Collision Warning System for Locomotives Carrying Molten Pig-iron in Kakogawa Works

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This paper describes a collision alert system for locomotives that carry molten pig iron in the Kakogawa Works of Kobe Steel. This system comprises a process computer that stores the positional information, determined by the GPS, of locomotives along with their railroad track information in order to generate warnings. The railroad tracks laid in the steel works are more complicated than those of railroad companies and may cause various types of collisions. Hence, the railroad tracks are represented in a computer on the basis of graph theory to establish an algorithm for predicting collisions accurately and quickly. The newly developed system has been utilized continuously, promoting the safety of the locomotive operation.

Introduction

This paper describes a collision warning system (hereinafter referred to as the "present system") constructed to strengthen the safety of the locomotives running in the molten-iron treatment area of Kakogawa Works of Kobe Steel. All the locomotives in that area are equipped with GPS enabling the measurement of their positions. In addition, each driver carries an exclusive handy terminal, which makes it possible to transmit various kinds of information via wireless LAN. Hitherto, the collision avoidance of locomotives has been dependent on the driver's visual attention. The development of the present system aims at realizing safer locomotive operations by utilizing the above information equipment.

This paper is organized as follows: Section 1 outlines the locomotive logistics in the molten-iron treatment area and describes the expression method using symbols and two types of collisions that are important subjects in the collision avoidance problem of the locomotives (hereinafter referred to as "the present problem"). Section 2 introduces collision prevention technologies for various vehicles and shows that the collision prevention technologies for automobiles and aircraft cannot easily be applied to the present problem. Section 3 introduces two issues specific to the present problem through comparison with the automatic train control applied to ordinary railways. Lastly, Section 4 shows the method for solving the problems and the algorithm that has been developed.

1. Locomotive logistics in molten-iron treatment area of Kakogawa Works

1.1 Outline of subject logistics

In the Kakogawa Works of Kobe Steel, molten iron is tapped off from a blast furnace at about 1,500°C and charged into a torpedo car (hereinafter referred to as a "torpedo") to be transported to a molten-iron treatment plant or other area by diesel locomotives. The molten iron is transferred into a pot in the molten-iron treatment plant; and the now-empty torpedo, slag and metallic adhesions having been removed, is sent to the blast furnace for a repeated charging of molten iron. The term, "molten-iron treatment area," refers to an area to which molten-iron is transported.

Fig. 1 outlines the processes carried out in the molten-iron treatment area. The transportation time for molten iron affects the energy cost and iron & steel yield, and the efficiency of logistics is important. To this end, various measures have been attempted.[1)] Meanwhile, the damage caused by molten iron leakage in the event of an accident would be enormous, and ensuring safety is of utmost importance as a major premise for efficiency.

The locomotive railway track laid in the molten-iron treatment area has a total extension of about 25 km, and there are approximately 100 junction/branching points (hereinafter referred to as (a) "branch(es)"). The locomotives are operated at speeds less than 10km/h, which is slower than those

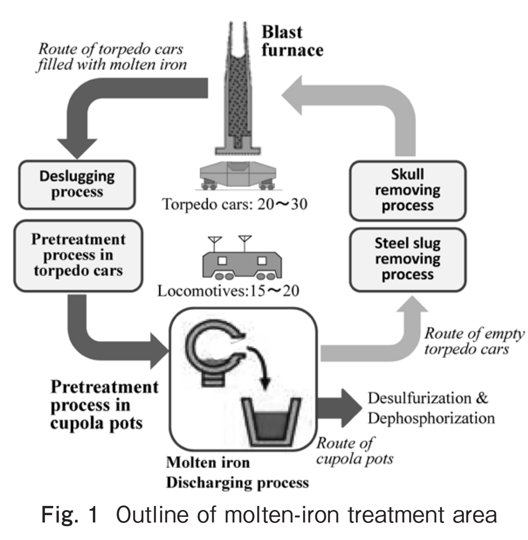


Fig. 1 Outline of molten-iron treatment area

of the ordinary railway.

