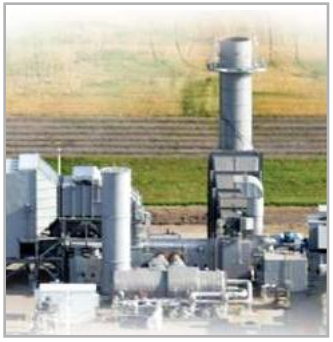
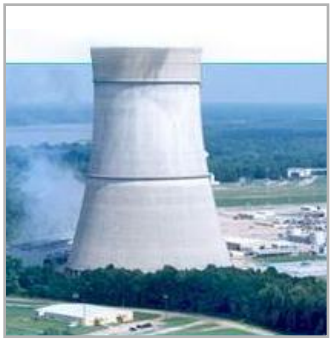
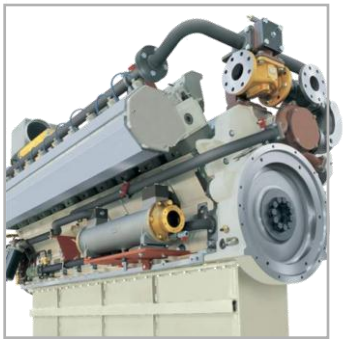
WINDPOWER2012

Analytic Approaches for Improving Wind Farm Operations & Maintenance





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06 June 2012
Atlanta, GA

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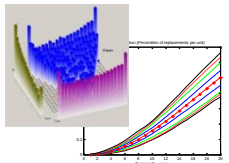
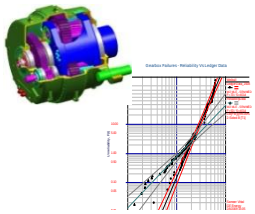
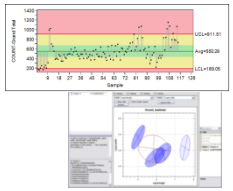
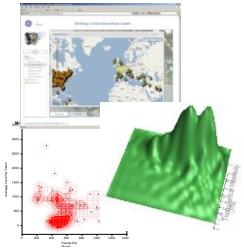
Analytics for Physical Asset Management

	Technology / Capability		Business Impact
Decision Optimization	• Long term service agreements • Optimize Spares & Logistics • Optimize Maintenance • Risk-Based Capital Budgeting		• Optimal capital outlays • Minimal O&M costs • Maximize financial returns • Enterprise Risk Mgmt.
Reliability & Life Mgmt.	• Weibull Analysis • Prognostics Health Mgmt. • Life Odometers • Performance-Life Tradeoff		• Identify "high risk" subpopulations in fleet • Prioritize maintenance • Safety .. Low OPEX
Anomaly Detection	• Statistical Process Control • Fault Detection • Fault Root Cause Diagnosis • Sensor & Data Fusion		• Reduce unplanned maintenance costs • Improve availability • Improve performance
Data Mining & Reporting	• Statistical Summaries Of Performance & Reliability • Unit Vs. Fleet Comparisons • Mission & Usage Analysis		• Quantify costs, resources • Enable new O&M deals • Define & manage programs

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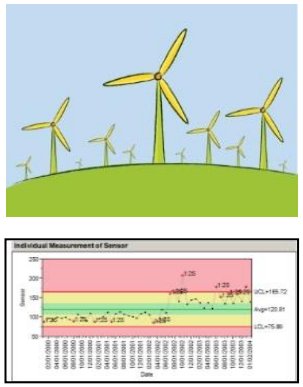
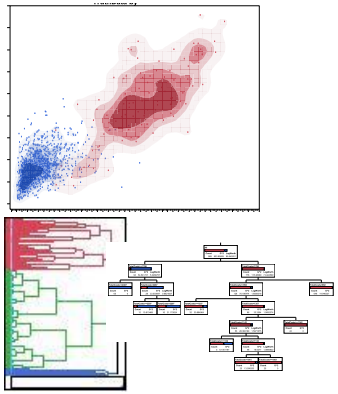
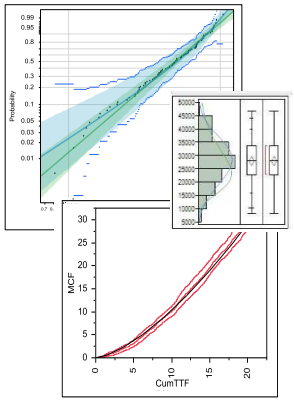
O&M Analytics Approach



