

A WAYSIDE INSPECTION STATION

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ABSTRACT

Temperature data from commercial analog hot box detector equipment is digitalized, the mean and standard deviation are calculated for each side of a train, and wheels with temperature values above a predefined upper limit are identified as hot boxes. The upper limit is measured in standard deviation units above the mean. The results of the statistical analysis of the heat data, alarms generated by other detection equipment, such as high and wide load detectors, other inspection data, such as train length, direction, and location of the inspection site, are reported to a control site in ASCII over a communication channel.

INTRODUCTION

The advent of electronic hot box detectors in the late 1960s and early 1970s permitted railroads to replace wayside personnel with non-human detectors. All of the early hot box detection stations used analog electronics to detect overheated wheel bearings. A heat impulse from a wheel that was above a predetermined level sounded an alarm. The operating crew was notified, if they didn't see the alarm, so that they could stop the train and inspect the cars for the defective bearing. More often than not, the stop was a false positive, a stop for a hot box that wasn't really there.

False positives can be reduced with frequent maintenance of the detection equipment, as often as once per week for some models, and by changing alarm settings as the ambient temperature changes. Unfortunately, both activities are fairly expensive, and they do not suppress many false positives.

Another source of false positives was the way alarms are reported to the operator of the territory. The raw analog data was transmitted as narrow-band FM on an audio frequency carrier. A bank of strip chart recorders printed the raw data at the operator's station. A hot box was reported by breaking the carrier. A drop of the carrier would sound an alarm at the operator's console. Unfortunately, any short term fault in the communication channel, such as a lightning strike on open wire lines, would also cause a break in the carrier. The operator would receive a false positive, while the train crew would see no alarm at the inspection site.

A microprocessor-based electronic wayside inspection station was designed and developed to overcome these problems. The analog heat sensor signals from a commercially available hot box detector were digitalized, and the data were analyzed. A statistical analysis of the data from each side of a train was used to detect warm wheels and hot boxes. Alarms were reported in ASCII code along with other information about the train. The operator could request a retransmission, and even a transmission of the digitalized raw data, if there was an error in transmission.

The wayside inspection station was used to relay other information from the site. All sites reported the name and location of the station, the time of the inspection, any hot boxes detected and their location in wheels from the rear of the train, the speed of the train at the site, and the train length. The system will also report the presence of high and wide loads if appropriate commercial detectors are installed at the site. The location of the excessive loads is reported in wheels from the rear. The system is extensible. It will report the binary outputs of other commercial detectors and the location of any alarms they produce.

Some of the details have been reported elsewhere [1] [2]. This paper describes some of the features of the equipment not previously reported, the statistical approach used to analyze the hot box sensor data, and experience using the system to inspect trains.

INSPECTION STATION

Fig. 1 shows a block diagram of the electronic inspection station. All of the components, except for the modem, commercial detection equipment, and sensors, are housed in a 19 inch (48.26 cm.) rack inside a steel wayside equipment cabinet. The cabinet is large enough for two people to work in.

The Motorola 6800 processor system acquires the hot box data through two 8-bit A/D converters. The A/D converters are connected to the output of the signal conditioning circuits of the commercially available analog detection equipment. (The commercial equipment makes excellent lightning suppressors.)

The presence of a wheel is determined directly from the wheel sensors. (Some, but not all, commercial analog hot box detection systems condition this signal and provide an output signal every time a moving wheel is present on the track.) The system can process data from other sensors, such as dragging equipment, high equipment, and wide equipment sensors, and report problems. Hot boxes detected by the analog hot box detector are reported as "hot wheels."

The mean and standard deviation of the temperature data for each side of the train are calculated after a train passes an inspection station. The calculations are done with integer arithmetic. The mean and standard deviation from each side of the train are used to determine "warm wheels" (potential hot boxes) on that side. The train is assumed to have passed the site if no wheel is sensed for seven seconds.

The computer system records the location of all alarms. The location is specified as wheels from rear since some passenger locomotives have six axles. (All freight locomotives apparently have four axles.)

All reports are made in ASCII over a phone system through a commercially available MODEM. A call that does not complete the modem handshake is attempted again after about a minute's delay. A

new train at the inspection site aborts the transmission of any previous train's data.

The computer system has some built-in self-test and will report problems, such as a defective analog hot box detection system, as part of its report. The self-test feature of the analog system can be used to stimulate a functional test of the computer system.

The computer system can receive phone calls. The caller can run diagnostics remotely, secure a retransmission of the data, set the time in a local 24-hour clock, or run a monitor program. The processor will break the connection when it detects a new train and will not accept new phone calls until the system has attempted at least one transmission of the data from that train.

