4A.2 ANALYSIS OF WEATHER EVENTS ON U.S RAILROADS

Michael A. Rossetti*

Volpe National Transportation Systems Center, Cambridge, MA

1. BACKGROUND

Weather conditions exert a major influence on U.S. railroads. These conditions may affect operating efficiency, physical infrastructure, and the safe passage of freight and people. Railroad companies operate within a variety of meteorological conditions, some of which are particularly problematic for rail transportation. These also have significant seasonal and time-of-day components. Precipitation and fog lead to decreased visibility of signals, flash floods can wash out tracks, and excessive heat can warp tracks. Crosswinds can reduce stability or lead to blow-over of railcars. Snow and ice may cause regional delays or shutdowns. Serious problems can also result from preexisting accumulations of rain, ice and snow not associated with current weather conditions.

Over 140,000 miles of railroad track comprise the U.S network. Railroads account for about 28-percent of total ton-miles of U.S. freight shipments, second only to trucking. There are now seven major freight railroads and one intercity passenger railroad. Line-haul railroads primarily transport cargo over a long distance within a rail network. They provide for the intercity movement of trains between the terminals and stations on main and branch lines of a line-haul rail network. Short line railroads transport cargo over a short distance on local rail lines, and are not part of a rail network. Local operations may result in lower overall exposure to adverse weather. Based on data derived from Federal Railroad Administration (FRA) statistics, there were at least 861 railroad incidents associated with existing or pre-existing weather conditions over the period 1995-2005.

Despite the growing availability and sophistication of weather information and introduction of new technologies, adverse weather conditions continue to cause problems for operators. Weather phenomena present many real-time and forecast problems that challenge the abilities of railroad operators and crews to confront, recover from, avoid and communicate specific weather hazards. Some hazards impact railroads by geographic areas, by time-day, or by seasonal factors, while others present more general exposure problems. Accordingly, reducing weather effects on the railroad system have potential benefits, primarily through the prevention of injuries and fatalities, and reduction in economic damages realizable from the better weather information to support railroad decision-making.

2. DATA ISSUES

This analysis examines records from the FRA Railroad Accident and Incident Reporting System (RAIRS) database for the period 1995-2005. The RAIRS exists to provide the FRA with accurate information concerning the hazards and risks that exist on the Nation's railroads. RAIRS statistics tend to understate or obscure the true impact of weather as a causal factor in railroad incidents and accidents. Fields are sometimes miscoded or they contradict other data in the record, or the person filling out the accident form may report the proximate cause as something other than weather. Moreover, unless there is a reportable incident or accident, RAIRS data do not reflect the impact on railroads of weather events such as mesoscale winter storms or major floods that result in regional service interruptions or shutdowns of rail infrastructure.

The RAIRS database is comprised of 356 unique cause codes, of which over 70 are track-related. These are further distributed into primary and secondary causes. Fifteen cause codes bear directly or indirectly on weather. This paper is based on a review of over 40,000 records which, through a process of filtering, validation and evaluation, led to the final list of 861 records deemed weather-related. Certain extraneous fields from RAIRS were eliminated, others were regrouped, and several new fields added. Analysis of narrative information in each record enabled validation of the final list selected for this paper.

These adjustments allowed a more accurate representation of weather and environmental conditions on accidents and incidents. Results are compared to the initial consequence or type of accident (e.g., derailment, collision, etc), and secondary consequences such as fatalities, injuries, economic damage, and the release of hazardous materials. Table 1 gives the final recoded list of weather events employed in this study.

* Corresponding author address: Michael A. Rossetti, RTV-4A, Volpe National Transportation Systems Center, 55 Broadway, Cambridge, MA 02142: e-mail: rossetti@volpe.dot.gov.

Table 1. Categorization of rail weather events.

Liquid Precipitation (LP)	Current LP
	Antecedent LP
Frozen Precipitation (FP)	Current FP
	Antecedent FP
Wind Velocity	
Temperature Extremes	Heat
	Cold
	Variation
Fog	
Slides (snow, mud, rock)	
Frozen Load	
Lightning	
Other	

Note: see Table 3 for descriptions

3. CAUSES, CONSEQUENCES, AND RISK FACTORS

As shown in Table 2, derailments are the initial consequence in about 75-percent of all weather-related railroad accidents and incidents. Over half of all such derailments were most closely associated with extreme heat, antecedent rainfall, and antecedent snow and ice conditions. The derailments also generated more fatalities, injuries, hazmat releases and evacuations than other types of accidents. Collisions are less common than derailments. They include head-on, rear end, side impact, raking, and grade-crossing accidents. High winds, fog, and preexisting accumulations of snow and ice are among the most common weather-related causes of collision events. Obstruction type events result in rail track being blocked by debris from rock slides, mudslides, avalanches, fallen trees and similar objects. Obstructions such as these are most often associated with weather-induced slides and high winds.

