Study on identification and classification of hidden dangers in highway toll stations based on accident causation theory

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Abstract. Aiming at high safety risk of expressway toll station, based on the theoretical model of accident cause, this paper makes a systematic analysis and correlation test on the unsafe state of object, personal unsafe behaviour, and the imperfection of safety management system within the jurisdiction of expressway toll stations. Through statistical analysis, the types and distribution areas of unsafe physical state, the types and main causes of unsafe behaviours within the jurisdiction of toll stations are identified. The results show that: education and training, risk management and control, hidden dangers, operating procedures, equipments and facilities management, emergency management, etc., have a great impact on the physical safety of highway toll stations; bad driving habits, trouble free mentality, poor safety awareness, lack of safety knowledge are the main reasons for unsafe behaviours. The results of the study have guiding significance for the risk management of toll station.

1. Introduction
Toll station is the basic unit of highway operation management and an important facility for collecting the cost of passing vehicles. Located at the entrance and exit of the highway, it has become a necessary passage for vehicles to enter and leave, a gathering area for people and vehicles and also an area with frequent traffic accidents [1]. Toll station accidents usually include frontal collision, rear-end collision, scratching and etc, and the occurrence of accidents has a great impact on subsequent vehicles. It easily causes large-scale traffic jams, and even rear-end collisions and chain collisions, which may lead to secondary accidents [2-3]. For example, on the evening of November 3, 2018, a 31-car continuous collision accident occurred at the Lanzhou South Toll Station, causing 15 deaths and 44 severe injuries [4]. In addition to causing direct casualties and vehicle damage, the toll station accidents often cause serious damage to the power, communication and other highway equipment and facilities. What’s worse, it may even cause the operation of the entire highway to be interrupted, and bring a huge threat to the life of employees in the organization. Therefore, the accident prevention work in the highway toll station jurisdiction is particularly important.

The occurrence of toll station accidents is closely related with the driver’s behaviors outside the organization, the performance of vehicle, the location of toll stations, the management of equipment and facilities, and the management of operating organizations [5-6]. Previous studies have proved that unsafe behaviors such as fatigue driving, speeding, illegal parking, and seizing lanes are the main causes of accidents [3]. Therefore, from the perspective of highway operators, if they can strengthen
daily safety management and standardize passing vehicles’ order, it can better prevent accidents in toll stations. In addition, the service and management of toll station will directly affect the driver’s behavior outside the organization and also their choices for the lanes. If the hidden dangers that affect the driving safety in operation areas can be timely identified and eliminated, it will effectively avoid traffic accidents or reduce accident losses, and will be very helpful for the emergency disposal work after the accidents.

Strengthening toll stations’ hidden danger elimination and risk management from the highway enterprise level is an effective measure to prevent accidents in the jurisdiction. At present, the investigation and elimination of hidden dangers in toll stations is mainly conducted from the following aspects, including the function of vehicles, the safety of employees, the safety of tolls, and the safety of toll equipment and facilities [7-8]. However, for the problems like what are the hidden dangers affecting the operation safety of toll stations, what methods should be used to identify those hidden dangers, and how to ensure the comprehensiveness and independence of accidents classification still remain to be the key issues that needs to be solved urgently. Based on study of accident causes, this paper firstly determined the influencing factors of accidents in the toll station jurisdiction, and then investigated the relevant contents involved in the hidden dangers, and then classified and analyzed the hidden danger data according to the accident causation model, and finally further put forward targeted governance measures to solve those problems.

2. Accident Causation Theory
Hidden dangers refer to the violation of safe production laws, regulations, rules, standards, regulations and management systems by producing and operating units, or the potential dangers caused by other factors like product’s dangerous state, operator’s unsafe behaviors and management deficiencies during production and operation [9]. These three factors are the main causes of accidents, and they are also the key points for the identification and classification of hidden dangers in the highway toll station jurisdiction. The accident causation model explains various causes and their logical relationships, and thus provides an effective tool for the identification and classification of accidents.