1.2 Railway tracks in molten-iron treatment area and their expressions

Fig. 2 depicts the actual railway track in the molten-iron treatment area. In the figure, the solid circles, ●, indicate branches (i.e., bifurcation points, hereinafter referred to "BPs"), and the pentagonal marks indicate locomotives (hereinafter referred to as "LMs"). The tip of each pentagonal mark indicates the traveling direction of the respective locomotive.

The study in this paper uses symbols to represent the railway track, which has such a complicated shape (**Fig. 3**). A branch is represented by a lowercase letter, a, b, c, and the railway tracks between branches (called Zones) are indicated by straight lines and labeled Zone A, Zone B, and so on. The starting points and ending points (hereinafter "EPs") of the railway track are not branches in a strict sense, but are treated as branches for simplicity of discussion.

Not all the zones that touch a branch are mutually transferable. For example, in the branch shown in Fig. 3, Zones A, B, and D are connected, and a locomotive can move from Zone A to both Zones B and D. It is also possible to move from Zone B or Zone D to Zone A. However, movement from Zone B to D, or from Zone D to B would require a sharp turn at a branch and is impossible. In order to predict the collision of two locomotives, it is necessary to derive the branches and zones that are reachable for the locomotives after satisfying this restriction.

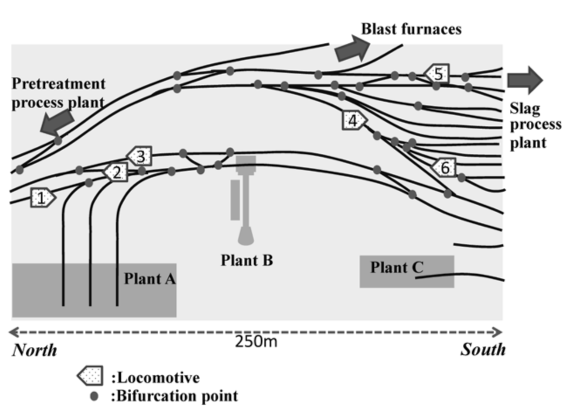


Fig. 2 Part of railway track map in Kakogawa Works

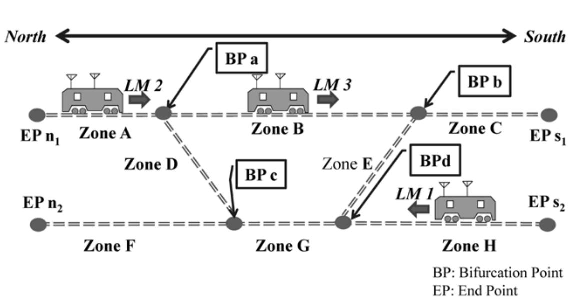


Fig. 3 BPs, EPs and Zones in rail track map

1.3 Two types of collisions involved in the present problem

In collision prediction for the ordinary railway, in which trains are traveling in the same direction on the same railway track, focus is placed on the prevention of rear-end collisions, in which a following train collides with one in front. For the present problem, two types of collisions, in addition to rear-end collisions, provide important solution tasks, as described in this section.

Two running directions are defined for the locomotives in the present problem, the "north bound" and "south bound," which are similar to the inbound and outbound in an ordinary railway. However, even if there are multiple railway tracks traveling in parallel as shown in Fig. 2, there is no provision for the north bound only, or south bound only, as in the case of an ordinary railway, and all railway tracks allow travelling in both directions. Therefore, there is a risk of frontal collision with Locomotives 4 and 6 in Fig. 2.

Also, the railway track in the molten-iron treatment area has branches at short intervals of several to several tens of meters. At a branch, a locomotive may come in from another railway track. In the case of Fig. 2, Locomotives 2 and 3 may collide at the junction.

Appropriate alarm generation for the above two types of collision is an important issue in the present problem.

2. Comparison with existing collision avoidance technologies

2.1 Outline of existing collision avoidance technologies

Collision avoidance and warning technologies for general transportation vehicles have been studied for a long time, mainly on aircraft and trains. The automatic driving technology for passenger cars also includes collision avoidance technology. These technologies have been developed independently, since there are significant differences in the degree of freedom of the traveling route of the target transportation vehicles, and in their collision avoidance targets. The outlines of those technologies are shown in **Table 1**, and the applicability of each technology to the present problem has been examined.