Table 2 also provides a distribution of rail weather events by type of accident. It should be noted that these are not mutually exclusive; other weather conditions may have existed at the time of the accident, and discriminating their individual effects may be difficult at times. Temperature extremes and temperature variability are the most frequently seen (about 25 percent of all records) weather-related cause of accidents in the database, especially those associated with high heat. Temperature driven events also exhibit some of the highest values for average damages. Fast moving trains traversing tracks that are kinked, misaligned or broken have the potential to derail many railcars. The next most common cause of these accidents was liquid precipitation, in particular those reportable events associated with antecedent rains, flooding, or runoffs that create soft and saturated roadbeds or that produce washouts that undermine tracks and switching equipment. Accidents associated with high winds and frozen precipitation also ranked high in the database.

Figure 1 illustrates how rail accidents are influenced by the seasonal effects of weather. The graph shows the total number of weather related accidents by month along with the most frequent type of causal event by month. There are two annual peaks; one in January and another in July. During the winter months of December through March, the highest accident numbers arose from preexisting snow and ice conditions such as buildups that cause malfunctioning switches and derailments. Accidents during the summer months of June, July, and August are predominantly caused by high temperatures. Transitional months such as April, September, and October have some of the lowest numbers of overall accidents, but show rain and saturated ground as the leading cause of those accidents that do occur.

Figure 2 shows the distribution of accidents by time of day. Similar to seasonal effects, some typically expected patterns emerge. From early afternoon through 4:00 PM, extremes of heat cause the greatest number of events, with the overall daily peak for all accidents occurring at 3:00 PM (whether this indicates greater risk or is simply a mirror of traffic volume requires further investigation). From very late afternoon through 9:00 PM, high winds emerge as the leading cause of rail accidents. This probably reflects convectively driven wind activity that follows the period of maximum daytime heating. From late evening through the early morning hours, the total number or accidents drops off, with some of their leading causes becoming antecedent snow and ice or rain.

Rains, Floods and Saturated Soil - High waters from flash floods, river floods, persistent heavy rains, and hurricanes have historically been one of the most prominent weather-related concerns facing the railroad industry, as well as the nation as a whole. Floods annually produce some of the largest amounts of economic damage and fatalities. The Midwestern river floods of 1993 devastated railways, with over 4,000 miles of track either flooded or idled and over $200 million in estimated losses (Changnon, 2006).

Washouts caused by runoffs from earlier heavy rains or rising waters have the potential to weaken bridge trestles, undermine ballast, and cause collapsed culverts. Derailments and spills can then occur when the roadbed or bridge gives out.
Snowmelt causes similar saturation problems by removing ballast, making soft roadbeds. Deteriorated ties further increase these risks.

Table 2. Weather related railroad accidents and incidents by primary and secondary consequences, 1995-2005.

Initial Consequence		Secondary Consequences						
				Railcars carrying hazmat				
Accident Type	Number	Fatalities	Injuries	Total number	Damaged or derailed	Released hazmat	Number of people evacuated	Total Damages (current $)***
Derailment	660	6	1,223	1,227	289	54	4,147	$163,588,208
Collision (all types)*	46	4	10	43	6	1	0	$6,913,096
Obstruction	46	0	4	19	0	0	0	$3,586,681
Fire/violent eruption	1	0	3	0	0	0	0	$35,000
Other**	108	0	2	88	18	2	0	$8,726,050
Totals	861	10	1,242	1,377	313	57	4,147	$182,849,035

* *Includes head-on, rear end, raking, side, and grade crossing accidents and incidents*

** *Accidents often miscoded, includes derailments, collisions, and grade crossing incidents*

*** *Includes damages to equipment, tracks, signals, ways, and structures*

Table 3. Railroad weather-related accidents and incidents, fatalities, injuries and damages, 1995- 2005.

