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Anomaly Analysis of Blockchain-based Decentralized Applications of Transportation

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Abstract: *Decentralized applications (DApps) refer to open-source applications that utilize blockchain technology. DApps of Transportation (DoT), as an important application of blockchain-based Intelligent Transportation Systems (ITS), is a new focus for current research. The survival analysis and activeness analysis of DoT are common life cycle analysis methods to give an overall understanding of the development of DoT, while the abnormal transactions analysis and token analysis help to discover possible problems in transactions of DoT. This paper conducts an anomaly analysis of DoT from four aspects: survival, activeness, abnormal transactions, and tokens. The survival, activeness, and abnormal transaction analysis are based on the graph, which provides analyzers with intuitive visualizations to discover problems. Specifically, we propose a framework in which a graph of DoT transaction network is constructed and an efficient algorithm is adopted to detect abnormal patterns in the graph. Additionally, the token analysis is done to find the problematic tokens of DoT and provide correction suggestions to developers. Our work presents exquisite visualizations as well as solid analysis for DoT market. The results show our methods can locate abnormal transactions and tokens that deviate from standards.*

Keywords: *Blockchain, Dapps, Transportation, Anomaly analysis, Survival analysis, Activeness analysis, Abnormal transaction analysis, Token analysis*

1. Introduction

Blockchain technology has developed rapidly in recent years and has become a research focus in academia and industry [1]. The blockchain has the characteristics of decentralization, anonymity, and auditability, so the value transfer between anonymous participants does not need to rely on an authoritative third party [2]. Blockchain is often called the next-generation Internet, and its application scenarios have expanded from finance, healthcare, Internet of Things, and ITS [3]. Blockchain technology has many successful applications such as Ethereum [4], which is the first and largest blockchain platform supporting smart contracts [5].

Blockchain-based DApps refer to decentralized applications based on blockchain and smart contracts. DApps have the same general properties as traditional applications, the main difference is that their data and calculations are provided by the blockchain [6]. DApps inherit the decentralization, openness, tamper resistance, and traceability of blockchain and smart contracts. As a result, it can increase the trustworthiness of their applications while reducing developer costs. DApps provide users with a safe and convenient platform environment in which users can transfer money, share information, and sign contracts.

Blockchain technology has been taken into action in the field of transportation. The Global Blockchain in Transport Alliance was established in August 2017 [7]. It is a global blockchain education and standard development industry organization. The application of blockchain-based ITS is developing rapidly. Major shipping and logistics companies around the world are actively participating. DoT is one of the popular applications of ITS.

This paper gives an anomaly analysis of the development and application status of DoT. We first visualize the basic information of the DoT, then analyze the abnormal transactions and trace back the

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abnormal account transactions. Besides, the tokens of the DApps are also checked according to an open project. The work shows a representative glance of the DoT. We also provide suggestions on the supervision of the DoT. Figure 1 shows the overview of our analysis process.

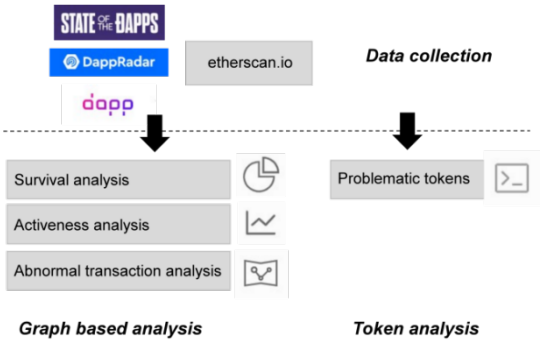

Figure 1: An overview of our analysis.

2. Research Background

2.1. Dapps

With the development and popularization of distributed ledger platforms such as Ethereum, the number of DApps has also maintained rapid growth in recent years [8]. DApps can call front-end code and user interface written in any language through its back-end. The backend code is deployed on the blockchain system, which we usually call a smart contract. Smart contracts are responsible for data storage and operating logic, and interact with the DApp's front-end or other multiple smart contracts through transactions.

