NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Networks: Blending and Integrating Data From Multiple Sources

Shawn Sheng, National Renewable Energy Laboratory

Jan Helsen, Vrije Universiteit Brussel/OWI-Lab

Wind Data North America Forum

March 13-15, 2017

Houston, Texas

NREL/PR-5000-68348

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Objectives

In this presentation, we will cover:

- Gathering data from turbines to provide full transparency for reporting purposes
- Validating human-entered data to eradicate errors
- Exploring data-enabled remaining useful life predictions
- Supervisory controls being used today.

Outline

- Problem Statement
- Gearbox Reliability Database
- Integration of Various Data Sources
- Concluding Remarks

GE 1.5-megawatt (MW) turbine at the National Wind Technology Center. *Photo by Lee Jay Fingersh, NREL 17245*

Problem Statement

Data Streams

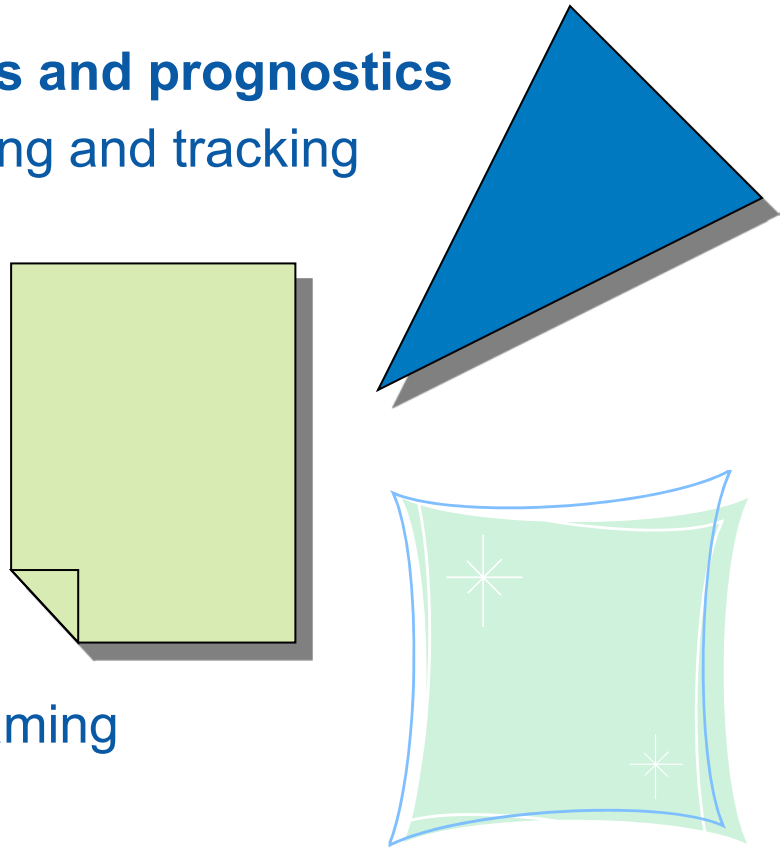
- A typical wind plant includes:
  - Supervisory control and data acquisition (SCADA)
  - Condition monitoring systems
  - Work orders
  - Inspection reports
  - Meteorological tower
  - Inventory
  - Finance
- A typical fleet includes:
  - Multiple turbine make models
  - Different SCADA and/or condition monitoring systems, communication protocols, and maintenance suppliers.

NM72 WTG wind turbines at TVIG's Kimball Windfarm installation. *NREL 12082*

1.5 MW GE wind turbine in Tehachapi, California. *Photo by Warren Gretz, NREL 11144*

Reporting Purposes and Challenges

- The purpose of reporting is to:
  - Assess performance
  - **Ensure reliability: diagnostics and prognostics**
  - Conduct maintenance scheduling and tracking
  - Ensure safety
  - Improve finance