STATISTICAL ANALYSIS

A statistical analysis of the heat sensor data is attractive since many phenomena affect a wheel bearing's temperature, and the relationship between the cause and the effect is complex. Some of the relationships appear to be non-deterministic. The temperature is a function of how long a train has been traveling at a speed, how fast the train was traveling prior to its current speed, the weight supported by a bearing, the ambient temperature, and the intensity of sunlight on a bearing.

The sensitivity of the heat sensor equipment will also affect the measured mean. Significant factors are the cleanliness of the sensor lens, ambient temperature, and the presence or absence of sunlight.

Individual variations among bearings will produce scatter around the mean of all the bearings on one side of a train. The type of bearing (roller or journal), the tolerance of the parts, the weight supported by the bearing, the volume of lubrication in the bearing, and the chemical composition of the lubrication in the bearing are all factors.

A statistical approach has several advantages. 1) While the mean and standard deviation will change as a function of the cleanliness of the sensor lens, speed of the train before passing through the inspection station, etc., the relative position of the temperature of a wheel should not change significantly when measured in standard deviation units from the mean. 2) Variations in ambient temperature should not affect alarm limits since this factor will primarily affect the mean. 3) Heat from the sun on one side of a train should not affect the

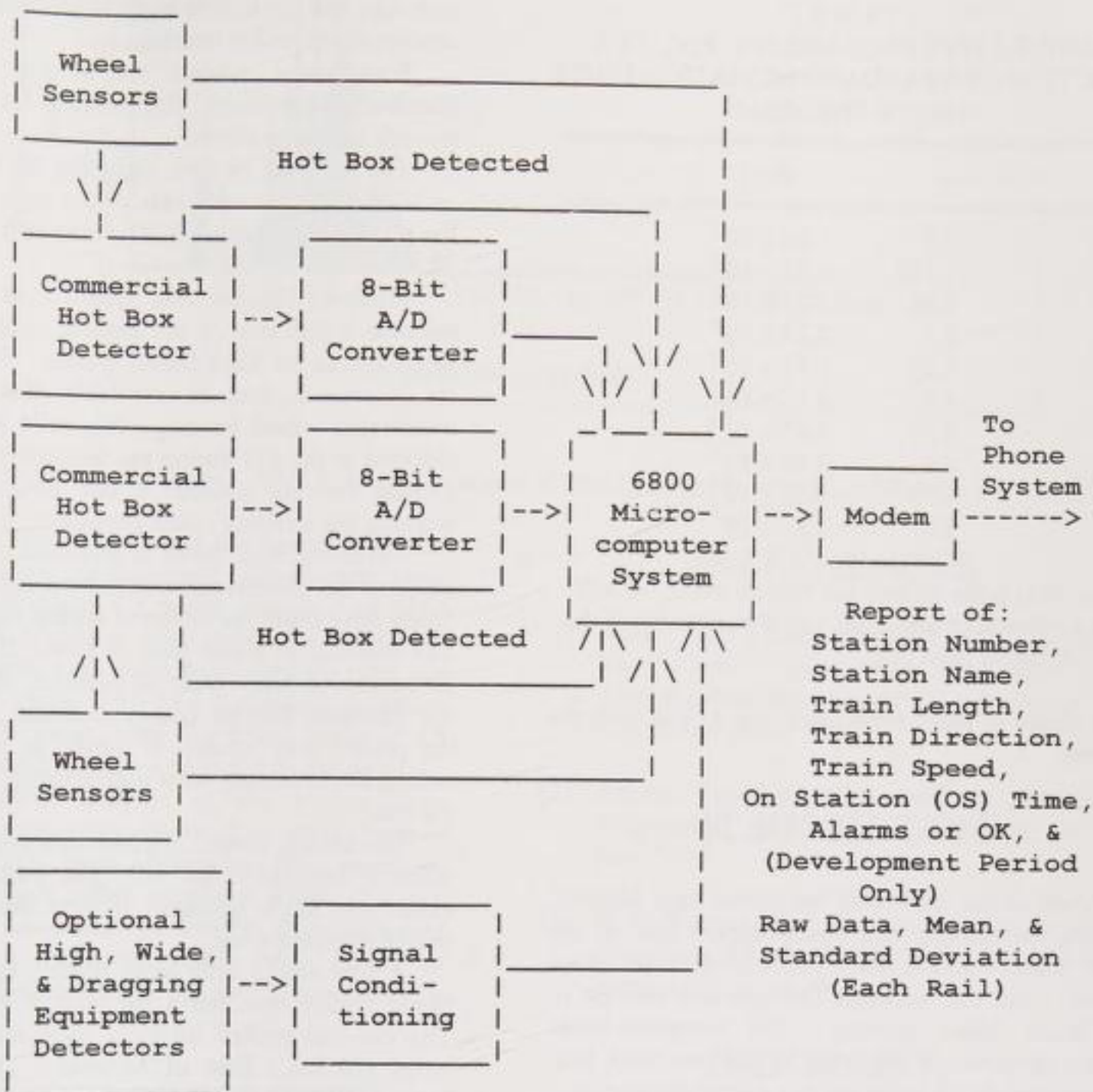


Fig. 1 - Block diagram of the electronic inspection station.

results, provided separate statistics are calculated for each side of a train.

