NATIONAL TRANSPORTATION SAFETY BOARD
Investigative Hearing

Norfolk Southern Railway general merchandise freight train 32N derailment with subsequent hazardous material release and fires, in East Palestine, Ohio, on February 3, 2023

GROUP	H
EXHIBIT	
22	

Agency / Organization

Norfolk Southern

Title

Summary of Norfolk Southern Wayside Detector System and Hot Bearing Detectors (produced to NTSB on March 22, 2023)

The Norfolk Southern ("NS") wayside detector network employs algorithms that allow the on-shift Wayside Detector Desk Operator ("Operator") sitting in a central monitoring station to receive informational alerts and then monitor the performance of a train, or an individual car, even when temperature readings have not risen to a level that triggers an audible alarm, which is transmitted from the detector itself, to the crew. These informational alerts assist, in particular, in identifying and alerting NS to conditions associated with braking issues, such as sticking brakes on a single car or multiple cars in a train.

The algorithm flags potential anomalies in bearing temperature by calculating what is called a "K" value for each individual bearing. There are two "K" designations that are considered by the algorithm calculation – Kt, and Ke. The bearing temperatures are compared against the overall train distribution and assigned values showing their deviation from the train (Kt)[1] and against the car (Ke).[2] **Appendix 1** includes a detailed explanation of how these "K" values are calculated.

The Wayside Detector data is transmitted to NS's back office once the last car of a train has fully cleared the Wayside Detector. Once that data is received, NS's back-office algorithms determine whether any equipment alerts are appropriate. The alerts that might be triggered, but would not be accompanied by an audible on-train alarm, are:

- 953 Alert (Bearing Temperature Spike)
- 850 Alert (Bearing Temperature Deviation Alert)
- 851 Alert (Bearing Temperature Deviation Alert)
- 853 Alert (Trending Bearing Alert)
- 870 "Differential" Alert (where a bearing's temperature is 115 degrees Fahrenheit higher or greater than its mate or opposite bearing on the same axel)
- 871 "Differential" Alert (where a bearing's temperature is 115 degrees Fahrenheit higher or greater than its mate or opposite bearing on the same axel)

These alerts are generated automatically when the algorithm determines that the criteria for the specific alert is met. NS's system then pushes the alerts to the Wayside Help Desk's diagnostics dashboard, where the Operator should see a new alert highlighted in red (see image below for an example). The Operator can then analyze the readings and take appropriate measures, up to and including requesting that the train crew stop the train and inspect the equipment. This process is distinct from and supplements alerts announced directly to the train crew.

[1] Kt = (Compares bearing temperature values against values on same side of train)

[2] Ke = (Compares bearing temperature values on all bearings on a single piece of equipment)

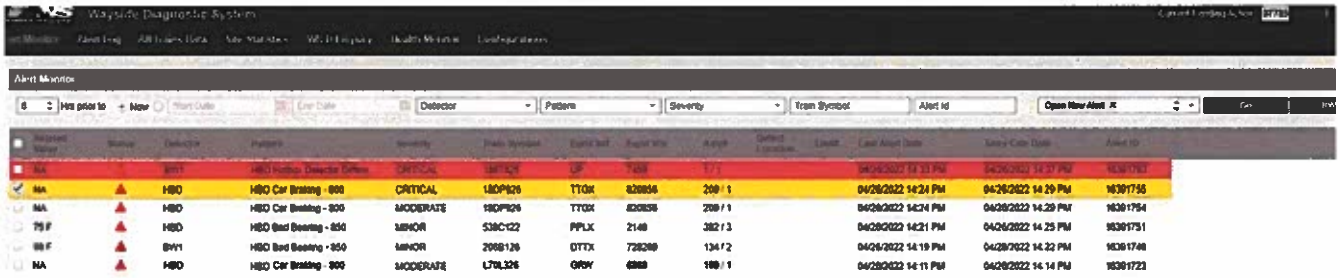
Separately, Wayside Detector readings that exceed certain absolute bearing temperature "audible alarm" thresholds automatically transmit an audible announcement[3] to the train crew, alerting the crew to the presence of a temperature reading that requires inspection. This alarm can occur in connection with the following alerts:

- 870 "Warm Alarm" Alert and "Absolute Alarm" Alert (where a bearing has reached over 170 degrees Fahrenheit above ambient temperature (for a "warm alarm" alert); or over 200 degrees Fahrenheit above ambient temperature) (for an "absolute alarm" alert))

- 871 "Warm Alarm" Alert and "Absolute Alarm" Alert (where a bearing has reached over 170 degrees Fahrenheit above ambient temperature (for a "warm alarm" alert); or over 200 degrees Fahrenheit above ambient temperature) (for an "absolute alarm" alert))

Separate from the audible alarm, which sounds immediately upon the reading, the readings are sent to the Wayside Help Desk after the entire train has passed the detector and subsequently trigger Wayside Detector System ("WDS") alerts. Following the detector audible alarm, the train crew is expected to follow the safety steps for the specific alarm (which can include slowing the train down or stopping the train) and radio the Wayside Help Desk as soon as possible to confirm position of the equipment and to gather any other pertinent details available to the Wayside Help Desk prior to inspection of the equipment. Following the inspection, the train crew should provide feedback to the train Dispatcher and Wayside Desk for further handling instructions.

See below for an example of the Operator's Wayside Detector System alert dashboard from the afternoon of April 26, 2022:



Description of each of the alerts:

953 Alert (Bearing Temperature Spike)

- This alert is generated by the WDS back-office algorithm.[4]

- *Alert is triggered when:*

[3] Where the "warm alarm" thresholds are met (between 171 and 200 degrees Fahrenheit above ambient temperature), the detector will announce key information including position of the defect on the train. If "absolute" alarm thresholds are met (over 200 degrees Fahrenheit over ambient temperature), the detector immediately transmits the critical alarm followed by the other information.

[4] All 953 alerts are designated "critical" in WDS.

1. A bearing has a Kt value (which compares bearing temperature values against values on same side of train) greater than 4; and

2. The system, which automatically checks the absolute temperature, finds that the absolute temperature is more than 90 degrees Fahrenheit over ambient.

- *What happens when the alert is triggered?*

    1. The WDS sends an alert to the Operator on the WDS Dashboard; and then

    2. The Operator should analyze the alert and provide the train crew with instructions per the following criteria:

        1. Is K value for the bearing greater than 4 across 3 detectors over the course of the train's journey?

            - If yes:

                - Then: the Operator should radio train to stop and inspect --

                    - If bearing damage is visible:

                        - Then: the train Dispatcher should call the mechanical department for assistance if necessary and the train crew should set car out of train (LOR). The Operator should continue to monitor the bearing for alerts as the train passes additional detectors en route. The train crew should take necessary safety precautions based on instructions from the Operator and the crew's findings.

                    - If braking defect is identified as source of heat:

                        - Then: release brake or otherwise address braking issue, allow train to continue, and the Operator should continue to monitor the bearing for alerts as the train passes additional detectors.

            - If no:

                - Then: the Operator should continue to monitor the bearing for alerts as the train passes additional detectors and allow train to continue.

        2. Is it possible based on specific detector's set reading capabilities (i.e., whether the detector takes a measurement of the wheel heat), for the Operator to check wheel heat?

            - If yes, then: the Operator should check whether a single wheel is 500 degrees Fahrenheit above ambient temperature or greater.

- If yes, then: application and release of the train's air brakes is requested by the Operator. The Operator should continue to monitor the bearing for alerts as the train passes additional detectors.

- If no, then: are multiple wheels 400 degrees Fahrenheit or more above ambient temperature?

    - If yes, then: application and release of the train's air brakes is requested by the Operator. The Operator should continue to monitor the bearing for alerts as the train passes additional detectors.

    - If no, then: the Operator should continue to monitor the bearing for alerts as the train passes additional detectors.

3. Based on action requested by the Operator or the crew's findings, the crew should be instructed by the Operator on next steps, if any.

850 Alert (Bearing Temperature Deviation Alert)

- This alert is generated by WDS's back-office algorithm, which calculates trending with respect to this alert. Specifically, it calculates trending from up to 7 detector passings immediately before detector has triggered an alert where the bearing is deemed "hot" (flagged as an "H" in the Wayside Detector System).[5] The number of detectors that indicate a hot condition will determine the level of severity assigned by the system (see table below).