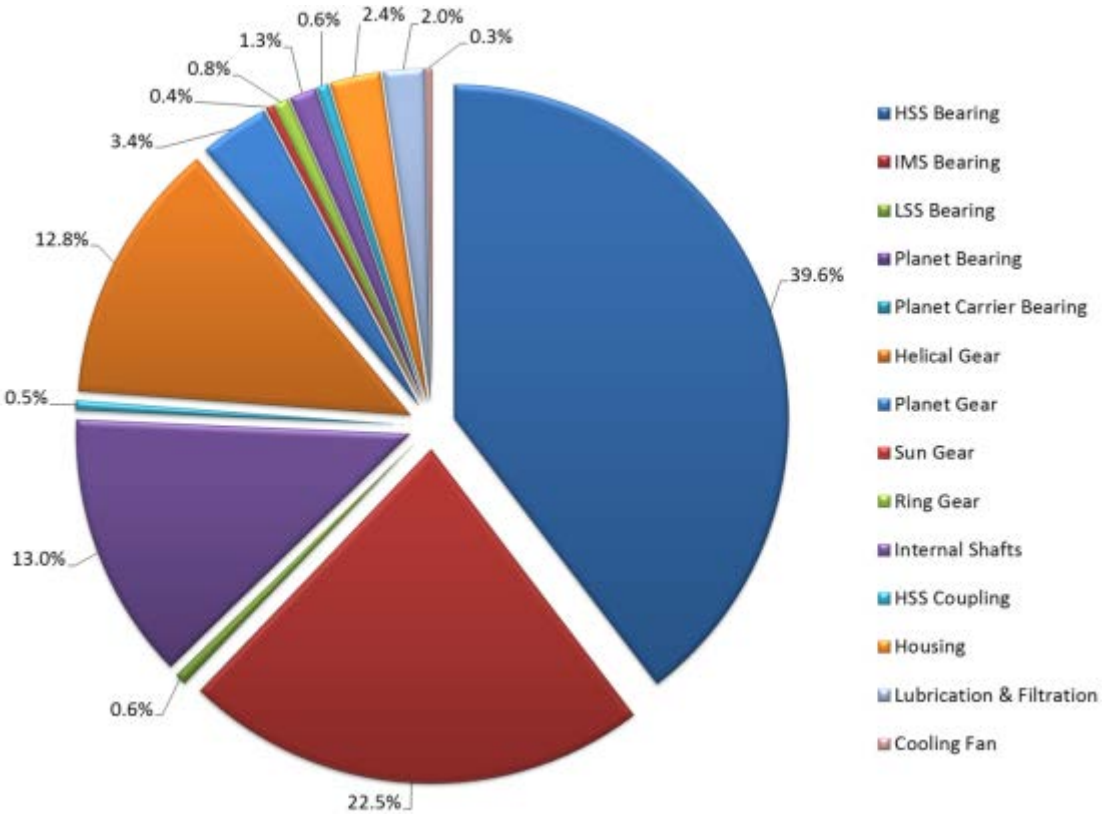
- Report challenges include:
  - Different formats of reporting
  - Various types of data
  - Inconsistent terminology/tag naming
  - Human errors, such as:
    - Manual data inputs
    - Lack of data validation
    - Time constraints when performing maintenance (downtime).

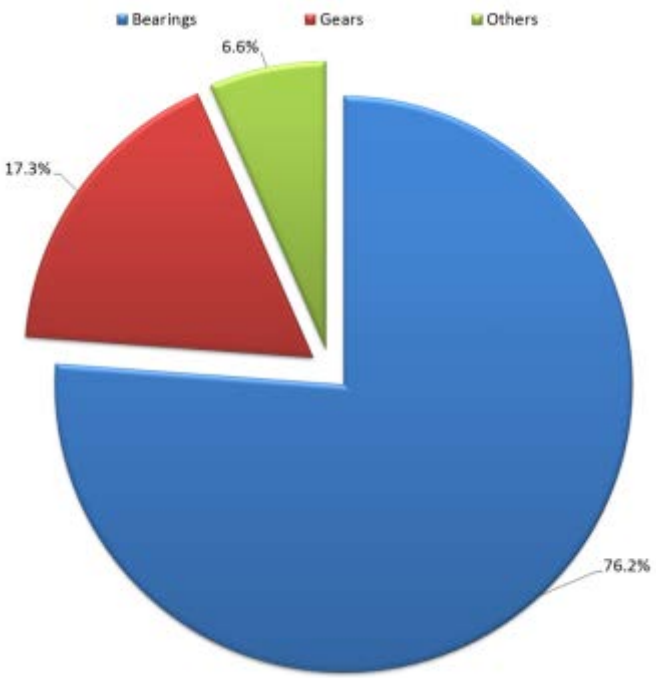
Other Considerations

- Offshore:
  - Maintenance driven by weather conditions → weather windows need to be used optimally
  - Meteorological predictions are essential → data source needs to be taken into account in data streams
  - Vessel availability for large replacements
- Both Land-based and Offshore:
  - Prognostics can help optimize the maintenance planning process
  - Accurate feedback is necessary for learning algorithms and alarm definition → failure documentation essential.

