Special edition paper

Study of a Strong Wind Warning System

Noritoshi Kobayashi* and Makoto Shimamura*

To prevent train derailment due to strong wind, JR East issues operating restriction orders in the event of a strong wind. The current operating restriction orders contain some inconsistent points. For example, operating restriction orders are issued after a strong wind has been observed, and they remain in force across the board for 30 minutes after strong wind is not observed any more. To solve this problem, we are currently engaged in developing a strong wind warning system. Using only the time series of the wind velocity data observed on the anemometer installed along the railway tracks, this system predicts the wind velocity about 30 minutes ahead according to the time series analysis technique and issues operating restriction orders. So far we have confirmed the reliability of this system through monitored running and verification of the algorithm using the wind velocity data of meteorological offices.

● Keyword : Train operating restriction order, wind damage, time series analysis

1 Introduction

To prevent train derailment and rollover due to strong wind, operating restriction orders (for example, to stop train runs) are issued to ensure that the train is not exposed to the wind velocity in excess of the regulated wind velocity for protecting the train against rollover accidents. To support decision making in such operation control, JR East is developing a strong wind warning system. This paper introduces and discusses this system.

2 Rules for decision making in operation control against strong wind

JR East is developing a disaster prevention information system, where meteorological observation facilities for disaster prevention such as rain gauges and anemometers are installed along tracks, and information from such facilities is sent to the traffic dispatcher room on a real-time basis. Such information is effectively used in train operation control and protection against natural disaster. Operation control is formulated into rules to ensure that trains stop running or the traveling speed is reduced (speed control) if the data observed by equipment has exceeded the regulated value established in advance.

Train operation control in the event of a strong wind was based on the "10-minute average wind velocity." According to the train rollover accidents having been caused by strong wind so far, the decision is now made by on the basis of the instantaneous wind velocity observed by a three-cup anemometers installed along the track.

The following shows the operation control decision rule for strong wind that is currently in force by JR East:

(a) Issue an operating restriction order upon detection of strong wind whose velocity exceeds a regulated value (e.g. a wind velocity of 30 meters per second in the general service section)

(b) Lift the operating restriction order if wind velocity exceeding the regulated value is not detected in a continuous time period of 30 minutes

These rules are very clear and can be easily observed by the personnel in charge. However, even if there is a rapid increase of the wind velocity, an operating restriction order is not issued until the regulated value has been reached. Operating restriction orders take effect for 30 minutes even if the regulated value has been exceeded only a short instant. These disadvantages suggest that, if safer and more effective operation control is taken in account, there is still room for improvement of the rules.

One of the solutions to these problems is to establish the following rule: The upper limit of the wind velocity is predicted according to the probability of a train passing through the regulated operation section. If the predicted upper limit of the wind velocity has exceeded the regulated value, an operating restriction order is issued. If not, normal operation is continued.

*Safety Research Laboratory, Research and Development Center of JR East Group

The object to be predicted is the wind velocity a few tens of minutes ahead - the time required by the train passing through the regulated area - and the existing facilities should be effectively utilized. Accordingly, we have developed a program for calculating the wind velocity in the future using a personal computer based on the time series analysis, based on the wind velocity data observed by the anemometers installed along the tracks.

3 Development of a wind velocity prediction program

3.1 Algorithm

The following shows the specific algorithm for calculation:

(1) Create the time series of the maximum wind velocity at intervals of 3 minutes based on the observed continuous data on wind velocity

(2) Use the Kalman filter to estimate the trend component of the maximum wind velocity time series

(3) Calculate the point estimate of the maximum wind velocity of each time instant within the production period using trend components

(4) Estimate the probability distribution of maximum wind velocity in the prediction period based on the distribution of errors between the above-mentioned point-estimated maximum wind velocity and observed wind velocity

(5) Calculate the upper wind velocity corresponding to the preset over-limit probability from the above-mentioned probability distribution

One of the characteristics of this method is that

the operating restriction order is issued based on an upper limit wind velocity from a predicted value. The predicted value obtained from time series analysis is the expected wind velocity within a given time. It may be different from the observed wind velocity. If the predicted value has deviated to be greater than the observed side, an incorrect alarm will be issued. If the predicted value has deviated to be smaller than the observed side, then the issue of an alarm will be missed.

In working out an operating restriction rule based on the predicted wind velocity, we have determined to use the upper limit value in the predicted confidence interval corresponding to the over-limit probability $e, based on the error distribution of the predicted wind velocity. The rule (hereafter referred to as "Prediction Rule") we have adopted requires that, if the upper limit value exceeds the predetermined regulated value, operating restriction order is issued; otherwise, the operating restriction order is cancelled (Fig. 1).