- *Alert is triggered when*:

    1. There is a detected "hot" bearing for up to 7 detector passings immediately prior to alert being triggered (the level of severity based on the number of "hot" passings (see table below)); and

    2. The algorithm calculates a temperature rate of increase between two consecutive detector passings (refer to table below detailing levels of severity based on criteria including specific rate of temperature increase); and

    3. Bearings of the same truck are experiencing an elevated Ke value.[6]

- *What happens when the alert is triggered?*

    1. The WDS sends an alert to the Operator on the WDS Dashboard; and then

[5] The software algorithm determines a bearing is "hot" by using a built-in analyzer that evaluates Ke and Kt values while also accounting for outside ambient air temperature.

[6] Elevated readings within the same truck can be an early indicator of potential sticking brakes and a high enough reading may trigger a separate brake alert.

2. The Operator should analyze the alert and provide the train crew with instructions per the following criteria:

    1. Determine the level of severity (see table below for how severity is calculated). Each level is handled using the same remedial steps. The level of severity indicates priority for the Operator.

    2. Is K value for the bearing greater than 4 across 3 detectors over the course of the train's journey?

        - If yes:

            - Then: the Operator should radio train to stop and inspect --

                - If bearing damage is visible:

                    - Then: the train Dispatcher should call the mechanical department for assistance if necessary and train crew should set car out of train (LOR). The Operator should continue to monitor the bearing for alerts as the train passes additional detectors en route. The train crew should take necessary safety precautions based on instructions from the Operator and the crew's findings.

                - If braking defect is identified as source of heat:

                    - Then: release brake or otherwise address braking issue, allow train to continue, and the Operator should continue to monitor the bearing for alerts as the train passes additional detectors.

        - If no:

            - Then: the Operator should continue to monitor the bearing for alerts as the train passes additional detectors or and allow train to continue.

    3. Is it possible based on specific detector's set reading capabilities (i.e., whether the detector takes a measurement of the wheel heat), for the Operator to check wheel heat?

        - If yes, then: the Operator should check whether a single wheel is 500 degrees Fahrenheit above ambient temperature or greater.

            - If yes, then: application and release of the train's air brakes is requested by the Operator. The Operator should continue to monitor the bearing for alerts as the train passes additional detectors.

- If no, then: are multiple wheels 400 degrees Fahrenheit or more above ambient temperature?

    - If yes, then: application and release of the train's air brakes is requested by the Operator. The Operator should continue to monitor the bearing for alerts as the train passes additional detectors.

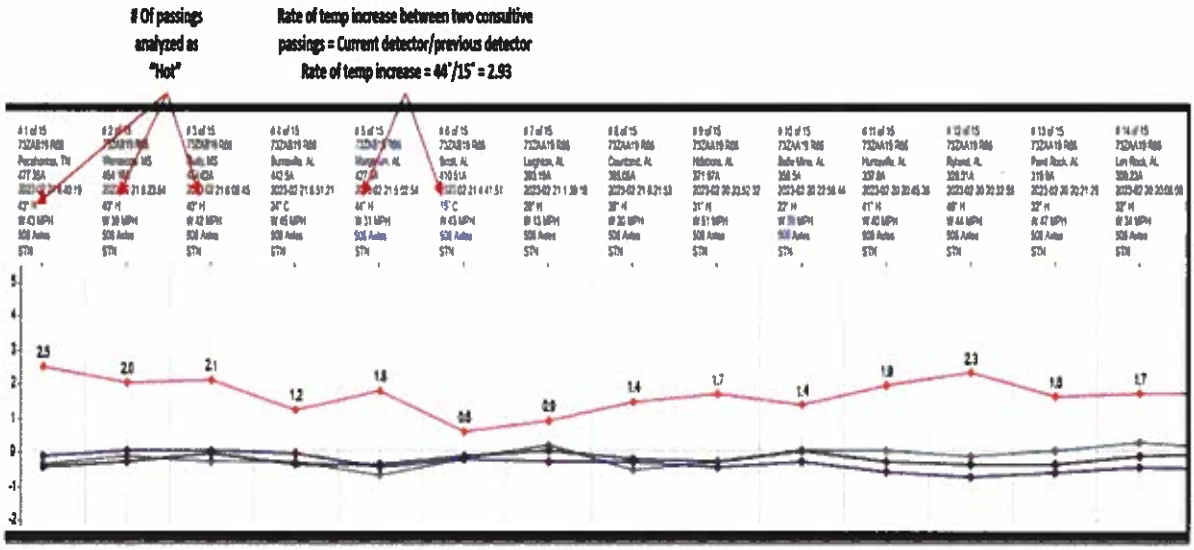
    - If no, then: the Operator should continue to monitor the bearing for alerts as the train passes additional detectors.