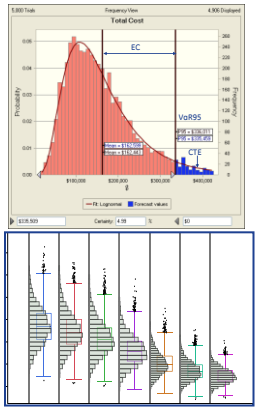
Text & Data Mining on Services/repair data



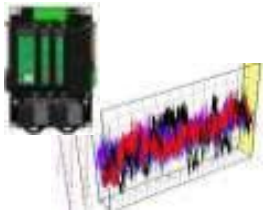
Fleet Segmentation, clustering & classification



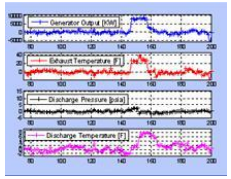
Survival Analysis
Recurrent Event Models
Partial Renewal Models



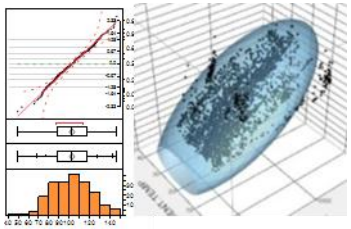
Scenario and Simulation-based optimization of O&M costs, spares, crews, RCM and CBM system design



Sensor Data



Multiple anomaly Detection



Prognosis

Case Study Overview

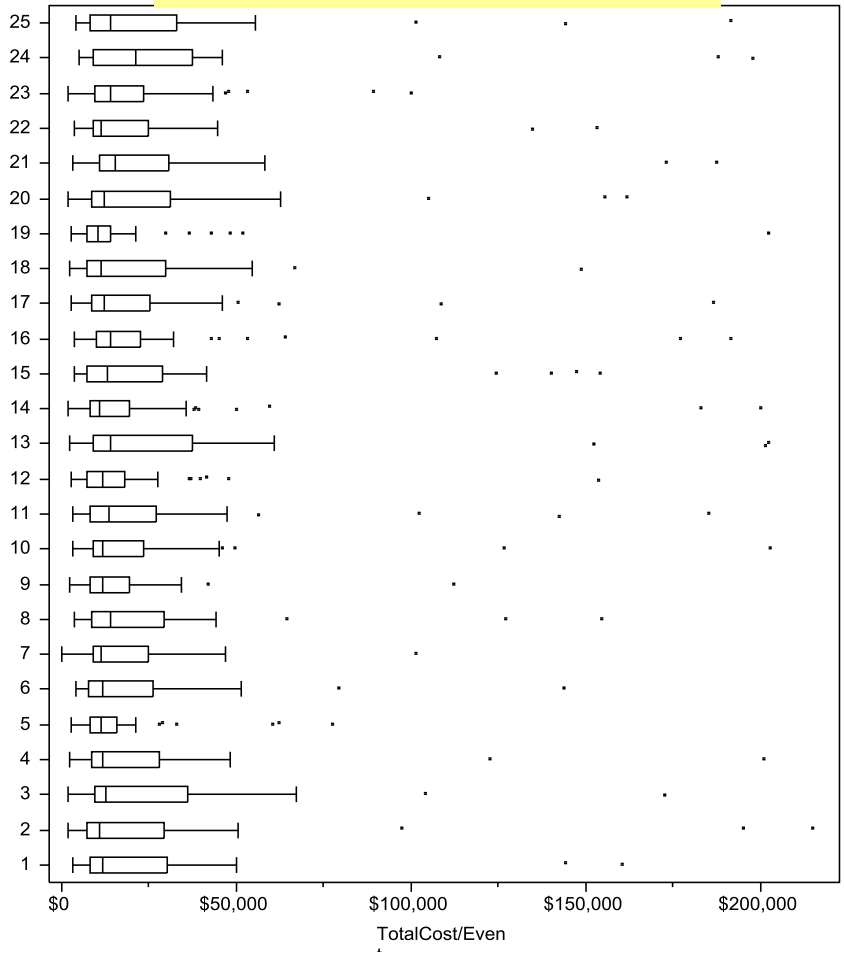
- A fleet of 25 units tracked for ~ 20 years from commissioning in early 1990 until end of observation in 2010.
- Operations and maintenance records are available and events manually classified as Major Repair, Minor Repair or Replacement (establish “truth data”)
- Services data aggregated to include event date, Turbine ID, Total parts costs ($/event) , total labor hours and costs ($/event) and total event costs
- Intent was to demonstrate how data-mining methods can be used to extract information about the underlying repair and renewal processes .. and build a predictive model to statistically estimate future costs