Table 1 Types of technology for collision avoidance

Target	Directions	Collision avoidance targets	Collision avoidance methods
Airplane (TCAS)	3 dimensions	Airplanes (limited)	Change direction, altitude (limited)
Automobile (Automated Driving System)	2 dimensions	Man, car and building (many types)	Breaking, Change direction, etc.
Trains (ATS)	1 dimension	Trains on the same railway (very limited)	Breaking (limited)
Locomotive in steel works(Our developed system)	1 dimension (with many branches)	Locomotives in the same area	Breaking (limited)

2.2 Applicability of aircraft collision warning technology to the present problem

In Japan, each aircraft with more than 20 seats is required to be equipped with a traffic alert and collision avoidance system (TCAS) to prevent aerial collisions.[2)] Aircraft carrying TCAS mutually recognize each other's positions. An alert is issued when a possible collision is identified from such information as distance, altitude, and navigational direction.

A similar warning system may be established for the locomotives in the molten-iron treatment area, since they all collect and record positional information with GPS. In the present problem, however, there are cases where it is impossible to properly determine the possibility of collision solely from the distance and travel directions of other vehicles.

Among the three locomotives shown in Fig. 3, LM1 is north bound, and LM2 and LM3 are south bound. There is a possibility that LM1 in Zone H will move to Zone G, and even to Zone D. At this time, if LM2 in Zone A also enters Zone D or Zone G, it may collide head-on with LM1. Meanwhile, the only reachable zone for LM3 in Zone B is Zone C (Zone E is not reachable because of the acute angle turn.), and there is no possibility of LM3 colliding with LM1. In other words, LM1 has a risk of colliding with LM2, which is at a greater distance, rather than with the nearby LM3. Thus, the collision determination method focused on distances that is used for locomotives is inadequate as a solution for the present problem, in which the moving range is restricted by the railway track.

2.3 Applicability of automatic driving technology for passenger cars to the present problem

The automatic driving technology for passenger cars has evolved remarkably in recent years,[3)] and it is envisaged that automatic driving on public roads will be realized within a few years in Japan. As shown in **Table 2**, the automatic driving technologies are classified into 5 levels. In this classification, only level 3 or higher is called automatic driving technology, and the levels below it are regarded as driving support technology.

First, the difference between driving support technology and automatic driving technology is outlined. Driving support technology of level 2 or below recognizes obstacles from images in the traveling direction and, from the recognition results, determines the possibility of a collision accident, whereas the automatic driving technology of level 3 or higher comprises highly accurate 3D map information in addition to obstacle recognition. In addition to the static information, it also has a digital map that integrates time-varying information, such as traffic jam information and vehicle position and progress information, in addition to information on road traffic laws and traffic regulations. Such maps are called "dynamic maps" and are being developed on a national level because the development task involves highly complicated, large-scale technology.[4)] By integrating the spatial (railway track, road, etc.) recognition technology making use of the information and the aforementioned image recognition results, accurate collision risk recognition is realized, enabling automatic driving.

Now, a case is considered where the driving support technology or automatic driving technology is applied to the situation shown in **Fig. 4**. In the molten-iron treatment area, there are many places in which two curved railway tracks, as shown in Fig. 4, are laid almost in parallel. When two locomotives

Table 2 Definition of automatic driving technology

Level	Name	Execution of steerling, acceleration, and deceleration	Monitoring of driving environment	Fallback performance of dynamic driving task	System capability (driving mode)
0	**No Automation**	Human driver	Human driver	Human driver	n/a
1	**Driving Assitance**	Human driver and	Human driver	Human driver	Some driving modes
2	**Partial Automation**	System	Human driver	Human driver	Some driving modes
3	**Conditional Automation**	System	System	Human driver	Some driving modes
4	**High Automation**	System	System	System	Some driving modes
5	**Full Automation**	System	System	System	Full driving modes

