METHOD, APPARATUS, DEVICE, SYSTEM, AND MEDIUM FOR SAFETY PROTECTION OF TRAINS IN COOPERATIVE FORMATION

CROSS REFERENCE TO RELATED APPLICATION

[0001] The present application claims priority to Chinese Patent Application No. 202111397928.4 filed on November 23, 2021, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present application relates to the technical field of train automatic protection, and particularly to a method, apparatus, device, system, and medium for safety protection of trains in a cooperative formation.

BACKGROUND

[0003] Cooperative formation of trains is a new type of cooperative driving mode for the trains, in which based on moving block, information interaction and sensing between the trains are achieved to guarantee the safety of the trains, and moreover, the virtual coupling technology is adopted to achieve flexible formation for two or more trains, the district speeds and inbound/outbound times of the trains tend to be the same, so as to improve the efficiency of subway operation and reduce operating costs.

[0004] In the related art, in the cooperative formation of the trains, the relative speed safety protection model may be adopted for safety protection, in which when a train follows a front train, the front train may be seen as an obstacle with a speed and the rear of the front train, when it stops, is used as the MA end of the back train, and the speed and braking capability of the front train are fully considered to guarantee the safety of train operation based on the relative braking distance between the two trains. However, when the relative speed safety protection model is affected by factors such as communication delay and speed and distance measurement error, the ceiling speed of the back train will be inevitably limited, resulting in that the stopping time interval between the front train and the back train becomes longer, which

reduces the inbound and outbound efficiency of the trains in the formation.

SUMMARY

[0005] Embodiments of the present application provide a method, apparatus, device, system, and medium for safety protection of trains in a cooperative formation, which can solve the problems in the related art that the stopping time interval between the front train and the back train becomes longer, and the inbound and outbound efficiency of the trains in the formation is low.

[0006] In a first aspect, some embodiments of the present application provide a method for safety protection of trains in a cooperative formation, including: obtaining running state information and distance information of a first train and a second train, and an allowable collision speed of a formation corresponding to the first train and the second train, in which the first train and the second train are two adjacent trains in the formation; establishing, under a condition that the first train is in an emergency braking phase, a safety protection model according to a travelling phase of the second train, the running state information, the distance information, and the allowable collision speed; and determining a safety protection speed for the second train according to the safety protection model, in which the safety protection speed causes that the second train does not collide with the first train or that the second train collides with the first train at a speed not greater than the allowable collision speed.

[0007] In a second aspect, some embodiments of the present application provide an apparatus for safety protection of trains in a cooperative formation, including: an obtaining module configured to obtain running state information and distance information of a first train and a second train, and an allowable collision speed of a formation corresponding to the first train and the second train, in which the first train and the second train are two adjacent trains in the formation; an establishing module configured to establish, under a condition that the first train is in an emergency braking phase, a safety protection model according to a travelling phase of the second train, the running state information, the distance information, and the allowable collision speed; and a determining module configured to determine a safety protection speed for the second train according to the safety protection model, in which the safety protection

speed causes that the second train does not collide with the first train or that the second train collides with the first train at a speed not greater than the allowable collision speed.

[0008] In a third aspect, some embodiments of the present application provide a device for safety protection of trains in a cooperative formation, including a processor, a memory, and a program or instructions stored on the memory and executable on the processor, in which the program or instructions implement, when executed by the processor, steps of the method for safety protection of trains in the cooperative formation of the first aspect.

[0009] In a fourth aspect, some embodiments of the present application provide a system for safety protection of trains in a cooperative formation, including the device for safety protection of trains in the cooperative formation of the third aspect.

[0010] In a fifth aspect, some embodiments of the present application provide a computer-readable storage medium storing computer program instructions thereon, in which the computer program instructions implement, when executed by a processor, steps of the method for safety protection of trains in the cooperative formation of the first aspect.

[0011] The present application provides a method, apparatus, device, system, and medium for safety protection of trains in a cooperative formation, in which the running state information and the distance information of the first train and the second train, which are adjacent in the formation, and the allowable collision speed of the formation corresponding to the first train and the second train are obtained. On this basis, under a condition that the first train is in the emergency braking phase, the safety protection model may be established according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed. Since the safety protection model is established based on the allowable collision speed, the safety protection speed determined based on the safety protection model may allow the first train and the second train to collide at a speed less than or equal to the allowable collision speed during the inbound stopping phase, which breaks the traditional safety bottom line that the trains cannot come into contact with each other directly, and allows the trains to collide at a speed within a certain safety range and considers such collision as safe, so as to further increase the running speed of the back train, shorten the stopping time interval between the trains, and improve the inbound and outbound efficiency of the trains in the

formation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] In order to more clearly illustrate the technical solutions of the embodiments of the present application, the accompanying drawings to be used in the embodiments of the present application will be briefly introduced below. For those of ordinary skill in the art, other accompanying drawings can be obtained based on these accompanying drawings without inventive effort.

[0013] Fig. 1 shows a schematic flow chart of a method for safety protection of trains in a cooperative formation according to the embodiments of the present application;

[0014] Fig. 2 shows a schematic diagram of an example of a scenario for safety protection of trains in a cooperative formation according to the embodiments of the present application;

[0015] Fig. 3 shows a schematic diagram of an example of a first scenario according to the embodiments of the present application;

[0016] Fig. 4 shows a schematic diagram of an example of a second scenario according to the embodiments of the present application;

[0017] Fig. 5 shows a schematic diagram of an example of a third scenario according to the embodiments of the present application;

[0018] Fig. 6 shows a schematic diagram of an example of a fourth scenario according to the embodiments of the present application;

[0019] Fig. 7 shows a schematic diagram of an example of a fifth scenario according to the embodiments of the present application;

[0020] Fig. 8 shows a schematic structural diagram of an apparatus for safety protection of trains in a cooperative formation according to the embodiments of the present application;

[0021] Fig. 9 shows a schematic structural diagram of hardware of a device for safety protection of trains in a cooperative formation according to the embodiments of the present application.

DETAILED DESCRIPTION

[0022] Features and exemplary embodiments of various aspects of the present application will be described in detail below, and in order to make the purpose, technical solutions, and advantages of the present application clearer, the present application is described in further detail below in conjunction with the accompanying drawings and specific embodiments. It should be understood that the specific embodiments described herein are intended only to explain the present application and not to limit the present application. For those skilled in the art, the present application can be implemented without some of these specific details. The following description of the embodiments is intended only to provide a better understanding of the present application by illustrating examples of the present application.

[0023] As described above in the background, in the cooperative formation of the trains, the relative speed safety protection model may be adopted for safety protection, in which when a train follows a front train, the front train may be seen as an obstacle with a speed and the rear of the front train, when it stops, is used as the MA end of the back train, and the speed and braking capability of the front train are fully considered to guarantee the safety of train operation based on the relative braking distance between the two trains. However, when the relative speed safety protection model is affected by factors such as communication delay and speed and distance measurement error, the ceiling speed of the back train will be inevitably limited, resulting in that the stopping time interval between the front train and the back train becomes longer, which reduces the inbound and outbound efficiency of the trains in the formation.

[0024] In order to solve the problems in the related art, the embodiments of the present application provide a method for safety protection of trains in a cooperative formation, in which the running state information and the distance information of the first train and the second train, which are adjacent in the formation, and the allowable collision speed of the formation corresponding to the first train and the second train are obtained. On this basis, under a condition that the first train is in the emergency braking phase, the safety protection model may be established according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed. Since the safety protection model is established based on the allowable collision speed, the safety protection

speed determined based on the safety protection model may allow the first train and the second train to collide at a speed less than or equal to the allowable collision speed during the inbound stopping phase, which breaks the traditional safety bottom line that the trains cannot come into contact with each other directly, and allows the trains to collide at a speed within a certain safety range and considers such collision as safe, so as to further increase the running speed of the back train, shorten the stopping time interval between the trains, and improve the inbound and outbound efficiency of the trains in the formation, thereby solving the problems in the related art that the stopping time interval between the front train and the back train becomes longer, and the inbound and outbound efficiency of the trains in the formation is low.

[0025] The method for safety protection of trains in a cooperative formation according to the embodiments of the present application is described in detail below in conjunction with the accompanying drawings through specific embodiments and application scenarios thereof.

[0026] Fig. 1 shows a schematic flow chart of a method for safety protection of trains in a cooperative formation according to the embodiments of the present application, and the executive subject of the method for safety protection of trains in a cooperative formation may be a device for safety protection of trains in a cooperative formation. For simplicity, the device for safety protection of trains in a cooperative formation is referred to as the device hereinafter.

[0027] It should be noted that the above executive subject does not constitute a limitation of the present application.

[0028] As shown in Fig. 1, the method for safety protection of trains in a cooperative formation according to the embodiments of the present application may include the following steps 110-130.

[0029] Step 110: obtaining running state information and distance information of a first train and a second train, and an allowable collision speed of a formation corresponding to the first train and the second train.

[0030] Herein, the first train and the second train are two adjacent trains in the formation, the first train may be the front train, and the second train may be the back train.

[0031] It should be noted that in the embodiments of the present application, since the restriction on safety protection of the trains is loosened and the trains are allowed to slightly

collide at a low speed, a strong structural strength is needed for the train body of the first train and the second train, and the design of the first train and the second train should satisfy the following conditions: under a condition that the first train and the second train collide based on the allowable collision speed, the first train and the second train will not be deformed and/or the passengers in the trains will not be significantly affected.

[0032] The allowable collision speed may be a preset speed. Since the different types of trains are affected differently in the event of a collision, the allowable collision speed is related to the types of the trains within the same formation.

[0033] Specifically, the allowable collision speed corresponding to a formation may be determined according to the types of the trains in the same formation, and the allowable collision speed may be the maximum speed at which the trains will not be deformed when a collision occurs.

[0034] If the trains in the same formation are of different types, the allowable collision speed corresponding to the formation is the smallest one of the allowable collision speeds corresponding to all types of trains in the formation.

[0035] Step 120: establishing, under a condition that the first train is in an emergency braking phase, a safety protection model according to a travelling phase of the second train, the running state information, the distance information, and the allowable collision speed.

[0036] Step 130: determining a safety protection speed for the second train according to the safety protection model, in which the safety protection speed causes that the second train does not collide with the first train or that the second train collides with the first train at the allowable collision speed.