Photo courtesy of Jan Helsen

Valuable Statistics Enabled by Consistent Data Collection





The above charts were released December 30, 2016, and are based on ~1,050 damage records with confirmed components or locations:

- Bearings: 76.2%, dominated by high-speed-shaft and intermediate-shaft bearings
- Gears: 17.3%, dominated by helical gears
- Others: 6.6%, dominated by housing and the lubrication and filtration system
- Both bearing and gear faults are concentrated in the parallel section.

https://grd.nrel.gov/#/stats

Gearbox Reliability Database

An Example to Mitigate Reporting Challenges

- **Failure documentation: in-shop and field**
  - High-resolution photos
  - Embedded failure atlases
- Inconsistent terminology/tag naming
  - Data fields
  - Gearbox layout, gear, and bearing locations
  - Failure modes for both bearings and gears
- Human errors
  - Data inputs
  - Data validation.

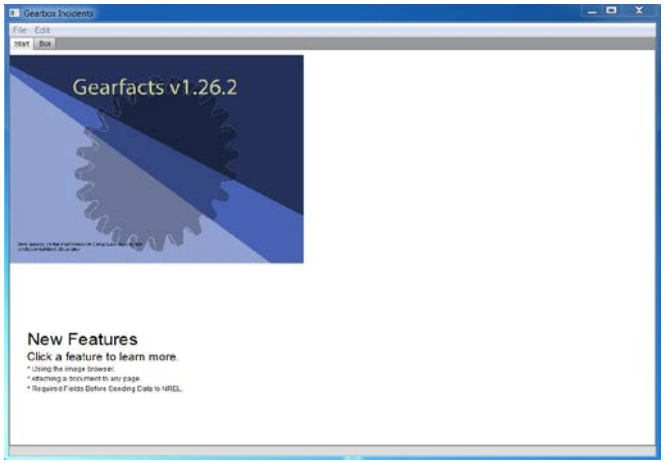
Gearbox Reliability Collaborative improved gearbox 3. *Photo by Jonathan Keller, NREL 36514*

Siemens 2.3-MW offshore wind turbine. *Photo by Paul Langrock Agentur Zenit, NREL 27853*

Data Fields

Wind Site Name
Wind Site State Province Region
Wind Site Country
WTG Make/Model
WTG Pad No.
WTG Total Run Hours Estimation
WTG Total Production kWh Estimation
WTG Type of Power Conversion
WTG Type of Generator
Gearbox Maker/Model
Gearbox Serial No.
Gearbox Originally New or Rebuilt
Install Date
Failure Date
Gearbox Run Hours Estimation
Gearbox Production Estimation (kWh)
Original Lubricant Type
Current Lubricant Type
Inline Filter Rating
Offline Filter Rating
How was Damage Detected
Dominant Failure (Worst) Location
Secondary Failure (Second Worst) Location
Dominant Failure (Worst) Mode
Secondary Failure (Second Worst) Mode
Corrective Actions
Other Drivetrain Component Failures Before This Damage
Other Drivetrain Component Failures After This Damage
Additional Notes

- **Defined based on typical failure analysis reports and feedback from project partners**
- **Incorporated in various data collection tools**



