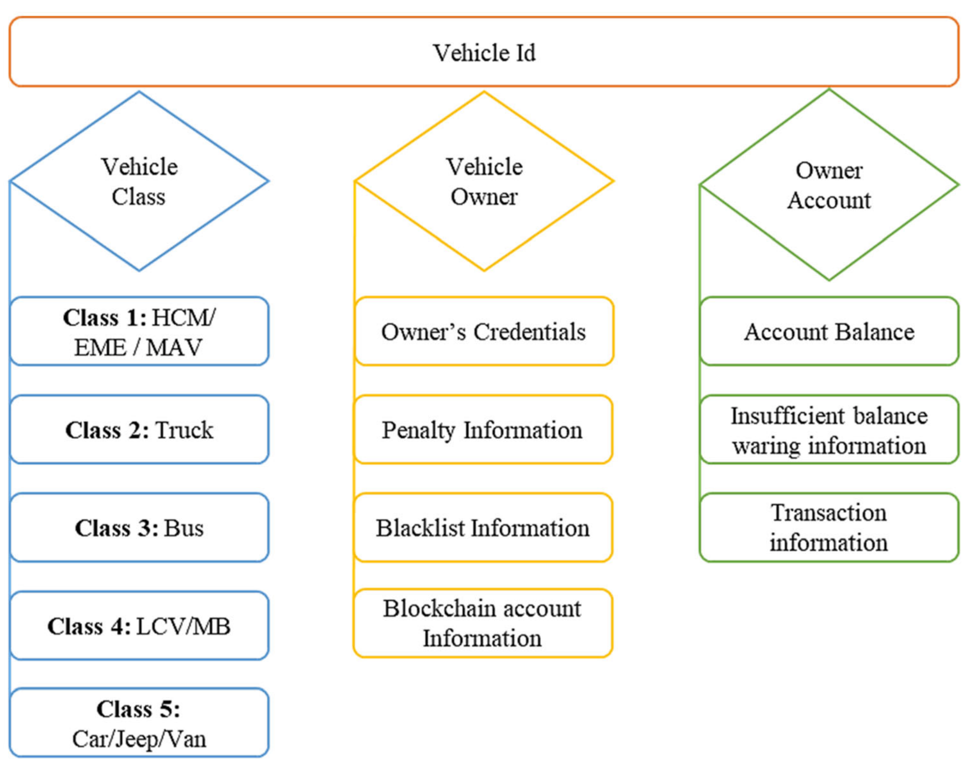


Fig. 1 System overview of the intelligent transportation management framework

can be searched, classified, and retrieved in software. The accuracy of the conversion of OCR software is 98–99%. Herein, OCR software is used to covert images of vehicles plate numbers to text that is easy to read and access by the application software. Smart contracts [21] are also designed to verify the vehicle data and collect the TA automatically while the vehicle passes the toll plaza. The TA will be collected from the linked bank account of the vehicle owner based on the vehicle's type.

A vehicle number plate can be detected to collect the vehicle data while it passes the toll plaza. The collected data will be stored in the local storage of the toll plaza. The speed of the vehicle can be detected and stored in the same place. The local storage information will be transmitted to the application storage using the synchronous data transmission [22]. In the BATCS framework, three nodes are taken that are connected using a Blockchain network. They are responsible for various services such as the smart contract's deployment, mining policy, transaction

Fig. 2 Data accessing mechanism using the vehicle Id



management, and toll plaza management based on their mutual strategy management. At first, the smart contract is deployed to the Blockchain to verify the vehicle credential and collect the appropriate TA. So, after receiving the vehicle data, the smart contract automatically collects the TA for the vehicle. Every successful transaction will be stored on the Blockchain ledger. Finally, a notification will send to the vehicle's owner about the successful or failed transaction.

