Railways 2014
The Second International Conference on Railway Technology:
Research, Development and Maintenance
Ajaccio, Corsica, France, 8-11 April 2014

UTPA
THE UNIVERSITY OF TEXAS-PAN AMERICAN

UNIVERSITY TRANSPORTATION CENTER FOR RAILWAY SAFETY

Field Implementation Statistical Analysis of an Emerging Bearing Health Monitoring System

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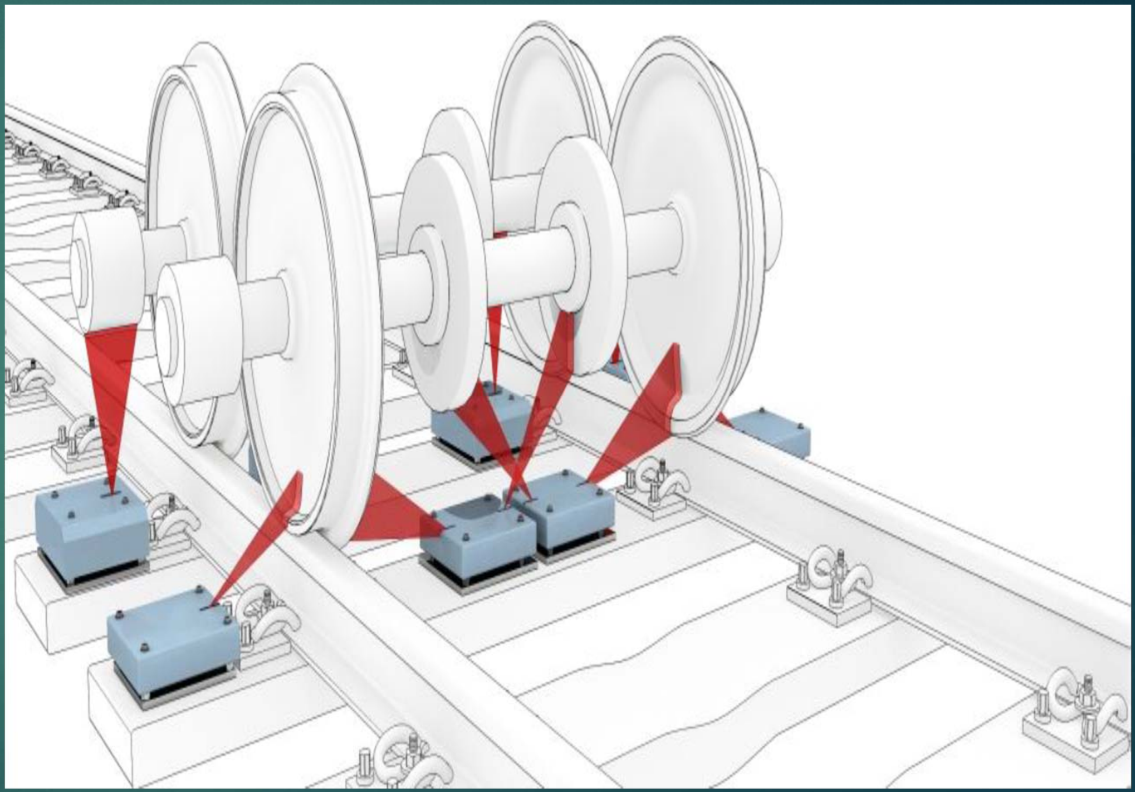
Abstract

- Current detection methods - Current wayside detection methods utilized for freight wagon bearing health monitoring do not constitute a true continuous bearing condition monitoring system.
- Onboard Sensor Technology - One such system uses battery-operated Wireless Sensor Nodes (WSNs) attached to the bearing adapters and managed by a Central Monitoring Unit (CMU).
- Problem - The main drawback of this system, however, is battery life.
- Attempted Solutions - the WSN-based system has undergone several optimization processes which include prototype redesign and reductions in the data sampling rate, frequency, storage, and upload in order to prolong the battery life of the WSNs and CMU.
- Objective - The main objective of the study presented here is to examine the effects of the latter factors on the developed WSN criteria in an attempt to determine the optimal parameters and thresholds that will provide uncompromised system accuracy while maximizing battery life.

Background

- Hot-box detectors - The railroad industry has predominantly relied on wayside hot box detection systems as the main method of bearing condition monitoring
- Trending detection - Some railroads have adopted a new practice of tracking the temperature data and comparing individual bearings against the averages of the remainder along a train.
- Non-verified bearings - A non-verified bearing is one that, upon disassembly and inspection, is found not to exhibit any of the commonly documented causes of bearing failure.
- Statistics - According to data collected by Amsted Rail from 2001 to 2007, an average of nearly 40% of bearing removals are non-verified.



Introduction

- UTPA Research - The University of Texas-Pan American (UTPA) Railroad Research Group in collaboration with Amsted Rail Industries Inc. have concentrated their research efforts on innovations in bearing health monitoring systems.
- WSNs - On this premise, it was decided that Wireless Sensor Nodes (WSNs) mounted on bearing adapters, shown in Figure 1, can monitor the bearing condition more frequently, and with better accuracy.
- SCT - To evaluate the efficacy of the developed WSNs as a continuous bearing condition monitoring system, a year-long field test was conducted in Australia as a collaborative effort between Amsted Rail Industries Inc. and SCT Logistics.
- Success (86,000 km) - In what proved to be a staggering validation of the developed algorithm, one of removed bearings failed on the test rig at just 86,000 km (53,438 mi).