Nowadays, DApps have received a lot of attention, and some DApps are quite popular. The Non-Fungible Tokens (NFT) is a popular category of DApps. The fans of famous singer Jay Chou send him 9999 NFT digital roses as a birthday gift. Many celebrities such as Leo Messi and Justin Bieber have entered the NFT world. NFT becomes known to the public. One famous game DApp named "CryptoKitties" allows players to collect and sell virtual cats [9]. All operations in the virtual cat game are recorded on the blockchain, so the fairness of the game can be guaranteed. DApps have many advantages, but there are also some problems, such as "CryptoKitties" may cause the Ethereum network congestion when users use the highest peak. Therefore, having the anomaly analysis of the DApps market and detecting their abnormal transactions are worth researching.

2.2. Ethereum

Ethereum, established in 2014, is by far the largest blockchain platform supporting smart contracts. Its market value is second only to that of the blockchain platform Bitcoin [10]. Ethereum and its smart contracts promote the development of DApps. Any developer can create DApps through smart contracts. Then they deploy and publish them on the Ethereum platform. As of this writing, the Ethereum blockchain is over 14 million blocks tall, and each block contains a huge number of transactions. Ethereum also has its own cryptocurrency called Ether. The same as other digital currencies, Ether can also be traded between users. Developers can pay Ether, including transaction fees and computing services, to keep their applications running [11].

2.3. Transaction

Blockchain is an open-source shared transaction database. A block can contain many transaction information, which is messages sent from one account to another. The main data activities in Ethereum are triggered by transactions, including transferring Ether, calling smart contracts, and creating contracts.

There are two types of transactions: external transactions and internal transactions. External transactions are transactions initiated from external owned accounts, while transactions sent from smart contracts to other accounts are called internal transactions [12]. Every participant in a blockchain network can synchronize and verify transaction data on the blockchain. It is worth noting that since the internal transaction data are not stored in blocks, the internal transaction cannot be obtained directly by parsing

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the block [13]. The dataset we use in this paper is external transactions (on-chain transactions).

2.4. Smart contract and token

For Ethereum, the essence of a smart contract is a program composed of bytecodes that can be automatically executed when trigger conditions are met. One of the features of the smart contract is that, once a smart contract is deployed on the blockchain, it cannot be modified by anyone, including its developers.

The token contract (often briefly called token) on Ethereum is a type of proof of stake based on smart contracts [14]. The technical threshold for deploying a token-type smart contract application on the Ethereum platform is far lower than deploying a native blockchain currency like Bitcoin. Therefore, after the opening of Ethereum platform, the issuance of token contracts is almost out of official control, resulting in a large number of smart contracts. To standardize the token interaction method of the platform, Ethereum has officially launched a series of token contract implementation standards. The ERC20 protocol is relatively early and widely used. The ERC20 protocol standard defines a template for the core functions and interfaces of token contracts [15], applied to a fungible type of cryptocurrency implementation. The protocol specifies standard access interfaces for token name, symbol, base, total supply, user balance, user authorization balance, etc. At the same time, combined with the event submission mechanism of the Ethereum, the event submission format for token transfer and token authorization is defined.

3. Related Work

The research on Ethereum mainly focuses on the analysis of its transactions and tokens. Chen et al. [16] construct a transaction graph with accounts in Ethereum as nodes and transactions as edges. Based on the analysis of this transaction network graph, they proposed an identification scheme for Ethereum phishing fraud accounts. By processing the extracted Ethereum transaction information, Chen et al. [5] construct three kinds of graphs, which are respectively associated with transfer and remittance information, contract creation information, and contract invocation information. Comprehensively analyzing the three transaction graphics, they propose a novel scheme for detecting abnormal transactions and conducting attack forensics. Guo et al. [17] make an in-depth study of Ethereum transaction properties using graph analysis methods and explored the statistical properties behind transactions. Rouhani et al. [18] analyze the performance of Ethereum nodes in a private chain environment, and mainly used two different client implementations, Geth and Parity, as experimental nodes. Its performance testing method has certain inspiration for the token analysis in this paper. Spain et al. [19] reveal the regularity of the transaction delay time of Ethereum transactions during Initial Coin Offering (ICO) by studying the level of supply and demand in the Ethereum transaction network. Pierro et al. [20] study the main factors affecting the gas consumption of Ethereum transactions.