Weather Condition		Wx Accidents and Incidents		Fatalities		Injuries		Damages		
		Total	Percent	Total	Percent	Total	Percent	Sum	Percent	Average
Liquid Precipitation (LP)	Current LP	32	3.7%	--	--	7	0.6%	$4,809,881	2.6%	$150,309
	Antecedent LP	167	19.4%	--	--	10	0.8%	$43,199,342	23.6%	$258,679
Frozen Precipitation (FP)	Current FP	21	2.4%	--	--	1	0.1%	$2,338,509	1.3%	$111,358
	Antecedent FP	139	16.1%	--	--	11	0.9%	$11,985,711	6.6%	$86,228
Wind Velocity		180	20.9%	--	--	3	0.2%	$31,936,667	17.5%	$177,426
Temperature Extremes	Heat	196	22.8%	1	10.0%	41	3.3%	$58,351,574	31.9%	$297,712
	Cold	13	1.5%	--	--	--	--	$1,516,766	0.8%	$116,674
	Variation	16	1.9%	5	50.0%	1,132	91.1%	$9,688,834	5.3%	$605,552
Fog		22	2.6%	3	30.0%	6	0.5%	$7,790,640	4.3%	$354,120
Slides (snow, mud, rock)		43	5.0%	--	--	9	0.7%	$8,558,048	4.7%	$199,024
Frozen Load		10	1.2%	--	--	1	0.1%	$430,596	0.2%	$43,060
Lightning		4	0.5%	--	--	--	--	$187,152	0.1%	$46,788
Other		18	2.1%	1	10.0%	21	1.7%	$2,055,315	1.1%	$114,184
TOTALS		861	100.0%	10	100.0%	1,242	100.0%	$182,849,035	100.0%	$212,573

Notes:
'Fatalities" ranking based on injuries due to damage from flooding, snow, ice and mud on tracks, and high wind speeds.
"Injuries" ranking based on injuries due to damage from flooding, snow, ice and mud on tracks, and high wind speeds.
"Liquid Precipitation" due to storms and hurricanes may cause flooding and earth movement that results in partial or complete washout of track beds. Antecedent means pre-existing weather conditions caused or contributed to the accident or incident.
"Frozen Precipitation" from winter storms collects on the tracks and causes mainly derailments. Antecedent means pre-existing weather conditions caused or contributed to the accident or incident.
"Wind Velocity" from severe winter or summer storms or in some cases winds generated by frontal passage results in mainly derailments and a significant amount of other accident events.
"Temperature Extremes" refer to sunkinks, thermal expansion of track or catennaries, brittle track, uneven thermal expansion or contraction, or other temperature-induced influences on the accident or incident.
"Slides" refer to weather-induced slides of snow, mud and rock that caused or contributed to the accident or incident.
"Fog" from impaired visibility caused by various types of fog.
"Frozen Load" refers to load imbalances caused by freezing in cold weather conditions.
"Lightning" refers to lightning strikes to trains or infrastructure.
"Other" refers to all other weather-related accidents and incidents, e.g., collisions between snow plows and rail cars.
Source: Adapted from the US DOT/Federal Railroad Adminstration, Railroad Accident and Incident Reporting System (RAIRS), 1995-2005.