No assumption is made about the shape of the distribution for the wheel bearing temperatures. While the distribution is probably Gaussian, or close to Gaussian, that is not assumed. Indeed, some commercial hot box detection units, such as the Servo 8808, have a bimodal distribution that is a mix of two populations, journal bearings and roller bearings. While the assumption that the distribution is Gaussian is not needed to detect hot boxes, it does give some insight into determining an alarm limit

that is measured in standard deviation units above the mean. Table 1 shows a short table of cumulative probabilities derived from [3]. The values in the table are at the extreme high end of a Gaussian, or normal, distribution.

The initial "warm wheel" limit programmed into the EPROMs of the 6800 system was 3.125 standard deviation units above the mean. The initial limit was deliberately set low, not only to avoid false negatives, but also to gain experience detecting warmer than normal wheel bearings. The limits

TABLE I
 CUMULATIVE PROBABILITY, P(x), AS A
 FUNCTION OF STANDARD DEVIATION UNITS
 ABOVE THE MEAN

x	P(x)
3.0	1.35×10^{-3}
3.125	8.92×10^{-4}
3.25	5.77×10^{-4}
3.5	2.33×10^{-4}
3.75	8.84×10^{-5}
4.0	3.17×10^{-5}
4.25	1.07×10^{-5}
4.5	3.40×10^{-6}
4.75	1.02×10^{-6}
5.0	2.87×10^{-7}

Notes: P(x) is the probability that an event, x, will have a value at or above the value of x shown in the table. Adapted from [3].

were raised as more experience was gained with the system.

TEST RESULTS

Most of the tests were conducted near Mineral, Illinois, an existing hot box detection site on the Rock Island's double track ABS (Automatic Block Signal) main line between Chicago and the rest of the Rock Island system. The computer-based system operated on one track of the two track line. Approximately 24 trains per day passed the station.

The analog electronic detection system at Mineral was a Servo 8808. However, the computer-based system was designed to work with all four commercially available analog hot box detector units, including those made by GE, GRS, and Marine. The system was tested temporarily at Waynesboro, Virginia in conjunction with a General Electric system operating on the Norfolk and Western tracks next to the GE factory.

Fig. 2 shows a histogram for a typical train. The data is from the North side of the train. The data for the South side is not shown since it has less scatter than the North side data. The bimodal distribution clearly illustrates the mixture of two populations expected for a Servo detector. The smaller, lower mode is associated with cars equipped with journal

bearings, and the higher mode is associated with cars equipped with roller bearings.

Four warm wheels are at the top of the distribution, although the wheels are not warm enough to trip an alarm.

The train has 76 cars, including the locomotives, or 304 wheels on each side of the train. The mean for the distribution is 59. The standard deviation is 18.

Mineral, Illinois was selected as a test site because it had one of the highest rates of hot box detections in the Rock Island system. Unfortunately, no measured data is available that shows an overheated wheel bearing. No valid hot box was detected at the site during the test period, one of the longest periods without a hot box that anyone working the territory could remember.

Never the less, there is antidotal evidence that supports the effectiveness of the statistical approach. Many false positives occurred during the test period. The operator at Kelly yard in Silvis, Illinois, about 30 miles (48 km.) West of Mineral, usually called the Chicago, Illinois communications room where the printer was located to verify an alarm before calling the operating crew and ordering them to stop the train.

The analog system tripped a flashing blue light when it detected a hot box. The train crew often called the Silvis operator, if they saw the signal, before stopping a train.

A few weeks after tests started, the computer-based system detected a car with 7 warm wheels. The car was picked up by a local train about 10 miles (16 km.) East of Mineral. The train had between 10 and 15 cars when it passed through the inspection station. The car was visually inspected after it arrived at the Kelly yard in Silvis. The hand brakes were on. The brake shoes were missing from the eighth wheel.

CONCLUSIONS

A statistical analysis of the data clearly cut down false positives. Most of the false positives from the commercial hot box detector were eliminated. All of the false positives from breaks in the carrier were eliminated. Any faults in the communication channel would scramble the data, and the operator could request a retransmission if there was any question about an alarm.