In the BATCS framework, vehicle identification is done by using the unique vehicle number called vehicle Id that is shown in Fig. 2. The vehicle type, vehicle owner, and owner account can be retrieved using the vehicle Id from the Blockchain database. The deployed smart contract can access these data to complete the TA collection process. The proposed BATCS is comprised of different stages, which are described in detail in the following:

3.1.1 Vehicle data collection

Vehicle identification is required to collect the appropriate TA. The identified vehicle will be stored on the local storage of the toll plaza, and it will be sent to the Blockchain application's server. Vehicle identification is required to collect the appropriate TA. An automatic license plate recognition (ALPR) software [19] can be used to detect, scan and identify the vehicle number plate by processing the video footage in real-time. The scanned and processed data will be sent to the local storage using a wireless connection. The data will be sent to the application server through synchronized transmission. Therefore, Blockchain nodes can access the data. The V_{Id} and V_{Speed} will be transmitted continuously, where V_{Id} is the vehicle Id, and V_{Speed} is the vehicle speed at the time of passing the toll plaza. The vehicle speed can be detected using image processing. Vehicle speed detection is required to know the V_{Speed} of the vehicle at the time of passing the toll plaza. In this proposed system, V_{Speed} shouldn't be more than 40 km/h that is taken as a threshold speed to capture the vehicle number with better accuracy.

A vehicle number plate is captured while it passes the toll plaza. The OCR method can provide better identification of the V_{Id}. After processing the image, the V_{Id} is stored on the local server of the toll plaza and frequently sent to the Blockchain application server. Finally, the smart contract authenticates the V_{Id} and accesses all related data, and collects the TA.

3.1.2 Data verification and TA collection

An essential perspective of deploying smart contracts in Ethereum [23] is their addresses in the Blockchain. If a node needs to access any methods defined by a smart contract; it can send a message to the address. Used techniques of the smart contract can access data as input and return an output. Even the smart contract methods can store data.

Algorithm: Data Verification and TA Collection

Input: V_{Id}, V_{Speed}, IB_{count}
Output: $AC_{Balance}$, Transaction Status

Step1: Smart contract reads the input value
Step2: reads the value of TA, V_{Class}, penalty, $AC_{Balance}$, IB_{count}
Step3: **if** (V_{Id} exists and V_{Speed} <=40) **then**
Step3: **if** ($AC_{Balance}$ >= TA) **then**
    $AC_{Balance} = AC_{Balance} - TA$;
    return $AC_{Balance}$;
    notify the owner;
  End
Step5: **Else**
    if (IB_{count} == 1) **then**
      Notify the owner to credit the $AC_{Balance}$;
    End
    else if (IB_{count} >= 1) **then**
      the V_{Id} has been sent to the blacklist;
    End
  End
End
Else
Step6: **if** (V_{Id} exists && $AC_{Balance}$ >= TA) **then**
    $AC_{Balance} = AC_{Balance} - (TA + penalty)$;
    return $AC_{Balance}$, V_{Class}, Transaction Status;
    notify the owner;
    Set IB_{count}=0;
  End
Step7: **Else**
    go to step5;
  End
End

There is a need for a suitable mechanism to validate the collected vehicles data after receiving it. Thus, the smart contract is used in the BATCS framework. The smart contract can receive TA automatically based on the class of the vehicle, where the vehicle class is already associated with its vehicle number. The smart contract can access and verify the vehicle data to collect the TA. A vehicle has to register while buying it. Each vehicle owner has to provide their identification and account details at the time of registration. The smart contract can verify the vehicle and the linked account number by using the V_{Id} to collect the TA. All the information has already been taken at the time of registration and stored in the Blockchain ledger. Finally, the smart contract receives the TA by accessing the V_{Class} and $AC_{Balance}$ using V_{Id}, Where the V_{Class} is the vehicle class, and $AC_{Balance}$ is the account balance of the vehicle owner's account.

Figure 3 illustrates the workflow diagram of the proposed BATCS framework. The TA will be collected from the linked bank account of a vehicle's owner if the required TA is available to the account. A fixed amount will be collected as a penalty, while the VSpeed will be greater than 40. When the required TA is not available, the number of counts of the Insufficient Balance (IBCount) will be set to 1 with sending a warning message to the owner. Concerning this, the vehicle owner should credit the account within a given time by the appropriate authority. When the value of the IBCount is greater than 1, the application will send the VId to the blacklist. After completion of a transaction, the application will send a notification to the owner.