The transfer behavior of the token is triggered by submitting an Ethereum transaction. The relevant research on the transaction data characteristics and transaction mechanism characteristics of Ethereum is of great significance for how to guarantee the token transfer behavior efficiently in the transaction.

Token transfer transaction is an important transaction type in Ethereum platform transactions. Di Angelo et al. [21] investigate the types and implementation standards of token contracts on the Ethereum platform. Combined with the actual transaction data on the Ethereum platform, they propose a classification scheme for the purposes and functions of token contracts. For the first time, Somin et al. [22] analyze the properties of the token trading network conforming to the ERC20 standard protocol. They used all trading wallet accounts as nodes and token transfer transactions as edges to construct a token transfer transaction network. The analysis results show that the ERC20 token transaction network has a strong power-law distribution characteristic. Chen et al. [23] systematically investigate the ecology of ERC20 token contracts and reveal the deep connection between token contract creation accounts, token holding accounts, and token transfer behaviors through graph analysis. Angelo et al. [24] propose a method for identifying the types of smart contracts on the Ethereum platform. Their idea is to statically analyze the contract bytecodes and identify the types of contracts combined with the transaction communication relationship between contracts, so that the types of tokens can be identified.

DApps is a relatively new research topic, not to mention DoT. However, it is the exact reason for us to analyze DoT. We expect to let researchers in ITS field know more about the blockchain-based DApps in their ITS field. There has been DApps research in many fields. Xu et al. [25] propose Edgence (EDGe

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+ intelligENCE) to intelligently manage large-scale DApps in IoT applications. Li et al. [26] present DoERS attack, a denial of Ethereum remote procedure call (RPC) service that incurs zero Ether cost to the attacker. They test the attacks on nine RPC between blockchain and DApps. Wang et al. [27] extract effective user characteristics of DApps from three scenarios. They conclude fifteen general user behaviors which represent the performance of DApps. There will be more DApps with blockchain applications.

4. Data Collection

Blockchain is a promising technology of ITS. DoT are applications of the blockchain-based ITS. There is no ready-to-use dataset for DoT, so we organize and collect data by ourselves. DoT is not as much as other DApps such as DApps of finance, and we select 57 DoT about transportation from three websites: StateoftheDApps, DAppradar, and DApp.com. DoT in these websites are all based on Ethereum, achieving applications on renting cars, finding chargers, and sharing routes. We search in the websites with keywords “transport”, “transporations”, “transportation”, “car”, “cars”, “vehicle”, “vehicles”. At last we conclude them into four categories: Energy, Market Places, Social, and Game. We download the data of all DoT including basic information about these DoT and the transaction data from Etherscan. For exanple, we down the transaction data from Etherscan of DoT-CryptoCars-the first NFT Racing game developed by the team that used to work for Gameloft & Genshin Impact project.

Table 1 shows the statistical information of our dataset. We find 57 DoT in 4 categories: E nergy, Market Places, Social, and Game. The DApp’s number of the 4 categories are 10, 12, 1 6, 19 separately with 24855, 38339, 114752, and 189430 records of transactions from the contr acts, till the date of Oct 25, 2022. In the original dataset, there are many unsuccessful transact ion records because of out of gas and other reasons. We preprocess them by deletion operatio n. This hand-made dataset has been published on the IEEE dataport, accessed: https://ieee-datap ort.org/documents/transaction-data-sender-and-receiver-dapps-transportation.

Table 1: Statistics of DoT dataset.

Category	DApp number	The transaction volume of contacts
Energy	10	24855
Market Places	12	38339
Social	16	114752
Game	19	189430

5. Graph-based Analysis of DoT

5.1. Survival Analysis

Survival data not only refers to the data of whether life is life or death; broadly speaking, survival outcome refers to whether the research object has a positive endpoint event that our researchers are interested in; more broadly speaking, survival outcome is a phenomenon Whether a failure event occurred. Survival analysis refers to the method of analyzing and inferring the time of occurrence of a given event, and studying the relationship between survival time and outcome and prognostic factors and their degree. It is a data analysis method for dealing with censored data, also known as survival rate analysis or survival analysis.