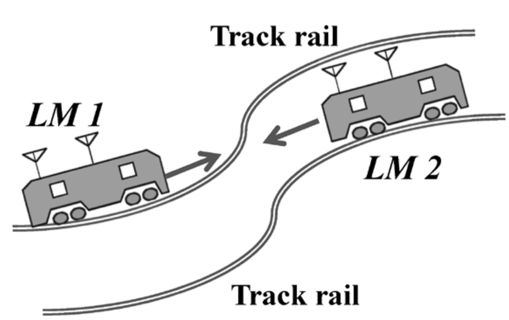


Fig. 4 Example of possible situation of false warning

pass each other at such a place, there is no risk of collision, since the locomotives travel on different railway tracks. However, if the two locomotives were equipped with driving support technology, it is highly likely that each locomotive would recognize the other in front of it and in its direction of travel, erroneously determining a risk of collision. On the other hand, an automatic driving function, if implemented, can refer to the information of the dynamic map and recognize that the other, oncoming locomotive is running on another railway track, determining that there is no risk of collision.

The image processing technology that recognizes obstacles for driving support is certainly applicable to the present problem. However, in order to realize the dynamic map, which is the core of the automatic driving technology, it is necessary to keep renewing various sorts of information accurately in real time, and it is not easy for Kobe Steel to accomplish this alone.

In this way, it is difficult to extract a part of the automatic driving technology and apply it directly to the present problem. Hence, it is considered necessary to develop a level of technology intermediate between driving support technology and automatic driving technology and specialized for the present problem.

3. Comparison with ATC and realization of problem-solving method for the present problem

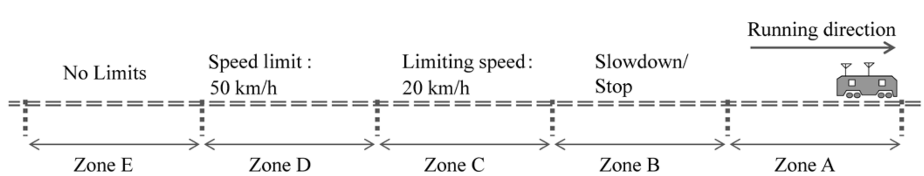
In order to consider the mechanism for displaying and sounding appropriate collision warning using the information on the connection branches and zones in railway track, an overview of the automatic operation technology for railway follows.[5), 6)]

Japan's first system for automatically stopping vehicles on railway track was introduced in the 1950s as automatic train stop (ATS). There is a system, Automatic Train Control (hereinafter "ATC"), which is similar to ATS, and it is difficult to strictly distinguish between them. The former is a system that performs an auxiliary brake operation when the driver misses an existing ground signal, whereas the latter system constantly monitors the vehicle speed and intervenes in the brake operation when the speed limit derived in accordance with each zone is exceeded. Thus, ATC is regarded as a more sophisticated function, and only ATC is considered in the comparison made here.

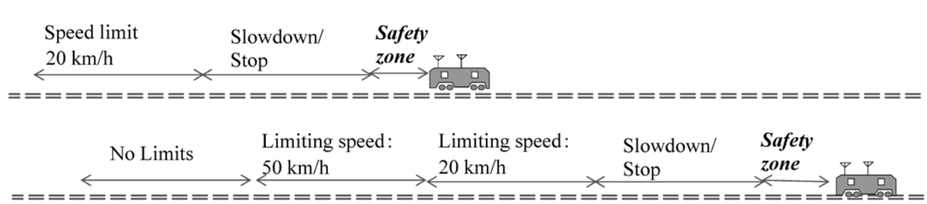
3.1 Fixed block ATC and moving block ATC[7)]

There are two types of ATC, namely, a fixed block system and a moving block system. **Fig. 5** (a) shows an example of the fixed block system realized in the 1960s. The railway track is divided into zones in advance. When there is a vehicle in Zone A, the locomotive in adjacent Zone B is slowed down and prohibited from entering Zone A. The upper speed limit for Zone C in the rear is set at 20 km/h, and the upper speed limit for Zone D, further to the rear, is set at 50 km/h. There is no special control for Zone E and beyond. Each zone provided for performing a different control is called a "blocked zone," and the fixed block system is so called because the control is performed with the blocked zones fixed.

