A New Short-Term Wind Alert System for High Speed Train Operation

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Abstract

Deutsche Bahn (German Rail) has developed an intelligent and fully automatic short-term wind forecasting system known as 'Nowcasting'. The system involves the continuous measurement of wind data along sections of a high-speed line exposed to cross winds. These measurements are used by a forecasting model to make short-term predictions of peak winds. If gusts are predicted with wind speeds above the permissible level, the speed of the relevant trains is automatically reduced by the continuous automatic train control system "LZB". The Nowcasting system represents an important option of counteracting the effects of cross winds on high-speed lines.

1. Introduction

Two new generations of high-speed trains have been introduced since 1997 at Deutsche Bahn AG (DB). The use of a driving trailer on the 280 km/h top speed ICE2 and, respectively, the electrical multiple-unit concept implemented in the ICE3 (design speed 330 km/h) gave rise to end coaches weighing approximately 54 tonnes. In the light of this, Deutsche Bahn has been investigating the effects of cross winds on train operation for several years [1, 2, 3]. Similar research has also been carried out by railway companies in Japan, Britain, Sweden and France (e.g. [4, 5, 6]).

In 1998, Deutsche Bahn decided to develop an intelligent short-term wind alert system known as 'Nowcasting'. The fundamental idea underlying such a wind alert system is to achieve a substantial risk reduction by temporarily limiting train speed whenever this is rendered necessary by prevailing wind conditions.

Thus, the system has to account for safety and operational concerns. The German Nowcasting concept primarily relates to high-speed operation of ICE2 and ICE3 trainsets. The objective in developing the Nowcasting system was to provide a tool, clearly defined in terms of both its protective and operational effects, for planning precautionary measures to deal with cross winds on current and future high-speed lines. In the process, Nowcasting will supplement and compete with other countermeasures such as the installation of wind breakers.

The general approach of counteracting cross-wind effects by means of short-term wind prediction is also being pursued by East Japan Railway Corporation (JRE) [7, 8] and French National Railways (SNCF) .

This paper outlines the basic ideas behind DB's Nowcasting concept and focuses on the technical layout of the hazard alert system and on its functionality within the LZB automatic train control system. The development and testing of the prediction model were dealt with in previous papers ([9, 10]). The general methodology for assessing cross wind risks and the corresponding risk reduction delivered by a Nowcasting system was set out in [11].

2. Basic Concept

The Nowcasting system involves continuous measurements of wind data along the high-speed sections of a high-speed line. The wind sensors are set several km apart, the actual spacing depending on the wind and risk characteristics of the high-speed line in question. Short-term predictions for wind gusts are made on the basis of wind data recorded in conjunction with the meteorological prediction model. Where inadmissible wind gusts are anticipated, the speed of the train is automatically reduced by an appropriate amount by means of a corresponding functionality within the LZB automatic train control system. Information on speed restrictions invoked is then retransmitted to the responsible traffic controller.

For technical and operational reasons, the smallest operational unit for the Nowcasting system was designed to coincide with the area covered by an LZB automatic train control unit. This area is meteorologically subdivided into wind reporting sections (WRS), each of which is represented by a wind measuring station (WMS). Any speed restrictions which might be imposed correspond to a given Nowcasting control section (NCS), which generally consists of several wind reporting sections. The division of the high-speed line into wind reporting sections and Nowcasting control sections is illustrated in Figure 1.

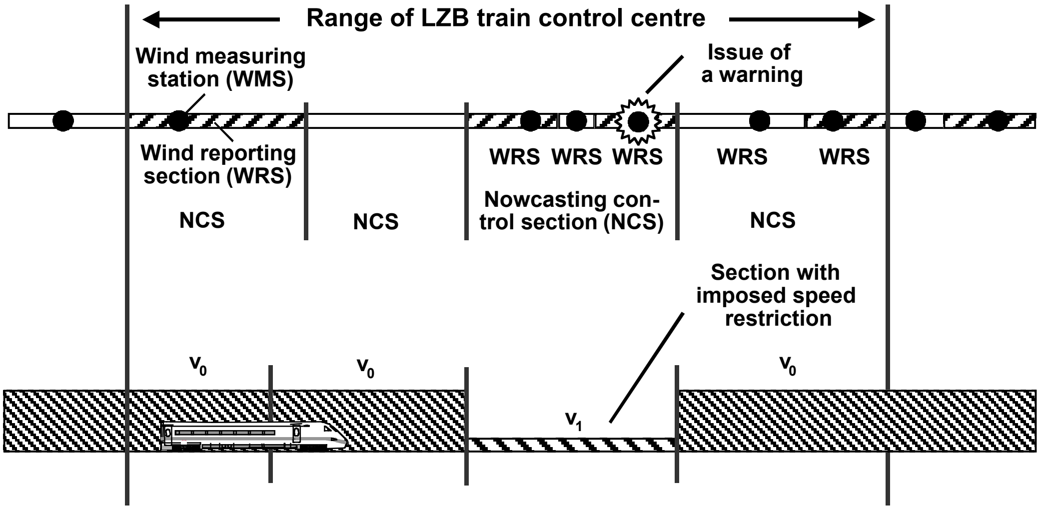

Figure 1: Illustration of a Nowcasting section with wind measuring stations (WMS), wind reporting sections (WRS) and Nowcasting control sections (NCS).