Introduction(cont.)

- Current field tests – Two differing field tests:
  - 10 wagon (coal cars) – Temperature recorded every four minutes
  - 2 wagon (tank cars) – Temperature recorded every fifteen minutes
- Different operating conditions and systems – environment, load, speed, and cell phone coverage
- Objective
  - Identify minimum system requirements necessary for real-time monitoring of railroad bearing health

Criteria

- Levels - The three levels range in urgency from potential imminent failure requiring immediate attention.
  - Level 1 (AAR) - imminent failure requiring immediate attention
  - Level 2 - near- or mid-term (~3-6 months)
  - Level 3 - potential long-term (beyond 9 months)
- Criteria within levels
  - Overall temperature
  - Above ambient
  - Standard deviation vs. wagon
  - Standard deviation vs. fleet
  - Rate of temperature increase

Criteria(Table) - Thresholds

Level	Criteria	Metric
1	1	$T_i \geq 160^0C$ (320^0F)
	2	$\Delta T_i \geq 94.4^0C$ (170^0F)
	3	$T_i - T_{i,mate} \geq 58.3^0C$ (105^0F)
2	1	$\geq$ 25% of T_i readings $\geq 93.3^0C$ (200^0F)
	2	$\geq$ 25% of ΔT_i readings $\geq 66.7^0C$ (120^0F)
	3	$(T_{i,avg} - T_{wagon,avg})/\sigma_{wagon} \geq 1$
	4	$(T_{i,avg} - T_{fleet,avg})/\sigma_{fleet} \geq 1$
	5	$dT_i/dt \geq 0.694^0C/min$ ($1.25^0F/min$)
3	1	Count T_i readings $\geq 93.3^0C$ (200.0^0F)
	2	Count ΔT_i readings $\geq 66.7^0C$ (120.0^0F)
	3	Calculate $(T_{i,avg} - T_{wagon,avg})/\sigma_{wagon}$
	4	Calculate $(T_{i,avg} - T_{fleet,avg})/\sigma_{fleet}$
	5	Calculate dT_i/dt

Statistical analysis

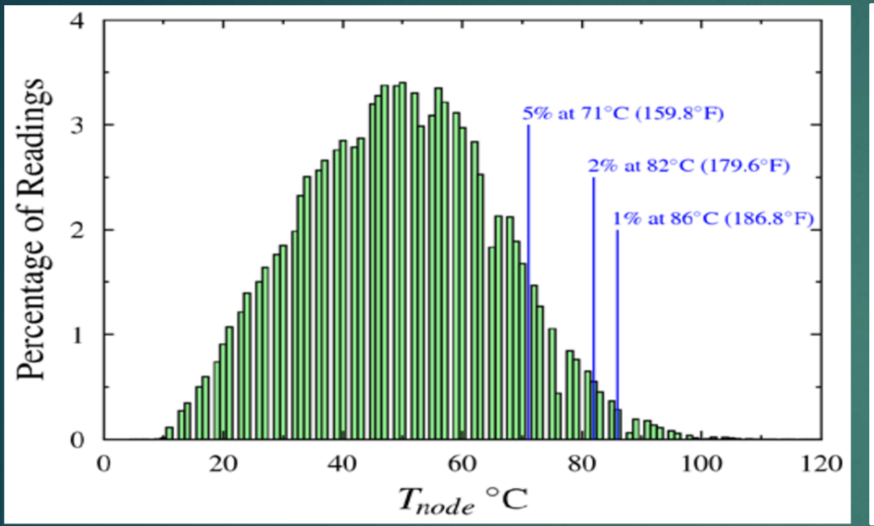
- Derivation - The thresholds used in the Level 2 criteria were obtained by preforming detailed statistical analyses on one full year worth of data acquired from the SCT Logistics field test in Australia and observing any statistical outliers.
- Differences in field tests
  - The two new ongoing field tests differ from the Australia trial in terms of the environment, bearing class, wagon type, operating conditions of the freight wagons which includes loading capacity and traveling speeds, and the programming of the WSNs and CMUs which is set to conserve battery life by reducing the data acquisition frequency.
- Statistical study - The statistical study presented here investigates the effects of the latter differences on the previously determined thresholds with the objective of optimizing and generalizing these thresholds for use in railroads across the globe.