[0037] Exemplarily, Fig. 2 shows a schematic diagram of an example of a scenario for safety protection of trains in a cooperative formation according to the embodiments of the present application. As shown in Fig. 2, curve 1 is a relationship curve between the speed and the location of the first train, and curve 2 is a relationship curve between the safety protection speed and the location of the second train, i.e., the safety protection model established according to the embodiments of the present application. The second train may travel at the safety protection speed corresponding to curve 2 in the emergency braking establishment (BE) phase and the

emergency braking (EB) phase, and based on the safety protection speed, it can be ensured that the first train and the second train do not collide in the whole travelling phase, or that after a second time t_2' at which the second train decelerates to the allowable collision speed, the second train collides with the first train at a speed less than or equal to the allowable collision speed v_{col}. In this way, even if a collision occurs, it can still be ensured that the first train and the second train will not be deformed, the safety is guaranteed, and moreover, the ceiling speed of the second train is increased, the stopping time interval and the stopping distance between the trains are shortened, which is closer to an idealized scenario in which the inbound/outbound times of the trains in the formation are synchronized.

[0038] The embodiments of the present application provide a method for safety protection of trains in a cooperative formation, in which the running state information and the distance information of the first train and the second train, which are adjacent in the formation, and the allowable collision speed of the formation corresponding to the first train and the second train are obtained. On this basis, under a condition that the first train is in the emergency braking phase, the safety protection model may be established according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed. Since the safety protection model is established based on the allowable collision speed, the safety protection speed determined based on the safety protection model may allow the first train and the second train to collide at a speed less than or equal to the allowable collision speed during the inbound stopping phase, which breaks the traditional safety bottom line that the trains cannot come into contact with each other directly, and allows the trains to collide at a speed within a certain safety range and considers such collision as safe, so as to further increase the running speed of the back train, shorten the stopping time interval between the trains, and improve the inbound and outbound efficiency of the trains in the formation.

[0039] In step 110, the running state information and the distance information of the first train and the second train, and the allowable collision speed of the formation corresponding to the first train and the second train are obtained.

[0040] In some embodiments of the present application, the device for safety protection of

trains in a cooperative formation may be the second train, and the step 110 may include: receiving running state information and location information of the first train sent by the first train through virtual coupling technology; obtaining running state information and location information of the second train; and determining, according to the running state information and the location information of the first train and the second train, the distance information of the first train and the second train.

[0041] In some embodiments of the present application, the running state information may include a speed and an acceleration. The device may determine the current travelling phase of the second train according to the speed and the acceleration of the second train, which may include a traction phase, a coasting phase, an emergency braking establishment phase, and an emergency braking phase. The device may determine the current travelling phase of the first train according to the speed and the acceleration of the first train, which may include an emergency braking phase and a stopping phase.

[0042] In some embodiments of the present application, if merely the inbound stopping phase is considered, the travelling phase of the second train may include an emergency braking establishment BE phase and an emergency braking EB phase, the running state information may include a first initial speed v_0^l of the first train at an initial time, a second initial speed v_0^f of the second train at the initial time, a first acceleration a_{eb}^l of the first train in the emergency braking phase, a second acceleration a_{eb}^f of the second train in the emergency braking phase, and a third acceleration a_{be}^f of the second train in the emergency braking establishment phase, and the distance information includes an initial distance s_0 between the first train and the second train at the initial time and an emergency braking distance s_p^l of the first train.

[0043] Exemplarily, as shown in Fig. 2, the first train is represented as 201, the second train is represented as 202, the first initial speed v_0^l is the speed of 201 at the initial time (t=0), the second initial speed v_0^f is the speed of 202 at the initial time, and the initial distance s_0 is the distance between 201 and 202 at the initial time. The first acceleration a_{eb}^l is the acceleration

of 201 in the emergency braking phase, the second acceleration a_{eb}^{f} is the acceleration of 202 in the emergency braking phase (t_1-t_2), and the third acceleration a_{be}^{f} is the acceleration of 202 in the emergency braking establishment phase (0-t_1). The emergency braking distance s_p^l may be the travelling distance of 201 during the emergency braking phase.

[0044] It should be noted that the emergency braking establishment phase and the emergency braking phase shown in Fig. 2 are only related to the train 202, i.e., the back train.

[0045] In step 120, under a condition that the first train is in an emergency braking phase, a safety protection model is established according to a travelling phase of the second train, the running state information, the distance information, and the allowable collision speed.

[0046] When the first train and the second train enter the inbound stopping phase, considering the most unfavorable situation, the first train experiences the emergency braking phase and the stopping phase, and the second train experiences the emergency braking establishment phase and the emergency braking phase. With the premise that a collision is allowed, the device determines, according to whether the second train is currently in the BE phase or the EB phase and in conjunction with whether the speed of the front train is zero, the maximum speed, i.e., the safety protection speed, for the second train when the speed difference between the second train and the first train is less than a certain threshold value.

[0047] In some embodiments of the present application, step 120 may specifically include: establishing, under a condition that the first train is in the emergency braking phase and a first time is earlier than a second time, a first safety protection model according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed; establishing, under a condition that the first train is in the emergency braking phase and the second time is earlier than the first time, a second safety protection model according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed, in which the first time t_3' is a time when the first train decelerates to the allowable collision speed, and the second time t_2' is a time when the second train decelerates to the allowable collision speed.

[0048] Specifically, in the first case, the braking performance difference between the first

train and the second train is small, and under the normal running state, the first train decelerates to the allowable collision speed faster than the second train, and thus the first time t_3' is earlier than the second time t_2', as shown in Fig. 2, in which case the first safety protection model may be established; in the second case, if the braking performance of the first train is relatively poor, the second train decelerates to the allowable collision speed faster than the first train, and thus the second time is earlier than the first time, in which case the second safety protection model may be established.

[0049] In an embodiment, the device may: calculate, according to the running speed and the acceleration of the first train at the current time, the emergency braking time of the first train, and determine, according to the emergency braking time, the end time of the emergency braking phase of the first train, i.e., a third time; calculate the emergency braking distance of the first train according to the first initial speed and the first acceleration, $s_p^l=\frac{{v_0^l}^2}{a_{eb}^l}$; calculate, according to the running state information of the second train, the time duration of each travelling phase of the second train from the current time to the stopping time, for example, if the second train is in the traction phase, the time duration of the traction cutting-out phase is calculated according to the current speed, the acceleration, and the traction cutting-out time, and similarly, the time duration of the coasting phase, the time duration of the emergency braking establishment phase (t_1-0), and the time duration of the emergency braking phase (t_2-t_1) are calculated; calculate, according to the emergency braking time of the first train, the time duration from the current time to the time when the first train decelerates to the allowable collision speed, so as to determine the first time t_3' when the first train decelerates to the allowable collision speed; and calculate, according to the time duration of each travelling phase of the second train from the current time to the stopping time, the time duration from the current time to the time when the second train decelerates to the allowable collision speed, so as to determine the second time t_2' when the second train decelerates to the allowable collision speed.

[0050] In an embodiment, the first safety protection model may satisfy the following conditions: a travelling distance of the first train from the initial time to a fifth time is greater than or equal to a travelling distance of the second train from the initial time to the fifth time,

in which the fifth time is any time prior to the second time t_2'; and travelling speeds of the first train and the second train at a sixth time are both less than or equal to the allowable collision speed, in which the sixth time is any time between the second time t_2' and the stopping time t_2 of the second train.

[0051] Specifically, the above conditions may be represented as the following formula (1):

$$\begin{cases} S_l(t) - S_f(t) \geq 0 & \forall t \in [0, t_2'] \\ v_f(t), v_l(t) \leq v_{col} & \forall t \in [t_2', t_2] \end{cases} \quad (1)$$

[0052] where $S_l(t)$ is the travelling distance of the first train at the current time t, $S_f(t)$ is the travelling distance of the second train at the current time t; $v_f(t)$ is the travelling speed of the second train at the current time t, $v_l(t)$ is the travelling speed of the first train at the current time t.

[0053] In the embodiments of the present application, since the travelling distance of the first train is greater than or equal to the travelling distance of the second train before the second time when the second train decelerates to the allowable collision speed, it can be ensured that the first train and the second train will not collide at any time before the time when the speeds of the two trains both reach the allowable collision speed, and thus safety of the trains is guaranteed; and moreover, after the second time when the second train decelerates to the allowable collision speed, since the travelling speeds of both the first train and the second train do not exceed the allowable collision speed, the two trains may collide within and only within the allowable collision range, and thus the maximum ceiling speed of the second train is increased to the allowable collision speed, and the inbound stopping time difference between the two adjacent trains is reduced.

[0054] It should be noted that based on the different performances and states of the first train and the second train, the chronological order of the first time, the second time, the third time (i.e., the end time of the emergency braking phase of the first train), and a fourth time (i.e., the start time of the emergency braking phase of the second train) varies, and the present application may divide the application scenarios according to the chronological order and establish different first safety protection models based on different application scenarios.

[0055] In some embodiments of the present application, step 120 may specifically include:

determining, under a condition that the first train is in the emergency braking phase and the first time is earlier than the second time, a first safety protection scenario corresponding to the second train according to a chronological order of the first time, the second time, a third time, and a fourth time; establishing the first safety protection model associated with the first safety protection scenario according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed, in which the third time t_3 is an end time of the emergency braking phase of the first train, and the fourth time t_1 is a start time of the emergency braking phase of the second train.

[0056] The first safety protection model according to the embodiments of the present application is described in detail below in conjunction with Figs. 3 to 5 through specific embodiments and application scenarios thereof.

[0057] It should be noted that in Figs. 3 to 5, curve ① is a safety protection speed-location curve of the second train in the emergency braking establishment phase and the emergency braking phase, curve ④ is a speed-location curve of the first train in the emergency braking phase and the stopping phase, curve ② is a safety protection speed-location curve of the second train in the coasting phase and the emergency braking phase, and curve ③ is a safety protection speed-location curve of the second train in the traction phase and the emergency braking phase.

[0058] In some embodiments of the present application, Fig. 3 shows a schematic diagram of an example of a first scenario according to the embodiments of the present application. As shown in Fig. 3, under a condition that the chronological order is that the first time t_3' is the earliest, then the third time t_3, then the fourth time t_1, and then the second time t_2', the first safety protection scenario corresponding to the second train may be a first scenario, and the first safety protection model associated with the first scenario may be represented as the following formula (2) which is corresponding to curve ① shown in Fig. 3:

$$v_f(t) \le \begin{cases} \frac{v_0^l}{2}\left(1+\frac{a_{be}^f}{a_{eb}^l}+\frac{s_0}{s_p^l}\right), t \in [0, t_3] \\ 0.5 * a_{be}^f * t_f + \frac{s_0+\frac{(v_0^l)^2}{2*a_{eb}^l}}{t_f}, t \in [t_3, t_1] \\ \sqrt{(v_{col})^2 + 2 * a_{eb}^f * \left[0.5 * \left(a_{eb}^f - a_{be}^f\right) * t_f^2 + \left(s_0 + s_p^l\right)\right]} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_2'] \\ v_{col}, t \in [t_2', t_2] \end{cases} \quad (2)$$

[0059] where t is a current time, t_1 is the fourth time, t_f is a time length from the initial time to the fourth time, t_2 is a stopping time of the second train, t_3 is the third time, t_2' is the second time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l is the first initial speed, a_{eb}^l is the first acceleration, a_{eb}^f is the second acceleration, a_{be}^f is the third acceleration, s_0 is the initial distance, s_p^l is the emergency braking distance, and v_{col} is the allowable collision speed.