	TotalCost/Event	X (Parts)	Y (Labor)	
UnitID	Sum	Sum	Sum	N
1	$891,256.00	$732,622.00	$158,634.00	37
2	$1,359,585.00	$1,113,758.00	$245,827.00	54
3	$899,574.00	$729,138.00	$170,436.00	35
4	$1,386,120.00	$1,143,546.00	$242,574.00	61
5	$647,767.00	$535,182.00	$112,585.00	40
6	$994,097.00	$807,202.00	$186,895.00	48
7	$642,511.00	$519,321.00	$123,190.00	33
8	$954,903.00	$776,798.00	$178,105.00	38
9	$872,841.00	$692,877.00	$179,964.00	54
10	$1,232,365.00	$989,857.00	$242,508.00	57
11	$916,032.00	$751,655.00	$164,377.00	32
12	$1,083,290.00	$908,070.00	$175,220.00	51
13	$1,561,625.00	$1,269,248.00	$292,377.00	51
14	$1,127,644.00	$938,414.00	$189,230.00	50
15	$1,380,994.00	$1,113,258.00	$267,736.00	56
16	$1,318,246.00	$1,115,271.00	$202,975.00	52
17	$998,526.00	$810,504.00	$188,022.00	44
18	$973,761.00	$781,638.00	$192,123.00	46
19	$684,169.00	$571,752.00	$112,417.00	35
20	$1,320,797.00	$1,074,194.00	$246,603.00	52
21	$1,128,581.00	$900,972.00	$227,609.00	41
22	$776,298.00	$630,680.00	$145,618.00	33
23	$1,285,913.00	$1,022,990.00	$262,923.00	64
24	$1,435,259.00	$1,132,172.00	$303,087.00	47
25	$1,099,025.00	$870,330.00	$228,695.00	40

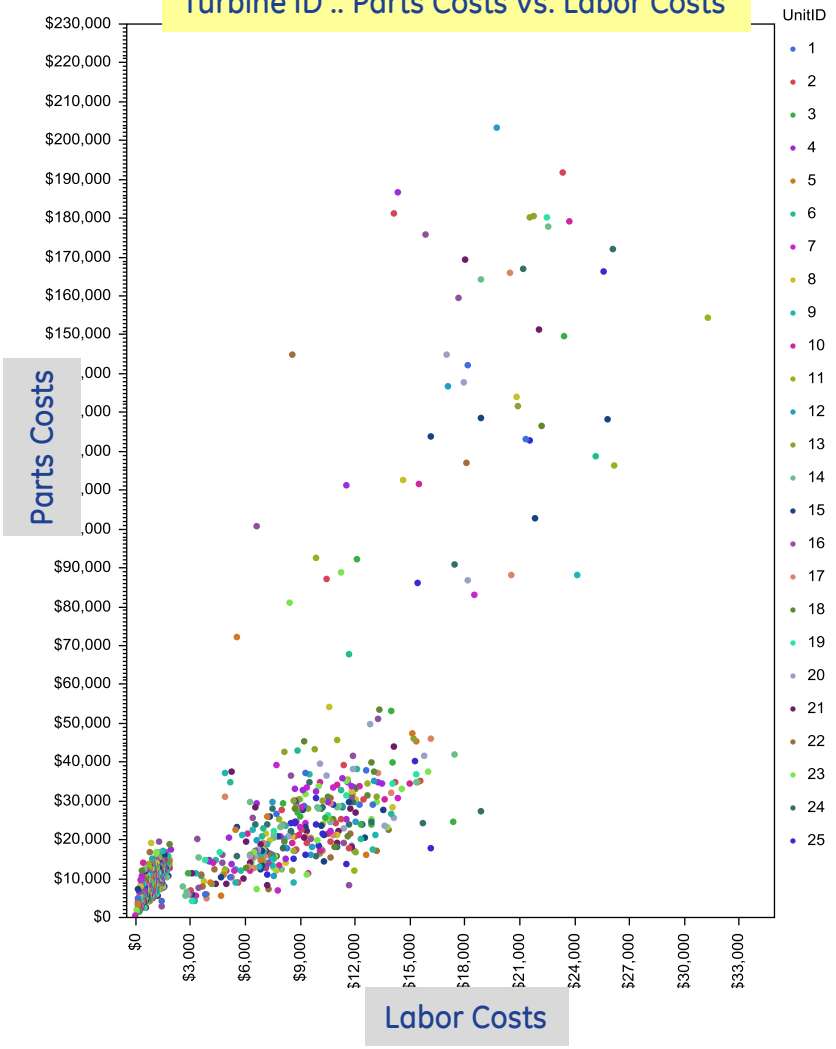
Note : All data has been scaled and made anonymous