4. Based on action requested by the Operator or the crew's findings, the crew should be instructed by the Operator on next steps, if any.

Levels of severity of the alert:

	Y	X	A	B	C
Severity	Number of Past Events Used	Rate of temp increase between two consultive passings	# Of passings analyzed as "Hot"	# Of passings above Rate of temp increase found in Column X.	# Of passings with increased Ke on same truck where Ke > 0
850 Minor	1	1.4	1	1	1
	3	0	3	0	3
	4	0.8	3	2	1
850 Moderate	2	4	2	1	1
	4	1.4	3	2	3
	7	1.4	5	2	5
	7	1.4	6	2	4
850 Critical	2	0	2	0	3
	2	9	2	1	1
	4	1.4	4	3	4
850 Very Critical	2	0	2	0	4
	2	0	2	1	3

See below for a chart with an illustrative example of how bearing heat trends are measured in the context of the 850 alert class:



851 Alert (Bearing Temperature Deviation Alert)

- This alert is generated by WDS's back-office algorithm. Handling is the same as handling of the 850 alert described above, however, it also takes into account the frequency of the 850 alerts with respect to a single bearing by calculating the number of 850 alerts that have been triggered for the bearing in question over the prior seven detectors.

853 Alert (Trending Bearing Alert)

- This alert conforms to AAR guidance (derived from Standard S-6001 (section 4.1)).[7] The alert calculates trending as described in that section.[8]

- *What happens when the alert[9] is triggered?*

    1. The WDS sends an alert to the Operator on the WDS Dashboard; and then

    2. The Operator should analyze the alert and provide the train crew with instructions per the following criteria:

[7] Simultaneous to alert, an intercept message is created for the mechanical department to address.
[8] The regulation reads: "4.1.1 The bearing has a calculated value of Kt > 3.5 within the train and the bearing has a value of KE > 2 with respect to the equipment and the bearing is detected 50° F hotter than any other bearing on the equipment. 4.1.2 The bearing has a calculated value of Kt > 3.5 within the train and the second hottest bearing on the equipment has a value of Kt < 45% of the bearing in question."
[9] All 853 alerts are designated "very critical" in WDS.

1. Is K value for the bearing greater than 4 across 3 detectors over the course of the train's journey?

    - If yes:

        - Then: the Wayside Desk should provide details to the train crew and further instructions based on the following inspection criteria:

            - If bearing damage is visible:

                - Then: the train Dispatcher should call the mechanical department for assistance if necessary and train crew should set car out of train (LOR). The Operator should continue to monitor the bearing for alerts as the train passes additional detectors en route. The train crew should take necessary safety precautions based on instructions from the Operator and the crew's findings .

            - If braking defect is identified as source of heat:

                - Then: release brake or otherwise address braking issue, allow train to continue, and the Operator should continue to monitor the bearing for alerts as the train passes additional detectors.

    - If no:

        - Then: the Operator should continue to monitor the bearing for alerts as the train passes additional detectors and allow train to continue.

2. Is it possible based on specific detector's set reading capabilities (i.e., whether the detector takes a measurement of the wheel heat), for the Operator to check wheel heat?

    - If yes, then: the Operator should check whether a single wheel is 500 degrees Fahrenheit above ambient temperature or greater.

        - If yes, then: application and release of the train's air brakes is requested by the Operator. The Operator should continue to monitor the bearing for alerts as the train passes additional detectors.

        - If no, then: are multiple wheels 400 degrees Fahrenheit or more above ambient temperature?

- If yes, then: application and release of the train's air brakes is requested by the Operator. The Operator should continue to monitor the bearing for alerts as the train passes additional detectors.

- If no, then: the Operator should continue to monitor the bearing for alerts as the train passes additional detectors.

3. Based on action requested by the Operator or the crew's findings, the crew should be instructed by the Operator on next steps, if any.

4. In any event (whether or not defects are found), the mechanical department at destination territory should be instructed via email to capture the equipment for repair.