The fixed block system ensures the avoidance of rear-end collisions. In this case, however, other locomotives in Zone B are not allowed to enter Zone A, regardless of where the locomotive in Zone A is located, and this hinders the efficient operation of locomotives. In order to solve this problem, a technique is needed to eliminate fixed zones and find the distance between vehicles on the basis of



(a) ATC with fixed block



(b) ATC with moving block

Fig. 5 Examples of ATC system

the position of each locomotive, which changes from time to time, so as to control the following locomotive. It was the moving block ATC that realized such control in the 2000s.[7] As shown in Fig. 5 (b), a safety zone is dynamically set in the immediate rear of the locomotive in accordance with its movement, prohibiting other locomotives from entering said zone and, in addition, speed control is performed on the following zones. In this way, the moving block system keeps the distance between locomotives shorter than does the fixed block system, while securing safety.

However, the moving block system needs to accurately grasp the locomotive positions with no delays. In the molten-iron treatment area, it is not easy to thoroughly, unfailingly and accurately grasp the positions using GPS, due to the radio disturbance caused by the building for large equipment. Therefore, the moving block system ATC is regarded to be as infeasible.

3.2 Function for searching branches and zones with potential collision risks

In the railway where ATC is used, all the zones are set to be of almost equal length. This enables safety to be secured by speed control based on the number of zones to the rear of the locomotive, as shown in Fig. 5(a), whereas the railway track that is the subject of this study (Fig. 2) has inter-branch zone lengths greatly varying from several to several hundreds of meters. Therefore, the possibility of collision cannot be determined only by the number of zones between the following locomotive and the one in the forefront.

Accordingly, it is necessary to derive all zones and branches reachable within a certain time for each locomotive on the basis of the branch/junction information for the railway track. Furthermore, if there is a zone/branch that is reachable by multiple locomotives, this is regarded as a collision risk and as an object of warning or an advisory, one rank lower.

3.3 Dynamic function applying warning algorithm

For locomotive collision warning in the molten-iron treatment area, the possibility of two locomotives colliding cannot be determined merely from their respective zones. The reasons are described below:

Each car carrying a torpedo has no GPS, and only the position of the locomotive is collected. Hence, if torpedo cars are connected, it is necessary to correct the position for the length of the torpedo cars with respect to the positional information of the locomotive. There are two ways of connecting torpedo cars with a locomotive for transportation; i.e., a towing connection, in which the torpedo cars are connected to the rear of a locomotive, and a pushing connection, in which torpedo cars are connected to the front of a locomotive (**Fig. 6**).

The length of a torpedo car falls in the range of 20 to 30 m depending on the type, and multiple cars may be connected. Since a collision usually occurs near the head of a train, it is important to grasp that position. Hence, no positional correction is required for a towing connection; however, a pushing connection requires a positional correction of several tens of meters. The distance corresponding to the length of the torpedo cars in the traveling direction of a locomotive is herein called a "correction distance."

In addition, as with automobiles, each locomotive has a braking distance, and even if braking is applied, the locomotive will not at once stop completely. The braking distance changes depending on the speed of the locomotive, the weight of the torpedo cars during transportation, and/or the weather, and the difference can reach several tens of meters. Hence, the braking distance must be corrected in accordance with the circumstances.

3.4 Two types of collision avoidance

As described in Section 1.3, there are two typical patterns of collision that may occur due to the present problem. One is the case where two locomotives with different traveling directions (travelling face to face) cause a frontal collision in a zone, as shown in **Fig. 7** (a): this is hereafter called "zone collision." The other is the case where two locomotives traveling on different railway tracks towards a branch collide in the vicinity of the branch (Fig. 7(b)): this is hereafter called "branch collision." For these two types of collisions, different methods must be applied to determine the collision possibilities.