If, on the basis of wind data from the wind measuring station for a reporting section, a wind gust is predicted that is inadmissibly strong for a given category of train travelling at v_0, a warning is sent to the relevant Nowcasting control section (also referred to as a “warning section”). Through normal service brake application, speed profile v_1 is then imposed on all trains of such a category which are in or entering the Nowcasting control section in question at the time. The train maintains its reduced speed profile at least until it has left the Nowcasting control section. Reporting sections are connected up into Nowcasting control sections for operating reasons mainly, though this also affords added protection.

3. Principle Structure of the Nowcasting System

In both development and approval-process terms, the system breaks down into two subsystems, namely a wind alert system (hazard alert system) and a new functionality within an existing automatic train control system.

Within the wind alert system it is possible, in turn, to distinguish between meteorological and technical constituents. The meteorological constituent involves the procedure and algorithms for analysing readings and generating wind predictions. The technical constituent embraces all hardware and software required to record, transmit and evaluate wind data as well as to store or retransmit the information generated on the basis of these data together with the appropriate testing and proving procedures. Fig. 2 provides a schematic overview of the Nowcasting concept and its various elements.

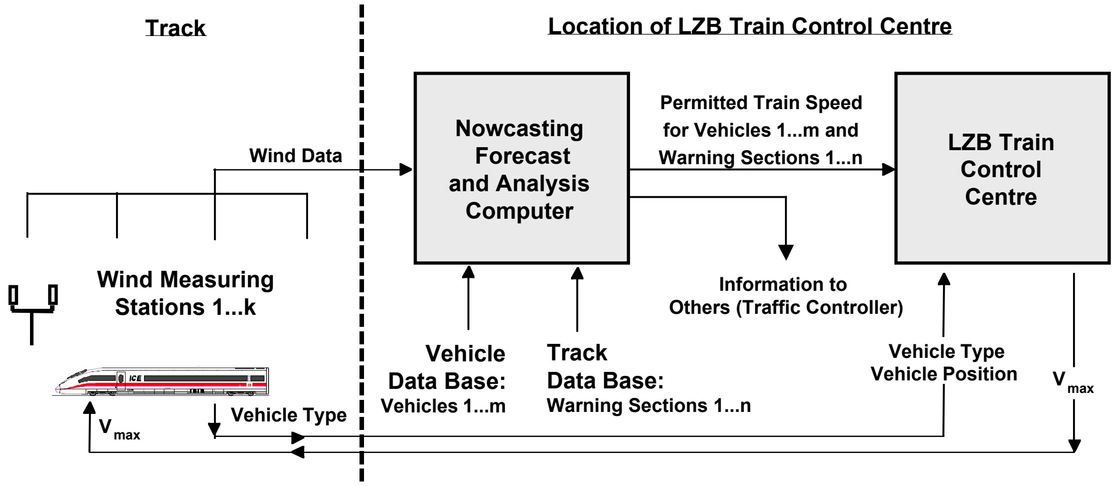

Figure 2: Schematic overview of the Nowcasting System.

4. Overall performance parameters and demands

4.1 Operative range

The system has been designed for high-speed trains with maximum speeds of up to 330 km/h and works with a lead time, or forecast horizon, of 120 s. If a warning is issued, the speed of an affected train must be reduced to an appropriate level by application of the service brake within this time. The system is designed to cover the entire range of wind speeds above 20 m/s.

4.2 Wind forecasting

The short-term forecast is performed purely on the basis of wind data collated by wind measuring stations along the track. The model is to be capable of predicting at least 97.5% of all strong wind gusts above 20 m/s experienced at the location of an anemometer. Tests showed that this aim allows a reasonable compromise between targeted risk reduction and the corresponding operational disturbances due to unjustified wind alerts. Wind predictions for other locations than those of the anemometers are generated using universal spatial transferability functions [10].

4.3 Safety and availability

The design of the Nowcasting System satisfies the demand that data acquisition and processing must not have any significant influence on the safety of the overall system. Safety as well as availability are dominated by the quality of wind forecasting. Failure of Nowcasting subsystems is detected in accordance with the underlying fail-safe design adopted, i.e. affected train services sensitive to cross winds are assigned the correspondingly most restrictive speed reduction (e.g. v = 200 km/h).

5. Layout of the hazard alert system

5.1 Tasks of the hazard alert system

The hazard alert system is required to fulfil various tasks:

- measure the force and direction of winds at one or several points selected on the basis of line analysis,
- derive parameters from local readings,
- transmit parameters to a central evaluation unit,
- provide a wind forecast for each measuring point,
- define wind levels on the basis of prediction figures,
- store parameters, wind levels and system status in the central evaluation unit,
- communicate wind levels to the LZB system and to traffic control centres.