At present, there are many typical accident causation models both at home and abroad, and this paper applied the accident-causing “2-4” model [10-11] as the tool for identifying and classifying the hidden dangers in the highway toll station because of its clear definition, logical clarity, practical operation and wide application. The model was shown in Figure 1. The accident causation "2-4" model firstly classified the accident causes into the internal and external two parts of the organization in which the accident was triggered. On one hand, external supervision, nature, family, and political, economic, cultural, legal and other factors are collectively referred to as organizational external causes. On the other hand, the internal organizational causes are divided into two phases: safety culture and safety management system. Safety culture is a collection of safety concepts and a guiding ideology for organizing safety work, and its imperfections are the original cause of accidents. The safety management system includes safety policy, organizational structure, safety management procedures and etc., and it could be fully implemented during running. Its deficiency is the root cause of accidents. The individual internal causes within organization are divided into habitual behavior and two stages of one-time behavior and physical state, among which the unsafe habits are considered as the indirect cause of accidents. It involves five aspects of deficiencies in knowledge, consciousness, habits, physiology, and psychology. The one-time behavior, that is, unsafe act, is a direct cause of an accident, including both the unsafe acts of the driver directly involved in the accident, and also the unsafe acts associated with the accident by other personnel in the organization. Unsafe physical state includes the missing or imperfection of safety guards and equipment, unsafe state of site environment and operating objects, which may be existingat the time of the accident, or may be caused by unsafe acts or habits.
Deficiencies in safety culture
Deficiencies in safety management system
Flaws in safety knowledge, safety awareness, safety habits, psychological status, physiological status
Unsafe acts
Unsafe conditions
Accident

Legend: Boundary line of organization

Figure 1. Accident causation "2-4" model [10, 11]

According to the accident causation model, various hidden dangers that easily cause accidents in the highway toll station can be identified one by one. The content contained in the hidden danger is refined on the basis of the original definition: one is the direct cause of the accident, that is, unsafe physical state and unsafe acts; the other is the deficiency of individual knowledge, consciousness, habits and psychology that causes the unsafe acts to generate or activate unsafe physical state. The third one is the factor imperfection of organizational management system which leads to unsafe behavior and physical state, and this one is the deep cause of accidents. In addition, the identification of organizational safety culture deficiencies in the model is difficult to determine, and it is mainly obtained by the measurement of scales, so no further study is conducted here.

3. Accident Causes Identification and Classification

The selected object of this study is the highway toll operating jurisdiction under the Qilu Transportation Development Company with altogether 52 toll stations. The study has shown that if unsafe physical state and acts near accident area, it can directly lead to accidents, and it is a key point for identifying the hidden dangers. However, in order to fundamentally eliminate these two hidden dangers, it is necessary to determine the organizational deficiencies which cause their emergence. Therefore, the identification and classification of hidden dangers in the toll station should firstly start from the unsafe acts of the operator and the unsafe state of the equipment and facilities, and then based on the results obtained, it can be inferred the organizational safety management system deficiency, and finally correlation tests can be used to determine the specific deficiency factors that must be focused on safety construction and improvement.

3.1. Unsafe physical state analysis

There are 25 types of unsafe physical states involved in the toll station jurisdiction, which are mainly distributed in four working places of toll sheds, toll booths, toll plazas and toll lanes. The names, descriptions and causes of hidden dangers are shown in Table 1 below. According to statistics, the types and frequencies of unsafe physical states appearing in the toll lanes are the most (as shown in Figure 2), which is the key and difficult point for the investigation and control of hidden dangers. The date from Classification of Enterprise Workers' Casualty Accidents have shown that besides the vehicles accidents (traffic accidents) outside the organization, the types of accidents such as electric shock, fire, object blow, and mechanical injury have also become the common hidden dangers in toll station jurisdiction, so it is imperative to strengthen risk control and emergency management.