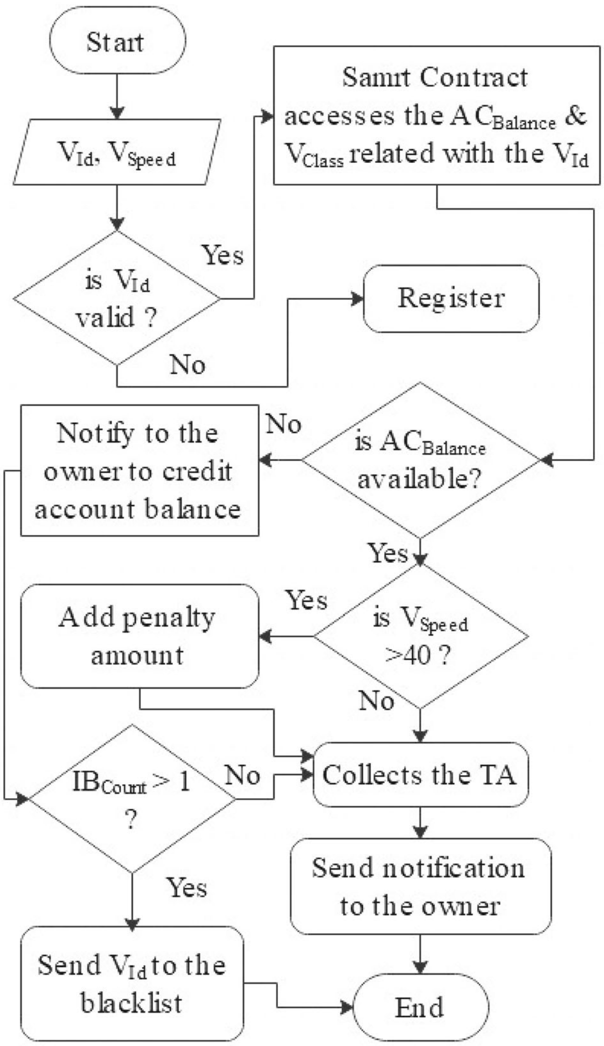


Fig. 3 Workflow diagram of the BATC

4 Performance evaluation

This section provides the performance of the proposed framework based on time and fuel consumption. The proof is established using an equation that the BATCS is better than the RFID-based system. Table 2 shows the useful notations and their descriptions. Figure 4 shows what time is required by using the proposed BATCS framework. The vehicle needs to pass the toll plaza at a threshold speed, where the maximum speed is 40 km/h. So, time can save for the passing vehicle through the toll plaza.

Cost (in time) analysis: The following equation can be used to evaluate the required time of vehicles by using the RFID based system in the region of the toll plaza [24]:

$$T_{RFID} = \sum_{i=1}^{n} (AD_i/AV_i + DD_i/DV_i + P_i),\ 1 \le i \le n \tag{1}$$

The following equation can be used to evaluate the required time of vehicles by using the BATCS system in the region of the toll plaza:

$$T_{BATCS} = \sum_{i=1}^{n} ((AD_i + DD_i)/V_i),\ 1 \le i \le n \tag{2}$$

The BATCS framework takes less time than the RFID based system and the equation of proof is established in the following for a vehicle:

$T_{BATCS} = (AD + DD)/V$ [taken from the Eq. 2]

$T_{BATCS} = (AD/V + DD/V)$

$T_{BATCS} + P = (AD/V + DD/V) + P$ [adding P in both side].

$T_{BATCS} + P < AD/AV + DD/DV + P$ [since, $AV < V$ and $DV < V$]

$T_{BATCS} + P < T_{RFID}$

$$T_{BATCS} < T_{RFID} \tag{3}$$

Equation 3 depicts that time consumption is more in RFID-based systems. Thus, the BATCS is better than the RFID-based system.

Fuel consumption analysis: The following is the fuel consumption per hour equation [25] while a vehicle is moving:

$$F_C = \sum_{i=1}^{n} (V_i/DF_i),\ 1 \le i \le n \tag{4}$$

where DF_i is the average distance that can be passed i^{th} vehicle using one-liter fuel.

If F_C is assumed as the fuel consumption of vehicles per one second, then total fuel consumption using RFID based system can be computed as:

$$F_R = F_C \times T_{RFID} \tag{5}$$

total fuel consumption using BATCS can be computed as:

$$F_B = F_C \times T_{BATCS} \tag{6}$$

As the time consumption is more in RFID-based Systems, more fuel is required using this system. Thus, the BATCS is better than the RFID-based system.