[0060] In some embodiments of the present application, Fig. 4 shows a schematic diagram of an example of a second scenario according to the embodiments of the present application. As shown in Fig. 4, under a condition that the chronological order is that the fourth time t_1 is the earliest, then the first time t_3', then the third time t_3, and then the second time t_2', the first safety protection scenario corresponding to the second train is a second scenario, and the first safety protection model associated with the second scenario may be represented as the following formula (3) which is corresponding to curve ① shown in Fig. 4:

$$v_f(t) \le \begin{cases} \frac{s_0 - 0.5*\left(a_{eb}^l - a_{be}^f\right)t_f^2}{t_f} + v_0^l, t \in [0, t_1] \\ v_0^l + \frac{0.5a_{eb}^l\left(a_{eb}^f - a_{be}^f\right)t_f^2 + a_{eb}^l s_0}{v_0^l} - \frac{0.5\left(a_{eb}^l - a_{be}^f\right)v_0^l}{a_{eb}^l} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_3] \text{ and } a_{eb}^l \ge a_{eb}^f \\ v_0^l + \sqrt{\left(a_{eb}^f - a_{eb}^l\right)\left(\left(a_{eb}^f - a_{be}^f\right)t_f^2 + 2s_0\right)} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_3] \text{ and } a_{eb}^l < a_{eb}^f \\ \sqrt{(v_{col})^2 + 2 * a_{eb}^f * \left[0.5 * \left(a_{eb}^f - a_{be}^f\right) * t_f^2 + \left(s_0 + s_p^l\right)\right]} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_3, t_2'] \\ v_{col}, t \in [t_2', t_2] \end{cases} \quad (3)$$

[0061] where t is a current time, t_1 is the fourth time, t_f is a time length from the initial

time to the fourth time, t_2 is a stopping time of the second train, t_3 is the third time, t_2' is the second time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l is the first initial speed, a_{eb}^l is the first acceleration, a_{eb}^f is the second acceleration, a_{be}^f is the third acceleration, s_0 is the initial distance, s_p^l is the emergency braking distance, and v_{col} is the allowable collision speed.

[0062] In some embodiments of the present application, Fig. 5 shows a schematic diagram of an example of a third scenario according to the embodiments of the present application. As shown in Fig. 5, under a condition that the chronological order is that the fourth time t_1 is the earliest, then the first time t_3', then the second time t_2', and then the third time t_3, the first safety protection scenario corresponding to the second train is a third scenario, and the first safety protection model associated with the third scenario may be represented as the following formula (4) which is corresponding to curve ① shown in Fig. 5:

$$v_f(t) \leq \begin{cases} \frac{s_0 - 0.5*\left(a_{eb}^l - a_{be}^f\right)t_f^2}{t_f} + v_0^l, t \in [0, t_1] \\ \frac{2av_{col} + a_{eb}^f v_{col} + \sqrt{\Delta}}{a_{eb}^l + a_{eb}^f} + v_0^l - \left(a_{eb}^f - a_{be}^f\right) * t_f, \text{and satisfying } av_{col}^2 - \left(a_{be}^f\right)^2 c > 0, \\ t \in [t_1, t_2'] \,\&\, a_{eb}^l > a_{eb}^f \\ \frac{v_{col} + \sqrt{v_{col}^2 + 4a_{eb}^f[0.5*(a_{eb}^f - a_{be}^f)*t_f^2 + s_0])}}{2} + v_0^l - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_2'] \,\&\, a_{eb}^l = a_{eb}^f \\ v_0^l + \sqrt{\left(a_{eb}^f - a_{eb}^l\right)\left(\left(a_{eb}^f - a_{be}^f\right)t_f^2 + 2s_0\right)} - \left(a_{eb}^f - a_{be}^f\right) * t_f \quad , \\ t \in [t_1, t_2'] \,\&\, a_{eb}^l < a_{eb}^f \\ v_{col}, t \in [t_2', t_2] \end{cases} \tag{4}$$

[0063] where t is a current time, t_1 is the fourth time, t_f is a time length from the initial time to the fourth time, t_2 is a stopping time of the second train, t_2' is the second time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l is the first initial speed, a_{eb}^l is the first acceleration, a_{eb}^f is the second acceleration, a_{be}^f is the third acceleration, s_0 is the initial distance, s_p^l is the emergency braking distance, v_{col} is the allowable collision speed. Δ is b^2-4ac, in which $a=0.5*(a_{eb}^l - a_{eb}^f)$, $b=v_0^f - v_0^l + \left(a_{eb}^f - a_{be}^f\right) * t_f$, $c=0.5*$

$\left(a_{eb}^{f}-a_{be}^{f}\right)*t_{f}{}^{2}-\mathrm{s}_{0}$, $\Delta=\left(\mathrm{a}_{\mathrm{be}}^{\mathrm{f}}\right)^{2}[\mathrm{v}_{\mathrm{col}}{}^{2}+2\left(a_{eb}^{l}+a_{eb}^{f}\right)c]$, and $\Delta\geq 0$. $\mathrm{v}_{0}^{\mathrm{f}}$ is the second initial speed.

[0064] The first safety protection model associated with any one of the first scenario, the second scenario, and the third scenario provided above can satisfy the safety protection conditions of formula (1), therefore under different application scenarios, the safety protection speed of the trains may be determined based on the first safety protection model associated with the application scenario, the second train is controlled to travel based on the safety protection speed, and if the travelling speed of the second train exceeds the safety protection speed, emergency braking is applied to guarantee travelling safety of the trains.

[0065] In an embodiment, the third time is an end time of the emergency braking phase of the first train, and the second safety protection model may satisfy the following conditions: a travelling distance of the first train from the initial time to a seventh time is greater than or equal to a travelling distance of the second train from the initial time to the seventh time, in which the seventh time is any time prior to the first time t_3'; and travelling speeds of the first train and the second train at an eighth time are both less than or equal to the allowable collision speed, in which the eighth time is any time between the first time t_3' and the third time t_3.

[0066] Specifically, the above conditions may be represented as the following formula (5):

$$\begin{cases} S_l(t)-S_f(t)\geq 0 & \forall t\in[0,t_3'] \\ v_f(t),v_l(t)\leq v_{col} & \forall t\in[t_3',t_3] \end{cases} \quad (5)$$

[0067] where $S_l(t)$ is the travelling distance of the first train at the current time t, $S_f(t)$ is the travelling distance of the second train at the current time t; $v_f(t)$ is the travelling speed of the second train at the current time t, $v_l(t)$ is the travelling speed of the first train at the current time t.

[0068] In the embodiments of the present application, since the travelling distance of the first train is greater than or equal to the travelling distance of the second train before the first time when the first train decelerates to the allowable collision speed, it can be ensured that the first train and the second train will not collide at any time before the time when the speeds of the two trains both reach the allowable collision speed, and thus safety of the trains is guaranteed; and moreover, after the first time when the first train decelerates to the allowable collision

speed, since the travelling speeds of both the first train and the second train do not exceed the allowable collision speed, the two trains may collide within and only within the allowable collision range, and thus the maximum ceiling speed of the second train is increased to the allowable collision speed, and the inbound stopping time difference between the two adjacent trains is reduced.

[0069] It should be noted that based on the different performances and states of the first train and the second train, a chronological order exists for the stopping times of the first train and the second train, and the present application may divide the application scenarios according to the chronological order and establish different second safety protection models based on different application scenarios.

[0070] In some embodiments of the present application, the establishing, under a condition that the first train is in the emergency braking phase and the second time is earlier than the first time, the second safety protection model according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed includes: determining, under a condition that the first train is in the emergency braking phase and the second time is earlier than the first time, a second safety protection scenario corresponding to the second train according to a chronological order of the first time and a stopping time of the second train; and establishing the second safety protection model associated with the second safety protection scenario according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed.

[0071] The second safety protection model according to the embodiments of the present application is described in detail below in conjunction with Figs. 6 and 7 through specific embodiments and application scenarios thereof.

[0072] It should be noted that in Figs. 6 and 7, curve ① is a safety protection speed-location curve of the second train in the emergency braking establishment phase and the emergency braking phase, curve ④ is a speed-location curve of the first train in the emergency braking phase and the stopping phase, curve ② is a safety protection speed-location curve of the second train in the coasting phase and the emergency braking phase, and curve ③ is a safety

protection speed-location curve of the second train in the traction phase and the emergency braking phase.

[0073] In some embodiments of the present application, Fig. 6 shows a schematic diagram of an example of a fourth scenario according to the embodiments of the present application. As shown in Fig. 6, under a condition that the first time t_3' is earlier than the stopping time t_2, the second safety protection scenario corresponding to the second train is a fourth scenario, and the second safety protection model associated with the fourth scenario may be represented as the following formula (6) which is corresponding to curve ① shown in Fig. 6:

$$v_f(t) \leq \begin{cases} \frac{s_0 - 0.5*\left(a_{eb}^l - a_{be}^f\right)t_f^2}{t_f} + v_0^l, t \in [0, t_1] \\ \frac{(a_{eb}^l)^2\left[0.5\left(a_{eb}^f - a_{be}^f\right)t_f^2 + s_0\right] - 0.5\left(a_{eb}^l - a_{eb}^f\right)\left(v_0^l - v_{col}\right)^2}{a_{eb}^l\left(v_0^l - v_{col}\right)} \\ +v_0^l - \left(a_{eb}^f - a_{be}^f\right)t_f, t \in [t_1, t_3'] \,\&\, a_{eb}^l \geq a_{eb}^f \\ v_0^l + \sqrt{\left(a_{eb}^f - a_{eb}^l\right)\left(\left(a_{eb}^f - a_{be}^f\right)t_f^2 + 2s_0\right)} - \left(a_{eb}^f - a_{be}^f\right) * t_f \ , \\ t \in [t_1, t_3'] \,\&\, a_{eb}^l < a_{eb}^f \\ v_{col}, t \in [t_2', t_2] \end{cases} \quad (6)$$

[0074] where t is a current time, t_1 is a fourth time which is a start time of the emergency braking phase of the second train, t_f is a time length from the initial time to the fourth time, t_2 is the stopping time of the second train, t_2' is the second time, t_3' is the first time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l is the first initial speed, a_{eb}^l is the first acceleration, a_{eb}^f is the second acceleration, a_{be}^f is the third acceleration, s_0 is the initial distance, s_p^l is the emergency braking distance, and v_{col} is the allowable collision speed.