To better analyze the survival time distribution of DoT, we make some definitions. We consider that the time of publication on the website is not the time when the DApp actually starts to be used. For example, “DAV” is a DApp of transportation in the “Social” category, and its submission date in StateoftheDApps is December 21, 2018. However, we find that its transaction records started on June 9, 2018. Therefore, we consider that its real creation date should be June 9, 2018.

We define the start time, termination time, and survival time of DoT as follows:

- Start time: We take the earliest transaction time in the DoT as the start time of the DoT.
- Termination time: DoT has not generated transactions for more than 3 months, and has not generated any transactions since then. We take the time of its last transaction as the termination time of the DoT.

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- Survival time: The number of days from the creation of a DoT to the termination of use.

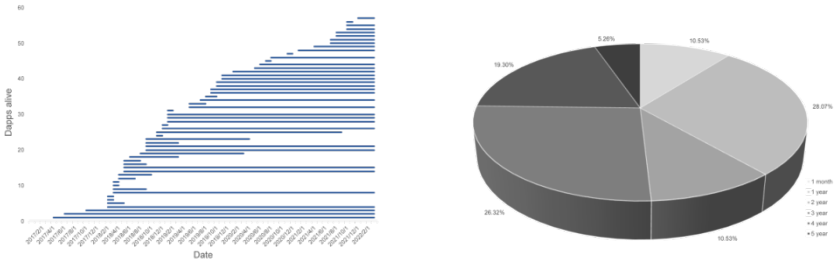

Figure 2: (a) Survival time of DoT. (b) Survival time proportion of DoT.

Figure 2 (a) shows the survival time of DoT. Most DoT survive till now, but some DoT only survive for no more than one month. Since 2018, the number of DoT grows at a stable speed. Before April 2019, most DoT cannot live till now, but after April 2019, the number of DoT surviving till now increases. Figure 2 (b) is the survival time proportion of DoT. 10.53\% DoT live less than 1 month. DoT living for 1 year and 3 years account for 28.07\% and 26.32\%. 5.26\% of DoT live for about 5 years. The year 2018 is starting the trendy year of the DoT, so some DoT living till now have survived for about 5 years. However, many DoT cannot live till now. Therefore, their survival time is usually 1 year to 3 years.

5.2. Activeness Analysis

The degree of activeness of DoT is an indicator of the degree of the economic health of DoT. The more successful transactions the DoT have, the higher degree of activeness of the DoT. We consider DoT without transaction for 3 months to be dead DoT. To analyze the degree of activeness of different categories of DoT, we draw the figure of activeness degree of DoT in 4 categories: Energy, Market Places, Social, and Game.

In Figure 3, the horizontal axis represents the date, the vertical axis represents the accumulative frequency of transactions of different categories of DoT. Generally, four categories of DoT all have increasing trends in the number of transactions, which means these DoT keep an active state in an overall view. It is shown in Figure 3 (a) that the increasing trend of the energy category is in unstable way. There are some jitters in the survival period, which may because of some news about the energy. Figure 3 (b) shows the activeness degree of the market places category is more stable compared with the activeness degree of the energy category, and its number of transactions rises at a smooth speed. From Figure 3 (c) and (d), the activeness degree of social and game is similar. The numbers of transactions increase sharply in the early stage and slow down gradually. The difference is that the activeness degree of the game is steadier than the activeness degree of the social category.

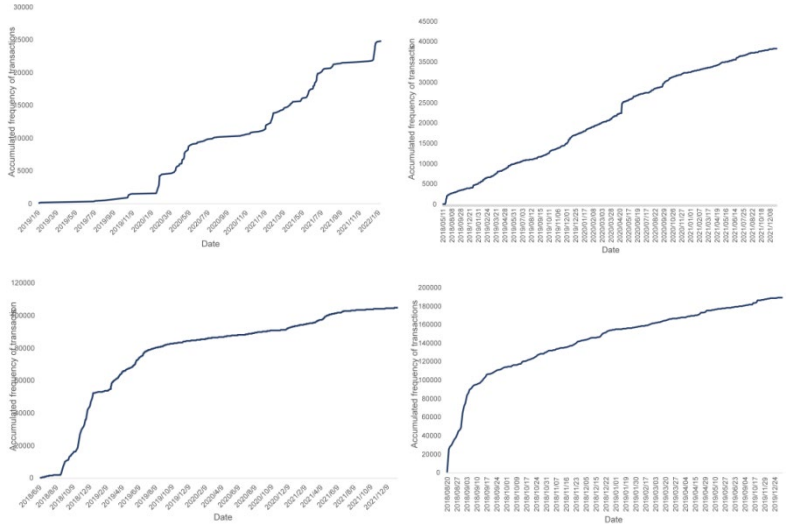

Figure 3: Activeness of four categories of DoT. (a) Activeness degree of energy DoT. (b) Activeness degree of market-place DoT. (c) Activeness degree of social DoT. (d) Activeness degree of game DoT.