5 Testing and results

This section illustrates the testing results of the designed smart contract, which has the most vital role in the proposed BATCS framework. The proposed algorithms are implemented using the smart contract. The smart contract is implemented and tested by accessing the Remix IDE [26]. It is a web-based platform to write and compile codes.

Table 2 Useful notations and descriptions

Notation	Description
n	Total number of vehicles
i	Index variable that denotes the passing vehicle at a particular time
AD_i	Distance for the ith vehicle to decelerate speed to stop the vehicle at approach time in Toll Plaza, called ramp1
AV_i	The average speed of the ith vehicle during deceleration at approach time in Toll Plaza
DD_i	Distance for the ith vehicle to accelerate the speed to maintain regular speed at depart time in Toll Plaza, called ramp2
DV_i	The average speed of the ith vehicle during acceleration at depart time in Toll Plaza
P_i	Total required time of ith vehicle for waiting in the queue
V_i	The average speed of ith vehicle at the time of crossing the toll plaza
T_{RFID}	Required time for the vehicle to complete payments using the RFID based system
T_{BATCS}	Required time for the vehicle to complete payments using the BATCS system

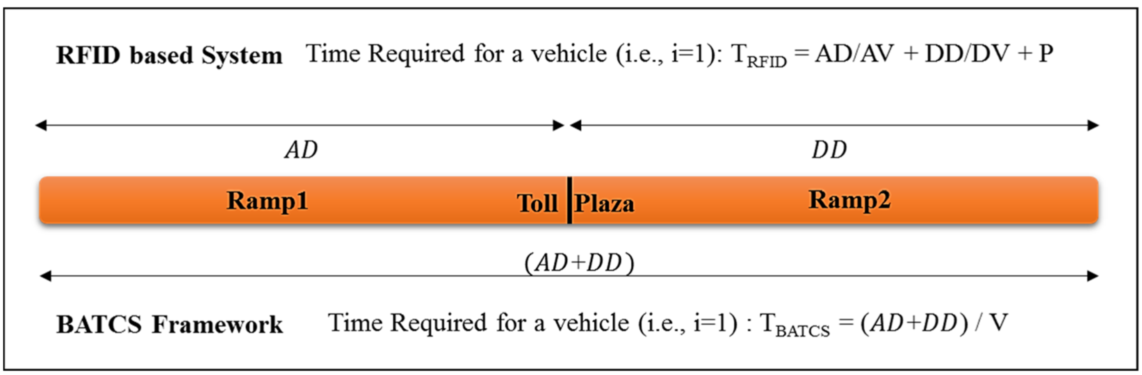


Fig. 4 The distance diagram of the toll plaza

Smart contracts code can write and experiment with within solidity [27] language using Remix. Solidity is a language to write smart contract code. It can provide blockchain-specific services that are run on ethereum virtual machine (EVM). It can also support writing, compile and deploying smart contract code. The preferred solidity compiler version is 0.5.17, and the EVM version is set to compiler default. The selected environment to deploy and run the smart contract's code is JavaScript VM. Table 3 presents TAs for the different types of vehicles.

Figure 5 shows developed smart contract has been compiled and deployed successfully. The smart contract contains two functions that are *CollectTA* and *StoreVehicleDetails*. At first, a database will be created to store vehicles details by inserting the data through the *StoreVehicleDetails* function. We have inserted data manually in the smart contract using the web. Practically, vehicles data can be accessed by the smart contract from the database. This database contains V_{Id}, V_{Class}, and $AC_{Balance}$. As shown in Fig. 6, the smart contract received the V_{Id} and V_{Speed} of

Table 3 TAs for the different vehicle's type

Vehicle type	V_{Class}	Toll-tax amount (Rupees)
Heavy construction machinery (HCM)/earth moving equipment (EME)/multi axle vehicle (MAV) (4 to 6 Axles)	1	100
Truck	2	80
Bus	3	60
Light commercial vehicles (LCV), light goods vehicle (LGV), mini bus (MB)	4	40
Car, Jeep, Van, Light Motor Vehicle and Motorized Three-wheelers	5	20