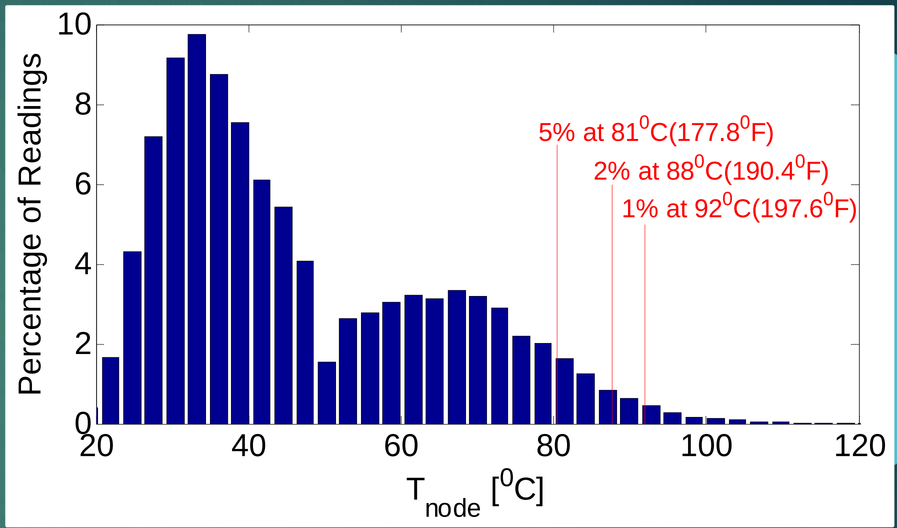
Number of temperature reports

Number of Temperature Reports per Wagon for each WSN (1 Year)									
	L1	R1	L2	R2	L3	R3	L4	R4	Ambient
WAGON 1	1070	1080	795	1035	1036	1080	1036	947	1036
WAGON 2	6002	6096	6162	32066	7676	16762	7678	6823	31972
WAGON 3	14832	15367	15008	15514	13777	14931	14931	14947	14789
WAGON 4	6602	13047	8462	11812	10945	13237	13237	13012	13129
WAGON 5	2948	2948	2948	3011	3092	3012	2883	2884	2883
WAGON 6	15290	15499	15239	93	16142	15740	14633	15976	15936
WAGON 7	6072	6017	6021	5980	5997	25895	6144	6116	25634
WAGON 8	12492	20935	25468	25685	6387	12092	6434	17489	25781
WAGON 9	15299	15328	15402	15722	15840	15805	15457	15330	15433
WAGON 10	11452	24106	11293	11483	11536	11594	11429	11419	24189

Statistical Analysis of Existing Thresholds on New Field Trials

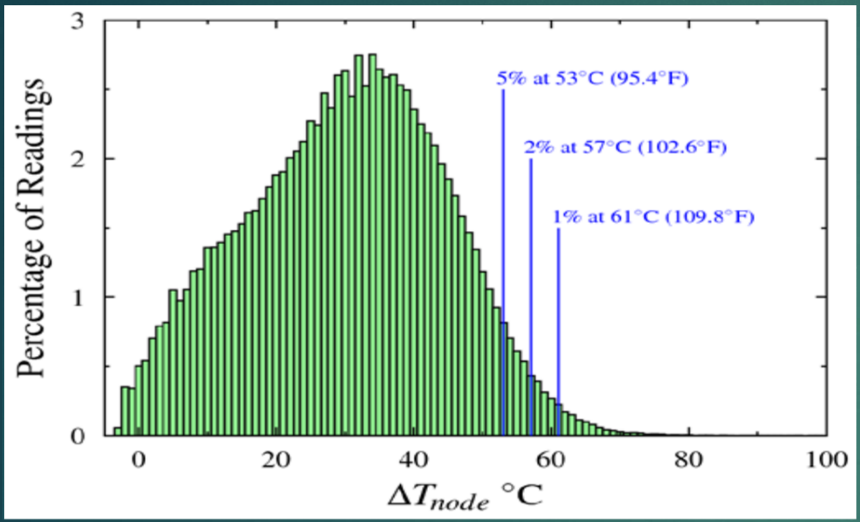
Overall temperature

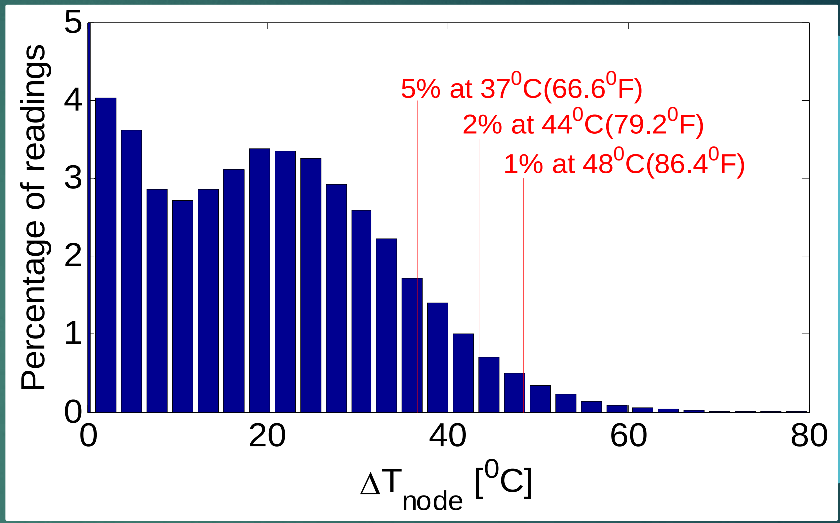




Cut-off	SCT Logistics Field Test	Ongoing Ten-Wagon Field Test
5%	71^0C (159.8^0F)	81^0C (177.8^0F)
2%	82^0C (179.6^0F)	88^0C (190.4^0F)
1%	86^0C (186.6^0F)	92^0C (197.6^0F)