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5.3. Abnormal Transaction Analysis

Research proves that there exist abnormal transactions in the blockchain exchange market. Gandal et al. [28] use the regression method to prove that the activities of some suspicious accounts affect the Bitcoin price. Based on this, another paper [29] not only proves the manipulated relationship between the abnormal accounts and the Bitcoin price, but also concludes some transaction patterns of these abnormal accounts. We construct a transaction network graph of DoT to further trace these suspicious user addresses of the abnormal transactions, and to dig out their abnormal transaction behaviors.

Loops Definition:

Self-loop:

$$\forall G(V, E)\ (V=\{v_1\} \wedge (v_1,v_1) \in E \rightarrow \in \{g | g \in \text{Self-loop}\}),$$

Many-node loop:

$$\forall G(V, E)\ (\forall i \in [1, n-1]((v_i,v_{i+1}) \in E) \wedge (v_n,v_1) \in E \rightarrow \{\text{Many-node loop}\}),\ V=\{v_1,v_2,...v_n\}.$$

We construct the transaction network graph of DoT according to the graph definition we proposed. The holistic visualization of the graph is shown in Figure 4, in total 27620 nodes and 30508 edges.

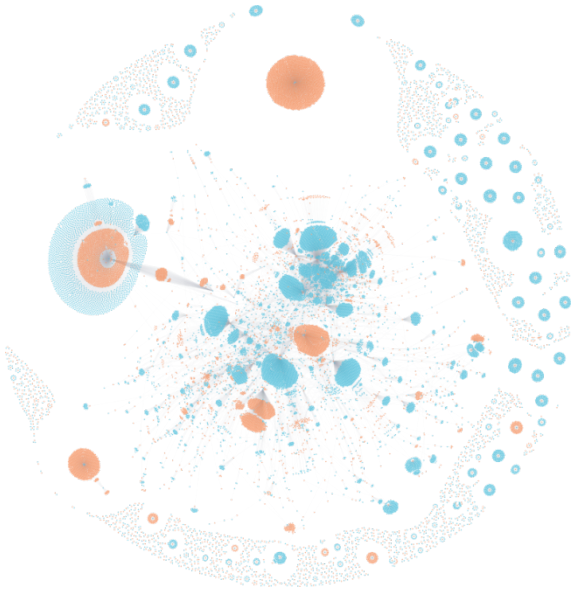

Figure 4: Transaction network graph of DoT.

According to Chen et al. [29], there are some typical patterns such as self-loop, unidirectional, bi-directional patterns, and so on. We search in the transaction network graph of DoT to find these abnormal patterns. There do not exist self-loop and bi-directional patterns by search in our transaction network graph. It is also obvious to find a star pattern whose account has many transactions with many accounts. For example, the account 96 has transactions with 182 accounts, as shown in Figure 5 (a). Triangle and polygon are another two abnormal patterns. In our work, we extend the patterns to many-node loops. However, the time complexity is very high to find loops because the number of nodes in the transaction network graph is too huge. We overcome it with an efficient algorithm to find loops based on the Tarjan algorithm [30] with time complexity O(n).

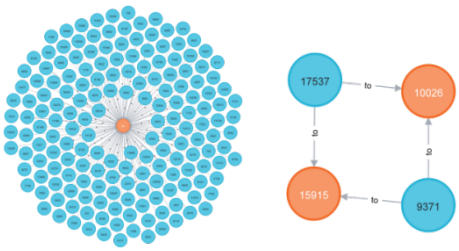

Figure 5: A star pattern example (a) and a polygon pattern example (b) in the transaction network graph.