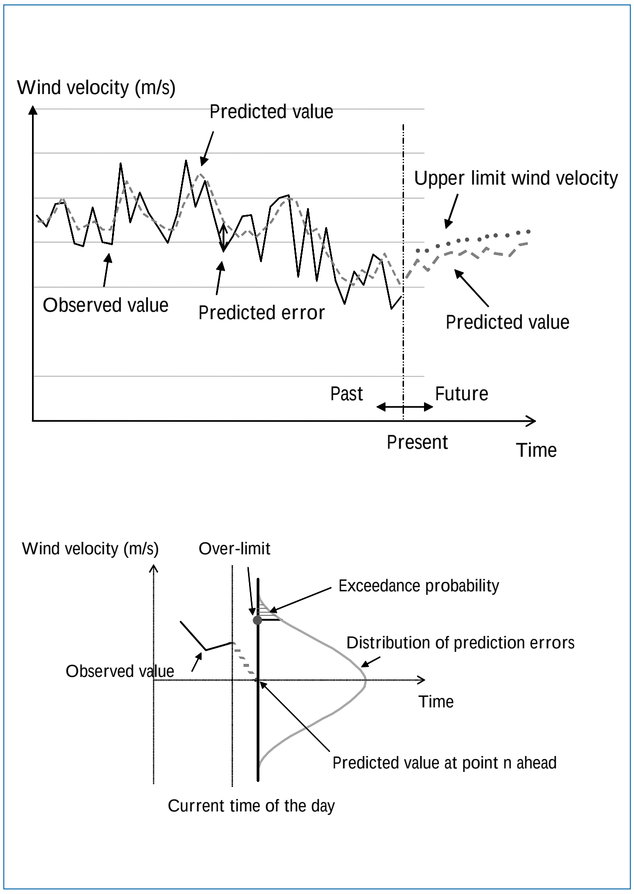


Fig. 1 Prediction of wind velocity using time series analysis

For example, if the train takes twelve minutes to pass through the regulated operation section, the decision to issue or call off an operating restriction order can be made by calculating the upper limit wind velocity twelve minutes ahead of the current time (the wind velocity that is likely to occur at probability $e in twelve minutes), and comparing it with the regulated value.

The probability of over-limit required to work out the upper limit wind velocity has been determined by collecting the data on strong wind recorded by JR East's anemometers installed along tracks and the data obtained from the 40 meteorological offices within JR East's operating areas, and by simulating the operating restriction order patterns of both the current rule and a new rule based on wind velocity prediction. More specifically, it can be described as follows: we calculated the loss function from the event where the wind velocity exceeding the regulated velocity while the train is running in the regulated section, and the amount of the loss is by the square of the excess wind velocity. We have determined the probability of over-limit of the upper limit wind velocity in such a way that the value of the loss function in the rule based on prediction does not exceed that according to the current rule, and the operating restriction time is minimized.

In this way, the decision to issue or cancel an operating restriction order can be made using the future wind velocity predicted only by the time series of observed data.

3.2 Program

Based on the above-mentioned algorithm, and using LabVIEW TM (National Instrument Inc.) as a renowned graphical programming language, we have created a program that executes predictive computation on a real-time basis utilizing the data from the anemometers and automatically issues or cancels the operating restriction order. We use LabVIEW ™ because it reduces the program creating time as compared with the case using the development environment such as C^{++}, and it is easier for a third party to change the program later on.

Fig. 2 shows a part of the restriction display screen. It displays the current wind velocity (observed value) for each anemometer, upper limit wind velocity (produced maximum value) and status of operation control. While the operating restriction order is issued, the status of operation control is given in red or yellow. For comparison with the current rule, the screen also displays the state of operation control according to the current rule in the phase of prototype production.

Fig. 2 Rule display screen (partial)

Fig. 3 shows the screen displaying a graphical representation of the history of wind velocity for each anemometer and the upper limit wind velocity 36 minutes ahead of the present time. The solid line to the left of the current time denotes the history of the observed wind velocities, the dotted line shows the predicted value, and the circle to the right of the current time indicates the upper limit wind velocity 36 minutes ahead at intervals of 3 minutes.