[0075] In an embodiment, in the fourth scenario, the chronological order of the various times is that the fourth time is the earliest, then the second time, then the first time, then the stopping time, and then the third time.

[0076] In some embodiments of the present application, Fig. 7 shows a schematic diagram of an example of a fifth scenario according to the embodiments of the present application. As shown in Fig. 7, under a condition that the stopping time t_2 is earlier than the first time t_3', the second safety protection scenario corresponding to the second train is a fifth scenario, and

the second safety protection model associated with the fifth scenario may be represented as the following formula (7) which is corresponding to curve ① shown in Fig. 7:

$$v_f(t) \le \begin{cases} \frac{s_0 - 0.5*\left(a_{eb}^l - a_{be}^f\right)t_f^2}{t_f} + v_0^l, t \in [0, t_1] \\ \frac{a_{eb}^f v_0^l + \sqrt{\left(a_{eb}^f v_0^l\right)^2 + 2*c*(a_{eb}^f)^2\left(a_{eb}^l + a_{eb}^f\right)}}{a_{eb}^l + a_{eb}^f} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_2] \,\&\, a_{eb}^l \ge a_{eb}^f \\ v_0^l + \sqrt{\left(a_{eb}^f - a_{eb}^l\right)\left(\left(a_{eb}^f - a_{be}^f\right)t_f^2 + 2s_0\right)} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_2] \,\&\, a_{eb}^l < a_{eb}^f \\ \frac{a_{eb}^l\left[0.5*\left(a_{eb}^f - a_{be}^f\right)*t_f^2 + (s_0 + s_p^l)\right]}{2(v_0^l - v_{col})} + \frac{a_{eb}^f(v_0^l - v_{col})}{2a_{eb}^l} \\ -\left(a_{eb}^f - a_{be}^f\right) * t_f, t \in [t_2, t_3'] \\ v_{col}, t \in [t_2', t_2] \end{cases} \quad (7)$$

[0077] where t is a current time, t_1 is a fourth time which is a start time of the emergency braking phase of the second train, t_f is a time length from the initial time to the fourth time, t_2 is the stopping time of the second train, t_3' is the first time, t_2' is the second time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l is the first initial speed, a_{eb}^l is the first acceleration, a_{eb}^f is the second acceleration, a_{be}^f is the third acceleration, s_0 is the initial distance, s_p^l is the emergency braking distance, and v_{col} is the allowable collision speed.

[0078] In an embodiment, in the fifth scenario, the chronological order of the various times is that the fourth time is the earliest, then the second time, then the stopping time, then the first time, and then the third time.

[0079] The second safety protection model associated with the fourth scenario or the fifth scenario provided above can satisfy the safety protection conditions of formula (5), therefore under different application scenarios, the safety protection speed of the trains may be determined based on the second safety protection model associated with the application scenario, the second train is controlled to travel based on the safety protection speed, and if the travelling speed of the second train exceeds the safety protection speed, emergency braking is applied to guarantee travelling safety of the trains.

[0080] In an embodiment, in the first scenario to the fifth scenario, the speed of the first train

at t3 is $v_{t3}^{l}=0$, and the speed of the second train at t1 is $v_{t1}^{f}=v_{0}^{f}-a_{be}^{f}*t_{f}$.

[0081] In some embodiments of the present application, a model prediction algorithm, such as the Model Predictive Control (MPC) algorithm, can achieve rolling prediction of the state of an object in a certain time domain, therefore the device may predict, based on the Automatic Train Operation (ATO) control algorithm of MPC or other predictable algorithms, the state change in several future cycles according to the state (speed, acceleration) of the train in the current and several previous cycles, and determine the actual travelling phase of the train according to the predicted state change; the first safety protection model and the second safety protection model of the embodiments of the present application are extended based on the actual travelling phase of the train, and the extended safety protection model is adaptable to the safety protection of the trains in the formation under a plurality of application scenarios. The plurality of application scenarios may include: the first train is in the emergency braking phase, the second train is in the traction phase or the normal braking phase; the first train is in the emergency braking phase, the second train is in the coasting phase; the first train is in the emergency braking phase, the second train is in the emergency braking establishment phase; and the first train is in the emergency braking phase, the second train is in the emergency braking phase

[0082] For the above plurality of application scenarios, the device may subdivide the plurality of application scenarios into different safety protection scenarios according to the emergency braking time of the first train, the time for the first train to decelerate to the allowable collision speed, the traction cutting-off time of the second train, the coasting time of the second train, the emergency braking establishment time of the second train, the time for the second train to emergency brake to decelerate to the allowable collision speed, and the time for the second train to emergency brake to stop.

[0083] It should be noted that, the executive subject of the method for safety protection of trains in a cooperative formation according to the embodiments of the present application may be an apparatus for safety protection of trains in a cooperative formation, or a control module for executing the method for safety protection of trains in a cooperative formation in the apparatus for safety protection of trains in a cooperative formation. In the embodiments of the

present application, an apparatus for safety protection of trains in a cooperative formation which executes the method for safety protection of trains in a cooperative formation is taken as an example to illustrate the apparatus for safety protection of trains in a cooperative formation according to the embodiments of the present application. The apparatus for safety protection of trains in a cooperative formation is described in detail below.

[0084] Fig. 8 shows a schematic structural diagram of an apparatus for safety protection of trains in a cooperative formation according to the embodiments of the present application. As shown in Fig. 8, the apparatus 800 for safety protection of trains in a cooperative formation may include: an obtaining module 810, an establishing module 820, and a determining module 830.

[0085] Herein, the obtaining module 810 is configured to obtain running state information and distance information of a first train and a second train, and an allowable collision speed of a formation corresponding to the first train and the second train, in which the first train and the second train are two adjacent trains in the formation; the establishing module 820 is configured to establish, under a condition that the first train is in an emergency braking phase, a safety protection model according to a travelling phase of the second train, the running state information, the distance information, and the allowable collision speed; and the determining module 830 is configured to determine a safety protection speed for the second train according to the safety protection model, in which the safety protection speed causes that the second train does not collide with the first train or that the second train collides with the first train at a speed not greater than the allowable collision speed.

[0086] In some embodiments of the present application, the travelling phase of the second train includes an emergency braking establishment phase and an emergency braking phase, the running state information includes a first initial speed of the first train at an initial time, a second initial speed of the second train at the initial time, a first acceleration of the first train in the emergency braking phase, a second acceleration of the second train in the emergency braking phase, and a third acceleration of the second train in the emergency braking establishment phase, and the distance information includes an initial distance between the first train and the second train at the initial time and an emergency braking distance of the first train.

[0087] In some embodiments of the present application, under a condition that the first train is in the emergency braking phase, the establishing module 820 is specifically configured to: establish, under a condition that the first train is in the emergency braking phase and a first time is earlier than a second time, a first safety protection model according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed; establish, under a condition that the first train is in the emergency braking phase and the second time is earlier than the first time, a second safety protection model according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed, in which the first time is a time when the first train decelerates to the allowable collision speed, and the second time is a time when the second train decelerates to the allowable collision speed.

[0088] In some embodiments of the present application, under a condition that the first train is in the emergency braking phase and the first time is earlier than the second time, the establishing module 820 is specifically configured to: determine, under a condition that the first train is in the emergency braking phase and the first time is earlier than the second time, a first safety protection scenario corresponding to the second train according to a chronological order of the first time, the second time, a third time, and a fourth time; establish the first safety protection model associated with the first safety protection scenario according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed, in which the third time is an end time of the emergency braking phase of the first train, and the fourth time is a start time of the emergency braking phase of the second train.

[0089] In some embodiments of the present application, under a condition that the chronological order is that the first time is the earliest, then the third time, then the fourth time, and then the second time, the first safety protection scenario corresponding to the second train is a first scenario, and the first safety protection model associated with the first scenario includes:

$$v_f(t) \leq \begin{cases} \frac{v_0^l}{2}\left(1+\frac{a_{be}^f}{a_{eb}^l}+\frac{s_0}{s_p^l}\right), t \in [0, t_3] \\ 0.5 * a_{be}^f * t_f + \frac{s_0+\frac{(v_0^l)^2}{2*a_{eb}^l}}{t_f}, t \in [t_3, t_1] \\ \sqrt{(v_{col})^2 + 2 * a_{eb}^f * \left[0.5 * \left(a_{eb}^f - a_{be}^f\right) * t_f{}^2 + \left(s_0 + s_p^l\right)\right]} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_2'] \\ v_{col}, t \in [t_2', t_2] \end{cases},$$

[0090] where t is a current time, t_1 is the fourth time, t_f is a time length from the initial time to the fourth time, t_2 is a stopping time of the second train, t_3 is the third time, t_2' is the second time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l is the first initial speed, a_{eb}^l is the first acceleration, a_{eb}^f is the second acceleration, a_{be}^f is the third acceleration, s_0 is the initial distance, s_p^l is the emergency braking distance, and v_{col} is the allowable collision speed.

[0091] In some embodiments of the present application, under a condition that the chronological order is that the fourth time is the earliest, then the first time, then the third time, and then the second time, the first safety protection scenario corresponding to the second train is a second scenario, and the first safety protection model associated with the second scenario includes:

$$v_f(t) \leq \begin{cases} \frac{s_0 - 0.5*\left(a_{eb}^l - a_{be}^f\right)t_f{}^2}{t_f} + v_0^l, t \in [0, t_1] \\ v_0^l + \frac{0.5a_{eb}^l\left(a_{eb}^f - a_{be}^f\right)t_f{}^2 + a_{eb}^l s_0}{v_0^l} - \frac{0.5\left(a_{eb}^l - a_{eb}^f\right)v_0^l}{a_{eb}^l} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_3] \text{ and } a_{eb}^l \geq a_{eb}^f \\ v_0^l + \sqrt{\left(a_{eb}^f - a_{eb}^l\right)\left(\left(a_{eb}^f - a_{be}^f\right)t_f{}^2 + 2s_0\right)} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_3] \text{ and } a_{eb}^l < a_{eb}^f \\ \sqrt{(v_{col})^2 + 2 * a_{eb}^f * \left[0.5 * \left(a_{eb}^f - a_{be}^f\right) * t_f{}^2 + \left(s_0 + s_p^l\right)\right]} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_3, t_2'] \\ v_{col}, t \in [t_2', t_2] \end{cases},$$

[0092] where t is a current time, t_1 is the fourth time, t_f is a time length from the initial time to the fourth time, t_2 is a stopping time of the second train, t_3 is the third time, t_2' is the second time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l

is the first initial speed, a_{eb}^{l} is the first acceleration, a_{eb}^{f} is the second acceleration, a_{be}^{f} is the third acceleration, s_0 is the initial distance, s_p^{l} is the emergency braking distance, and v_{col} is the allowable collision speed.