Stand-alone software

Web interface

Gearbox Layout and Gears

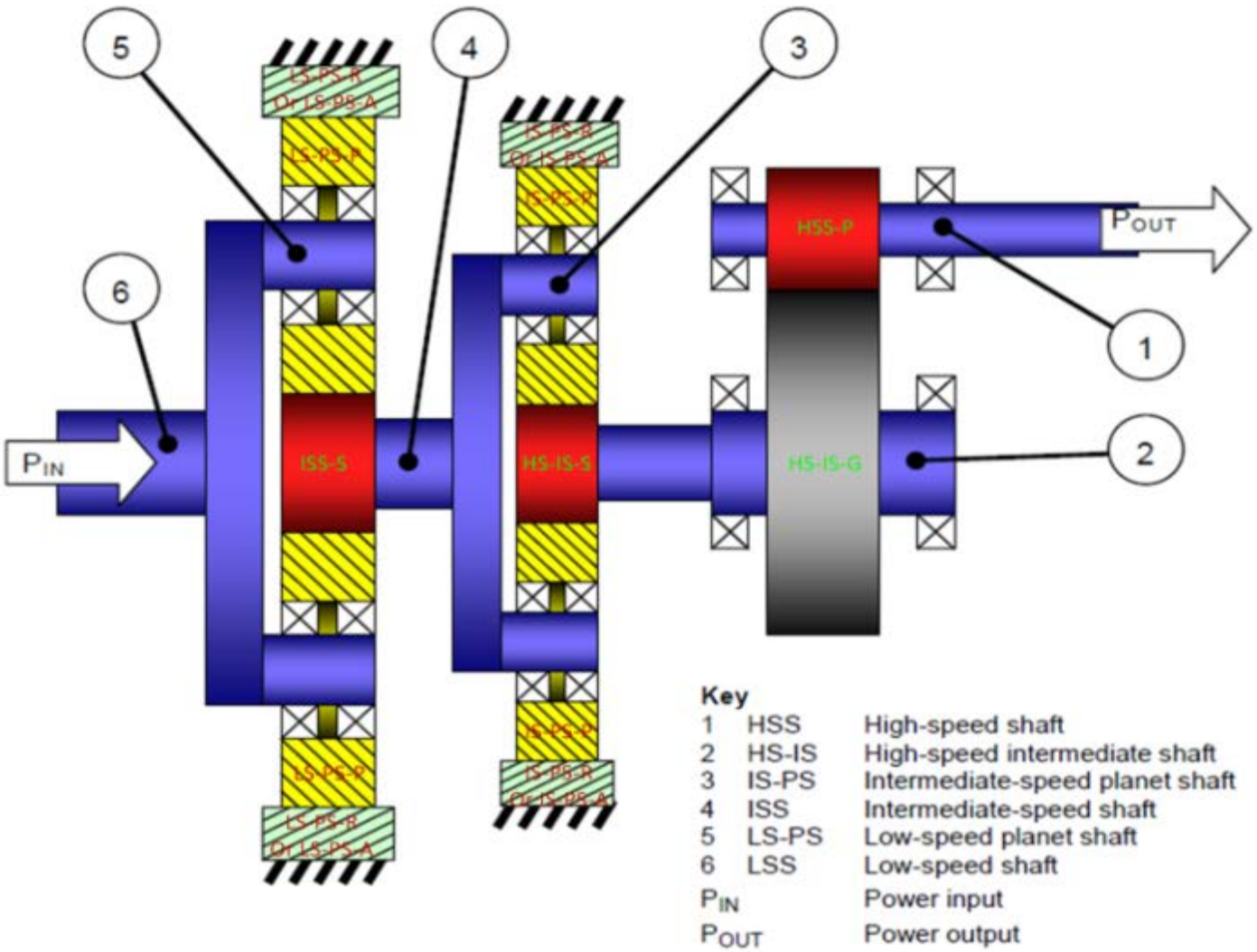


*Illustration based on International Electrotechnical Commission 61400-4**

*International Electrotechnical Commission, ISO/IEC 61400-4:2012, Wind Turbines – Part 4: Design Requirements for Wind Turbine Gearboxes.

Bearings

No: [a]	Shaft position	Shaft label	Bearing label	Bearing designation
1	Low speed planet carrier	LS-Car	RS	LS-PLC-A
2			GS	LS-PLC-B
3	Low speed planet	LS-Plan	RS	LS-PL-A
4			GS	LS-PL-B
5	Intermediate speed planet carrier [b]	IS-Car	RS	IS-PLC-A
6			GS	IS-PLC-B
7	Intermediate speed planet [b]	IS-Plan	RS	IS-PL-A
8			GS	IS-PL-B
9	Low speed intermediate shaft [b]	LSIS	RS	LSIS-A
10			GS-in	LSIS-B
11			GS-out [b]	LSIS-C
12	High speed intermediate shaft	HSIS	RS	HSIS-A
13			GS-in	HSIS-B
14			GS-out [b]	HSIS-C
15	High speed shaft	HSS	RS	HSS-A
16			GS-in	HSS-B
17			GS-out	HSS-C

