# Design of Active Safety Warning System for Hazardous Chemical Transportation Vehicle

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**Abstract** As the hazardous chemical transportation traffic accident is getting more and more serious, this paper designs a kind of active safety warning system for hazardous chemical transportation vehicle. The content of this paper mainly includes the composition and principle, establishment of theoretical model of safety distance, design of avoidance control strategy and algorithm and so on. This paper firstly introduces the composition and function of the active safety warning system for hazardous chemical transportation vehicle, and claries its working principle. And then establishes a safety distance model according to the theory of vehicle dynamics, and another four models of key vehicle distance which include safety critical, target vehicle, dangerous critical and limit critical. According to the different dynamic models, the paper designs four control strategies including safety control, alarm control, deceleration control and brake control and the algorithm. In this paper, the active safety warning system for hazardous chemical transportation vehicle can help the driver avoid traffic accident in the course of transportation, detect the safety state of the tank, improve the safety performance of the vehicle at the greatest degree and realize the intelligent monitoring of the hazardous chemical transportation vehicle.

**Keywords** Active safety · Safety distance · Acoustooptic alarm · Hazardous chemical transportation

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## 1 Introduction

With the acceleration of the industrialization process, the demand for the hazardous chemical is increasing, the production and transportation of hazardous chemical are increasing year by year. The hazardous chemical is flammable, explosive, corrosive, radioactive or toxic, and so on. In the course of transportation, a traffic accident, high pressure, or high temperature, may lead to leak, burning out, corrosive, poison or other malignant accidents. According to incomplete statistics, hazardous chemical transportation accidents accounted for 30–40 % of the total number of hazardous chemical. A series of hazardous chemical transportation accidents seriously threaten the safety of road transportation and the life and property of the people, resulting in huge economic loss and bad social influence.

Through the analysis of the causes of a large number of hazardous chemical transportation accidents, the main reasons are summarized [1]:

(1) The driver's negligence, fatigue driving or failure of judgment and other reasons will lead to traffic accidents.

(2) The vehicle is at a high speed or doesn't maintain a safety distance on the highway, so when the danger comes the driver can't timely take a brake.

(3) High temperature, large pressure, high liquid level or the discharge valve's abnormal opening may lead to spontaneous combustion, explosion of the hazardous chemical.

In view of the above reasons, this paper designs a kind of active safety warning system for hazardous chemical transportation vehicle based on sensor technology, communication technology and data processing technology, which can realize the intelligent monitoring of road transportation of hazardous chemical and improve the safety level of road transportation of hazardous chemical in China.

## 2 System Composition and Working Principle

The system is composed of information collection module, data processing module and sound and light alarm module.

### *2.1 Information Collection Module*

Information collection module is composed of speed sensor, laser ranging sensor, temperature sensor, pressure sensor, liquid level sensor, and discharge valve state monitoring switch, used to obtain the speed of the vehicle, relative distance, temperature, pressure, liquid level in the tank, and the discharge valve state and other information.

### 2.2 Data Processing Module

Data processing module receives the signals of the laser sensor and the speed sensor, determines the vehicle travel state according to the safety state of the logic algorithm; receives the singles of temperature sensor, pressure sensor, liquid level sensor and discharge valve state monitoring switch, determines whether it beyond the safety range. At last, the analysis results transmit to the sound and light alarm module.

### 2.3 Sound and Light Alarm Module

The sound and light alarm module is installed in the driving room of the vehicle, with a display and a buzzer. The relative distance and relative speed between the vehicle and the target vehicle and the temperature, pressure, liquid level and the state of the discharge valve in the tank are shown on the display.

### 2.4 Working Principle

When the system starts to work, the pre laser sensor measures the distance between the vehicle and the target, and the vehicle speed sensor which is installed on the vehicle measures the speed of itself [2, 3]. Data processing module receives the above singles and calculates the real time vehicle distance using the vehicle information and target vehicle information according to the safety distance models. Compared to the target distance obtained by the laser sensor, determines whether the driving state is safe and determines the risk level according to analysis results [4]. In the end, the alarm signal is send to sound and light alarm module.

Temperature sensor, pressure sensor, liquid level sensor, and the discharge valve state monitoring switch can be used to receive the singles in the tank. The data processing module receives the singles and judges whether it beyond the safety range and sends alarm signal to sound and light alarm module.