[0093] In some embodiments of the present application, under a condition that the chronological order is that the fourth time is the earliest, then the first time, then the second time, and then the third time, the first safety protection scenario corresponding to the second train is a third scenario, and the first safety protection model associated with the third scenario includes:

$$v_f(t) \leq \begin{cases} \frac{s_0 - 0.5*\left(a_{eb}^{l} - a_{be}^{f}\right)t_f^{\,2}}{t_f} + v_0^{l}, t \in [0, t_1] \\ \frac{2av_{col} + a_{eb}^{f}v_{col} + \sqrt{\Delta}}{a_{eb}^{l} + a_{eb}^{f}} + v_0^{l} - \left(a_{eb}^{f} - a_{be}^{f}\right) * t_f, \text{and satisfying } av_{col}^2 - \left(a_{be}^{f}\right)^2 c > 0, \\ t \in [t_1, t_2'] \,\&\, a_{eb}^{l} > a_{eb}^{f} \\ \frac{v_{col} + \sqrt{v_{col}^2 + 4a_{eb}^{f}[0.5*(a_{eb}^{f} - a_{be}^{f})*t_f^{\,2} + s_0])}}{2} + v_0^{l} - \left(a_{eb}^{f} - a_{be}^{f}\right) * t_f, \\ t \in [t_1, t_2'] \,\&\, a_{eb}^{l} = a_{eb}^{f} \\ v_0^{l} + \sqrt{\left(a_{eb}^{f} - a_{eb}^{l}\right)\left(\left(a_{eb}^{f} - a_{be}^{f}\right)t_f^{\,2} + 2s_0\right)} - \left(a_{eb}^{f} - a_{be}^{f}\right) * t_f, \\ t \in [t_1, t_2'] \,\&\, a_{eb}^{l} < a_{eb}^{f} \\ v_{col}, t \in [t_2', t_2] \end{cases}$$

[0094] where t is a current time, t_1 is the fourth time, t_f is a time length from the initial time to the fourth time, t_2 is a stopping time of the second train, t_2' is the second time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^{l} is the first initial speed, a_{eb}^{l} is the first acceleration, a_{eb}^{f} is the second acceleration, a_{be}^{f} is the third acceleration, s_0 is the initial distance, s_p^{l} is the emergency braking distance, v_{col} is the allowable collision speed, Δ is $\left(a_{be}^{f}\right)^2[v_{col}^{\,2} + 2（a_{eb}^{l} + a_{eb}^{f}）c]$, and c is $0.5 * \left(a_{eb}^{f} - a_{be}^{f}\right) * t_f^{\,2} - s_0$.

[0095] In some embodiments of the present application, the first safety protection model satisfies the following conditions: a travelling distance of the first train from the initial time to a fifth time is greater than or equal to a travelling distance of the second train from the initial time to the fifth time, in which the fifth time is any time prior to the second time; and travelling speeds of the first train and the second train at a sixth time are both less than or equal to the

allowable collision speed, in which the sixth time is any time between the second time and the stopping time of the second train.

[0096] In some embodiments of the present application, under a condition that the first train is in the emergency braking phase and the second time is earlier than the first time, the establishing module 820 is specifically configured to: determine, under a condition that the first train is in the emergency braking phase and the second time is earlier than the first time, a second safety protection scenario corresponding to the second train according to a chronological order of the first time and a stopping time of the second train; and establish the second safety protection model associated with the second safety protection scenario according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed.

[0097] In some embodiments of the present application, under a condition that the first time is earlier than the stopping time, the second safety protection scenario corresponding to the second train is a fourth scenario, and the second safety protection model associated with the fourth scenario includes:

$$v_f(t) \leq \begin{cases} \frac{s_0 - 0.5*\left(a_{eb}^l - a_{be}^f\right)t_f^2}{t_f} + v_0^l, t \in [0, t_1] \\ \frac{(a_{eb}^l)^2\left[0.5\left(a_{eb}^f - a_{be}^f\right)t_f^2 + s_0\right] - 0.5\left(a_{eb}^l - a_{eb}^f\right)\left(v_0^l - v_{col}\right)^2}{a_{eb}^l\left(v_0^l - v_{col}\right)} \\ +v_0^l - \left(a_{eb}^f - a_{be}^f\right)t_f, t \in [t_1, t_3'] \,\&\, a_{eb}^l \geq a_{eb}^f \\ v_0^l + \sqrt{\left(a_{eb}^f - a_{eb}^l\right)\left(\left(a_{eb}^f - a_{be}^f\right)t_f^2 + 2s_0\right)} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_3'] \,\&\, a_{eb}^l < a_{eb}^f \\ v_{col}, t \in [t_2', t_2] \end{cases},$$

[0098] where t is a current time, t_1 is a fourth time which is a start time of the emergency braking phase of the second train, t_f is a time length from the initial time to the fourth time, t_2 is the stopping time of the second train, t_2' is the second time, t_3' is the first time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l is the first initial speed, a_{eb}^l is the first acceleration, a_{eb}^f is the second acceleration, a_{be}^f is the third acceleration, s_0 is the initial distance, s_p^l is the emergency braking distance, and v_{col} is the allowable collision speed.

[0099] In some embodiments of the present application, under a condition that the stopping time is earlier than the first time, the second safety protection scenario corresponding to the second train is a fifth scenario, and the second safety protection model associated with the fifth scenario includes:

$$v_f(t) \leq \begin{cases} \frac{s_0 - 0.5*\left(a_{eb}^l - a_{be}^f\right)t_f^2}{t_f} + v_0^l, t \in [0, t_1] \\ \frac{a_{eb}^f v_0^l + \sqrt{\left(a_{eb}^f v_0^l\right)^2 + 2*c*(a_{eb}^f)^2\left(a_{eb}^l + a_{eb}^f\right)}}{a_{eb}^l + a_{eb}^f} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_2] \& a_{eb}^l \geq a_{eb}^f \\ v_0^l + \sqrt{\left(a_{eb}^f - a_{eb}^l\right)\left(\left(a_{eb}^f - a_{be}^f\right)t_f^2 + 2s_0\right)} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_2] \& a_{eb}^l < a_{eb}^f \\ \frac{a_{eb}^l\left[0.5*\left(a_{eb}^f - a_{be}^f\right)*t_f^2 + (s_0 + s_p^l)\right]}{2(v_0^l - v_{col})} + \frac{a_{eb}^f(v_0^l - v_{col})}{2a_{eb}^l} \\ -\left(a_{eb}^f - a_{be}^f\right) * t_f, t \in [t_2, t_3'] \\ v_{col}, t \in [t_2', t_2] \end{cases}$$

[00100] where t is a current time, t_1 is a fourth time which is a start time of the emergency braking phase of the second train, t_f is a time length from the initial time to the fourth time, t_2 is the stopping time of the second train, t_3' is the first time, t_2' is the second time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l is the first initial speed, a_{eb}^l is the first acceleration, a_{eb}^f is the second acceleration, a_{be}^f is the third acceleration, s_0 is the initial distance, s_p^l is the emergency braking distance, and v_{col} is the allowable collision speed.

[00101] In some embodiments of the present application, the third time is an end time of the emergency braking phase of the first train, and the second safety protection model satisfies the following conditions: a travelling distance of the first train from the initial time to a seventh time is greater than or equal to a travelling distance of the second train from the initial time to the seventh time, in which the seventh time is any time prior to the first time; and travelling speeds of the first train and the second train at an eighth time are both less than or equal to the allowable collision speed, in which the eighth time is any time between the first time and the third time.

[00102] The apparatus for safety protection of trains in a cooperative formation according to

the embodiments of the present application can implement the various processes implemented by the device in the method embodiments of Figs. 1-7 and achieve the same technical effects, which will not be repeated herein to avoid repetition.

[00103] The apparatus for safety protection of trains in a cooperative formation in the embodiments of the present application may be an apparatus, a component in a terminal, an integrated circuit, or a chip. The apparatus may be a mobile electronic device or a non-mobile electronic device. Exemplarily, the mobile electronic device may be a cell phone, a tablet computer, a laptop computer, a handheld computer, an in-vehicle electronic device, a wearable device, an ultra-mobile personal computer (UMPC), a netbook, or a personal digital assistant (PDA), etc., and the non-mobile electronic device may be a server, a Network Attached Storage (NAS), a personal computer (PC), a television (TV), a teller machine, or a kiosk, etc., which are not specifically limited in the embodiments of the present application.

[00104] The apparatus for safety protection of trains in a cooperative formation in the embodiments of the present application may be an apparatus having an operating system. The operating system may be an Android operating system, an iOS operating system, and other possible operating systems, which are not specifically limited in the embodiments of the present application.

[00105] It is should be noted that, the executive subject of the method for safety protection of trains in a cooperative formation according to the embodiments of the first aspect of the present application may be a device for safety protection of trains in a cooperative formation, or a control module for executing the method for safety protection of trains in a cooperative formation in the device for safety protection of trains in a cooperative formation.

[00106] Fig. 9 shows a schematic structural diagram of hardware of a device for safety protection of trains in a cooperative formation according to the embodiments of the present application.

[00107] As shown in Fig. 9, the device 900 for safety protection of trains in the cooperative formation in the embodiment may include a processor 901 and a memory 902 storing computer program instructions.

[00108] Specifically, the above processor 901 may include a central processing unit (CPU), an

Application Specific Integrated Circuit (ASIC), or one or more integrated circuits that may be configured to implement the embodiments of the present application.

[00109] The memory 902 may include a mass memory for data or instructions. As an example, rather than limitation, the memory 902 may include a Hard Disk Drive (HDD), a floppy disk drive, a flash memory, an optical disk, a magneto-optical disk, a magnetic tape or a Universal Serial Bus (USB) drive, or a combination of two or more thereof. Where appropriate, the memory 902 may include removable or non-removable (or fixed) media. Where appropriate, the memory 902 may be internal or external to the integrated gateway disaster recovery device. In particular embodiments, the memory 902 is non-volatile solid state memory. The memory may include Read Only Memory (ROM), Random Access Memory (RAM), magnetic disk storage media devices, optical storage media devices, flash memory devices, electrical, optical, or other physical/tangible memory storage devices. Therefore, the memory generally includes one or more tangible (non-transitory) computer-readable storage media (e.g., memory devices) encoded with a software including computer-executable instructions, and when the software is executed (e.g., by one or more processors), it is operable to perform the operations described with reference to the method according to the embodiments of the present application.