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The main idea of the L-Tarjan algorithm (see Table 2) is to use a stack to reduce the computation time. Firstly, we set node u and the Low's value and put node u in the stack. Then every edge in G is traversed. The trick is if the node v is not visited, keep traversing; if node u is in the stack, update the Low's value. We do the iteration until the node u is the loop's root, so we pop out v, and let it be the loop's vertex.

With L-Tarjan Algorithm, loops are searched in limited time. We select one polygon example (Figure 5 (b)) whose single transaction number reaches 8980 to illustrate the abnormal reason. According to the polygon pattern descriptions, the account 9371 sends ether to account 17537 through the "bridge accounts" 15915 and 11026 for over ten thousand transactions, which is harmful to the transaction market.

Table 2: L-Tarjan Algorithm.

$L-Tarjan\ Algorithm\ (u, G, index)\{$	
$DFN[u] = Low[u] = ++ Index$	/* set node u and Low's value */
$Stack.push\ (u)$	/* put node u in stack */
$for\ each\ (u, v)\ in\ E$	/* traverse every edge in G */
$if\ v\ is\ not\ visited$	/* if node v is not visited */
$L-Tarjan\ (v)$	/* keep traverse*/
$Low[u] = min(Low[u], Low[v])$	
$else\ if\ v\ in\ Stack$	/* if node u in stack */
$Low[u] = min(Low[u], DFN[v])$	
$if\ (DFN[u] == Low[u])$	/* if node u is the loop's root */
$repeat\ v = Stack.pop$	/* pop out v, being the loop's vertex */
$print\ v\ until\ (u = v)\}$	

5.4. Token Analysis

Token is an indispensable part of the contract in blockchain, affecting the transactions in Ethereum. The ERC20 token standard, as a widely accepted token standard, makes a huge contribution to the development of contracts and blockchain. However, many ERC20 tokens exist major loopholes, causing incalculable economic losses to developers, investors, and even the Ethereum community. On June 18, 2016, an attack on the DAO contract resulted in the loss of over 3600000 Ether [31]. The attack originated from the introduction of a reentrancy vulnerability in a key contract of DAO. Hackers can recursively re-enter the transfer function to continuously withdraw ether without reducing the personal balance. The Ethereum hard fork that followed this attack led to a split in the Ethereum community. In addition, many token contracts are not implemented regrading to the ERC20 standard, which brings great trouble to DApps development. Thousands of deployed token contracts have referenced the Ethereum official website (now fixed) and the non-standard template code given by OpenZeppelin. Many function implementations did not follow the ERC20 specification, which resulted in serious compatibility issues such as unable to transfer normally when the Solidity compiler was upgraded to 0.4.22 [32].

Security organizations and experts around the world are also paying attention to the alarming security issues in smart contracts. Ten categories of security issues including reentrancy, access control, and arithmetic issues are summarized by NCC Group, a group of global experts in cyber security and risk mitigation.

In the creating process of smart contracts, many problematic tokens come from imprecise code reference, copying, and modification and the use of incorrect template code. The project [33] includes the security risk issues that have been disclosed in the tokens, and makes a summary of the known vulnerabilities and defects. The types of token issues mainly include token code implementation vulnerability, compatibility issues caused by not complying with the ERC20 specification, and token contract rights management issues.

We pick out the problematic tokens from the tokens of DoT according to the bad token list [33]. Table 3 shows problematic tokens of DoT and the corresponding type of problems. Table 4 shows the irregular problems in writing tokens. "Transfer-no-return" means the function 'transfer()' does not have return value. According to the ERC20 token standard, the function 'transfer()' should return a Boolean value. However, a large number of deployed tokens are not implemented strictly following the EIP20 specification, and the 'transfer()' function has no return value. When the contract is upgraded to 0.4.22, the 'transfer()' function call will directly 'revert' [34]. For example, Figure 6 shows the problematic implementation and recommended implementation of tokens with the transfer-no-return problem. The "approve-no-return" and "transferFrom-no-return" problem in writing tokens is similar to the transfer-

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no-return problem. “Approve-no-return” means the function ‘approve()’ does not have return value. “transferFrom-no-return” means the function ‘transferFrom()’ does not have return value.