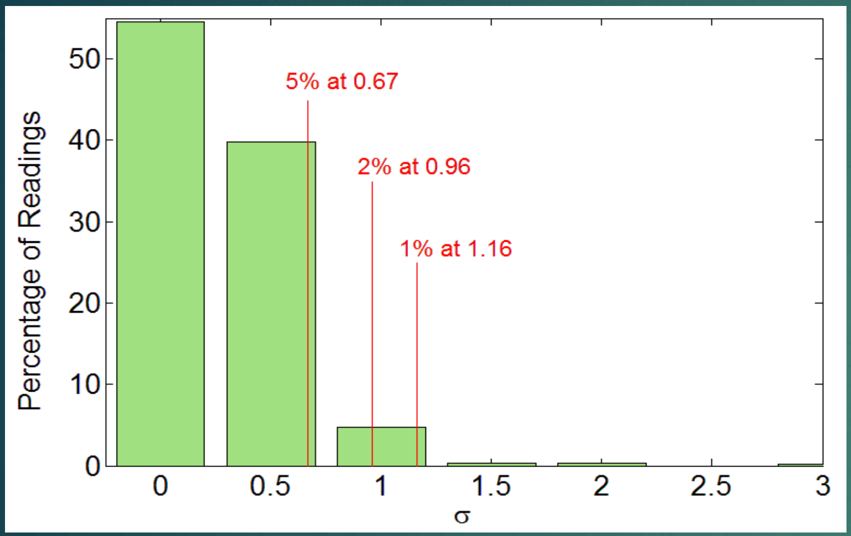
Above ambient

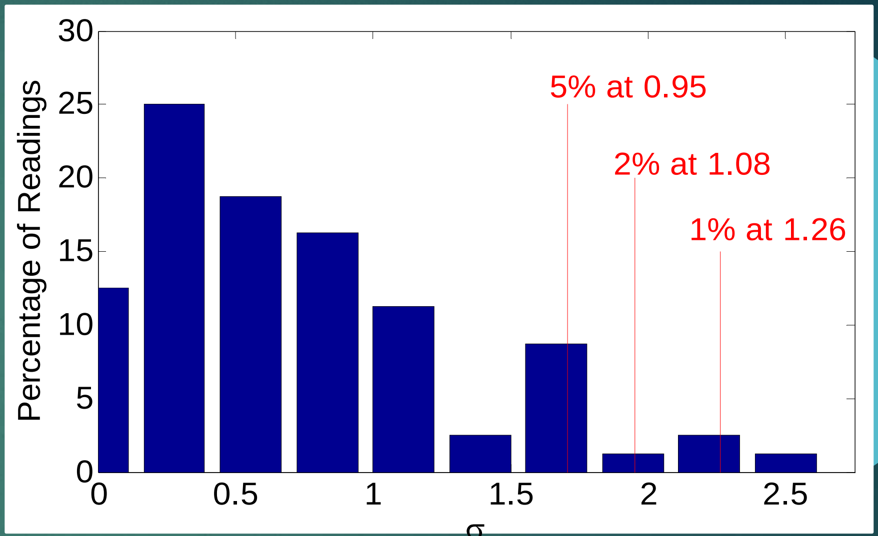




Cut-off	SCT Logistics Field Test	Ongoing Ten-Wagon Field Test
5%	53⁰C (95.4⁰F)	37⁰C (66.6⁰F)
2%	57⁰C (102.6⁰F)	44⁰C (79.2⁰F)
1%	61⁰C (109.8⁰F)	48⁰C (86.4⁰F)