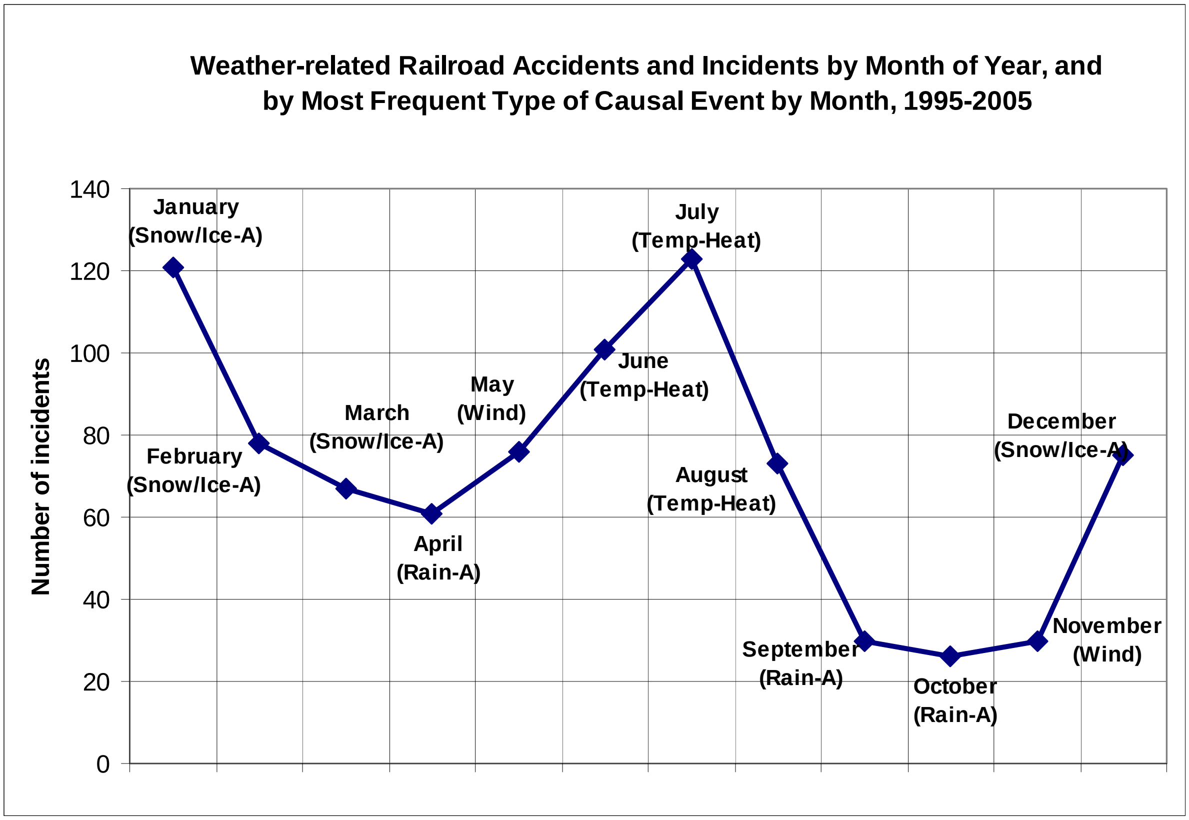

Figure 1

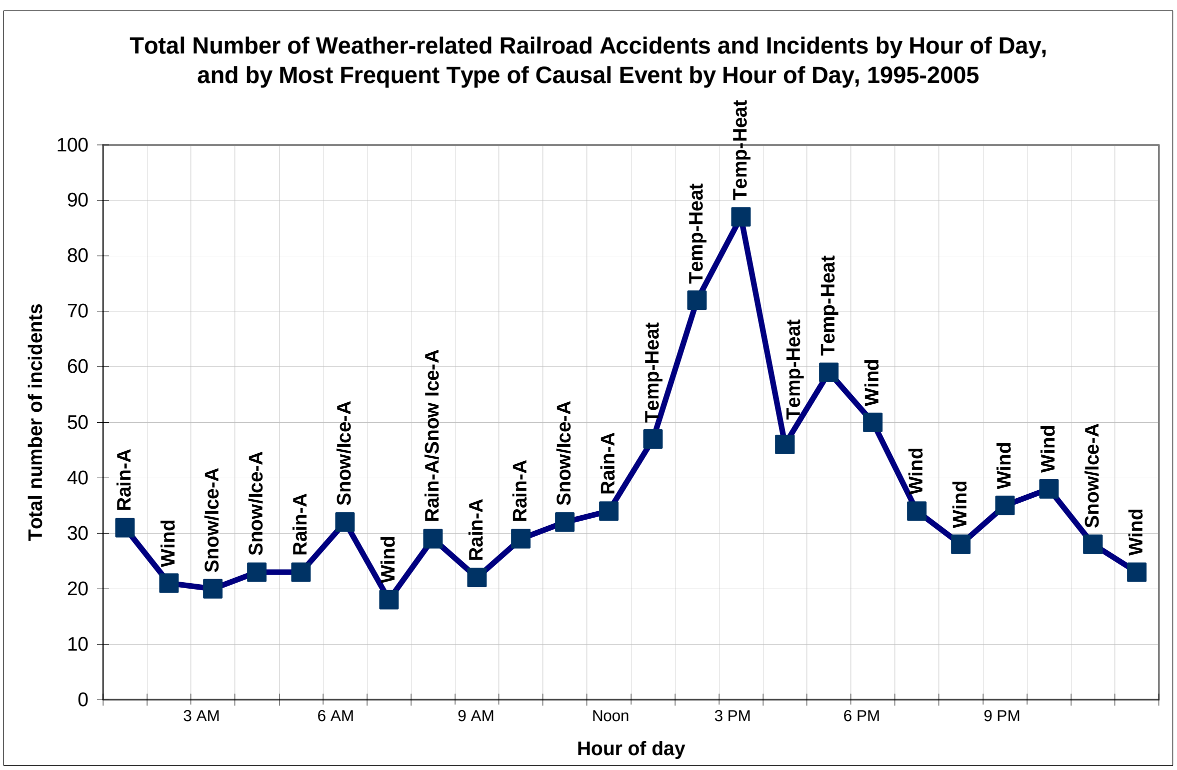

Figure 2

Landfalling hurricanes directly impact rail freight shipments at the local and regional levels. Their winds, intense rainfall, and storm surges pose safety risks, damage railcars and infrastructure, and cause temporary rerouting and suspension of operations. An approaching hurricane with the threat of storm surge requires the monitoring of bridges and low areas for indications of high water, wash-outs, or track debris that may affect service. In 2005, Hurricane Katrina devastated the supply chain through the port of New Orleans, resulting in national and international level impacts.

Snow and Ice - Across the eastern seaboard, the intermountain states and northern tier of the U.S., severe winter storms sometimes disrupt the entire transportation system. Railroad operations degrade in such conditions, due to lowered visibility, icing, snowdrifts, and cold temperatures. Due to exposure, ice buildups occur on overhead electrical catenaries.
Pieces of ice hanging from catenaries pose a risk of impact damage to pantographs

Snow and ice accumulations can occur in rail switches, brake riggings, track flangeways, and grade crossings, thereby reducing control and increasing the risk of derailments and other types of incidents. The wheels of locomotives and rails cars are at risk for slipping, sliding and loss of control on tracks coated with ice or frost.

Winter storms also adversely affect rail in an indirect way – by preventing producers of goods from shipping to intermodal terminals or delivering goods to rail sidings, causing freight traffic to become backlogged and trains being run at less than full economic efficiency. Either an actual event or the forecast of an impending storm can result in scheduling problems, rerouting of shipments, shutdowns of rail track, and discontinuance of services for hours and days. Train crews may become stranded, unable to reach rail yards. Infrastructure can be knocked out-of-service due to ice damage, downed power lines over tracks, and signal system damage.