The toll shed is the only large-scale construction facility in the entire toll station jurisdiction. Its hidden dangers involved are mainly distributed on the top of the toll shed, including the deficiencies in roofs, lights, signboards, lightning protection facilities and etc., which often cause the unexpected accidents like objects strike and collapse. The toll booth is the main area for charging transactions. One of the main problems involved is property security. The investigation have found that there are 35 toll booths with door and window damage, which can easily lead to public security incidents such as theft and robbery and then will bring economic losses to the organization. In addition, there are many hidden dangers of electrical equipment in toll booths where electric shocks and fire accidents
frequently happen; and the hidden dangers of fire extinguishers failure and medium non-compliance in toll booths is widespread, which seriously delays the emergency disposal after the accident. For the toll plaza, it is the main gathering area of personnel and vehicles. Once there is any hidden danger, it will affect the normal operation of vehicles, and even cause large-scale congestion or traffic accidents. Therefore, besides strengthening the maintenance of various equipment and facilities in the toll plazas, emergency measures should also be taken for the gathering vehicles (especially transport vehicles with dangerous goods). The toll lane space is relatively narrow, but the transportation equipment involved is very complicated. The study have shown that the type and number of hidden dangers related to it are also the most statistically. It would seriously interfere with the normal stoppage of the contributory vehicles, so the organization should strengthen the routine maintenance of road equipment, such as speed bump, vehicle poles and traffic signs.

Table 1. The unsafe physical state and frequency statistics of the toll station jurisdiction

| No. | Physical state name                                      | Key descriptions                                                                 | Frequencies | Causes                                      |
|-----|----------------------------------------------------------|----------------------------------------------------------------------------------|-------------|---------------------------------------------|
| 1   | Deficiency in the roof of the toll sheds                 | Shedding, looseness, corrosion, water leakage                                    | 18          | Object blow, electric shock, collapse       |
| 2   | Deficiency in the lights of the toll sheds               | Malfunction, looseness, aging                                                    | 14          | Vehicle damage, object blow, electric shock |
| 3   | Deficiency in the information board of the toll sheds    | Looseness, corrosion, rupture                                                    | 10          | Object blow                                |
| 4   | Deficiency in the lighting protection equipment of the toll sheds | Falling off, electricity failure, broken parts                         | 8           | Electric shock, object blow                |
| 5   | Honeycombs in the toll sheds                            |                                                                                  | 4           | Others                                      |
| 6   | Anti-theft door and window damage in toll booth          | Door locks, window locks, etc.                                                  | 35          | Other (public security incident)           |
| 7   | Defective socket in toll booth                          | Damage, looseness, aging                                                         | 10          | Electric shock, fire                       |
| 8   | Defective line in toll booth                            | Falling off, exposure                                                           | 6           | Electric shock, fire                       |
| 9   | Toll booth alarm failure                                |                                                                                  | 4           | Other (public security incident)           |
| 10  | Fire extinguisher failure                               | Being expired, under pressure, corrosion                                         | 20          |                                             |
| 11  | Not compliant of fire extinguisher media                | Carbon dioxide replace                                                          | 3           |                                             |
| 12  | Defect in the high pole light of the toll plaza         | Missing wiring cover, aging line, loose lamp cover, lighting failure, skewed column, column covered with plants | 17          | Electric shock, fire, object blow, vehicle damage |
| 13  | Hazardous chemicals vehicles gathered in toll plaza     | Early morning queues on high speed                                              | 8           | Vehicle damage, fire, explosion            |
| 14  | Damaged fence of toll plaza                             | Outsiders entering                                                              | 4           | Vehicle damage, other (public security incident) |
| 15  | Debris in the toll plaza                                |                                                                                  | 4           |                                             |
| 16  | Toll booth gantry loose                                 | Screw corrosion                                                                 | 2           | Collapse                                   |
| 17  | Defective lane deceleration belt in toll lane           | Abrasion, deficiency                                                            | 19          | Vehicle damage                             |
| 18  | Defect in the stop lane of toll lane                    | Damage, looseness, corrosion                                                    | 13          | Vehicle damage, mechanical damage          |
| 19  | Defective signage of toll lane                          | Skewed traffic signs; skewed, dropped, and damaged speed limit signs              | 12          | Vehicle damage, object blow                |
Table 1, cont

|   | Defects in toll lane roads                  | Water, ice, pits, loose slabs, debris | 10 | Vehicle damage, other (falling) |
|---|---------------------------------------------|----------------------------------------|----|---------------------------------|
| 20 | Defective lane markings                     | Damage, ageing, non-reflective film    | 10 | Vehicle damage                  |
| 21 | Defective lane collision column             | Skew, fracture, deformation             | 9  | Vehicle damage                  |
| 22 | Defects in the safe lane of the toll lane   | Damage, debris, exposed screws, exposed steel | 7  | Vehicle damage, mechanical damage |
| 23 | Defects in the toll lane isolation pier     | Skew, damage                           | 5  | Vehicle damage                  |
| 24 | Wore toll lane markings                     | -                                      | 4  | Vehicle damage                  |