[00110] The processor 901 reads and executes the computer program instructions stored in the memory 902 to implement any one of the methods for safety protection of trains in a cooperative formation in the above embodiments.

[00111] In an example, the device 900 for safety protection of trains in the cooperative formation may further include a communication interface 903 and a bus 910. Herein, as shown in Fig. 9, the processor 901, the memory 902, and the communication interface 903 are connected and communicate with each other through the bus 910.

[00112] The communication interface 903 is mainly used to implement the communications among various modules, apparatuses, units and/or devices in the embodiments of the present application.

[00113] The bus 910 includes hardware, software, or both, and couples the components of the device for safety protection of trains in the cooperative formation to each other. As an example, rather than limitation, the bus may include an accelerated graphics port (AGP) or other graphics

bus, an extended industry standard architecture (EISA) bus, a front side bus (FSB), a hyper transport (HT) interconnection, an industry standard architecture (ISA) bus, an infinite bandwidth interconnection, a low pin count (LPC) bus, a memory bus, a microchannel architecture (MCA) bus, a peripheral component interconnection (PCI) bus, a PCI-Express (PCI-X) bus, a serial advanced technology attachment (SATA) bus, a video electronics standards association local (VLB) bus, or other suitable buses, or a combination of two or more thereof. Where appropriate, the bus 910 may include one or more buses. Although the embodiments of the present application describe and illustrate specific buses, the present application contemplates any suitable bus or interconnection.

[00114] The device for safety protection of trains in a cooperative formation according to the embodiments of the present application can implement the various processes implemented by the device for safety protection of trains in a cooperative formation in the method embodiments of Figs. 1-7 and achieve the same technical effects, which will not be repeated herein to avoid repetition.

[00115] In combination with the method for safety protection of trains in a cooperative formation in the above embodiments, the embodiments of the present application may provide a system for safety protection of trains in a cooperative formation including the device for safety protection of trains in a cooperative formation in the above embodiments. Reference may be made to the related description in the above embodiments for the specific contents of the device for safety protection of trains in a cooperative formation, which will not be repeated herein.

[00116] In addition, in combination with the method for safety protection of trains in a cooperative formation in the above embodiments, the embodiments of the present application may provide a computer storage medium implementation. The computer storage medium stores computer program instructions thereon; the computer program instructions implement, when executed by a processor, steps of any one of the methods for safety protection of trains in the cooperative formation in the above embodiments. Examples of the computer storage media include non-transitory storage media such as electronic circuits, semiconductor memory devices, ROMs, flash memory, floppy disks, CD-ROMs, optical disks, or other

physical/tangible storage media.

[00117] It should be noted that, the present application is not limited to the specific configurations and processes described above and shown in the drawings. For simplicity, detailed description of well-known methods is omitted herein. In the above embodiments, several specific steps are described and shown as examples. Nonetheless, the flow of the methods of the present application is not limited to the specific steps as described and shown, and those skilled in the art can make various changes, modifications and additions, or change the order of the steps, after understanding the gist of the present application.

[00118] Functional blocks shown in the above structural diagrams may be implemented as hardware, software, firmware, or a combination thereof. When implemented in hardware, the functional block may be, for example, an electronic circuit, an application specific integrated circuit (Application Specific Integrated Circuit, ASIC), a suitable firmware, a plug-in, a function card and the like. When implemented in software, the elements of the present disclosure are programs or code segments used to perform the required tasks. The programs or code segments may be stored in a machine-readable medium or transmitted over a transmission medium or a communication link via data signals carried in carriers. The “machine-readable medium” may include any medium capable of storing or transmitting information. Examples of the machine-readable medium may include an electronic circuit, a semiconductor memory device, a ROM, a flash memory, an erasable ROM (EROM), a floppy disk, a CD-ROM, an optical disk, a hard disk, a fiber medium, a radio frequency (RF) link, and the like. The code segments may be downloaded via a computer network such as the Internet, an intranet.

[00119] It should be further noted that the exemplary embodiments described in the present application describe some methods or systems based on a series of steps or apparatuses. Nonetheless, the present application is not limited to the above order of steps, that is, the steps may be performed in the order described in the embodiments, or in a different order from the order in the embodiments, or several steps may be performed simultaneously.

[00120] Various aspects of the present application have been described above with reference to the flowchart and/or block diagram of the method, apparatus (system), and computer program product according to the embodiments of the present application. It should be

understood that each block in the flowchart and/or block diagram and a combination of blocks in the flowchart and/or block diagram can be implemented by computer program instructions. These computer program instructions may be provided to the processor of a general-purpose computer, a dedicated computer, or other programmable data processing devices to produce a machine, so that the execution of these instructions via the processor of the computer or other programmable data processing devices enables the implementation of the functions/actions specified in one or more blocks of the flowchart and/or block diagram. Such a processor may be, but not limited to, a general-purpose processor, a dedicated processor, a special application processor, or a field programmable logic circuit. It may be further understood that each block in the block diagram and/or flowchart and a combination of the blocks in the block diagram and/or flowchart may also be implemented by dedicated hardware that performs the specified function or action, or may be implemented by a combination of dedicated hardware and computer instructions.

[00121] The above are merely specific implementations of the present application, and those skilled in the art may explicitly appreciate that for convenience and conciseness of the descriptions, the specific working process of the above systems, modules and units may refer to corresponding processes in the forgoing method embodiments, which will not be repeated herein. It should be understood that the scope of protection of the present application is not limited thereto, and any of those skilled in the art can easily think of various equivalent modifications or substitutions within the technical scope disclosed in the present application, and all these modifications or substitutions should be encompassed within the scope of protection of the present application.

WHAT IS CLAIMED IS:

1. A method for safety protection of trains in a cooperative formation, comprising:

obtaining running state information and distance information of a first train and a second train, and an allowable collision speed of a formation corresponding to the first train and the second train, wherein the first train and the second train are two adjacent trains in the formation;

establishing, under a condition that the first train is in an emergency braking phase, a safety protection model according to a travelling phase of the second train, the running state information, the distance information, and the allowable collision speed; and

determining a safety protection speed for the second train according to the safety protection model, wherein the safety protection speed causes that the second train does not collide with the first train or that the second train collides with the first train at a speed not greater than the allowable collision speed.

2. The method according to claim 1, wherein the travelling phase of the second train comprises an emergency braking establishment phase and an emergency braking phase, the running state information comprises a first initial speed of the first train at an initial time, a second initial speed of the second train at the initial time, a first acceleration of the first train in the emergency braking phase, a second acceleration of the second train in the emergency braking phase, and a third acceleration of the second train in the emergency braking establishment phase, and the distance information comprises an initial distance between the first train and the second train at the initial time and an emergency braking distance of the first train.

3. The method according to claim 2, wherein the establishing, under a condition that the first train is in the emergency braking phase, the safety protection model according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed comprises:

establishing, under a condition that the first train is in the emergency braking phase and a

first time is earlier than a second time, a first safety protection model according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed;

establishing, under a condition that the first train is in the emergency braking phase and the second time is earlier than the first time, a second safety protection model according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed,

wherein the first time is a time when the first train decelerates to the allowable collision speed, and the second time is a time when the second train decelerates to the allowable collision speed.

4. The method according to claim 3, wherein the establishing, under a condition that the first train is in the emergency braking phase and the first time is earlier than the second time, the first safety protection model according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed comprises:

determining, under a condition that the first train is in the emergency braking phase and the first time is earlier than the second time, a first safety protection scenario corresponding to the second train according to a chronological order of the first time, the second time, a third time, and a fourth time;

establishing the first safety protection model associated with the first safety protection scenario according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed,

wherein the third time is an end time of the emergency braking phase of the first train, and the fourth time is a start time of the emergency braking phase of the second train.

5. The method according to claim 4, wherein under a condition that the chronological order is that the first time is the earliest, then the third time, then the fourth time, and then the second time, the first safety protection scenario corresponding to the second train is a first

scenario, and the first safety protection model associated with the first scenario comprises:

$$v_f(t) \leq \begin{cases} \frac{v_0^l}{2}\left(1+\frac{a_{be}^f}{a_{eb}^l}+\frac{s_0}{s_p^l}\right), t \in [0, t_3] \\ 0.5 * a_{be}^f * t_f + \frac{s_0+\frac{(v_0^l)^2}{2*a_{eb}^l}}{t_f}, t \in [t_3, t_1] \\ \sqrt{(v_{col})^2 + 2 * a_{eb}^f * \left[0.5 * \left(a_{eb}^f - a_{be}^f\right) * t_f{}^2 + \left(s_0 + s_p^l\right)\right]} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_2'] \\ v_{col}, t \in [t_2', t_2] \end{cases},$$

wherein t is a current time, t_1 is the fourth time, t_f is a time length from the initial time to the fourth time, t_2 is a stopping time of the second train, t_3 is the third time, t_2' is the second time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l is the first initial speed, a_{eb}^l is the first acceleration, a_{eb}^f is the second acceleration, a_{be}^f is the third acceleration, s_0 is the initial distance, s_p^l is the emergency braking distance, and v_{col} is the allowable collision speed.

6. The method according to claim 4, wherein under a condition that the chronological order is that the fourth time is the earliest, then the first time, then the third time, and then the second time, the first safety protection scenario corresponding to the second train is a second scenario, and the first safety protection model associated with the second scenario comprises:

$$v_f(t) \leq \begin{cases} \frac{s_0 - 0.5*\left(a_{eb}^l - a_{be}^f\right)t_f{}^2}{t_f} + v_0^l, t \in [0, t_1] \\ v_0^l + \frac{0.5a_{eb}^l\left(a_{eb}^f - a_{be}^f\right)t_f{}^2 + a_{eb}^l s_0}{v_0^l} - \frac{0.5\left(a_{eb}^l - a_{eb}^f\right)v_0^l}{a_{eb}^l} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_3] \text{ and } a_{eb}^l \geq a_{eb}^f \\ v_0^l + \sqrt{\left(a_{eb}^f - a_{eb}^l\right)\left(\left(a_{eb}^f - a_{be}^f\right)t_f{}^2 + 2s_0\right)} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_3] \text{ and } a_{eb}^l < a_{eb}^f \\ \sqrt{(v_{col})^2 + 2 * a_{eb}^f * \left[0.5 * \left(a_{eb}^f - a_{be}^f\right) * t_f{}^2 + \left(s_0 + s_p^l\right)\right]} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_3, t_2'] \\ v_{col}, t \in [t_2', t_2] \end{cases},$$

wherein t is a current time, t_1 is the fourth time, t_f is a time length from the initial time to the fourth time, t_2 is a stopping time of the second train, t_3 is the third time, t_2' is the

second time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l is the first initial speed, a_{eb}^l is the first acceleration, a_{eb}^f is the second acceleration, a_{be}^f is the third acceleration, s_0 is the initial distance, s_p^l is the emergency braking distance, and v_{col} is the allowable collision speed.