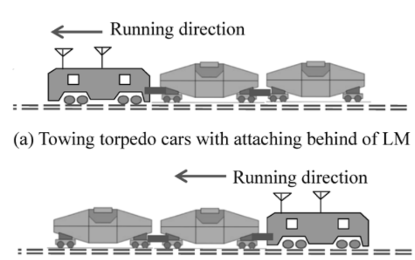


Fig. 6 Two ways to transport torpedo cars

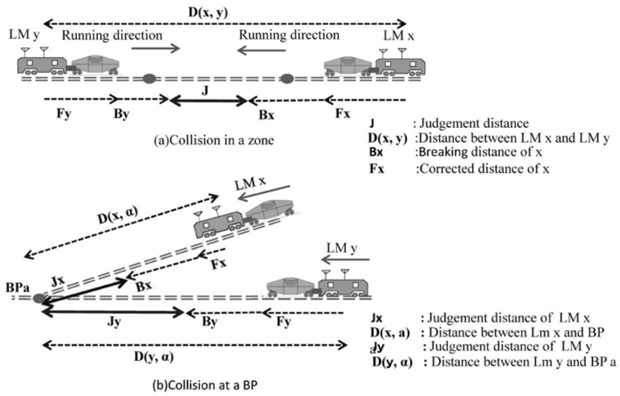


Fig. 7 Two types of locomotive collisions

4. Method of realizing collision warning system

4.1 Hardware configuration

As described in the previous sections, the determination of collision requires varied information on each locomotive. It is also necessary to indicate the result of collision risk determination to the locomotive drivers. **Fig. 8** shows the configuration of the hardware providing the foundation to do this.

The vehicle information on the position acquired from the GPS, direction, and transmission, as well as the information on the condition of the torpedo car connections, towing or pushing, is transmitted from the wireless LAN antenna of each locomotive. These pieces of information are received by ground antennas installed at several locations in the molten-iron treatment area and sent to the process computer for molten-iron logistics. The process computer holds all locomotive and railway track information in the molten-iron treatment area. From these two types of information, the collision risk of each locomotive is determined, and necessary display and sound warnings are given by the handy terminal carried by each locomotive driver.

4.2 Software configuration

The following describes, with examples, a method for implementing the function necessary to solve the present problem, described in Sections 3.2 - 3.4. **Fig. 9** is a symbolic representation of a railway track consisting of 14 branches and 15 zones. The number paired with each zone name indicates the zone length (unit: m). Three locomotives are assumed to be in service. In the initial state, LM1 is north bound and located at EPs1 without any torpedo car connected. LM2 is north bound with one torpedo car connected to its front (north side) and is located at EPs3, while LM3 is south bound with one

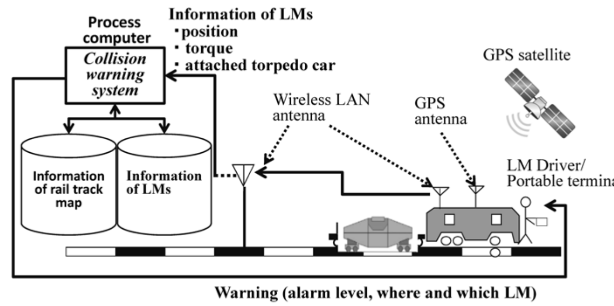


Fig. 8 Hardware configuration of developed collision warning system

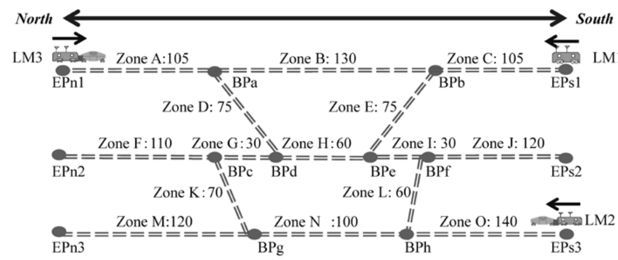


Fig. 9 Example of collision determination

torpedo car connected to its front (south side) and is located at EPn1. For convenience of explanation, all the locomotives are assumed to be initially located on branches; however, the argument in this section can readily be extended to cases where the initial locations are in the zones.

4.2.1 Preliminary calculation of inter-branch distances

As described in Section 3.2, the present problem requires the derivation of which zone and branch are reachable for each locomotive, and what is the shortest distance to reach it. Since the connection information for the railway track is predetermined, the reachability and shortest distance for each inter-branch can be calculated in advance.