## 3 Establishment of Theoretical Model of Safety Distance

### 3.1 Automobile Braking Process

From the point when the driver realizes the danger, takes the brake pedal to the stop of the vehicle, the process is composed of five stages [5, 6].

In the Fig. 1, $F_p$ is the maximum braking force, $a_{max}$ is the maximum deceleration.

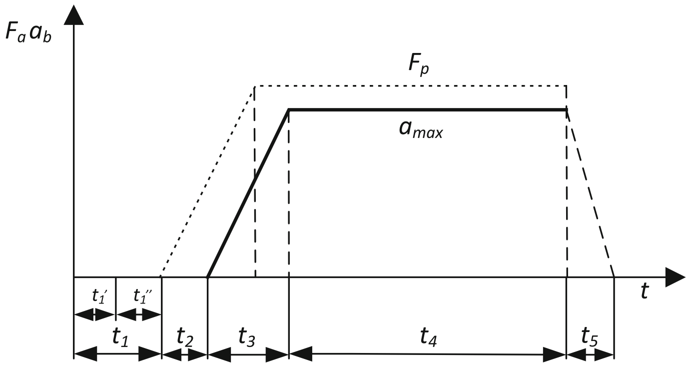


**Fig. 1** Automobile brake process

(1) The driver's reaction time $t_1$: when danger occurs, the driver realizes it after $t_1'$, then moves the foot from the accelerator pedal to the brake pedal after $t_1''$.

(2) Elimination of braking clearance time $t_2$: vehicle brake reserve brake clearance to prevent sensitivity, it spends $t_2$ to produce ground braking force after stepping the pedal.

(3) Build-up time of braking force $t_3$: when the brake pedal is stepped down by the driver and the brake clearance is overcome, the ground brake force increases linearly, and the braking deceleration increases linearly, too.

(4) Sustained braking phase $t_4$: in this period, the deceleration doesn't increase and stains the maximum, which is the key stage of the braking process.

(5) Release time $t_5$: after the vehicle stops, the driver releases the brake pedal, and the braking force gradually reduces to 0 after $t_5$.

## 3.2 *Derivation of Braking Distance*

The braking distance is the distance from the danger signal is found by driver to the stop of the vehicle. According to the analysis of Fig. 1, the first four stages of vehicle braking should be calculated [7, 8].

(1) During the period when the driver finds the single and reacts that lasts $t_1$, the vehicle is at a constant speed state, the distance is:

$$l_1 = v_0 t_1 \tag{1}$$

(2) During the period when the brake clearance is overcome that lasts $t_2$, the vehicle is at a constant speed state, the distance is:

$$l_2 = v_0 t_2 \tag{2}$$

(3) During the build-up time of braking force period that lasts $t_3$, the vehicle's braking deceleration increases linearly and the distance is:

$$l_3 = v_0 t_3 - \frac{a_{max} t_3^2}{6} \tag{3}$$

(4) During the sustained braking period that lasts $t_4$, the vehicle is at a constant deceleration state, the distance is:

$$l_4 = \frac{v_0^2}{2a_{max}} - \frac{v_0 t_3^2}{2} + \frac{a_{max} t_3^2}{8} \tag{4}$$

Ignore other secondary factors, the distance from where the driver receives an emergency stop signal to the point the vehicle stops completely:

$$L = l_1 + l_2 + l_3 + l_4 = v_0 \left( t_1 + t_2 + \frac{t_3}{2} \right) + \frac{v_0^2}{2a_{max}} - \frac{a_{max} t_3^2}{24} \tag{5}$$

As $t_3$ is too small, $\frac{a_{max} t_3^2}{24}$ is ignored in the theoretical calculation, so the theoretical braking distance is:

$$L = v_0 \left( t_1 + t_2 + \frac{t_3}{2} \right) + \frac{v_0^2}{2a_{max}} \tag{6}$$

## 3.3 Braking Safety Distance

As shown in Fig. 2, when vehicle A detects two vehicles may be a collision, it will warn the driver to slow down through the sound and light alarm module. Now A is at initial velocity $v_1$, acceleration $a_1$; B is at initial velocity $v_2$, acceleration $a_2$; the distance is $S_1$. When they come into another safety state, A is at speed $v_1^{`}$, acceleration $a_1^{`}$; B is at speed $v_2^{`}$, acceleration $a_2^{`}$; the distance is $S_2$. $L_0$ is the safety distance. Over the whole process, A travels $L_1$, B travels $L_2$. Set theory safety distance $S^{'}$, so $S^{'} = L_1 - L_2 + L_0$. Imagine the two vehicles both can reach the maximum deceleration $a_{max}$.