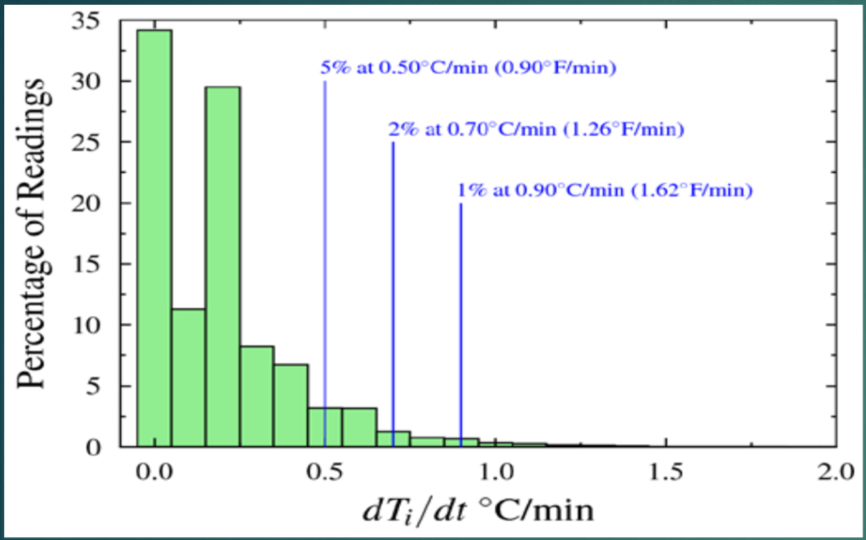
Standard deviation

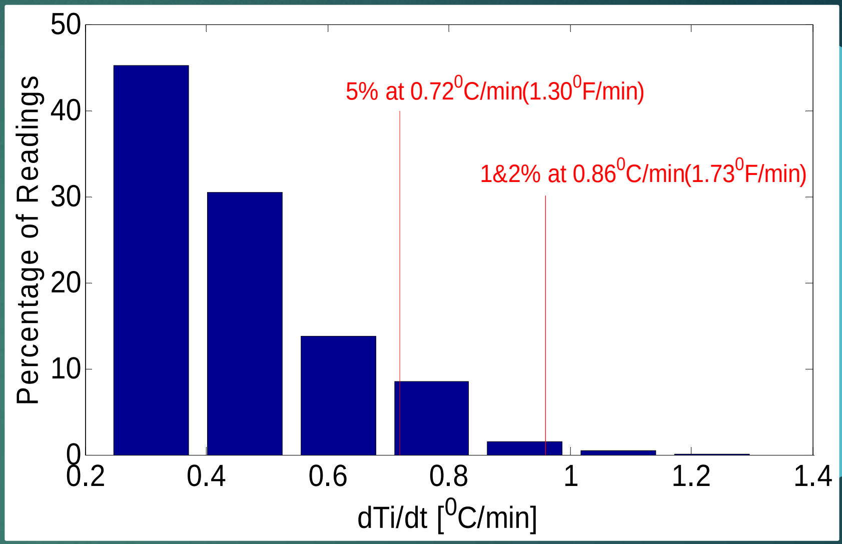




Cut-off	SCT Logistics Field Test	Ongoing Ten-Wagon Field Test
5%	0.67 σ	0.95 σ
2%	0.96 σ	1.08 σ
1%	1.16 σ	1.26 σ

Rate of temperature increase

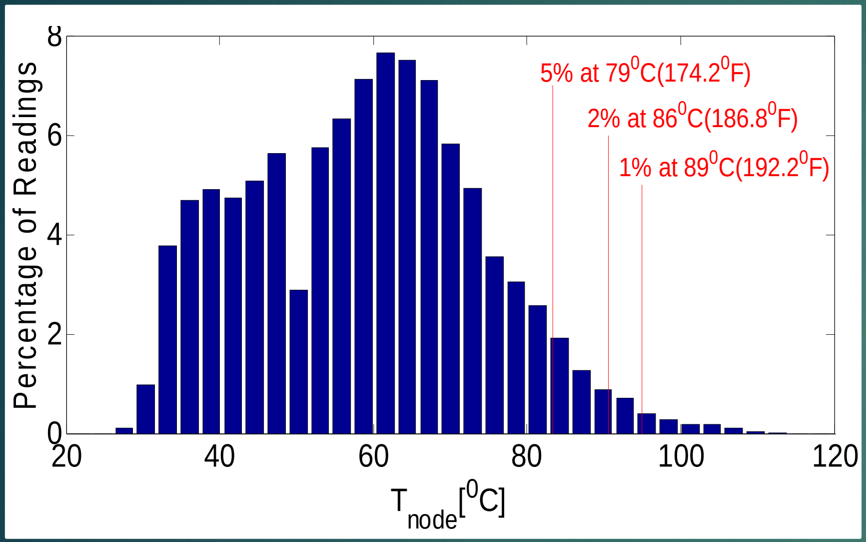


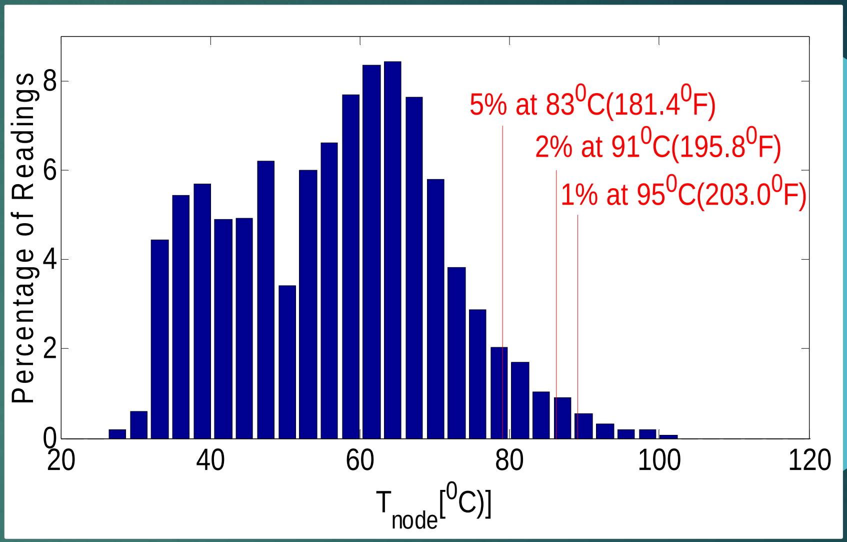


Cut-off	SCT Logistics Field Test	Ongoing Ten-Wagon Field Test
5%	0.50°C/min (0.90°F/min)	0.72°C/min (1.30°F/min)
2%	0.70°C/min (1.26°F/min)	0.96°C/min (1.73°F/min)
1%	0.90°C/min (1.62°F/min)	0.96°C/min (1.73°F/min)