High Winds, Thunderstorms and Tornadoes - High winds can be one of the most disruptive weather events for rail. High profile railcars are susceptible to potential rollovers and derailments from crosswinds in exposed areas such as mountain notches and the front ranges of mountains. Lightly loaded or empty hopper cars are particularly vulnerable. Wind induced accidents and derailments can occur whether the railcars are part of a train in motion or are stationary. Because of their exposure to weather in nearly all directions in parts of the Midwest and Western U.S., train operators are often direct, in-line targets of mesoscale convective complexes and supercells.

Thunderstorm activity may degrade or harm rail operations through flash flooding of poor drainage areas, high winds associated with microbursts and squall lines, and impaired visibility. Lightning strikes may interfere with signal circuitry for electrically activated pneumatic operated switches. Lightning can also strike and break the lightning arrestor on catenaries, causing the arrestor to hang from the cable and foul the catenaries.

Temperature - Extremes and Variations – The temperature at which railroad track is laid or when repairs are made is referred to as the “rail neutral temperature.” Any significant deviation above or below this temperature may result in expansion or contraction in the steel rail. When exposed to the hot summer sun, railroad track temperatures may exceed 130° and occasionally develop heat kinks that may create a hazardous condition for oncoming traffic.

Thermal misalignments caused by sun induced kinks have often been identified as a cause of train derailments with the potential for injuries, fatalities, property damage, and release of hazardous materials. A kink that occurs at a rail joint can cause the joint to give way under the weight of the train. Thermal misalignment of railroad tracks may be further compounded by poor ballast condition or a soft roadbed. A lead locomotive or railcars may derail when high heat causes a switch to open up, forcing the train up and over the switch Extreme heat may also produce misalignment and slack, as well as damage to catenaries and pantographs.