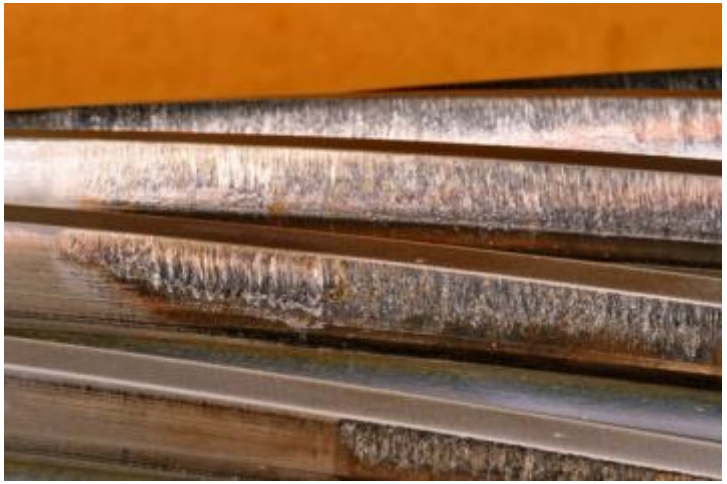
[a] The numbering corresponds to the torque flow from input to output shaft looking from rotor towards generator.

[b] Optional, depending on gearbox design.

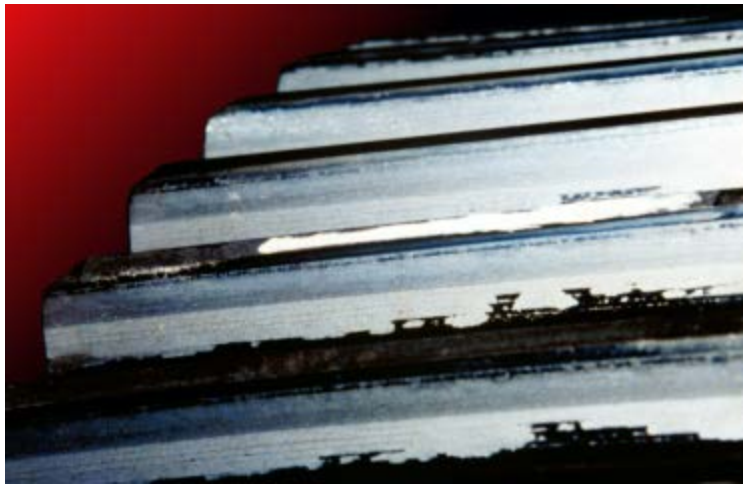
Illustration based on International Electrotechnical Commission 61400-4

Gear Failure Modes

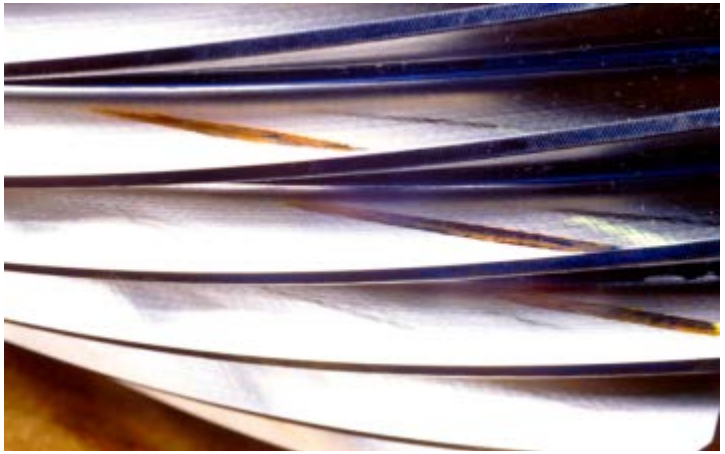
Bending fatigue (intermediate-stage pinion)



Scuffing (high-speed-stage pinion)



Micropitting



Fretting Corrosion

Photo Credits: Rainer Eckert, Northwest Laboratory (top left), and Bob Errichello, GEARTECH (top right and bottom two)

Bearing Failure Modes

Cracking (axial cracks)

Fatigue (spalling)

Wear (scuffing)

Fretting corrosion

Photo Credits: Robert Errichello, GEARTECH (bottom right); Andy Milburn, Milburn Engineering (bottom left); Gary Doll, University of Akron (top left); and Ryan Evans, The Timken Company (top right)

Database Entry Inputs: Standard Template

File Upload | Help

If you prefer to have NREL import your data into GRD please send your files to Shuangwen (Shawn) Sheng at shuangwen.sheng@nrel.gov