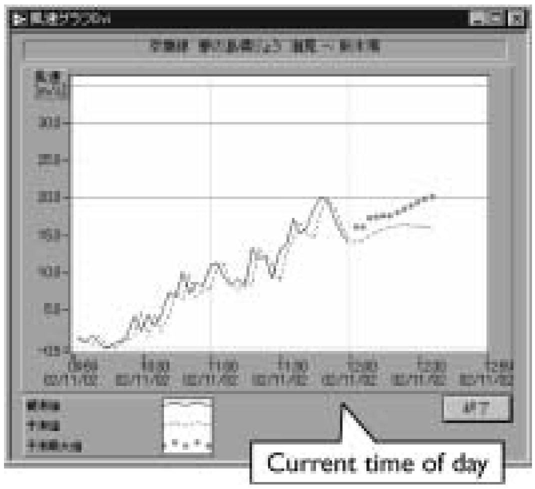


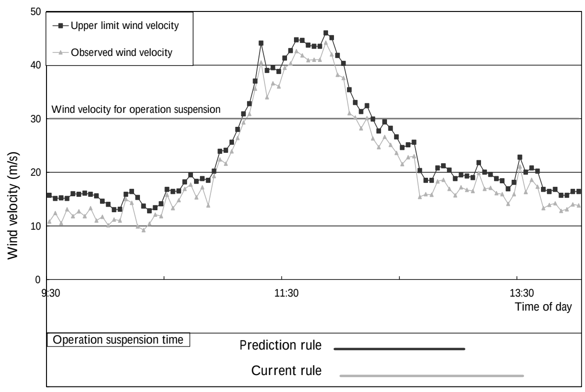
Fig. 3 Graphical representation of wind velocity

4 Cases of Application

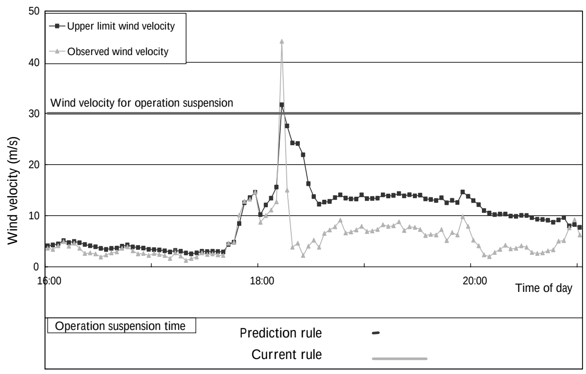
The following discusses the effects of using the strong wind warning system for several cases of strong wind. Fig. 4 shows the operation control patterns when using the current rule and prediction rule. It indicates the observed wind velocity, upper limit wind velocity and operation suspension time for the application of each rule.

In case a), the predicted wind velocity exceeds the wind velocity for operation suspension before the observed wind velocity actually exceeds the wind velocity for operation suspension. So the operation suspension order by prediction can be issued before the train is exposed to the strong wind whose velocity is higher than the wind velocity for operation suspension. Further, after passage of typhoon, the operating restriction order is lifted when the predicted wind velocity is reduced below the wind velocity for operation suspension. Thus, this method reduces the unwanted restriction time as compared to the current rule where the operating restriction order remains effective uniformly for 30 minutes.

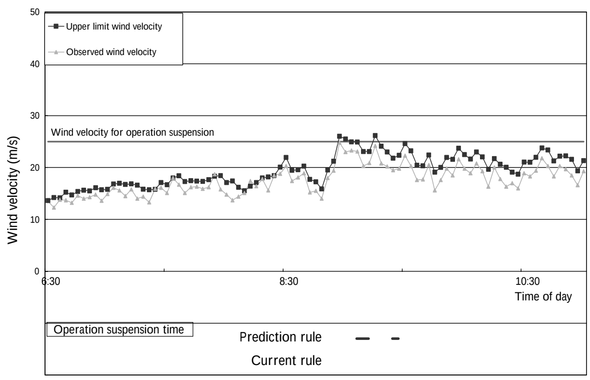
Case b) refers to a sudden gust of wind where a wind of high velocity independently of the pattern of the previous wind velocity time series suddenly appears for a short period of time. In this case, the operation suspension order cannot be issued before the strong wind whose velocity exceeds the wind velocity for operation suspension appears, despite application of the prediction rule, similarly to the current rule. However, the continued operating restriction time must be cut off substantially.



(a) Case of typhoon



(b) Case of a sudden gust of wind



(c) Case of transition close to standard restriction value

Fig. 4 Cases of application

In the meantime, use of prediction may impose more strict operating restrictions than the current rule, depending on the pattern of wind. For example, if the wind velocity has shifted close to the wind velocity for operation suspension (25 meters per second) and the maximum wind velocity does not exceed the wind velocity for operation suspension, as in the case of c), then the operating restriction according to the prediction rule may be placed on the safer side than the current rule, with the result that unwanted restriction time may be increased in some cases.