The following alerts (870 and 871) each include three alert sub-classes (differential, warm and absolute):

<u>870 Alert</u>

- **Differential alert**

  - This alert is generated by WDS's back-office algorithm.

  - *Alert is triggered when:*

    1. A bearing's temperature is 115 degrees Fahrenheit higher or greater than its mate or opposite bearing on the same axel.

  - *What happens when the alert is triggered?*

    1. The WDS sends an alert to the Operator on the WDS Dashboard; and then

    2. The Operator should analyze the alert and provide the train crew with instructions per the following criteria:

       - Is K value for the bearing greater than 4 across 3 detectors over the course of the train's journey?

         - If yes, then: the Operator should radio train to stop and inspect. Upon inspection –

           - If bearing damage is visible:

             - Then: the train Dispatcher should call the mechanical department for assistance if necessary and the train crew should set car out of train (LOR). The Operator should continue to monitor the bearing for alerts as the train passes additional detectors en route. The train crew

should take necessary safety precautions based on instructions from the Operator and the crew's findings.

- If braking defect is identified as source of heat:
  - Then: the train crew should release brake or otherwise address braking issue, allow train to continue, and the Operator should continue to monitor the bearing for alerts as the train passes additional detectors.

- If no:
  - Then: the Operator should continue to monitor the bearing for alerts as the train passes additional detectors and allow train to continue.

5. Is it possible based on specific detector's set reading capabilities (i.e., whether the detector takes a measurement of the wheel heat), for the Operator to check wheel heat?

   - If yes, then: the Operator should check whether a single wheel is 500 degrees Fahrenheit above ambient temperature or greater.
     - If yes, then: application and release of the train's air brakes is requested by the Operator and the Operator should continue to monitor the bearing for alerts as the train passes additional detectors.
     - If no, then: are multiple wheels 400 degrees Fahrenheit or more above ambient temperature?
       - If yes, then: application and release of the train's air brakes is requested by the Operator, who should continue to monitor the bearing for alerts as the train passes additional detectors.
       - If no, then: the Operator should continue to monitor the bearing for alerts as the train passes additional detectors.

1. Based on action requested by the Operator or the crew's findings, the crew should be instructed by the Operator on next steps, if any.

- **Warm Alarm Alert** (non-critical)
  - This alarm conforms to AAR guidance.
  - *Alarm and alert are triggered when:*

1. A bearing has reached over 170 degrees Fahrenheit above ambient temperature.

- *What happens when the alarm and alert are triggered?*

    1. Handled in accordance with Norfolk Southern's Operating Rules governing train inspections and wayside detectors and in conformity with AAR guidance.

- **Absolute Alarm Alert** (critical)

    - This alarm conforms to AAR guidance.

    - *Alarm and alert are triggered when:*

        1. A bearing has reached over 200 degrees Fahrenheit above ambient temperature.

    - *What happens when the alarm and alert are triggered?*

        1. Handled in accordance with Norfolk Southern's Operating Rules governing train inspections and wayside detectors and in conformity with AAR guidance.

871 Alert

- *Alert is triggered when:*

    - The corresponding 870 alert temperature threshold (differential, warm, or absolute, see above) is met; and

    - The 853 alert criteria for warm bearing trending thresholds are met (see above).

- **Differential alert**

    - This alert is generated by WDS's back-office algorithm.

    - *What happens when the alert is triggered?*

        1. The WDS sends an alert to the Operator on the WDS Dashboard; and then

        2. The Operator should radio the train to stop and inspect. The Wayside Desk should provide details to the train crew and further instructions based on the following inspection criteria:

            - If bearing damage is visible:

                - Then: the train Dispatcher should call the mechanical department for assistance if necessary and the train crew should set car out of train (LOR). The Operator should continue to monitor the bearing for alerts as the train passes additional detectors en route. The train crew should take necessary safety precautions based on instructions from the Operator and the crew's findings.

- If braking defect is identified as source of heat:

    - Then: the train crew should release brake or otherwise address braking issue and set car out of train (LOR). The Operator should continue to monitor the bearing for alerts as the train passes additional detectors en route, and take necessary safety precautions based on instructions from the Operator and the crew's findings.

3. Train crew should provide findings to the Wayside Desk and dispatch office.

- **Warm Alarm Alert** (non-critical)

    - This alarm conforms to AAR guidance.