Please **download this template** to get started

The first row of the CSV must contain the following headers:

failure_date required -*MM/DD/YYYY*: The failure date of this turbine

rts_date required -*MM/DD/YYYY*: The return to service date for this turbine

root_cause optional -*string*: The identified root cause of the failure

report_source optional -*string*: The source of the report

wtg_mfg required -*string*: The manufacturer of the turbine

wtg_model optional -*string*: The modle of the turbine

wtg_total_run_hours optional -*number*: The turbine total run time in hours

Database Automated

- Population
- Data validation

Edit	ID	Gearbox ID	Failure Date	RTS Date	Component	Failure Mode
	4194	5431-01	04/20/2013	05/10/2013	Gear	
	4198	2444-35	03/12/2011	03/26/2011	Bearing	
	4202	2444-6	08/14/2012	10/19/2012	Bearing	
	4203	2444-5	08/14/2012	10/25/2012	Bearing	
	4204	2444-18	04/12/2013	05/02/2013	Bearing	
	4206	2444-48	05/02/2012	06/02/2012	Bearing	
	4208	2444-21	08/09/2011	11/28/2011	Bearing	
	4210	2444-34	07/01/2010	08/05/2010	Bearing	

Correct Database Entries

Dashboard

Shawn Sheng

Gearbox Reliability Database

Gearbox ID
2444-21

Failure Date
08/09/2011

RTS Date
11/28/2011

Component
Bearing

Failure Mode
Select a Failure Mode

Failure Location
Select a Failure Location

Gearbox Manufacturer
Select a Gearbox Manufacturer

Turbine Manufacturer
Select a Turbine Manufacturer

Root Cause

Cancel Save

incidents missing critical information

Failure Date	RTS Date	Component	Failure Mode	Failure Location
04/20/2013	05/10/2013	Gear		
03/12/2011	03/26/2011	Bearing		
08/14/2012	10/19/2012	Bearing		
08/14/2012	10/25/2012	Bearing		
04/12/2013	05/02/2013	Bearing		
05/02/2012	06/02/2012	Bearing		
08/09/2011	11/28/2011	Bearing		
07/01/2010	08/05/2010	Bearing		
12/23/2013	01/24/2013	Bearing		

Database Reporting: Interactive Statistics

- Statistics comparison across plants

Integration of Various Data Sources

An Ideal Data Integration Strategy

- **A centralized platform for multiple data streams: a computerized maintenance management system (CMMS) augmented by other special tools => complete solutions possible in the long run.**

Grid Simulation.
Photo by Dennis Schroeder, NREL 41131

SCADA and Condition Monitoring System Data

- Typical SCADA time series data are 10-minute averages. These data include:
  - Wind parameters (e.g., speed, deviation)
  - Performance parameters (e.g., power output, rotor speed, blade pitch angle)
  - Vibration parameters (e.g., tower acceleration, drivetrain acceleration)
  - Temperature parameters (e.g., bearing and gearbox temperature)
- Integration of SCADA and vibration condition monitoring data involves:
  - Down-sampling vibration from high frequency to 10-minute averages.