(1) B is at static state

When B is static, $v_2 = a_2 = L_2 = 0$, $L_1 = v_1 \left( t_1 + t_2 + \frac{t_3}{2} \right) + \frac{v_1^2}{2a_{max}}$. So:

$$S^{'} = v_1 \left( t_1 + t_2 + \frac{t_3}{2} \right) + \frac{v_1^2}{2a_{max}} + L_0 \tag{7}$$

(2) B is at constantly driving state

When B is constantly driving, if A is at a higher speed and doesn't brake, they will make a crash. When A is at the same speed of B, they will be safe. So:

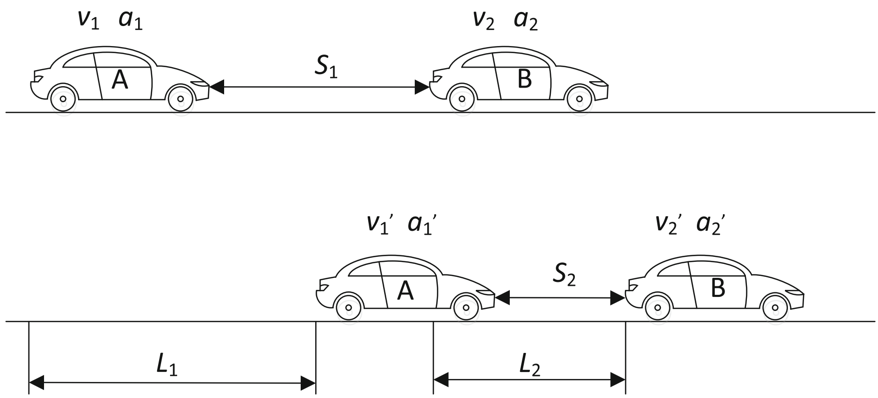


**Fig. 2** Braking safety distance model

$$L_1 = v_1\left(t_1 + t_2 + \frac{t_3}{2}\right) + \frac{v_1^2 - v_2^2}{2a_{max}} \tag{8}$$

$$L_2 = v_2\left(t_1 + t_2 + \frac{t_3}{2} + \frac{v_1 - v_2}{a_{max}}\right) \tag{9}$$

$$S^{'} = (v_1 - v_2)\left(t_1 + t_2 + \frac{t_3}{2}\right) + \frac{(v_1 - v_2)^2}{2a_{max}} + L_0 \tag{10}$$

(3) B is at uniform deceleration brake state

B is uniform deceleration brake, if A is at a higher or the same speed and doesn't brake, they will make a crash. So:

$$L_1 = v_1\left(t_1 + t_2 + \frac{t_3}{2}\right) + \frac{v_1^2}{2a_{max}} \tag{11}$$

$$L_2 = v_2\frac{t_3}{2} + \frac{v_2^2}{a_{max}} \tag{12}$$

$$S^{'} = v_1(t_1 + t_2) + (v_1 - v_2)\frac{t_3}{2} + \frac{(v_1^2 - v_2^2)}{2a_{max}} + L_0 \tag{13}$$

If $v_1 = v_2$, then:

$$S^{'} = v_1(t_1 + t_2) + \frac{(v_1^2 - v_2^2)}{2a_{max}} + L_0 \tag{14}$$

Compare the formula (7), (10) and (13), we can find the braking safety distance in formula (13) is the biggest. Considering the hazardous chemical transportation vehicle has high standard for safety, we choose formula (13) as the braking safety distance.