The branches reachable for LM1-LM3 in Fig. 9 and the shortest distances are shown in the third column of **Table 3**, and the reachable zones are shown in the fourth column of Table 3. LM1 can reach branch BPa via Zones C and B, or it can reach the same via Zones E, H and D. The distance of the former route, which is shorter, is adopted. This example is simple, and the determination of the shortest distance is easy. However, the actual railway track in the molten-iron treatment area is so complicated and large that intuitive determination is impossible. In graph theory,[8)] there are algorithms,[9) 10)] such as Dijkstra's algorithm,[11)] that can facilitate calculation, shortening the time.

Table 3 Present position, direction and reachable BPs and Zones of each LM

LM	Position/ Direction	Reachable BPs and Distances	Reachable Zones
LM1	EP s1/ Northbound	(s1, 0), (b, 105), (a, 235), (n1, 340), (e, 180), (d, 240), (c, 270), (N2, 380)	C, B, A, E, H, D, G, F
LM2	EP s3/ Northbound	(s3, 0), (h, 140), (g, 240), (N3, 360), (c, 310), (n2, 420)	O, N, M, K, F
LM3	EP n1/ Southbound	(n1, 0), (a, 105), (b, 235), (s1, 340), (d, 180), (e, 240), (f, 270), (s2, 390),	A, B, C, D, H, E, I, J

4.2.2 Collision possibility of each locomotive

The following describes the method for deriving the collision probability of the three locomotives in Fig. 9 using the information in Table 3. First, the combinations of locomotives that require verification on the occurrence of zone collision, i.e., the combinations of locomotives having different traveling directions, are LM1 & LM3, and LM2 & LM3. In the case of the former combination, there are many reachable zones, such as A, B, C, D, H, and E, shared by both locomotives and there are possibilities of zone collision, whereas in the latter combination, no reachable zone is shared, and it can be determined that there is no possibility of zone collision.

Next, the combinations of locomotives are considered in order to verify the occurrence of branch collision. The combination of locomotives traveling in the same direction is LM1 & LM2, and there is the possibility of collision in the reachable branch (BPc, EPn2) shared by the two locomotives. If the common reachable branch is none, it is determined that there will be no collision.

4.2.3 Determining the necessity of warning

The previous section described the occurrence possibility of zone collision between LM1 and LM3 and branch collision between LM1 and LM2. This section describes the algorithm for determining the necessity of warning.

First, the determination method of zone collision (Fig. 7 (a)) is shown. Once the positions of locomotives on the railway track are known, the distance D(x, y) between them can be derived using Table 3. Furthermore, the corrected distances, *Fx*, *Fy*, of LMx and LMy, respectively, are determined on the basis of the torpedo car connection information, and the braking distances *Bx*, *By* are also derived from the transmission information for each locomotive and the torpedo car connection information. It should be noted that these distance data are tabulated for quick determination.

Using the above data, the determination distance *J* is calculated by Equation (1):

$$J=D(x, y)-(Fx+Bx)-(Fy+By) \quad \cdots\cdots\cdots\cdots (1)$$

This determination distance J is compared with preset thresholds, L_1 and L_2 ($L_1 < L_2$), and if it is smaller than L_1, a "Warning" for a high degree of risk is declared, while, if $L_1 < J < L_2$, an "Advisory" milder than "Warning" is declared. Here, L_1 and L_2 are determined on the basis of the distance assumed to be traveled before the locomotive driver notices the warning (or advisory) and activates the brake, as well as the error of the position information obtained by GPS.

Next, the method of determining branch collision (Fig. 7 (b)) is described. Even when there is a possibility of collision at more than one branch, it should be sufficient to consider only the possibility of collision at the branch closest to both locomotives (BPc in Fig. 9). The algorithm of this determination is explained on the basis of Fig. 7 (b). In the case of branch collision, both distances D (x, α) and D (y, α) between the branch position (in this case BP α) and the two locomotives are derived. Then, the determination distances for the respective two locomotives are calculated by Equation (2):

$$\left.\begin{aligned} Jx &= D(x, \alpha)-(Fx+Bx) \\ Jy &= D(y, \alpha)-(Fy+By) \end{aligned}\right\} \quad \cdots\cdots\cdots\cdots (2)$$