Figure 2. Frequency classification of unsafe physical states in different operating locations of toll stations

3.2. Unsafe behavior analysis
The identification of individual unsafe behaviors in the toll station jurisdiction mainly includes two parts: one is the unsafe acts that directly cause the accident, and the other is the habitual behavior deficiencies corresponding to the unsafe acts. The types of unsafe acts and their causes are shown in Table 2 below. Compared with the unsafe state, the categories and frequencies of individual unsafe acts involved in the toll station jurisdiction are relatively reduced, but it also affects the normal operation of the organization and thus should not be ignored. Considering the work site, the toll booth is the main operating area of the operator, and the involved individuals have the most unsafe acts, which mainly related to the layout of the pavilion and the maintenance and use of the fire extinguisher. The sender of the unsafe acts in the toll plaza is mainly involved with foreign intrusion personnel, field personnel, relevant operators, and etc., so the organization should strengthen the behavior control of the relevant responsible operators. The unsafe acts involved in the toll lanes are only one case, but the frequency of its occurrence still remain high reflecting with no safety sign for lane construction, so the organization should also strengthen the safety supervision for the relevant parties. And finally no unsafe acts related to the toll sheds were found in this study.
Table 2. The unsafe behavior and frequency statistics of the toll station jurisdiction

| Number | Acts name                                      | Key descriptions                          | Frequencies | Corresponding unsafe habits                                      |
|--------|-----------------------------------------------|-------------------------------------------|-------------|-----------------------------------------------------------------|
| 1      | Not standardized toll booth wiring           | Messy, unused junction box, shedding      | 10          | Insufficient knowledge, bad driving habits, energy-saving mentality |
| 2      | Insufficient fire extinguisher of toll booth  | Toll booth                                 | 15          | Insufficient knowledge, low safety consciousness, and luck mentality |
| 3      | No annual inspection of fire extinguishers    | -                                         | 13          | Insufficient knowledge, bad driving habits, energy-saving mentality, irrelevant psychology |
| 4      | Improper extinguisher positions              | -                                         | 6           | Insufficient knowledge and bad driving habits                    |
| 5      | No ability of using fire extinguisher        | -                                         | 5           | Insufficient knowledge                                           |
| 6      | Untimely service vehicles                     | Traffic congestion                        | 4           | Physiological fatigue                                           |
| 7      | Non-staff entering the toll plaza            | -                                         | 8           | Low safety consciousness, herd mentality                         |
| 8      | Not standardized staff dress                 | -                                         | 6           | Bad driving habits, energy-saving mentality, herd mentality       |
| 9      | Not standardized wiring of toll plaza        | No pipe, wire, etc.                       | 5           | Insufficient knowledge, bad driving habits, energy-saving mentality |
| 10     | Private wiring in the construction site      | No electric box, etc.                     | 4           | Low safety consciousness, energy saving mentality, and luck mentality |
| 11     | Lane closed without safety signs             | Lane construction, temporary closure      | 11          | Low safety consciousness, bad driving habits, energy-saving mentality, and paralysis |

It can be seen from the accident causation model that unsafe acts are caused by the deficiencies of individual knowledge, consciousness, habits, physiology and psychology. Therefore, according to the unsafe acts and their specific performance, the corresponding unsafe habits can be derived. As shown in Figure 3 below, there are 9 types of unsafe habitual behaviors involved in the highway toll station jurisdiction. Among them, the individual's bad driving habits, their energy-saving mentality, lower safety awareness, and insufficient safety knowledge are most common, which become the main cause of unsafe acts. It is worth noting that the same unsafe act may be caused by multiple unsafe habitual behaviors, and the causes of unsafe acts in different working places and conditions may also be different.