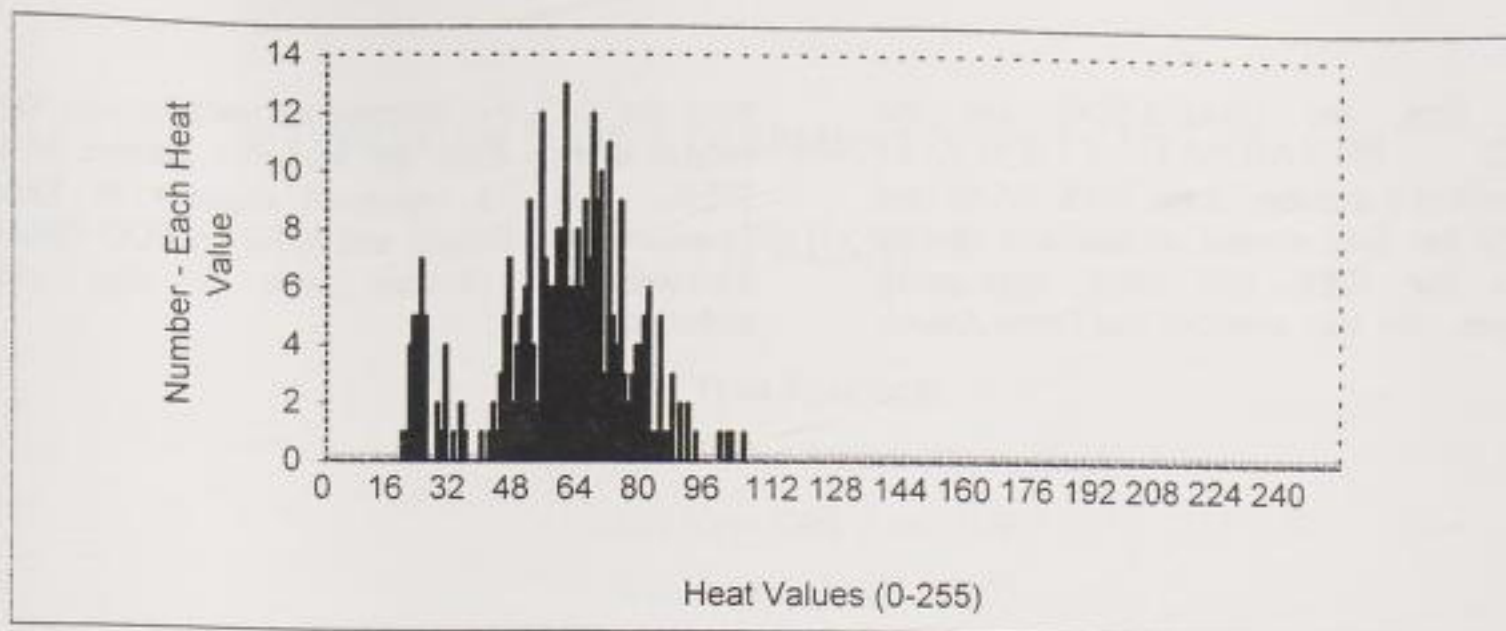


Fig. 2 - Histogram of heat values – 4997 ft. train westbound at 06:37 CT on North track at Mineral, IL, 12/14/77.

The final alarm limits had not been determined when the year's measurement period was over. However, the alarm for warm wheels had been raised to 3.5 deviation units above the mean. A recommendation was made to eventually raise the warm wheels alarm limit to 4.5 standard deviation units above the mean, after first trying limits of 4.0 and 4.25 standard deviation units above the mean.

The financial benefits of the system were impressive. Engineering estimated an internal rate of return of 1000% from eliminating false positives. The Comptroller's office calculated 675%. (Neither rate of return recognizes the benefits from improved supervision of local crews that were failing to release hand brakes when a car was removed from a siding.)

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REFERENCES

- [1] Anon., "Hot journal detection, the Rock tests a better way," *Employees' Newsletter, The Chicago, Rock Island and Pacific Railroad*, vol. 2, p. 2, Jan. 1978.
- [2] Anon., "The Rock tests electronic detection," *Progressive Railroading*, vol. 20, pp. 77-78, Nov. 1977.
- [3] H. P. Westman, Ed., *Reference Data for Radio Engineers*, 5th ed. Indianapolis, IN: Howard Sams, 1968, p. 45-19.

BIOGRAPHY

Dean Lance Smith was born in Detroit, Michigan on January 16, 1943. He received B.S.E.E., M.S.E.(E.E.), and Ph.D. (electrical engineering) degrees from The University of Michigan in Ann Arbor, MI.

Dr. Smith has taught and conducted research at The University of Michigan-Dearborn, Bradley University, Louisiana Tech University, the University of Houston, Memphis State University, Texas A&M University, Howard University, and Western Michigan University. He is currently an Assistant Professor of Engineering Technology at The University of Memphis. Dr. Smith has also worked for WCBN radio, the City of Detroit, several research laboratories of The University of Michigan, the Rock Island Railroad, his own engineering

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Dr. Smith is a member of the IEEE, ACM, and ASEE. He has held several section and chapter offices in the IEEE and other engineering organizations. He was awarded the Teetor Award

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