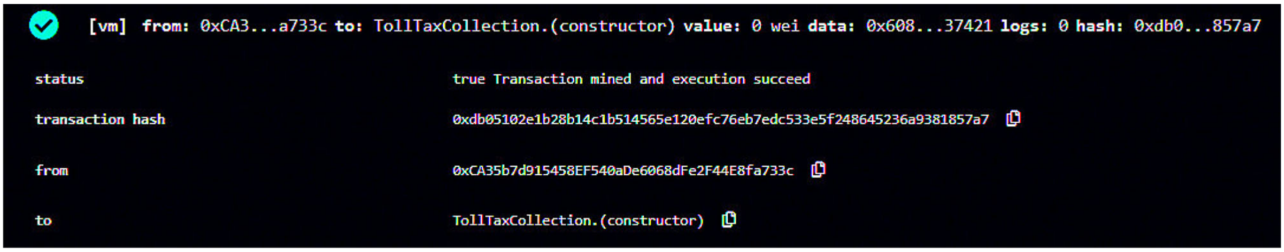


Fig. 5 The smart contract has been compiled and deployed successfully

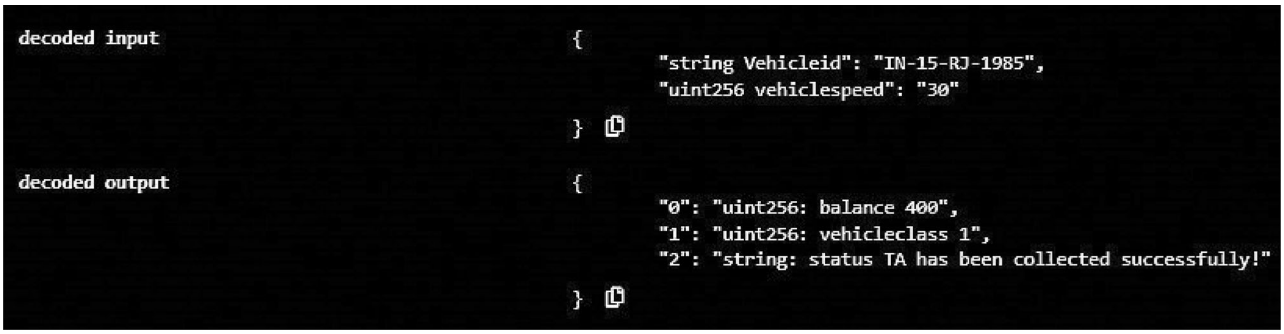


Fig. 6 TA has been collected successfully

the vehicle as input using the *CollectTA* function and collected TA automatically.

The dataset of Table 4 has been taken randomly for only the experimental purpose. The smart contract takes the V_{Id} and V_{Speed} as input and collects the corresponding TA with or without penalty based on the threshold value of the V_{Speed}. Here, the penalty amount is assumed 100 rupees.

Several scenarios of TAs collection using V_{Id} and V_{Speed} are shown in Table 5. Here, all the $AC_{Balance}$ before transactions are taken randomly.

Scenario 1: The smart contract collects the TA of 100 rupees for the V_{Id}: IN-15-RJ-1985. Figure 6 depicts that the TA has been collected successfully for the V_{Id}: IN-15-RJ-1985. The V_{Id} is the type of class 1, and the account balance is 500. TA for class 1 vehicles is 100. It does not violate the speed regulation. Thus, TA has been collected successfully without collecting the penalty amount. After collecting TA, the account balance is 400.

Scenario 2: V_{Id}: IN-19-SG-5465 is the type of class 4, and the account balance is 400. TA is 40 for class 4 vehicles. It violates speed control. Thus, TA has been collected successfully with a penalty amount of 100. TA has been collected successfully with a penalty for the Overspeed of the vehicle that is shown in Fig. 7. After collecting TA, the account balance is 260.

Scenario 3: As shown in Table 5, the $AC_{Balance}$ of the V_{Id}: IN-20-AS-2003 is 0. So, the TA hasn't been collected due to insufficient balance, which is shown in Fig. 8. So, the value of the IB_{Count} is set to 1. A notification will be sent to the owner to credit the account immediately. So, the owner has to credit the account before V_{Id} is sent to the blacklist.