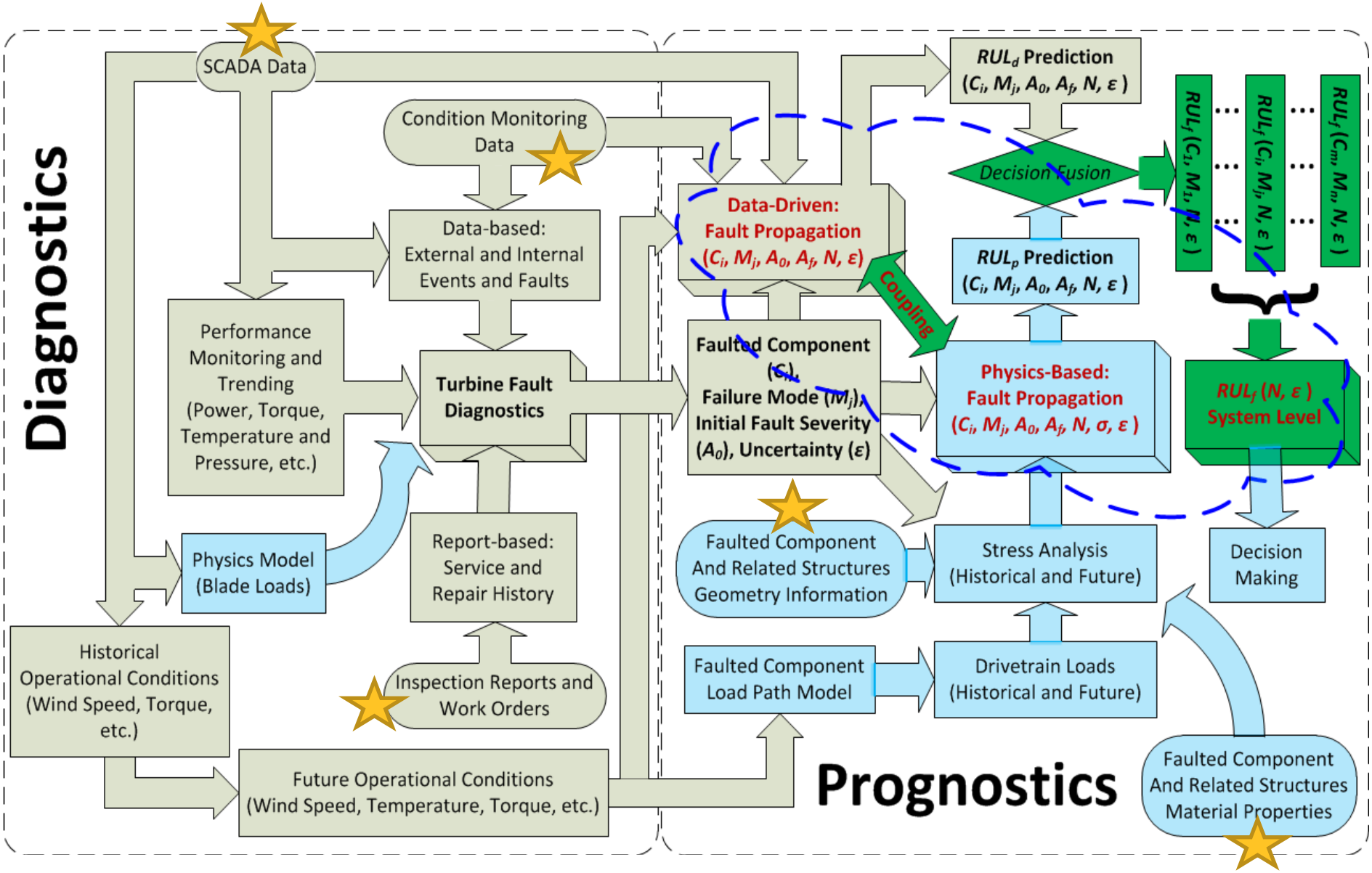
Synchronization of Time Stamps

- Time series data synchronized according to the same clock (e.g., satellite-based GPS)
  - Oil debris sensors vs. wind speed or power, and so on, channels in SCADA
- Discrete events recorded by SCADA and time series data from either SCADA or other instrumentation
- Maintenance reports time stamped throughout a turbine's life cycle → component replacement times known.

Significant Opportunities in Integration of Maintenance Reports

- Standardized templates
- Automatic tools
- Integration with other data streams through a centralized computerized maintenance management system
- Particularly for unstructured data (maintenance logs in text format), there are opportunities for intelligent text scanning algorithms based on pattern recognition or natural language processing technologies → knowledge
- Detailed ways of documenting component failures and maintenance records.

A Data Integration Example: Wind Turbine Prognostics and Health Management



Concluding Remarks

Data Networks: An Ideal Scenario

- Automate integration, including collection and analysis, of various data streams as much as feasible at a centralized location
  - Combine different data sources: time series and maintenance logs and failure documentation
- Standardization of templates and terminologies for all reporting purposes within an organization (or for the industry)
  - Used as a basis for software tools
  - Consistent tags harmonizing different SCADA systems
  - Clear taxonomy for asset tracking and failure documenting supported by high-resolution photos

Thank You!

Special thanks go to the U.S. Department of Energy and the database partners!

This presentation was supported by the U.S. Department of Energy under Contract No. DE-AC36-08GO28308 with the National Renewable Energy Laboratory. Funding for the work was provided by the DOE Office of Energy Efficiency and Renewable Energy, Wind Energy Technologies Office. The authors are solely responsible for any omissions or errors contained herein.

The Block Island Wind Farm—the first offshore wind farm in the United States.
Photo by Dennis Schroeder, NREL 40389

www.nrel.gov

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

shuangwen.sheng@nrel.gov, 303-384-7106
jahelsen@vub.ac.be, +32 479 85 58 79