Bad driving habits are manifested as a long-standing habitual violation, for example the drivers always installing and operating equipment and facilities according to their past cognitive methods, and they have been accustomed to it but without suffering any accident. It has a certain relationship with the deficiency of individual’s safety knowledge, and its improvement method is mainly to strengthen safety training and supervision. The energy-saving mentality is a lazy psychology on the purpose of saving trouble and taking shortcuts, for example, the acts of wiring without following specific requirements, not using the established protective facilities, simplifying the dangerous operation process, and etc. If all those individual misconducts or illegal operation continue for a long time, it will form bad driving habits, and the effective way to improve this is also to strengthen safety training and supervision. The safety awareness deficiency is manifested by the individual's poor danger awareness in the workplace. They cannot realize the serious consequences of the illegal operation, and this is closely related with their poor individual safety knowledge. Insufficient safety knowledge
means that individuals do not have the relevant skills like cannot use fire extinguishers; or they lack expertise or experience in certain areas, such as improper and irrational wiring. An effective way to both increase safety awareness and knowledge is to strengthen their safety training. In addition, for other unsafe habitual behaviors with relatively fewer frequencies, especially unsafe mentality, it should not be neglected. Staff training and psychological intervention must be strengthened, and the positions can be reasonably arranged through psychological assessment for employees.

3.3. Safety management system factors deficiency analysis

According to the principle of organizational behavior, organizational behavior influences and determines individual behavior, that is, the generation of individual unsafe behavior is ultimately caused by the management system factors deficiency at the organizational level. For the physical hidden dangers, it is closely related with the unsafe behavior or misconducts of the operators, and in essence, its deep causes still lie in the organization. Therefore, the organizational hidden dangers identification and risk control are of great significance in fundamentally preventing accidents. Based on the results of on-site investigations and combined with the relevant requirements of the Occupational Health and Safety Management System Requirements [12] and The Basic Standards for Enterprise Safety Production Standardization [13], 14 types of safety management system factors in the highway toll stations jurisdictions were identified in this study, and these factors and their causes are shown in Table 3 below.

Table 3. The management system factors deficiency of the toll station

| No. | System factors deficiency               | Description of causes                                                                 | Rank correlation coefficient | P-value |
|-----|--------------------------------------|--------------------------------------------------------------------------------------|-----------------------------|---------|
| 1   | Institutions and responsibilities    | Insufficient staffing; unclear personnel duty; not standardized duty records.       | 0.294*                      | 0.029   |
| 2   | Safety production investment         | Insufficient equipment for emergency equipment; inadequate fire-fighting equipment; no account for security funds. | 0.026                       | 0.853   |
| 3   | Operating procedure                  | Not standardized line layout; equipment facilities not being in place.              | 0.430**                     | 0.001   |
| 4   | Education and training               | Incomplete training materials; not standardized training records; missing training contents (missing plans, new equipment). | 0.602**                     | 0.000   |
| 5   | Equipment and facility management    | Improper selection; inadequate configuration; not standardized installation; maintenance not being in place. | 0.269*                      | 0.047   |

Figure 3. Classification of unsafe habitual behavior causes of accidents in toll station jurisdiction
Table 3, cont

|   | Operation safety | Temporary power management not being in place; workers not being dressed properly. | 0.090 | 0.514 |
|---|------------------|--------------------------------------------------------------------------------|-------|-------|
| 7 | Related party management | Temporary power management not being in place; safety signs not being set properly. | 0.041 | 0.767 |
| 8 | Safety sign management | Missing safety signs; worn out safety signs. | 0.171 | 0.211 |
| 10 | Risk management and hidden danger elimination | Incomplete scope of hidden danger investigation; insufficient number of hidden danger investigations; not closed-loop management of hidden danger investigation; not standardized hidden danger investigation records. | 0.586** | 0.000 |
| 11 | Emergency management | Insufficient emergency equipment configuration; poor management of fire protection facilities; defects in warning signs; imperfect emergency plans; not standardized emergency material records. | 0.370* | 0.038 |
| 12 | Safety production information construction | Insufficient use of hidden danger investigation and rectification system; failure of timely reporting safety work summary. | N/A | N/A |
| 14 | Document management | Not organized and archived safety records; incomplete safety self-examination data; not standardized safety data records. | N/A | N/A |

Note: ** Relevance is significant at the 0.01 level; * Relevance is significant at the 0.05 level.