Despite such differences depending on the pattern of strong wind, the overall effects are illustrated in Table 1. This Table shows the operating restriction time for each prediction time, when prediction calculation has been carried out using a great number of observed data items observed along tracks and in meteorological offices, and the probability of over-limit is set so as to ensure the same or better level of safety than that of the current rule as discussed in 3.1. The operating restriction time has been reduced about 20 to 50 percent, with respect to 36 minutes ahead, which is the maximum time required for a train to pass through the restricted section within the range under the control of JR East.

Table 1 Operation restriction time based on prediction
(The base value of 100 is the current value)

	Restriction time
3minutes ahead	42
6minutes ahead	53
9minutes ahead	64
12minutes ahead	70
15minutes ahead	71
18minutes ahead	79
21minutes ahead	81
24minutes ahead	83
27minutes ahead	85
30minutes ahead	79
33minutes ahead	80
36minutes ahead	75

5 Monitor running

To verify the stability, reliability and user interface convenience of the program we have developed under continuously operating conditions, we have configured a total system including the adjustment of the timing for transmission of wind velocity data, reception of data and prediction analysis required for actual operation, as well as method of displaying restriction information. Monitoring was carried out at sixteen positions in four sections shown in Table 2 for a period of two years. To prevent trains from being affected by an operation error, we have configured a new total system ranging from the anemometers to the prediction result display device installed in the traffic dispatcher room so that it may work as an independent system without using the anemometers or communications lines of the accident prevention system (Fig. 5).

In the Senzan Line provided with more than a sufficient number of existing facilities, data transmission is sent through the private line diverted for use as a wired line. At other positions, a wireless line based on Dopa of NTT DoCoMo is used for this purpose. TCP/IP is adopted as the communications protocol to allow any type of line to be used and to ensure compatibility with other operation control information systems in future.

The result of monitoring has verified that system functions such as calculation for wind velocity prediction and data display perform normal operations for a long time under the environment where operation is anticipated. Monitoring was a test trial not reflected in the train operation. So a monitor for displaying the screen shown in Fig. 3.2 was installed in the traffic dispatcher room to provide information under the same environment as that of the actual operation, and verification was made to check if the screen can be easily observed by a dispatcher.

Table 2 Positions for monitoring

System installation site	Line name	Anemometer installation site
Traffic dispatcher room, Chiba Branch	Keiyou Line	Yumenoshima bridge
		Arakawa bridge
		Edogawa bridge
		Edogawa discharge channel bridge
		Ebigawa bridge
		Hanami river bridge
Traffic dispatcher room, Sendai Branch	Senzan line	Second Hirose river bridge
		Okushinkawa station
Traffic dispatcher room, Morioka Branch	Ohminato line	Second Tanabe crossing
		Tanabe river bridge
Overall dispatcher room, Shinkansen Operation Headquarters	Tohoku Shinkansen	Arakawa bridge
		Shichikitada river bridge
		Naruse river bridge
		Ego river bridge
		Semine river bridge
		Haku river bridge

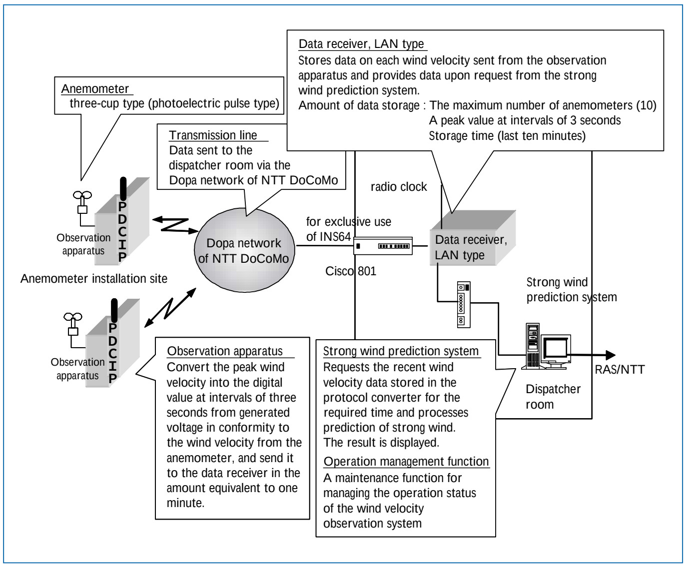


Fig. 5 Configuration of monitor running system (wireless type)

6 Conclusion

We have been engaged in the development of the system for the last several years. The system is considered to have reached the level of commercial use through the verification of the algorithm based on a large volume of wind velocity data provided by the meteorological offices and confirmation of program safety by monitoring. Through the in-house examination of a specific procedure of reflecting this system in commercial train operations, we are planning to introduce it in commercial lines.

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