Similarly, extreme cold may produce brittle tracks and separated or broken rail. Cold temperatures may also result in frozen air lines, when moisture present in the distal part of the line cannot be dislodged by heat from the locomotive.

Uneven or rapid variations in temperature present similar problems. Tracks exposed to uneven thermal expansion – e.g., when shade covers sections of rail near a point of high solar radiation – also pose the risk of warp and misalignment. Greater day to day temperature variations may increase track maintenance requirements. Especially in springtime, these temperature variations may result in more rapid changes in the thermal stresses in continuously welded rail, and thus more incidences of buckled track. When occurring in the winter, temperature variations may result in more freeze-thaw cycles, which have the cumulative effect of degrading track surface, especially in areas with a high water table and silty soils, such as the Midwest and upper Great Plains.

Slides of Snow, Mud, and Rocks - Slides can threaten the safety and efficiency of railroad operations. Slide mitigation planning and implementation requires the development of warnings that allow trains to safely stop in advance of a hazard. For heavy freight trains or faster passenger trains on descending grades, stopping distances are often between one and two miles. Furthermore, there are relatively few alternative railroad routes in some parts of the country, and the detour distances for accessing these may be hundreds of miles long.

Ground movements caused by heavy rains, freeze-thaw cycles, tremors and other factors, in canyons or mountainous areas, can dislodge large boulders or large fields of rocks. These may derail a train in motion, or block tracks and cause significant delays or damages.

4. RAILROAD RESPONSES TO ADVERSE WEATHER

When faced with weather conditions that have the potential to disrupt operations, railroads rely on a mix of procedures, professional judgment, and technologies. Companies obtain weather information from in-house meteorologists, the National Weather Service, private sector providers, and direct reports from trains experiencing adverse conditions.

Company Operating Procedures - General weather responses include advising and updating dispatch centers, crews, and stations. Operators may modify operations to forecast conditions and plan for rerouting, slowing, stopping or delayed departures. Companies inspect and repair tracks as necessary, distribute weather advisories and updates and initiate crew recall or re-crew notification as needed. If freight involves hazardous materials, the operator initiates a spill reaction plan or mitigation plan.

The CSX railroad issues three levels of "winter weather alerts" as a reference for its customers, an indication of the expected severity of the storm and its impacts on operations. The three levels are:

1) substantial inclement weather conditions are being encountered (or are expected imminently) within the specified region. Scheduled service and traffic connections will be maintained as practical to the situation;
2) adverse weather conditions have affected the specified region. Local switching, scheduled service and normal traffic connections will be affected; and
3) adverse weather conditions have severely affected the specified region. Only critical trains will be operated. Trains will operate on straight moves and limit use of crossover moves to the extent practical. Local switching, scheduled service, and normal traffic connections will definitely be affected.

Many railroads publish operating instructions on how to deal with specific types of weather such as tornadoes. For example the following passage appears in the publications of several rail companies. "During a tornado warning, all train movements and yard activities must stop. Any train enroute will stop and employees should seek appropriate shelter consistent with the safety of all involved, avoiding the stopping of a train on a high bridge, across railroad and highway crossings at grade, or anywhere the presence of a train could be a hindrance…"

Sun kinks and thermal expansion of rails present a significant hazard during the summer months. Although exact standards vary by company, most have similar prescriptive language. CSX for example states that, "heat orders are issued when the forecast is for temperatures to be around 90 degrees. The effect is to reduce speeds of freight trains by 10 mph, but not lower than 30 mph, and to reduce the speed of passenger trains by 20 mph, but not lower than 40 mph. The intent is to increase the measure of safety in hot weather that might cause continuous welded rail to bend or kink as a way of relieving pressure."

Railroads rely on a number of meteorological thresholds, such as winds in excess of 55 mph, rainfall intensity, etc. Private sector weather services often work with the railroad to establish customized criteria that generate automatic warnings to operators. There do not appear to be any industry-wide standards, however, for weather conditions and prescribed actions.

Union Pacific Railroad maintains a network of weather stations at 264 locations along its rail corridors in the West. Data are part of the MesoWest mesonet, which also feeds the MADIS system. Most of the stations report temperature (to detect track contraction and expansion). Wind conditions are also reported at many critical locations.