Exploratory Data Analysis (1)

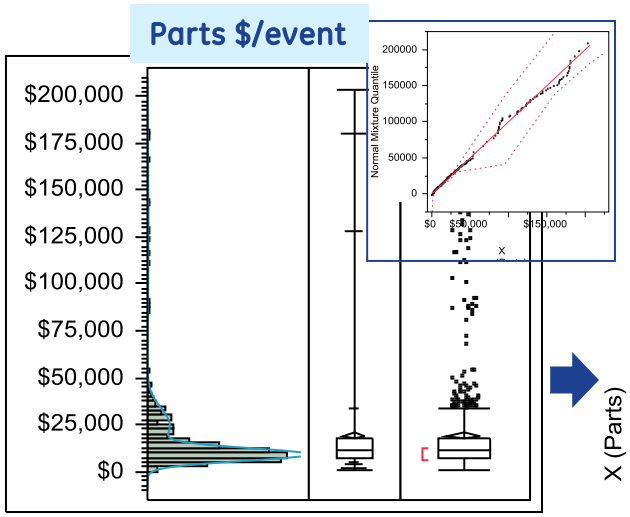
Turbine ID .. Total Cost/Event Box Plot

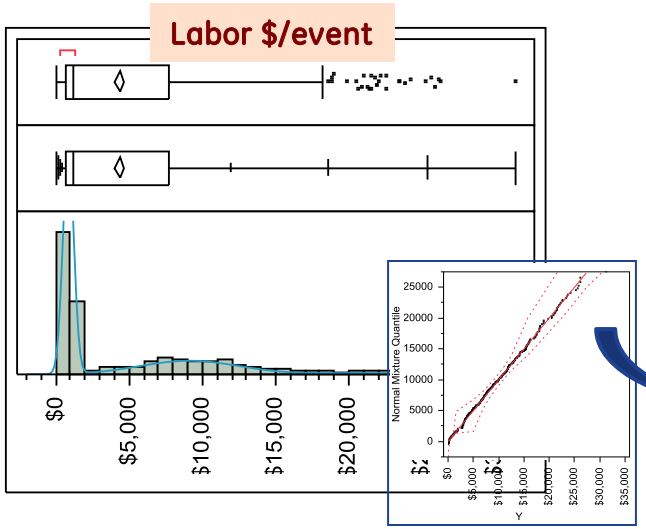


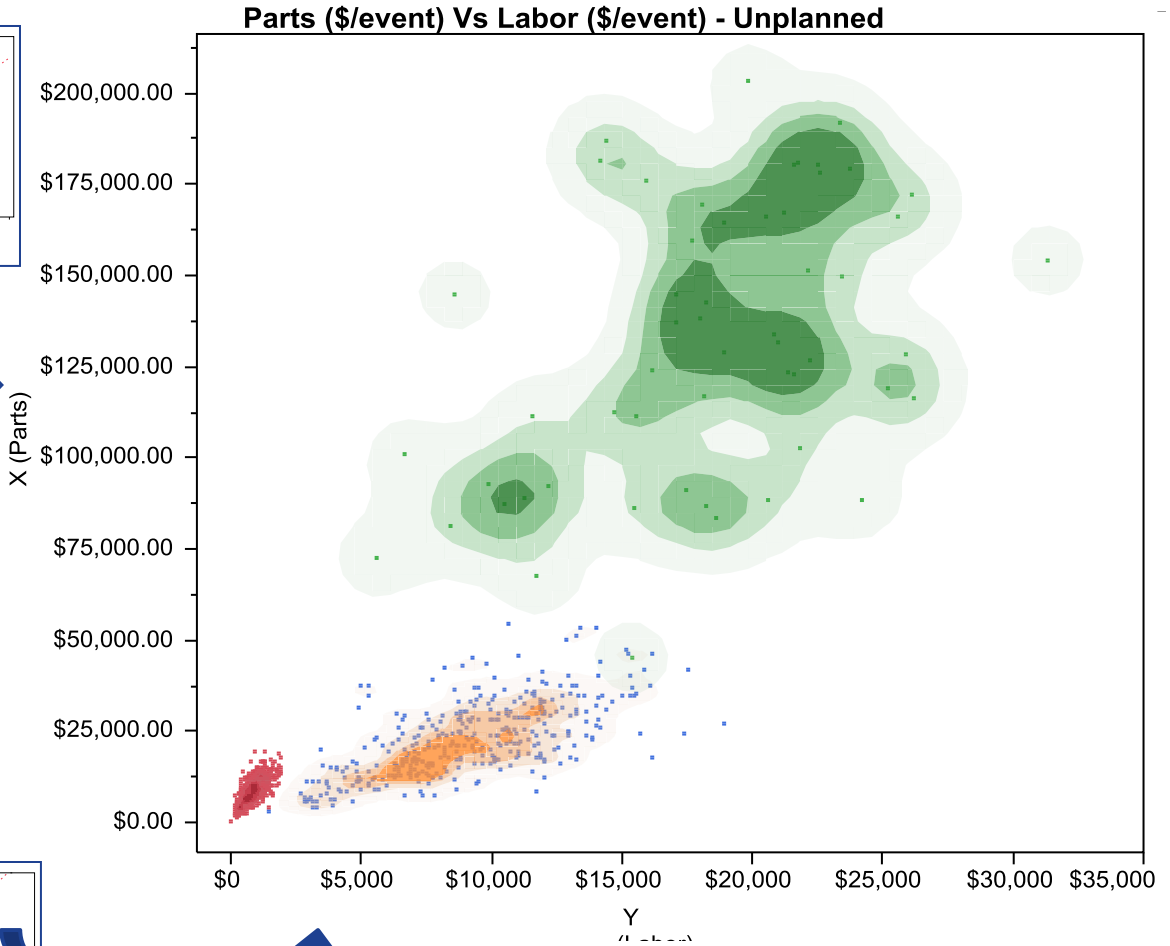
Turbine ID .. Parts Costs Vs. Labor Costs



Exploratory Data Analysis (2)







Mixture distributions fitted to the parts & labor cost data indicate potential sub-groups within the dataset ..