### 3.4 Safety Distance Model

(1) Safety critical distance

Vehicles keep a certain distance to the vehicle ahead when driving, this distance can ensure that in most cases the vehicle is safe, even sudden obstacles or sudden deceleration of the vehicle ahead will not threaten the safety. We call it safety critical distance $d_s$. From the above derivation:

$$d_s = v_1(t_1 + t_2) + (v_1 - v_2)\frac{t_3}{2} + \frac{(v_1^2 - v_2^2)}{2a_{max}} + L_0 \tag{15}$$

(2) Target vehicle distance

The safety critical distance $d_s$ can ensure the safety of the vehicle in most cases, but it can lead to a slow or operational failure due to the slow or poor psychological quality of some drivers. The target vehicle distance is composed by safety critical distance and another distance that the vehicle drives during $t_0$.

$$d_t = v_1(t_0 + t_1 + t_2) + (v_1 - v_2)\frac{t_3}{2} + \frac{(v_1^2 - v_2^2)}{2a_{max}} + L_0 \tag{16}$$

(3) Dangerous critical distance

Safety critical distance $d_s$ is the index that determines whether the vehicle's driving state is safe, when above this value it means that the vehicle is at a safe state, and another one is dangerous critical distance $d_d$, it can determine whether the driving state of the vehicle is dangerous, when below the value it means that the vehicle is at a dangerous state, and it may have a traffic accident. On the base of safety critical distance, the calculation of the dangerous critical distance is that distance minuses the distance of the vehicle in the driver's reaction stage.

$$d_d = v_1 t_2 + (v_1 - v_2)\frac{t_3}{2} + \frac{(v_1^2 - v_2^2)}{2a_{max}} + L_0 \tag{17}$$

(4) Limit critical distance

Safety critical distance $d_s$ is used to determine whether the driving state is safe, dangerous critical distance $d_d$ is used to determine whether the vehicle's driving state is dangerous. To this correspondence, limit critical distance $d_L$ is the smallest distance from rear-end collisions.

If the vehicle B slows down at deceleration $a_2$, vehicle A brakes at deceleration $a_{max}$. If $a_2$ is small, vehicle A and B will be both out of danger when $v_1 = v_2$ if the distance between them is at least $L_0$. If $a_2$ is large, vehicle A is still driving when B has stopped, that is $v_1 > v_2$, vehicle A and B will be both safe if the distance between them is at least $L_0$ after A has stopped.

Assume that at a certain time two vehicles are at the same speed, that is $v_1 = v_2 = v_3$, then $v_3 = v_1 - a_{max}t = v_2 - a_2 t$, $t = \frac{v_1 - v_2}{a_{max} - a_2}$, $v_3 = \frac{v_2 a_{max} - v_1 a_2}{a_{max} - a_2}$.

When $a_2 < \frac{v_2 a_{max}}{v_1}$, $v_3 > 0$, it means two vehicles are at the same speed when they get out of danger, It's $v_3$, thus $L_1 = v_1(t_2 + \frac{t_3}{2}) + \frac{(v_1^2 - v_3^2)}{2a_{max}}$, $L_2 = \frac{(v_2^2 - v_3^2)}{2a_2}$. So

$$d_L = v_1 \left( t_2 + \frac{t_3}{2} \right) + \frac{(v_1 - v_2)^2}{2(a_{max} - a_2)} + L_0 \tag{18}$$

When $a_2 < \frac{v_2 a_{max}}{v_1}$, $v_3 < 0$, it means $v_3$ is negative when two vehicles are at the same speed, it's not reasonable, so vehicle A and B have stopped when they get out of danger. Thus $L_1 = v_1(t_2 + \frac{t_3}{2}) + \frac{v_1^2}{2a_{max}}$, $L_2 = \frac{v_2^2}{2a_2}$. So:

$$d_L = v_1(t_2 + t_3) + \frac{v_1^2}{2a_{max}} - \frac{v_2^2}{2a_2} + L_0. \tag{19}$$

# 4 Avoidance Control Strategy and Algorithm

## *4.1 Avoidance Control Strategy*

Avoidance control unit is the core part of the active safety warning system, it calculates real-time critical distance between vehicles after receiving input information. According to avoidance control algorithm, the unit analysis current driving state of the vehicle, and gets the best control scheme to circumvent, conveys the singles to the output corresponding element.

Avoidance control strategy means measures the vehicles take when they avoid the traffic accident in a certain state. The working mode of the active safety warning system is determined by the avoidance control strategies.

(1) Safety control strategy

In general, it's safe when the actual relative distance is greater than safety critical distance. If a period of time (such as 0.5s) will be locked in front of a danger target, it can not only ensure the safety of driving, but also extend the reaction time of the driver, and it's conducive to improve the safety of driving. So in fact, when the actual distance is greater than target vehicle distance, the vehicle is safe and the green indicator light on the display works.