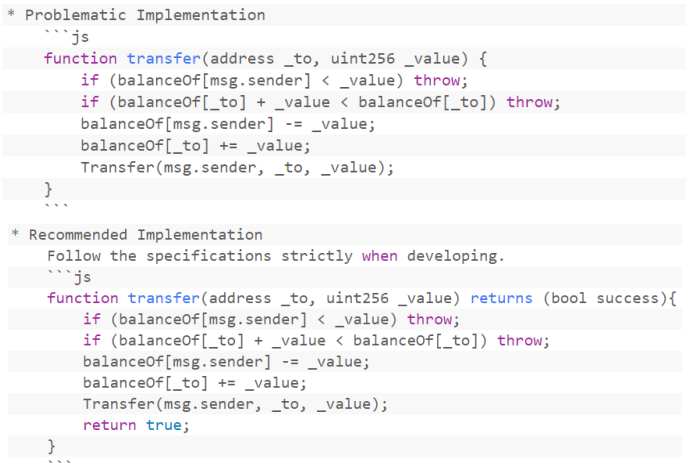
Table 3: Problematic Tokens of DoT.

Problematic tokens	Problem symbol
0x8200341fFA058A4b2fa5BEf16C8CcA0330d529ed	B1, B2, B3, B4
0x07222Fc4cdACEDfBcfc03CbeD6E72Fb329E8D0b6	B1, B2, B3, B4
0x8f3470A7388c05eE4e7AF3d01D8C722b0FF52374	B5, B6
0xe0a8A9b7C821d9BBd66b826129D4cF1B219EbB3a	B1, B2, B3, B4

Table 4: Irregular problems in writing tokens.

Problem symbol	Problems
B1	transfer-no-return
B2	approve-no-return
B3	transferFrom-no-return
B4	no-decimals
B5	no-name
B6	no-symbol

The “no-decimals”, “no-name” and “no-symbol” problems are all about the variables. In the token, the ‘decimals’ variable is usually used to represent the number of digits after the decimal point of the token, but in some contracts, the variable is not defined or the variable is not named strictly according to the specification, for example, using the case-insensitive ‘decimals’ to name the variable, makes it incompatible when external contract calls are made. The ‘name’ variable is to represent the name of the token, and the ‘symbol’ variable is to represent the alias of the token, but in some contracts, these variables are not defined, or variables are not named strictly according to the specification.



* Problematic Implementation

```js
function transfer(address _to, uint256 _value) {
    if (balanceOf[msg.sender] < _value) throw;
    if (balanceOf[_to] + _value < balanceOf[_to]) throw;
    balanceOf[msg.sender] -= _value;
    balanceOf[_to] += _value;
    Transfer(msg.sender, _to, _value);
}
```

* Recommended Implementation

Follow the specifications strictly when developing.

```js
function transfer(address _to, uint256 _value) returns (bool success){
    if (balanceOf[msg.sender] < _value) throw;
    if (balanceOf[_to] + _value < balanceOf[_to]) throw;
    balanceOf[msg.sender] -= _value;
    balanceOf[_to] += _value;
    Transfer(msg.sender, _to, _value);
    return true;
}
```

Figure 6: Problematic implementation and recommended implementation of tokens with the transfer-no-return problem..

6. Conclusions

ITS develops fast with science and technologies such as machine learning and blockchain. We have an anomaly analysis of one blockchain-based application of ITS - DoT. In the phase of data collection, we find DoT is relatively less than other DApps such as DApps of finance. Thus, we encourage developers to develop more DoT to help the applications of blockchain-based ITS. From the survival analysis, many DoT survive for less than one month, which shows the robustness of DoT should be improved. Basically, the transaction number of DoT increases slowly with time going by. Therefore, how to maintain the activeness of DoT is a problem worthy researching. Through the transaction network graph, we discover there exist many abnormal transactions such as sending other accounts ether by bridge accounts. The relevant supervision departments are supposed to dynamically detect the market to escape the abnormal transactions according to the observed abnormal transaction patterns. Tokens are related to the security of transactions. The token developers must be careful and make tokens in accord with standards, to ensure the transactions are secure and stable. In summary, as an important blockchain-based

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application of ITS, DoT need a positive and normative environment to develop and maintain. We hope this paper can provide practical suggestions for supervision and inspirations to researchers.

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