Statistical Analysis of Devised Thresholds Over a 1 Month Period

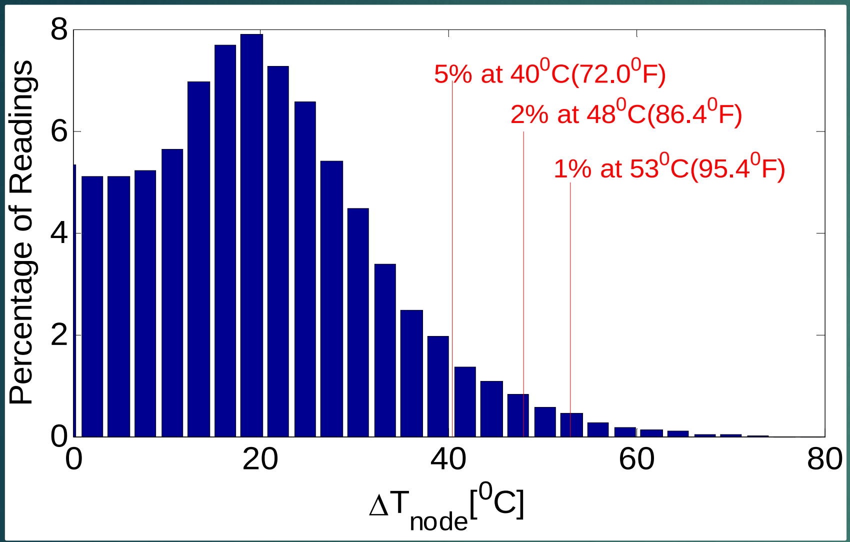
Overall temperature

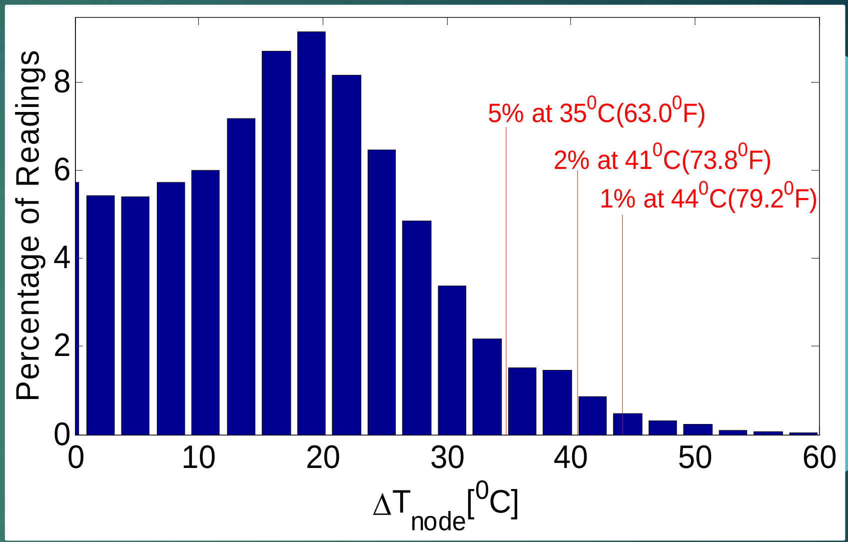




Cut-off	Ten-Wagon Fleet	Wagon 8
5%	79⁰C (174.2⁰F)	83⁰C (181.4⁰F)
2%	86⁰C (186.8⁰F)	91⁰C (195.8⁰F)
1%	89⁰C (192.2⁰F)	95⁰C (203.0⁰F)