Technological advances and opportunities - Railroads can be a consumer and producer of atmospheric and environmental data. Onboard sensors may one day prove useful as a data source for meteorological models and forecast decisions. Similarly, stationary sensors mounted in wayside bungalows and along track right-of-ways may provide meteorologists and railroad traffic managers with valuable, multipurpose observations from remote locations.

Advances in meteorology have led to advanced weather sensing technologies and also to improved forecasting capabilities. Railroad-specific smart systems, such as positive train control (PTC) technology, electronically controlled brakes, intelligent grade crossings, automatic equipment identification, and automated scheduling systems also facilitate the use of enhanced weather information. The FRA now encourages the railroad industry to implement these technologies as integrated systems, thus making more efficient use of communications lines, and achieving economies of scope in the deployment and integration of these systems.

Technologies, such as Runway Visual Range (RVR) developed for the aviation sector may also benefit railroads. Impaired visibility caused by fog conditions remains a critical safety problem for railroads. Nighttime saturation of air masses through lowland and mountainous terrain is a frequently a precursor to fog development that can result in reduced speed and increase the risks of accidents and incidents. RVR technology constitutes an effective means for providing a standardized, one-minute sampling means of accurately measuring visibility along airport runways. It could be adapted to serve similar applications along critical segments of railroad track by providing more accurate and timely visibility information to railroad operations centers, dispatchers, conductors and maintenance crews. It could also help management plan investment decision-making by offering targeted information on potential problem spots.

Dual polarization radar may also benefit railroads and other modes of surface transportation. Field applications and research have consistently demonstrated the principles and utility of dual polarization radar measurements for assessing the state of weather conditions during the last two decades. The technology has had dramatic impacts on the atmospheric sciences, and its practical utility for detecting and characterizing weather has led to a major initiative by the NWS and the FAA to modify the NEXRAD system to include this capability. Dual polarization radar measurements allow discrimination of hydrometeors (raindrops, snow crystals and hail) throughout a storm. Measurements enable the estimation of rainfall rates with excellent accuracy, the detection of hail size and intensity, and improved determination of cloud microphysics, storm evolution and storm dynamics, and other benefits. The radar provides valuable utility to surface modes of transportation.

Along with NEXRAD, even greater benefits would be possible from modifying the Terminal Doppler Weather Radar (TDWR) system. TDWR data have recently been integrated into the country's overall weather surveillance system. Modifying TDWR radars for improved weather surveillance could benefit rail transportation in regions where these radars are operational. A sample of benefits includes better measurement of reflectivity when heavy rainfall attenuates the radar wave, accurate measurement of rainfall rates and liquid water content, better detection of horizontal boundaries separating rainfall and snowfall regions, and improved estimation of snowfall intensity.

Intelligent Transportation Systems - The basic working model that the Federal Highway Administration (FHWA) has successfully set up provides potential guidance for railroad interests. The broad approach combines components of the Intelligent Transportation System (ITS) and advanced weather technologies focused on goals such as traffic safety, mobility and efficiency. It includes the development of partnerships such as the Clarus initiative, with collaborative activities among NOAA and other government agencies, industry and academia. The current suite of road weather technologies, such as maintenance decision support systems, road weather observation networks, and weather-sensitive traffic management strategies, supplies a core group of practical tools for timely utilization.

Clarus - An Integrated Observing System - Clarus is an initiative of the Federal Highway Administration to develop and demonstrate an integrated surface transportation weather observing, forecasting and data management system and to establish a partnership to create a Nationwide Surface Transportation Weather Observing and Forecasting System. The objective of Clarus is to provide information to all transportation managers and users to alleviate the effects of adverse weather (e.g., fatalities, injuries, property damage and delays).

The Clarus system will integrate the disparate set of observations from states' road weather information systems and environmental sensor systems, into a national forecasting and guidance resource available in near real-time. It will also support the network of railroad traffic that is often subject to adverse weather conditions. Table 4, for example, illustrates how selected Clarus data attributes may provide useful weather guidance to the railroad community.