(2) Alarm control strategy

When the actual vehicle distance is less than the target vehicle distance, the system considers that the driving state can not be fully guaranteed safe at this time, but as long as the actual vehicle distance is not less than the safety critical distance, there will be no danger. Therefore, when the actual vehicle distance is between the safety critical distance and target vehicle distance, the system will remind the driver to drive carefully, and at this time there is a low frequency "drops" alarm sound, and the yellow-green indicator light on the display flashes.

(3) Deceleration control strategy

When the alarm is not timely responded or responded error, and the actual vehicle distance is less than the safety critical distance, the system determines the current driving state is dangerous. But as long as the distance is not less than the dangerous critical distance, the dangerous state can be improved by vehicle deceleration. So when the relative distance is between the dangerous critical distance and safety critical distance, the system will remind the driver to decelerate, and at this time there is a higher frequency "drops" alarm sound, and the orange indicator light on the display flashes.

(4) Braking control strategy

After the deceleration control strategy, if the driver doesn't take measures or the target vehicle slows down at a high deceleration or other danger targets appear suddenly, and the relative distance is less than dangerous critical distance, the system will determine that the current driving state is very dangerous, the possibility of accident is very large. So the system will remind the driver emergency brake, and at this time there is a more high frequency "drops" alarm sound, and the red indicator light on the display flashes.

## 4.2 Avoidance Control Algorithm

Set a safety variable: $SF = \frac{R_{ref} - d_L}{d_s - d_L}$, where, $R_{ref}$ means the relative distance to the target vehicle at the moment, $d_L$ means limit critical distance, $d_s$ means safety critical distance, $SF$ is called safety variable.

(1) Safety state

If $SF > 1$, that is $R_{ref} > d_s$, it means the vehicle is at a safe driving state, and is safer when $SF$ increases, and should take safety control strategy.

(2) Alarm state

Defining variable $m = \frac{d_d - d_L}{d_s - d_L}$, obviously $0 < m < 1$.

If $m < SF \leq 1$, that is $d_d < R_{ref} \leq d_s$, it means the vehicle is at a unsafe driving state, and is more unsafe when $SF$ decreases, and should take alarm control strategy.

(3) Deceleration state

If $0 < SF \leq m$, that is $d_L < R_{ref} \leq d_d$, it means the vehicle is at a dangerous driving state, and is more unsafe when $SF$ decreases, and should take deceleration control strategy.

(4) Braking state

If $SF \leq 0$, that is $R_{ref} \leq d_L$, it means the vehicle is at an extremely dangerous driving state, and is more unsafe when $SF$ decreases, and should take braking control strategy.

### 4.3 Tank Safety Monitoring Algorithm

After receiving the sensor singles from the tank, the data processing module analysis and processes them.

In order to avoid the vehicle body temperature or pressure measurement's error is too large, the system uses two temperature sensors and two pressure sensors, which are installed in the front and rear of the hazardous chemical transportation vehicle. After receiving the sensor datas, the data processing module calculates the average data of temperature and pressure, then compares the average data with the preset safety range. If the range of safety is exceeded, the sound and light alarm device will be driven.

The singles that the liquid level sensor and discharge valve state monitoring switch send to the data processing module are switch variables. When the liquid level exceeds the preset value or the discharge valve state monitoring switch opens abnormally, the sensor sends a high level signal. The data process module receives it and sends it to the sound and light alarm module.

## 5 Conclusion

The active safety warning system for hazardous chemical transportation vehicle designed by the paper real-time detects the relative distance, relative speed and the speed of the vehicle. According to the control algorithm, the system determines whether the current vehicle driving state is safe, and timely warns the driver. At the same time, the system can monitor the vehicle tank body temperature, pressure, liquid level and the state of the discharge valve state monitoring switch, if the temperature, pressure or liquid level beyond the preset safety range or the discharge valve state monitoring switch opens abnormally, the system will timely warn to remind the driver.

The system can judge whether the vehicle's driving state is safe correctly and timely and monitor the state of the tank and assist the driver to complete the transportation task and realize the intelligent monitoring of the road transportation of hazardous chemical.

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