5.2 General requirements

In keeping with Sub-Section 4.3, no unidentified technical failure may contribute significantly to the probability of failure of the overall system. A hazard analysis drawing on [12] revealed that safety integrity level SIL 1 is to be set as a safety target for the technical system. In this case, the impact of the technical system on the degree of risk reduction is negligible relative to the prediction algorithm. Thus, the reduction of cross wind risks deliverable by a Nowcasting System can be easily assessed on the basis of the methodology described in [11].

Inherent factors may cause wind predictions to trigger false alerts that reduce the efficacy of the system. According to [10], the alarm rate for v = 25 m/s is < 1 %. So as not to substantially reduce the efficiency of the Nowcasting system, the permissible failure rate for the overall technical system is being set at $< 5 \cdot 10^{-4}$ (availability > 99.95 %). This ensures that, even in the relatively windless summer months, train speed restrictions are imposed largely on the basis of wind forecasting results and not in response to defects in the technical system.

5.3 Wind measuring station

A wind measuring station consists of two wind measuring devices with a two-dimensional ultrasonic anemometer mounted at a height of 4 m above track level. The measuring rate, on the basis of which 1s values for wind speed, wind direction and temperature are generated, is to be ≥ 10 measurements per second. Using the 1s values, on-going 3s means for wind speed are computed. Every 20 seconds, the mean values for 3s wind speeds and the square of, respectively, 3s wind speeds, wind direction and temperature are ascertained. Together with the maximum 3s mean for the speed and corresponding direction of the wind, these parameters are transmitted to the central forecast and analysis computer. Moreover, parameters are stored in a 10min memory to enable straightforward resumption of wind forecasting following data-line failure. The wind measuring stations are to be equipped with an uninterruptible power supply (UPS) which ensures operation for at least 10 min.

5.4 Data transfer system

All wind measuring stations within a Nowcasting section are required to report every 20 s to the central forecast and analysis computer. Transfer of data may be via free communication lines or trackside signalling cables. The wind measuring stations are connected to the data transfer system by a party line interface. To ensure the requisite availability, the communication circuit needs to embrace data lines on both sides of the track.

5.5 Forecast and analysis computer

Operating to a 20s cycle, the forecast and analysis computer is required to collect and check the parameters of up to 20 wind measuring stations via a party line master, to generate the wind predictions for up to 20 wind reporting sections and the corresponding warnings for up to 10 Nowcasting control sections, to store the relevant data and to transmit warnings to the LZB automatic train control system. The forecast and analysis computer is additionally required to supervise the overall Nowcasting system and to provide a diagnostics and service interface.

The forecast and analysis computer will be sited at the location of the LZB train control centre. The interface to the LZB train control system corresponds to that of an interlocking installation.

6. Layout of the functionality within the LZB train control system

Every 20 s the hazard alert system communicates predicted peak wind speeds, classified by wind level, to the LZB automatic train control system. The lead time (or forecast horizon) amounts to 120 s. As shown by [2, 3], permissible vehicle speeds for predicted wind levels can be determined on the basis of vehicle and line parameters for each train category and each Nowcasting control section. Permissible speeds apply regardless of the direction of traffic and are stored in the LZB control centre in the form of tables.

The permissible speed for a specified Nowcasting control section determined in this way, giving consideration to vehicle type and wind level, is to be made use of when establishing the nominal speed for the vehicle. Vehicles for which speed restrictions in respect of cross winds are applicable are all those which

- are travelling over the Nowcasting control section at the time,
- will reach the Nowcasting control section within the forecast horizon, or
- will not leave the Nowcasting control section within the forecast horizon.

Subsequent falls in the wind level are not to lead to increases in speed before the vehicle has left the Nowcasting control section. It is to be ensured that, when a train's speed is reduced to take account of cross winds, this is achieved through normal service brake application.

Partial failures of the Nowcasting hazard alert system are detected and assessed by the evaluation system and given due consideration when messages to the LZB are produced. Should the LZB not receive any fresh messages on wind levels from the Nowcasting evaluation system within 20 seconds, total failure is to be assumed. In such an instance, the most restrictive speed for the respective vehicle categories applies for all vehicles susceptible to cross winds. Overall, the safety level is determined by the existing LZB system and remains unaffected by the Nowcasting functionality.

7. Outlook

The concept phase of the Nowcasting system has been completed. Specifications and system requirements are completed. Risk reduction and operational effects are clearly defined, so that the system represents a dependable and serious option when planning cross wind measures for future high-speed lines.

Besides, the concepts and solutions developed might also have applications for other aspects of railway operation in which information gathered from the track area (e.g. rail temperature, overhead line current) is to dynamically affect (permitted) train speeds.

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