Scenario 4: The V_{Id}: IN-41-KV-5465 has not been inserted into the vehicle database. Thus, the smart contract cannot find the vehicle details. Figure 9 shows that the V_{Id}: IN-41-KV-5465 is not registered. Thus, the smart contract cannot collect the TA for this vehicle.

Scenario 5: As shown in Table 5, the $AC_{Balance}$ of the V_{Id}: IN-20-AS-2003 is 0. The smart contract reads the value of IB_{Count}, which is greater than 1. Thus, V_{Id} has been sent to the blacklist due to insufficient balance for a long time. Figure 10 shows the transaction for the V_{Id}.

Table 4 Input data to the smart contract

V_{Id}	V_{Speed}
IN-15-RJ-1985	30
IN-19-SG-5465	44
IN-20-AS-2003	25
IN-33-KH-3981	32
IN-41-KV-5465	22

6 Comparative analysis

The proposed BATCS is an efficient solution to collect an appropriate TA without using the toll barrier system. While vehicles pass the toll plaza, the proposed system can recognize and receive TAs by verifying their credentials automatically using the smart contract. All the created

Table 5 Results set of TAs collection

Input			Output		
V_{Id}	V_{Speed}	V_{Class}	$AC_{Balance}$		Transaction status
			Before transaction (Rupees)	After transaction (Rupees)	
IN-15-RJ-1985	30	1	500	400	The TA has been collected successfully
IN-19-SG-5465	44	4	400	260	The TA has been collected successfully with a penalty for the speed violation
IN-20-AS-2003	25	5	0	0	Insufficient balance! Credit your account soon
IN-41-KV-5465	22	N/A	N/A	N/A	The vehicle is not registered!
IN-20-AS-2003	25	5	0	0	The vehicle has been sent to the blacklist

N/A not available in the database

Fig. 7 The TA has been collected successfully with a penalty for the speed violation