7. The method according to claim 4, wherein under a condition that the chronological order is that the fourth time is the earliest, then the first time, then the second time, and then the third time, the first safety protection scenario corresponding to the second train is a third scenario, and the first safety protection model associated with the third scenario comprises:

$$v_f(t) \leq \begin{cases} \frac{s_0 - 0.5*\left(a_{eb}^l - a_{be}^f\right)t_f^2}{t_f} + v_0^l, t \in [0, t_1] \\ \frac{2av_{col} + a_{eb}^f v_{col} + \sqrt{\Delta}}{a_{eb}^l + a_{eb}^f} + v_0^l - \left(a_{eb}^f - a_{be}^f\right) * t_f, \text{and satisfying } av_{col}^2 - \left(a_{be}^f\right)^2 c > 0, \\ t \in [t_1, t_2'] \& a_{eb}^l > a_{eb}^f \\ \frac{v_{col} + \sqrt{v_{col}^2 + 4a_{eb}^f[0.5*(a_{eb}^f - a_{be}^f)*t_f^2 + s_0])}}{2} + v_0^l - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_2'] \& a_{eb}^l = a_{eb}^f \\ v_0^l + \sqrt{\left(a_{eb}^f - a_{eb}^l\right)\left(\left(a_{eb}^f - a_{be}^f\right)t_f^2 + 2s_0\right)} - \left(a_{eb}^f - a_{be}^f\right) * t_f \\ t \in [t_1, t_2'] \& a_{eb}^l < a_{eb}^f \\ v_{col}, t \in [t_2', t_2] \end{cases}$$

wherein t is a current time, t_1 is the fourth time, t_f is a time length from the initial time to the fourth time, t_2 is a stopping time of the second train, t_2' is the second time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l is the first initial speed, a_{eb}^l is the first acceleration, a_{eb}^f is the second acceleration, a_{be}^f is the third acceleration, s_0 is the initial distance, s_p^l is the emergency braking distance, v_{col} is the allowable collision speed, Δ is $\left(a_{be}^f\right)^2[v_{col}^2 + 2（a_{eb}^l + a_{eb}^f）c]$, and c is $0.5 * \left(a_{eb}^f - a_{be}^f\right) * t_f^2 - s_0$.

8. The method according to any one of claims 5-7, wherein the first safety protection model satisfies the following conditions:

a travelling distance of the first train from the initial time to a fifth time is greater than or equal to a travelling distance of the second train from the initial time to the fifth time, the fifth time being any time prior to the second time; and

travelling speeds of the first train and the second train at a sixth time are both less than or equal to the allowable collision speed, the sixth time being any time between the second time and the stopping time of the second train.

9. The method according to claim 4, wherein the establishing, under a condition that the first train is in the emergency braking phase and the second time is earlier than the first time, the second safety protection model according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed comprises:

determining, under a condition that the first train is in the emergency braking phase and the second time is earlier than the first time, a second safety protection scenario corresponding to the second train according to a chronological order of the first time and a stopping time of the second train; and

establishing the second safety protection model associated with the second safety protection scenario according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed.

10. The method according to claim 9, wherein under a condition that the first time is earlier than the stopping time, the second safety protection scenario corresponding to the second train is a fourth scenario, and the second safety protection model associated with the fourth scenario comprises:

$$v_f(t) \leq \begin{cases} \frac{s_0 - 0.5*\left(a_{eb}^l - a_{be}^f\right)t_f^2}{t_f} + v_0^l, t \in [0, t_1] \\ \frac{(a_{eb}^l)^2\left[0.5\left(a_{eb}^f - a_{be}^f\right)t_f^2 + s_0\right] - 0.5\left(a_{eb}^l - a_{eb}^f\right)\left(v_0^l - v_{col}\right)^2}{a_{eb}^l\left(v_0^l - v_{col}\right)} \\ +v_0^l - \left(a_{eb}^f - a_{be}^f\right)t_f, t \in [t_1, t_3'] \,\&\, a_{eb}^l \geq a_{eb}^f \\ v_0^l + \sqrt{\left(a_{eb}^f - a_{eb}^l\right)\left(\left(a_{eb}^f - a_{be}^f\right)t_f^2 + 2s_0\right)} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_3'] \,\&\, a_{eb}^l < a_{eb}^f \\ v_{col}, t \in [t_2', t_2] \end{cases},$$

wherein t is a current time, t_1 is a fourth time which is a start time of the emergency braking phase of the second train, t_f is a time length from the initial time to the fourth time, t_2 is the stopping time of the second train, t_2' is the second time, t_3' is the first time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l is the first initial speed, a_{eb}^l is the first acceleration, a_{eb}^f is the second acceleration, a_{be}^f is the third acceleration, s_0 is the initial distance, s_p^l is the emergency braking distance, and v_{col} is the allowable collision speed.

11. The method according to claim 9, wherein under a condition that the stopping time is earlier than the first time, the second safety protection scenario corresponding to the second train is a fifth scenario, and the second safety protection model associated with the fifth scenario comprises:

$$v_f(t) \leq \begin{cases} \frac{s_0 - 0.5*\left(a_{eb}^l - a_{be}^f\right)t_f^2}{t_f} + v_0^l, t \in [0, t_1] \\ \frac{a_{eb}^f v_0^l + \sqrt{\left(a_{eb}^f v_0^l\right)^2 + 2*c*(a_{eb}^f)^2(a_{eb}^l + a_{eb}^f)}}{a_{eb}^l + a_{eb}^f} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_2] \,\&\, a_{eb}^l \geq a_{eb}^f \\ v_0^l + \sqrt{\left(a_{eb}^f - a_{eb}^l\right)\left(\left(a_{eb}^f - a_{be}^f\right)t_f^2 + 2s_0\right)} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_2] \,\&\, a_{eb}^l < a_{eb}^f \\ \frac{a_{eb}^l\left[0.5*\left(a_{eb}^f - a_{be}^f\right)*t_f^2 + (s_0 + s_p^l)\right]}{2(v_0^l - v_{col})} + \frac{a_{eb}^f(v_0^l - v_{col})}{2a_{eb}^l} \\ -\left(a_{eb}^f - a_{be}^f\right) * t_f, t \in [t_2, t_3'] \\ v_{col}, t \in [t_2', t_2] \end{cases}$$

wherein t is a current time, t_1 is a fourth time which is a start time of the emergency braking phase of the second train, t_f is a time length from the initial time to the fourth time, t_2 is the stopping time of the second train, t_3' is the first time, t_2' is the second time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l is the first initial speed, a_{eb}^l is the first acceleration, a_{eb}^f is the second acceleration, a_{be}^f is the third acceleration, s_0 is the initial distance, s_p^l is the emergency braking distance, and v_{col} is the allowable collision speed.

12. The method according to any one of claims 9-11, wherein the third time is an end time of the emergency braking phase of the first train, and the second safety protection model satisfies the following conditions:

a travelling distance of the first train from the initial time to a seventh time is greater than or equal to a travelling distance of the second train from the initial time to the seventh time, the seventh time being any time prior to the first time; and

travelling speeds of the first train and the second train at an eighth time are both less than or equal to the allowable collision speed, the eighth time being any time between the first time and the third time.

13. An apparatus for safety protection of trains in a cooperative formation, comprising:

an obtaining module configured to obtain running state information and distance information of a first train and a second train, and an allowable collision speed of a formation corresponding to the first train and the second train, wherein the first train and the second train are two adjacent trains in the formation;

an establishing module configured to establish, under a condition that the first train is in an emergency braking phase, a safety protection model according to a travelling phase of the second train, the running state information, the distance information, and the allowable collision speed; and

a determining module configured to determine a safety protection speed for the second train according to the safety protection model, wherein the safety protection speed causes that the second train does not collide with the first train or that the second train collides with the first train at a speed not greater than the allowable collision speed.

14. The apparatus according to claim 13, wherein the travelling phase of the second train comprises an emergency braking establishment phase and an emergency braking phase, the running state information comprises a first initial speed of the first train at an initial time, a second initial speed of the second train at the initial time, a first acceleration of the first train

in the emergency braking phase, a second acceleration of the second train in the emergency braking phase, and a third acceleration of the second train in the emergency braking establishment phase, and the distance information comprises an initial distance between the first train and the second train at the initial time and an emergency braking distance of the first train.

15. The apparatus according to claim 14, wherein the establishing module is further configured to:

establish, under a condition that the first train is in the emergency braking phase and a first time is earlier than a second time, a first safety protection model according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed;

establish, under a condition that the first train is in the emergency braking phase and the second time is earlier than the first time, a second safety protection model according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed,

wherein the first time is a time when the first train decelerates to the allowable collision speed, and the second time is a time when the second train decelerates to the allowable collision speed.

16. The apparatus according to claim 15, wherein the establishing module is further configured to:

determine, under a condition that the first train is in the emergency braking phase and the first time is earlier than the second time, a first safety protection scenario corresponding to the second train according to a chronological order of the first time, the second time, a third time, and a fourth time;

establish the first safety protection model associated with the first safety protection scenario according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed,

wherein the third time is an end time of the emergency braking phase of the first train, and the fourth time is a start time of the emergency braking phase of the second train.

17. The apparatus according to claim 16, wherein under a condition that the chronological order is that the first time is the earliest, then the third time, then the fourth time, and then the second time, the first safety protection scenario corresponding to the second train is a first scenario, and the first safety protection model associated with the first scenario comprises:

$$v_f(t) \leq \begin{cases} \frac{v_0^l}{2}\left(1+\frac{a_{be}^f}{a_{eb}^l}+\frac{s_0}{s_p^l}\right), t \in [0, t_3] \\ 0.5 * a_{be}^f * t_f + \frac{s_0+\frac{(v_0^l)^2}{2*a_{eb}^l}}{t_f}, t \in [t_3, t_1] \\ \sqrt{(v_{col})^2 + 2 * a_{eb}^f * \left[0.5 * \left(a_{eb}^f - a_{be}^f\right) * {t_f}^2 + \left(s_0 + s_p^l\right)\right]} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_2'] \\ v_{col}, t \in [t_2', t_2] \end{cases},$$

wherein t is a current time, t_1 is the fourth time, t_f is a time length from the initial time to the fourth time, t_2 is a stopping time of the second train, t_3 is the third time, t_2' is the second time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l is the first initial speed, a_{eb}^l is the first acceleration, a_{eb}^f is the second acceleration, a_{be}^f is the third acceleration, s_0 is the initial distance, s_p^l is the emergency braking distance, and v_{col} is the allowable collision speed.