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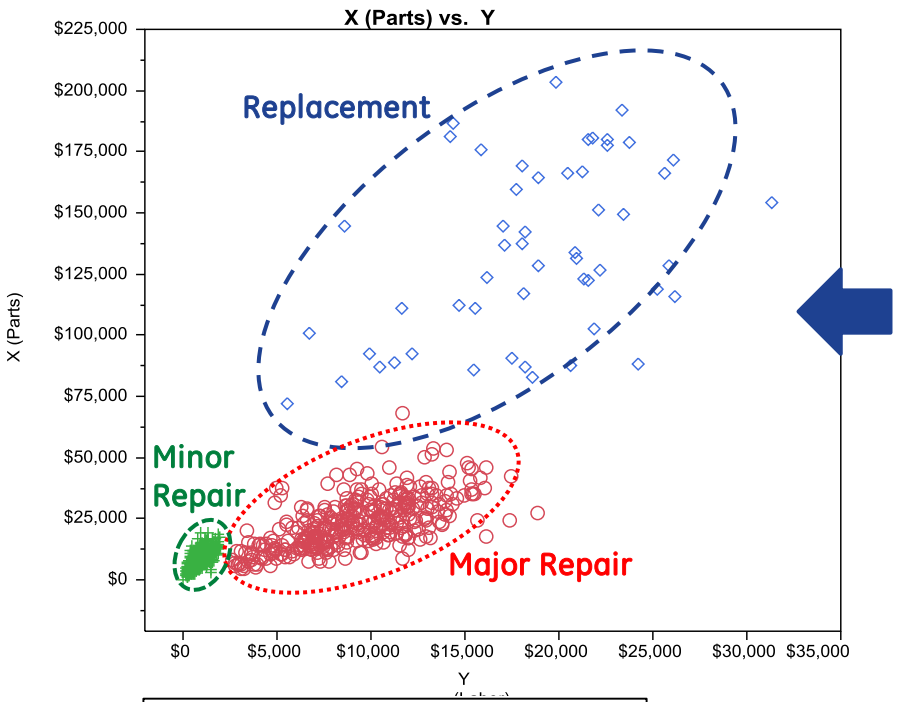
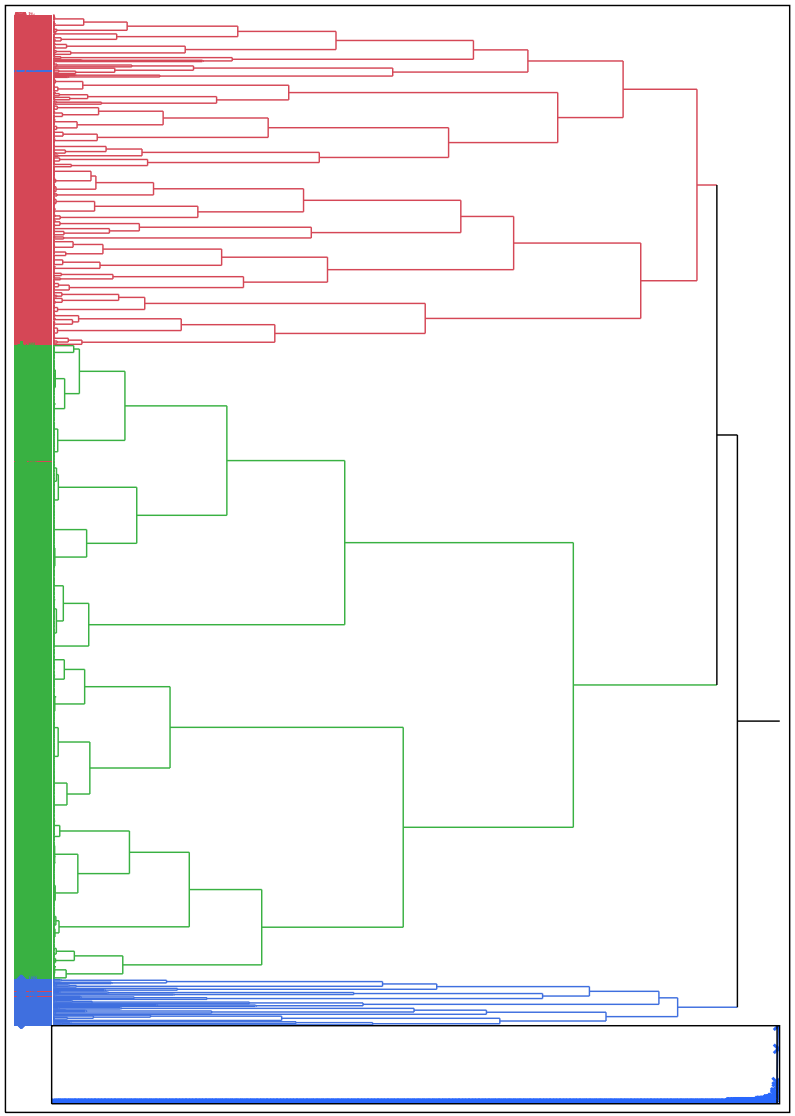
Segmenting the Data (Hierarchic Clustering)

Hierarchic clustering (unsupervised learning) used parts & labor costs to classify the events into three categories with 99.73% accuracy ..