    - *What happens when the alarm and alert are triggered?*

        1. Crew should reduce speed to 8 MPH and ensure the train clears the detector.

        2. Alert details sent to Wayside Help Desk to direct train crew inspection.

        3. Once the detector is cleared crew should contact the Wayside Desk and train Dispatcher. Wayside Desk should provide details to the train crew and further instructions on handling.

        4. Train crew should inspect the vehicle for defects and notify dispatch office of stop.

        5. With respect to the inspection, the Wayside Desk should provide details to the train crew and further instructions based on the following inspection criteria:

            a. If bearing damage is visible:

                i. Then: the train Dispatcher should call the mechanical department for assistance if necessary and train crew should set car out of train (LOR). The Operator should continue to monitor the bearing for alerts as the train passes additional detectors en route. The train crew should take necessary safety precautions based on instructions from the Operator and the crew's findings.

            b. If no defects are found:

                i. Then: the train crew should inspect 20 axles ahead and behind the equipment triggering the alarm (NS Operating Rule 150c);

                ii. Then: the train crew should set car out of train (LOR). The Operator should continue to monitor the bearing for alerts as the train passes additional detectors en route.

The train crew should take necessary safety precautions based on instructions from the Operator and the crew's findings.

c. If braking defect is identified as source of heat:

i. Then: the train crew should release brake or otherwise address braking issue and should set car out of train (LOR). The Operator should continue to monitor the bearing for alerts as the train passes additional detectors en route. The train crew should take necessary safety precautions based on instructions from the Operator and the crew's findings.

6. Train crew should provide findings to the Wayside Desk and dispatch office.

- **Absolute Alarm Alert** (critical)
  - This alarm conforms to AAR guidance.
  - *What happens when the alarm and alert are triggered?*

1. Train crew should bring the train to a safe stop immediately per safe train handling instructions.

2. Train crew should contact the Wayside Desk and train dispatcher (alert details sent to Wayside Help Desk to direct train crew inspection if the last car has passed the detector).

3. The Wayside Desk should provide details to the train crew and further instructions based on the following inspection criteria:

   - If bearing damage is visible:
     - Then: the train Dispatcher should call the mechanical department for assistance if necessary and the train crew should set car out of train (LOR).

   - If no defects are found:

     - Then: the train crew should inspect 20 axles ahead and behind the equipment triggering the alarm (NS Operating Rule 150c); and

     - Then: the train crew should set car out of train (LOR). The Operator should continue to monitor the bearing for alerts as the train passes additional detectors en route. The train crew should take necessary safety precautions based on instructions from the Operator and the crew's findings.

- If braking defect is identified as source of heat:
    - Then: the train crew should release brake or otherwise address braking issue and should set car out of train (LOR). The Operator should continue to monitor the bearing for alerts as the train passes additional detectors en route. The train crew should take necessary safety precautions based on instructions from the Operator and the crew's findings.

4. The train crew should provide findings to the Wayside Desk and dispatch office.

Appendix 1 - How "K" Values are calculated (per AAR Regulation S-6001)

- Tb = temperature of bearing
- K values: Statistical indicators that define the relative variation of one measurement to the overall population.
    - Q values (x = t for train side data) or (x = e for equipment data)
    - Q2_x = median of the dataset values
    - Q3_x (3rd quartile) = median of all values above Q2
    - Q1_x (1st quartile) = median of all values below Q2
- Qx_t indicates Q values calculated from all train side bearing temperatures
- Qx_e indicates Q values calculated from all bearing K values (Kt) on equipment
- Qx_e may also be calculated using all raw bearing temperatures (Tb) on equipment
    - Kt: Train side K-value for a bearing:
    - Kt = (Tb-Q3_t) / (Q3_t - Q1_t) using all bearing on that side as a basis

      Note: *(Q3_t – Q1_t) must be greater than 12.5 F or else be set to a minimum of 12.5 F*
- Ke: Equipment K-value for a bearing:
    - Ke = (Kt – Q3_e) / (Q3_e – Q1_e) using all bearings on that equipment as a basis
    - Ke = (Tb – Q3_e) / (Q3_e – Q1_e) if raw temperatures are used as a basis

      Note: *If (Q3_e-Q1_e) is zero (0) due to low temperature variation, the Kt value may be used in its place*