18. The apparatus according to claim 16, wherein under a condition that the chronological order is that the fourth time is the earliest, then the first time, then the third time, and then the second time, the first safety protection scenario corresponding to the second train is a second scenario, and the first safety protection model associated with the second scenario comprises:

$$v_f(t) \le \begin{cases} \frac{s_0 - 0.5*\left(a_{eb}^l - a_{be}^f\right)t_f^2}{t_f} + v_0^l, t \in [0, t_1] \\ v_0^l + \frac{0.5a_{eb}^l\left(a_{eb}^f - a_{be}^f\right)t_f^2 + a_{eb}^l s_0}{v_0^l} - \frac{0.5\left(a_{eb}^l - a_{eb}^f\right)v_0^l}{a_{eb}^l} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_3] \text{ and } a_{eb}^l \ge a_{eb}^f \\ v_0^l + \sqrt{\left(a_{eb}^f - a_{eb}^l\right)\left(\left(a_{eb}^f - a_{be}^f\right)t_f^2 + 2s_0\right)} - \left(a_{eb}^f - a_{be}^f\right) * t_f \ , \\ t \in [t_1, t_3] \text{ and } a_{eb}^l < a_{eb}^f \\ \sqrt{(v_{col})^2 + 2 * a_{eb}^f * \left[0.5 * \left(a_{eb}^f - a_{be}^f\right) * t_f^2 + \left(s_0 + s_p^l\right)\right]} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_3, t_2'] \\ v_{col}, t \in [t_2', t_2] \end{cases},$$

wherein t is a current time, t_1 is the fourth time, t_f is a time length from the initial time to the fourth time, t_2 is a stopping time of the second train, t_3 is the third time, t_2' is the second time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l is the first initial speed, a_{eb}^l is the first acceleration, a_{eb}^f is the second acceleration, a_{be}^f is the third acceleration, s_0 is the initial distance, s_p^l is the emergency braking distance, and v_{col} is the allowable collision speed.

19. The apparatus according to claim 16, wherein under a condition that the chronological order is that the fourth time is the earliest, then the first time, then the second time, and then the third time, the first safety protection scenario corresponding to the second train is a third scenario, and the first safety protection model associated with the third scenario comprises:

$$v_f(t) \le \begin{cases} \frac{s_0 - 0.5*\left(a_{eb}^l - a_{be}^f\right)t_f^2}{t_f} + v_0^l, t \in [0, t_1] \\ \frac{2av_{col} + a_{eb}^f v_{col} + \sqrt{\Delta}}{a_{eb}^l + a_{eb}^f} + v_0^l - \left(a_{eb}^f - a_{be}^f\right) * t_f, \text{and satisfying } av_{col}^2 - \left(a_{be}^f\right)^2 c > 0, \\ t \in [t_1, t_2'] \& a_{eb}^l > a_{eb}^f \\ \frac{v_{col} + \sqrt{v_{col}^2 + 4a_{eb}^f[0.5*(a_{eb}^f - a_{be}^f)*t_f^2 + s_0])}}{2} + v_0^l - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_2'] \& a_{eb}^l = a_{eb}^f \\ v_0^l + \sqrt{\left(a_{eb}^f - a_{eb}^l\right)\left(\left(a_{eb}^f - a_{be}^f\right)t_f^2 + 2s_0\right)} - \left(a_{eb}^f - a_{be}^f\right) * t_f \ , \\ t \in [t_1, t_2'] \& a_{eb}^l < a_{eb}^f \\ v_{col}, t \in [t_2', t_2] \end{cases},$$

wherein t is a current time, t_1 is the fourth time, t_f is a time length from the initial time to the fourth time, t_2 is a stopping time of the second train, t_2' is the second time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l is the first initial speed, a_{eb}^l is the first acceleration, a_{eb}^f is the second acceleration, a_{be}^f is the third acceleration, s_0 is the initial distance, s_p^l is the emergency braking distance, v_{col} is the allowable collision speed, Δ is $\left(a_{be}^f\right)^2[{v_{col}}^2 + 2（a_{eb}^l + a_{eb}^f） c]$, and c is $0.5 * \left(a_{eb}^f - a_{be}^f\right) * {t_f}^2 - s_0$.

20. The apparatus according to any one of claims 17-19, wherein the first safety protection model satisfies the following conditions:

a travelling distance of the first train from the initial time to a fifth time is greater than or equal to a travelling distance of the second train from the initial time to the fifth time, the fifth time being any time prior to the second time; and

travelling speeds of the first train and the second train at a sixth time are both less than or equal to the allowable collision speed, the sixth time being any time between the second time and the stopping time of the second train.

21. The apparatus according to claim 16, wherein the establishing module is further configured to:

determine, under a condition that the first train is in the emergency braking phase and the second time is earlier than the first time, a second safety protection scenario corresponding to the second train according to a chronological order of the first time and a stopping time of the second train; and

establish the second safety protection model associated with the second safety protection scenario according to the travelling phase of the second train, the running state information, the distance information, and the allowable collision speed.

22. The apparatus according to claim 21, wherein under a condition that the first time is earlier than the stopping time, the second safety protection scenario corresponding to the

second train is a fourth scenario, and the second safety protection model associated with the fourth scenario comprises:

$$v_f(t) \leq \begin{cases} \frac{s_0 - 0.5*\left(a_{eb}^l - a_{be}^f\right)t_f^2}{t_f} + v_0^l, t \in [0, t_1] \\ \frac{(a_{eb}^l)^2\left[0.5\left(a_{eb}^f - a_{be}^f\right)t_f^2 + s_0\right] - 0.5\left(a_{eb}^l - a_{eb}^f\right)\left(v_0^l - v_{col}\right)^2}{a_{eb}^l\left(v_0^l - v_{col}\right)} \\ +v_0^l - \left(a_{eb}^f - a_{be}^f\right)t_f, t \in [t_1, t_3'] \,\&\, a_{eb}^l \geq a_{eb}^f \\ v_0^l + \sqrt{\left(a_{eb}^f - a_{eb}^l\right)\left(\left(a_{eb}^f - a_{be}^f\right)t_f^2 + 2s_0\right)} - \left(a_{eb}^f - a_{be}^f\right) * t_f \,, \\ t \in [t_1, t_3'] \,\&\, a_{eb}^l < a_{eb}^f \\ v_{col}, t \in [t_2', t_2] \end{cases},$$

wherein t is a current time, t_1 is a fourth time which is a start time of the emergency braking phase of the second train, t_f is a time length from the initial time to the fourth time, t_2 is the stopping time of the second train, t_2' is the second time, t_3' is the first time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l is the first initial speed, a_{eb}^l is the first acceleration, a_{eb}^f is the second acceleration, a_{be}^f is the third acceleration, s_0 is the initial distance, s_p^l is the emergency braking distance, and v_{col} is the allowable collision speed.

23. The apparatus according to claim 21, wherein under a condition that the stopping time is earlier than the first time, the second safety protection scenario corresponding to the second train is a fifth scenario, and the second safety protection model associated with the fifth scenario comprises:

$$v_f(t) \leq \begin{cases} \frac{s_0 - 0.5*\left(a_{eb}^l - a_{be}^f\right)t_f^2}{t_f} + v_0^l, t \in [0, t_1] \\ \frac{a_{eb}^f v_0^l + \sqrt{\left(a_{eb}^f v_0^l\right)^2 + 2*c*(a_{eb}^f)^2(a_{eb}^l + a_{eb}^f)}}{a_{eb}^l + a_{eb}^f} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_2] \,\&\, a_{eb}^l \geq a_{eb}^f \\ v_0^l + \sqrt{\left(a_{eb}^f - a_{eb}^l\right)\left(\left(a_{eb}^f - a_{be}^f\right)t_f^2 + 2s_0\right)} - \left(a_{eb}^f - a_{be}^f\right) * t_f, \\ t \in [t_1, t_2] \,\&\, a_{eb}^l < a_{eb}^f \\ \frac{a_{eb}^l\left[0.5*\left(a_{eb}^f - a_{be}^f\right)*t_f^2 + (s_0 + s_p^l)\right]}{2(v_0^l - v_{col})} + \frac{a_{eb}^f(v_0^l - v_{col})}{2a_{eb}^l} \\ -\left(a_{eb}^f - a_{be}^f\right) * t_f \,, t \in [t_2, t_3'] \\ v_{col}, t \in [t_2', t_2] \end{cases}$$

wherein t is a current time, t_1 is a fourth time which is a start time of the emergency braking phase of the second train, t_f is a time length from the initial time to the fourth time, t_2 is the stopping time of the second train, t_3' is the first time, t_2' is the second time, $v_f(t)$ is the safety protection speed of the second train at the current time, v_0^l is the first initial speed, a_{eb}^l is the first acceleration, a_{eb}^f is the second acceleration, a_{be}^f is the third acceleration, s_0 is the initial distance, s_p^l is the emergency braking distance, and v_{col} is the allowable collision speed.

24. The apparatus according to any one of claims 21-23, wherein the third time is an end time of the emergency braking phase of the first train, and the second safety protection model satisfies the following conditions:

a travelling distance of the first train from the initial time to a seventh time is greater than or equal to a travelling distance of the second train from the initial time to the seventh time, the seventh time being any time prior to the first time; and

travelling speeds of the first train and the second train at an eighth time are both less than or equal to the allowable collision speed, the eighth time being any time between the first time and the third time.

25. A device for safety protection of trains in a cooperative formation, comprising a processor, a memory, and a program or instructions stored on the memory and executable on the processor, wherein the program or instructions implement, when executed by the processor, steps of the method for safety protection of trains in the cooperative formation according to any one of claims 1-12.

26. A system for safety protection of trains in a cooperative formation, comprising the device for safety protection of trains in the cooperative formation according to claim 25.

27. A computer-readable storage medium storing computer program instructions thereon, wherein the computer program instructions implement, when executed by a processor, steps of the method for safety protection of trains in the cooperative formation according to any one of claims 1-12.