In the case of branch collision determination, three thresholds, K_1, K_2, and K_3 ($K_1 < K_2 < K_3$), are used, and the degrees of risk, P_x and P_y of LMx and LMy, respectively, are classified into four levels using the determination distance (Equations (3), (4)). The larger the value, the greater the risk that a branch with collision risk is located nearby. As in the case of L_i, K_j is determined to take into account the distance travelled before the driver notices the alarm and GPS error.

$$\left.\begin{aligned} P_x &= 3 \ (\text{when } Jx < K_1) \\ &= 2 \ (\text{when } K_1 < Jx < K_2) \\ &= 1 \ (\text{when } K_2 < Jx < K_3) \\ &= 0 \ (\text{when } K_3 < Jx) \end{aligned}\right\} \quad \cdots\cdots\cdots\cdots (3)$$

$$\left.\begin{aligned} P_y &= 3 \ (\text{when } Jy < K_1) \\ &= 2 \ (\text{when } K_1 < Jy < K_2) \\ &= 1 \ (\text{when } K_2 < Jy < K_3) \\ &= 0 \ (\text{when } K_3 < Jy) \end{aligned}\right\} \quad \cdots\cdots\cdots\cdots (4)$$

On the basis of the combination of P_x and P_y, a warning/advisory report, and display/sound are determined. With this logic, if either P_x or P_y is 0, for example, no display / no sound is determined upon (there is no risk of branch collision), and if both are 2 or greater, an alarm is issued. This determination method is also tabulated in the system.

Fig.10 Alert message displayed on handy terminal

The warnings and advisories derived by the above logic are displayed on handy terminals carried by locomotive drivers. An example of the display screen is shown in **Fig.10**. This screen alerts the driver of Locomotive 217 that there is a risk of frontal collision with Locomotive 210.

Conclusions

This paper has outlined the warning system constructed for the collision problems of the locomotives travelling in the molten-iron treatment area of the Kakogawa Works of Kobe Steel. There are many technologies for detecting the collision possibility of transportation vehicles and the technologies for automatic driving. This paper has described why diverting these technologies cannot help with the present problem. Also introduced is the existence of many branches featuring in the logistics of the molten-iron treatment area, and an algorithm implemented to respond to the need for dynamically changing the collision determination logic.

The present system operates on real machines, and each locomotive driver refers to the warnings indicated on the handy terminal to realize safer and more secure operation. It is expected that this function will be extended to create safe and efficient routes and so on.

The automatic driving technology and driving support technology of transportation vehicles used in public areas are expected to progress steadily in the future. However, as described in this paper, there are many pieces of transportation equipment that are operated under special conditions on production work sites where general automatic driving technology cannot easily be applied. Even within steelworks, there are, for example, large special vehicles that transport semi-products and waste, and overhead cranes in the plants. We will strive to extend this development experience to benefit driving support and automation for these machines.

References

1) H. Tamaki et al. *TETSU-TO-HAGANE*. 2014, Vol.100, No.4, pp.485-490.
2) T. Inagaki. *The Institute of Electronics, Information and Communication Engineers, Engineering Sciences Society, Fundamentals Review*. 2008, Vol.2, pp.22-30.
3) T. Kurashiki. *NTN Technical Review*. 2017, No.85, pp.2-13.
4) H. Takada et al. *Transactions of the Institute of Systems, Control and Information Engineers*. 2016, Vol.60, No.11, pp. 457-462.
5) T. Mizuma. *Journal of the Society of Instrument and Control Engineers*. 2017, Vol.56, No.2, pp.93-98.
6) H. Arai. *RRR (Railway Research Review)*. 2008, Vol.65, No.07, pp.22-25.
7) S. Konno. *Transactions on Electrical and Electronic Engineering*. 2010, Vol.130, No.8.
8) R. J. Wilson. *Introduction to Graph Theory*. Addison Wesley Longman Ltd., 5th Edition (2012).
9) H. Terada et al. *Japanese Unexamined Patent Application Publication* 2014-210570.
10) H. Terada et al. *Japanese Unexamined Patent Application Publication* 2014-210571.
11) K. Ishihata. *Algorithms and Data Structures*. Iwanami Shoten, Publishers., 1989.