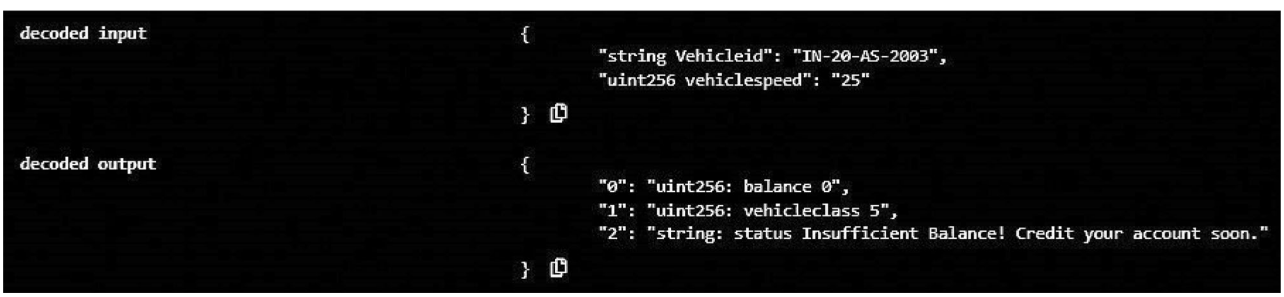


Fig. 8 Transaction of insufficient balance for the V_{Id}: IN-20-AS-2003

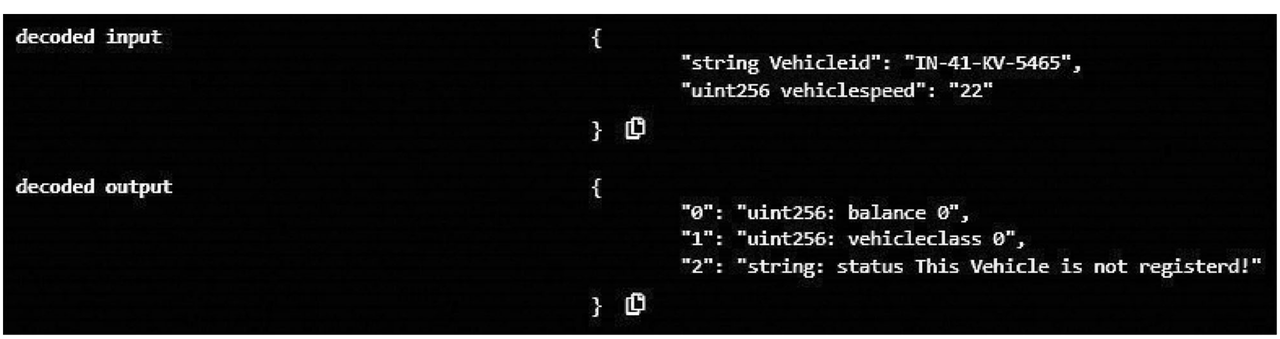


Fig. 9 Scenario for the un-registered vehicle

```
decoded input                    {
                                        "string Vehicleid": "IN-20-AS-2003",
                                        "uint256 vehiclespeed": "25"
                                 }
decoded output                   {
                                        "0": "uint256: balance 0",
                                        "1": "uint256: vehicleclass 5",
                                        "2": "string: status This vehicle has been sent to blacklist!"
                                 }
```

Fig. 10 The V_{Id}: IN-20-AS-2003 has been sent to blacklist due to insufficient balance again

transactions are transparent to every connected authority of the Blockchain network. So, there is no chance of any fraudulent activities with stored data in the Blockchain. The BATCS is the decentralized solution, where every authority can observe any violence (i.e., Overspeed of the vehicle, insufficient account balance) and take penalties from violators. As there is no usage of the toll barrier system, vehicles don't have to wait at the toll plaza. A comparative analysis has been done between the proposed BATCS and the RFID-based system.

Speed analysis: Fig. 11 shows the average vehicle speed during deceleration at approach time in the toll plaza [28]. Figure 12 shows the average speed of the vehicle during acceleration at depart time in the toll plaza. Therefore, Table 6 represents the average speed of the vehicle during deceleration and acceleration and waiting time to identify the vehicle in the toll plaza.

Figure 13 shows the required time by a vehicle to cross the toll plaza using RFID based system and BATCS. Equation 3 is established by using Eqs. 1 and 2. It proves that a lot of time is wasted by using the RFID-based system. Thus, a lot of time can be saved by using the proposed BATCS.

Fuel consumption can be saved more using the BATCS over the RFID-based system that is shown in Fig. 14. The RFID-based system takes time (see Table 6) to read the

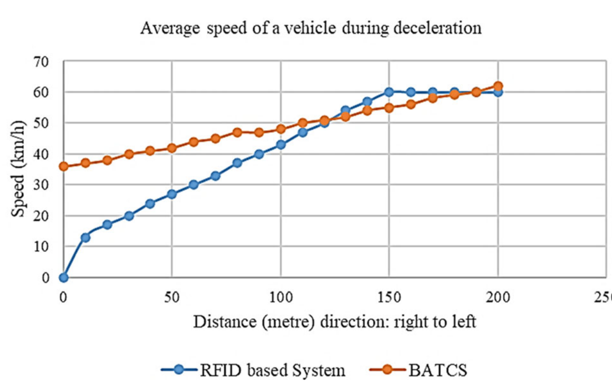


Fig. 11 Average speed of a vehicle during deceleration at approach time in the toll plaza

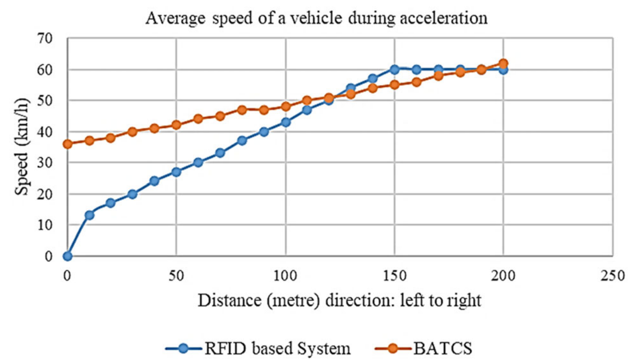


Fig. 12 Average speed of a vehicle during acceleration at depart time in the toll plaza

RFID tag and open the gate after scanning the tag. But using the proposed BATCS, vehicles don't have to wait at the toll plaza. When vehicles pass the toll plaza, the TA will be collected instantly. Table 7 represents that the proposed framework is better than the RFID-based system after analyzing the required time and fuel consumption by a vehicle to cross the toll plaza.

Table 8 represents key features and benefits of BATCS over the RFID-based system using Blockchain's security measures [29].