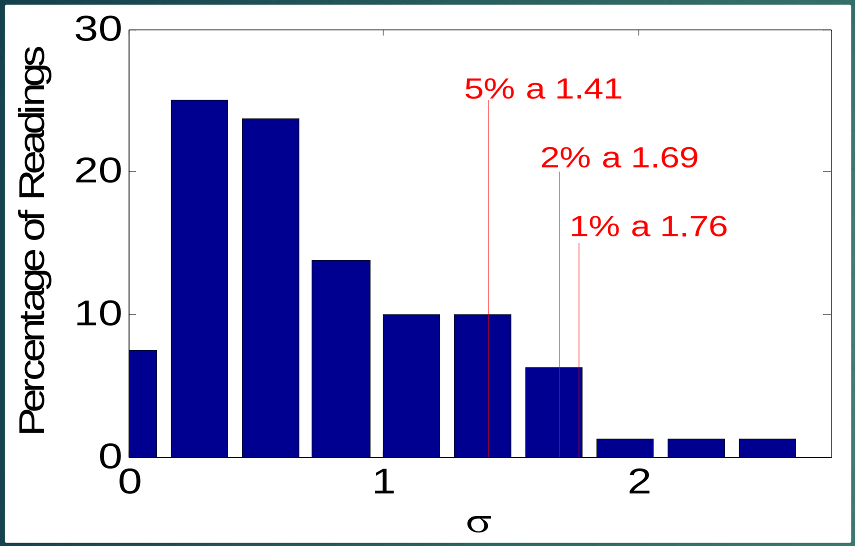
Above ambient

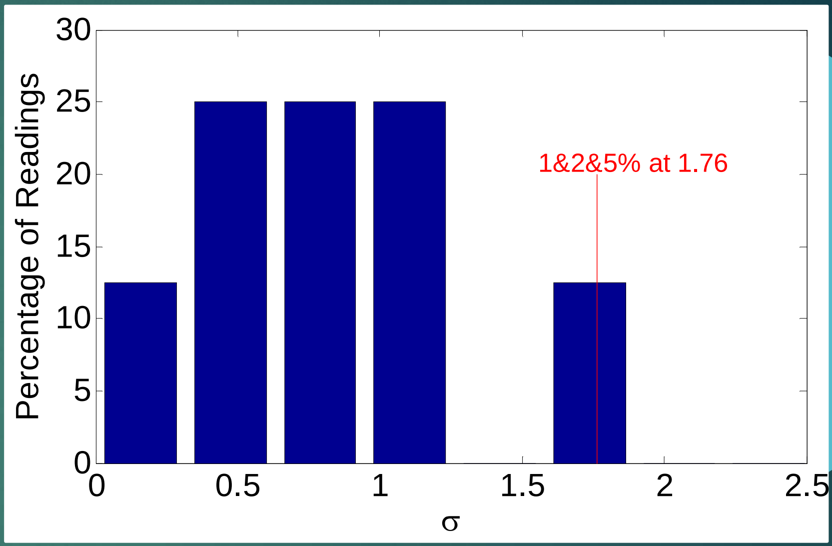




Cut-off	**Ten-Wagon Fleet**	**Wagon 8**
5%	40^0C (72.0^0F)	35^0C (63.0^0F)
2%	48^0C (86.4^0F)	41^0C (73.8^0F)
1%	53^0C (95.4^0F)	44^0C (79.2^0F)

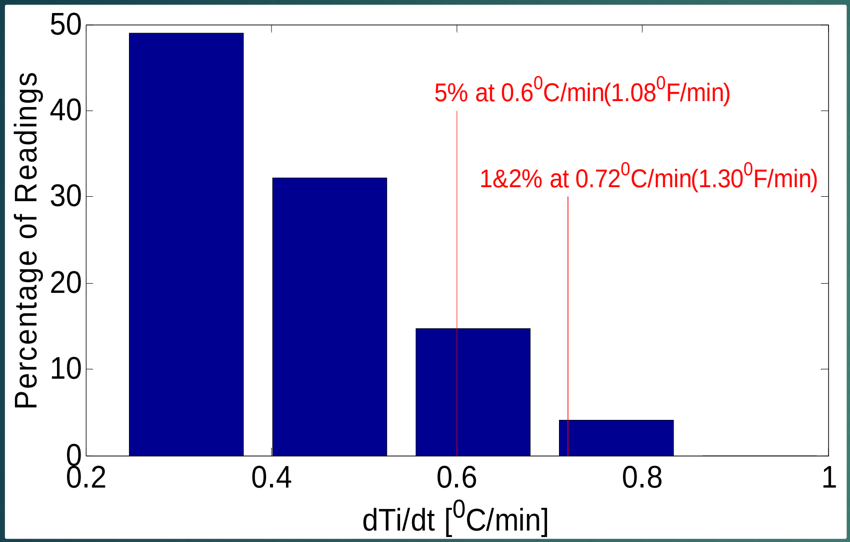
Standard deviation

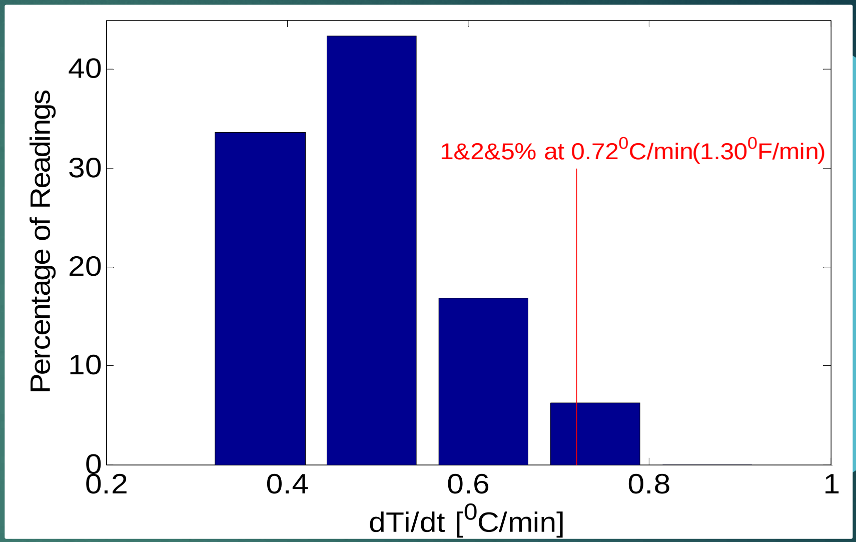




Cut-off	Ten-Wagon Fleet	Wagon 8
5%	1.41 σ	1.76 σ
2%	1.69 σ	1.76 σ
1%	1.76 σ	1.76 σ