In order to further determine the role relationship and cause path of the organizational imperfections on unsafe physical state and behavior, the correlation between the above statistics was analyzed in this study. Considering that the distribution of variables is non-normal, so the correlation is measured by the non-parametric rank correlation coefficient (Spearman), and the significance of the correlation coefficient is tested by t-test. And the study determines the p-value less than 0.05 as correlation and less than 0.01 as significant correlation. The rank correlation coefficient takes [-1, 1], and the positive result was expressed as positive correlation. If the result closer to 1, the positive correlation will be stronger. The negative result is expressed as negative correlation, and if the closer to -1, the negative correlation will be stronger. The Spearman rank correlation coefficient expression is as follows:

$$
\rho_s(i,j) = 1 - \frac{6\sum_{k=1}^{n}d_i^2}{n^3 - n}
$$

Where \(d_i\) is the difference between the rank of the independent variable \(X_i\) and the dependent variable \(Y_i\), \(di = rg(X_i) - rg(Y_i)\), where \(n\) is the total number of observations.

According to statistics, the factors deficiency of three management systems, including education and training, risk management and hidden danger elimination, and operational procedures, have a significant impact on the unsafe behaviors and physical states. So the organization should firstly add training contents, formulate targeted training programs, and make training records. At the same time, the organization should strengthen the investigation of hidden dangers in toll stations (expanding the scope and increasing the frequency), and then make full use of the information construction platform to achieve hidden danger’s closed-loop management and hierarchical management. For each type of operation, specific operational procedures should be established to achieve safety standardization of daily operations. For other management system deficiency factors, such as the insufficient safety personnel, the unclear division of duties, the poor management of the selection, arrangement, installation and maintenance of the relevant transportation equipment and facilities, the imperfect emergency plan, the insufficient emergency reserve, and the irregular records, are also the main causes
that can affect the unsafe physical state and behavior. For the insufficiency of the two safety production information construction and archive management, because it mainly acts on individual behavior and physical state through indirect means, so it is not easy to establish the correlation between individuals and organizations. Their accounting management deficiencies include the lower utilization rate of the hidden danger investigation and rectification system, the untimely compiled and archived’ safety data, and the not standardized records (including safety inspection, safety training, safety activities, etc.). Due to its higher frequencies, it is also very important for identifying and controlling hidden dangers, and it should also be strengthened.

4. Conclusions
Based on the accident causation model, this paper identified accidents hidden dangers in the highway toll station jurisdiction, and conducted classification and correlation test on the causal factors from aspects of physical states, individual acts and habitual behaviors, and organizational safety management system. The main conclusions are as follows:

   (1) The unsafe physical states involved in the toll station jurisdiction mainly distributed in four operating areas of toll sheds, toll booths, toll plazas and toll lanes. Among them, the types and frequencies of hidden dangers appearing in toll lanes are the most and the highest, which is the key and difficult area for hidden danger investigation and control.

   (2) The injuries and deaths in toll stations mainly included vehicle injury accidents (traffic accidents), electric shocks, fires, object strikes, and other (safety incidents). So the organization should strengthen the control and emergency management of related risks based on this.

   (3) The individual unsafe acts involved in the toll station jurisdiction with relatively fewer types and lower frequencies, so the organization should regulate the use and maintenance of toll booth firefighting facilities, and strengthen safety supervision of relevant parties in the jurisdiction. In addition, bad driving habits, energy-saving mentality, poorer safety awareness and insufficient safety knowledge are the main causes of unsafe acts, so the organization should strengthen the training, supervision and psychological intervention of operators.

   (4) The deficiencies in safety management system factors, such as education and training, risk management and hidden dangers elimination, operational procedures, equipments and facilities management, and emergency management, have a significant impact on the unsafe physical states and unsafe acts in highway toll stations. It is the key point of safety management system construction.

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