5. CONCLUSIONS

Railroad operations are significantly impacted by many types of weather. These impacts present themselves through the RAIRS accident reports both as safety concerns and as precursors of delay throughout the transportation network. Weather-

Table 4. Potential uses of Clarus attributes by the railroad sector

	Clarus Attribute (real-time to 24h)	Relevance to Railroads

Atmospheric Observations	Skies (cloud cover)
	Air temperature (max/min last 6h, 24h)
	  Wind chill index
	  Heat index
	Atmospheric pressure/tendency
	Water vapor
	  Relative humidity
	  Dewpoint
	Wind
	  Direction
	  Speed
	  Gust
	Precipitation
	  Occurrence
	  Type
	  Rate
	  Amount (last 3h, 6h, 24h)
	Radiation
	  Short wave and long wave
	Visibility
	Air quality
	  Index
	  Ozone level
		• Important to high profile railcars and double-stacked container trains
		• Go/no-go decisions
		• Scheduling
		• Estimation of delays and risk associated with certain cargoes
		• Operational improvements, just-in-time delivery
		• Establishing thrresholds for standard operating procedures
		• Estimating the risk of thermal misalignments and sun kinks
		• Local and regional profiles of fog formation and other restrictions to visibility
		• Nowcasts for flash floods
		• Initiatization of dispersion and hydro models to predict movements from hazmat spills and plumes

Pavement Observations	Track
	  Condition (wetness)
	  Temperature
	  Ice thickness
	  Snow depth (road)
	  Snow depth (banks)
	  Snow depth (adjacent level)
	  Water depth (road)
	  Water depth (stream)
	  Subsurface temperature
	  Subsurface moisture
	  Obstructions (rock, mud, snow)
		• Estimation of trip times for hours of service calculation, deployement of human resources, and intermodal connections
		• Contingency plans
		• Scheduling, dispatching and routing
		• Landslides, snow slides, mudslides, rock fall, and debris flow are problem areas for freight

Hydro	Adjacent rivers, streams, lakes, coast)
	  Levels
	  Flow rate
	  Flood stage
	  Tide height
	  Wave height
		• Routing decisions due to closures and debris
		• Timing connections for intermodal transfers
		• Relocation of railcars and staging equipment
		• Estimates of height and times of river crests

Other	CBRN hazards Camera imagery/Satellite imagery Active weather watches/warnings Restrictions on speed or vehicle type Accident/construction reports	• Hazmat carrier restrictions • Routing and scheduling decisions

induced rail accidents produce a number of initial and secondary consequences, including derailments and collisions, fatalities, injuries, property damage, and evacuations.

In certain cases, such as the transportation of hazardous materials by rail, the data may understate the true potential risk from weather. Although major spills and releases of toxic materials are relatively rare events, the occurrence may produce catastrophic results under certain conditions. That is why more diligence is needed to address the accidents through strategic and tactical approaches and by the use of new technology.

Not all weather-related events appearing in the RAIRS data are equally addressable through current mitigation strategies, better forecasts, or enhanced technology. Some will have higher or immediate payoffs than others. The timing and content of weather information delivered to rail dispatchers and crews is an important determinant of its value in building situational awareness and a common operating picture for decision making.

From a railroad perspective, the ITS based mechanisms such as Clarus and companion technologies, can perhaps be more fully realized through a thorough identification and understanding of those geographic areas most prone to disruptions caused by severe weather. Although the RAIRS data base offers partial insight into these effects, the data are not always organized in ways that would help to identify the most productive weather-mitigation investments.

Finally the weather information issues and needs of the railroad community are not being articulated nearly as well as those on the highway side. As part of the supply chain, railroads play a critical role in the intermodal transportation of goods, and are the mode of choice for certain types of shipments. The meteorological community, including both the public and private sectors providers, should find new ways of engaging the industry in order to develop products and services to meet the operational and safety needs of railroads. Concurrent with improving the informatics of weather and its effects on railroad transportation, parallel efforts are needed to ensure that rail systems are minimally susceptible to the effects of weather. This entails that specifications for new technology should also incorporate high standards for reliability and durability of the equipment in line with its deployment and intended operating environment.

REFERENCES

Changnon, S.A. 2006: *Railroads and Weather*. Boston, MA: American Meteorological Society

USDOT: Federal Railroad Administration. Railroad Accident and Incident Reporting System (RAIRS), 1995-2005. [Available online at http://safetydata.fra.gov/office of safety]

National Center for Atmospheric Research. 2004. Enhancing Rail Car Blow-over Prediction and Mitigation. Boulder CO: NCAR.

Rossetti, M. 2002. Potential Impacts of Climate Change on Railroads. Prepared for the DOT Center for Climate Change and Environmental Forecasting. (2003) *The Potential Impacts of Climate Change on Transportation. Workshop*, October 1-2.