The major contributions of this proposed BATCS over the existing ETC systems are presented in the following:

- An automated TA collection framework can provide the transparency of the transacted data of the TA collection and the security of the stored data of the vehicle. It can also enhance the usage of the ETC system.
- The BATCS system can also provide the TA collection feature without stopping the vehicle and without having any toll barrier system at the toll plaza.
- It provides a decentralized ETC system at a low cost and saves more time and reduces fuel consumption (see Table 7) over the existing ETC systems since the vehicle doesn't have to stop at the toll plaza.

Table 6 Average speed and waiting time of a vehicle at the toll plaza

	RFID based system	BATCS
Avg. speed during deceleration (km/h)	40.57	48.71
Avg. speed during acceleration (km/h)	40.57	48.67
Wating time at the toll plaza (sec)	3.5–4	0

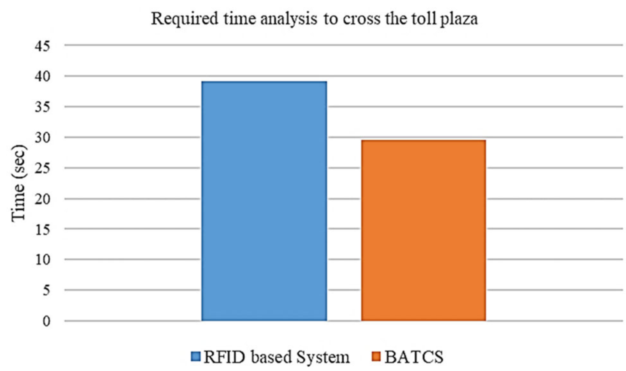


Fig. 13 Required time by a vehicle to cross the toll plaza

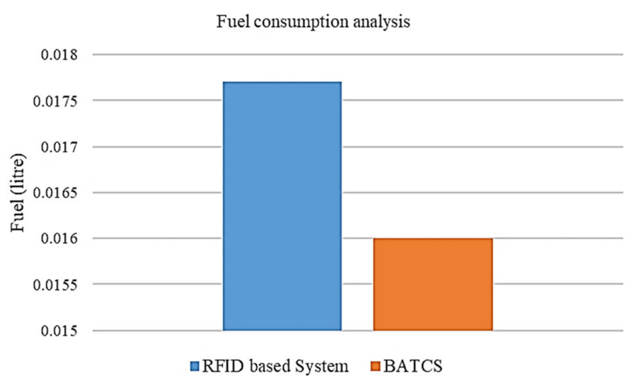


Fig. 14 Fuel consumption by a vehicle

Table 8 Key features and benefits of BATCS over the RFID-based system

Methods features	RFID based system [1]	BATCS
Confidentiality	×	✔
Availability	×	✔
Immutability	×	✔
Privacy & Security	×	✔
Transparency	×	✔
Required time	More	Less
Traffic congestion	More	Less
Fuel consumption	More	Less

× not applicable, ✔ applicable

7 Conclusion and future work

The ETC system is becoming the most common way for passengers to travel by bridge, highway. The ETC mechanism is a robust and fault-tolerant method to collect the TA at the toll plaza. The existing ATCSs have data security, transparency, and privacy issues that can be eliminated using the proposed I-TMS system. It can give an adequate solution for the ETC system as it is a transparent, secure, and privacy-preserving framework. It can save a lot of time and fuel consumption. Every node participating in the Blockchain network can perceive the TA collection transactions. So, there is no possibility of any fraudulent activities. Thus, blockchain has been used to provide a significant contribution to the proposed BATCS framework. Data privacy is a crucial issue in centralized systems, where data can be modified. But, in the BATCS framework, it is not possible to modify or delete the data, as it is a decentralized platform. Thus, blockchain can provide a stable and profitable ATCS in the domain of the ETC system. In the future, we want to extend this work by analyzing several applied technologies for ETC systems, such as the internet of things (IoT), GPS technology, GPS and RFID technology. So, significant contributions of the blockchain in the ETC system can enhance data transparency and security rather than other existing systems.

Table 7 Cost analysis of the BATCS over the RFID based system

	RFID based system	BATCS	Improvement using BATCS (%)
Required time (second)	39.24	29.58	32.65
Fuel consumption (litre)	0.0177	0.0160	10.62

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