Rate of temperature increase

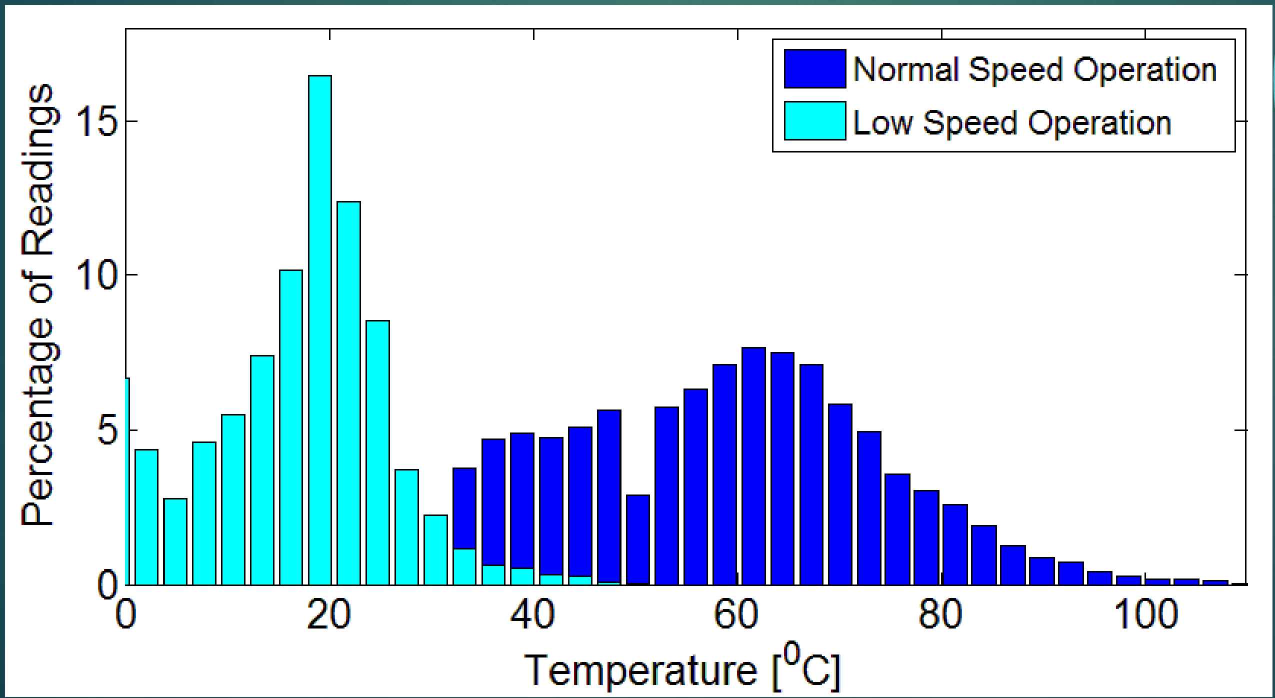




Cut-off	Ten-Wagon Fleet	Wagon 8
5%	0.60°C/min (1.08°F/min)	0.72°C/min (1.30°F/min)
2%	0.72°C/min (1.30°F/min)	0.72°C/min (1.30°F/min)
1%	0.72°C/min (1.30°F/min)	0.72°C/min (1.30°F/min)

Analysis of Results

- Changes in thresholds
- Effects of speed on temperature distribution



Conclusions

- Three field tests - One year worth of data was collected for each of the three field tests beginning with the SCT Logistics field test carried out in Australia.
- Thresholds - Specific threshold values were carefully selected to go with the devised criteria based on the data analysis performed on the SCT Logistics field test.
- Battery life - The statistical analysis provided here suggests that both objectives were met as the criteria and thresholds previously established seem to hold true, in general, regardless of the measures implemented to conserve WSN and CMU battery life.

Recommendations

- Threshold alterations - While the first two criteria, overall temperature and temperature above ambient, seem to be applicable for all field-tested operating conditions, a strong argument can be made to slightly modify the thresholds used in the remaining three criteria. The standard deviation (σ) Criteria 3 and 4 can benefit from increasing the threshold from 1σ to 1.25σ or 1.5σ to account for harsh service operating conditions. For the same reason, the rate of temperature increase Criteria 5 can be increased from $0.694^{0}C/min$ ($1.25^{0}F/min$) to $0.944^{0}C/min$ ($1.7^{0}F/min$).
- Requirements for meaningful analysis - The minimum requirements are: (1) number of acquired data points should not be less than 4000 per wagon, (2) number of WSNs reporting should not be less than 5 nodes per wagon, (3) ambient temperature should be available at all times, and (4) sampling frequency should not be less than one sample every four minutes.

Recommendations

- Trade-offs - It is ultimately left to the end-user to establish appropriate thresholds that are in line with their specific service operating conditions. It is estimated that the measures taken to prolong WSN and CMU battery life will result in an increase in the battery life from 2-3 years to 4-5 years depending on the reporting frequency, cell-phone coverage reliability, and environmental factors.

Acknowledgments

Special thanks to Amsted Rail's asset monitoring division, IONX, LLC, for providing us the opportunity to work on this project and to Amsted Rail for funding the research.

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Questions?