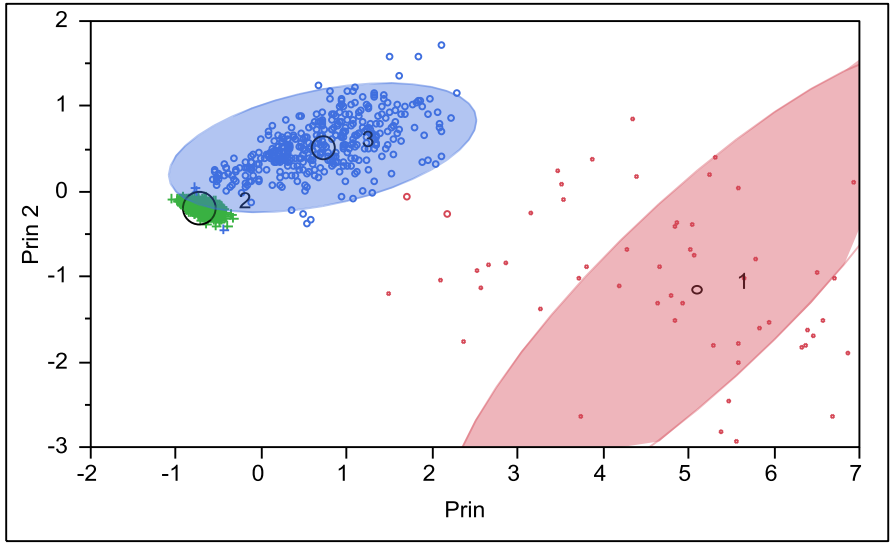
	ClusterID_Heirarchic		
Repair Category	**1**	**2**	**3**
Major_Repair	374	1	0
Minor_Repair	0	721	0
Replacement	2	0	53



Other Machine Learning Methods ..

Limited pre-classified data from other wind farms can be used to train models like k-means clustering & decision trees to classify new data into pre-defined repair/replacement categories ..

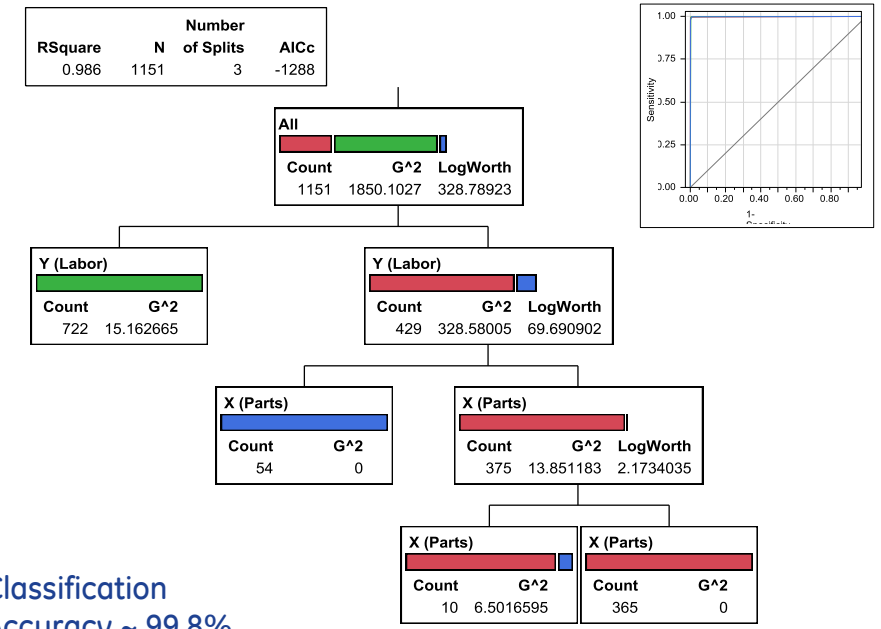
K-Means Clustering Algorithm
Using Robust Normal Mixtures



	ClusterID_KmeansRobNor		
Repair Category	**1**	**2**	**3**
Major_Repair	1	0	374
Minor_Repair	0	719	2
Replacement	54	0	1

Classification Accuracy ~ 99.6%

Decision Tree / Partition Classifier



Classification Accuracy ~ 99.8%

Actua Predicte

Training	Major_Repair	Minor_Repair	Replacement
Major_Repair	374	1	0
Minor_Repair	0	721	0
Replacement	1	0	54

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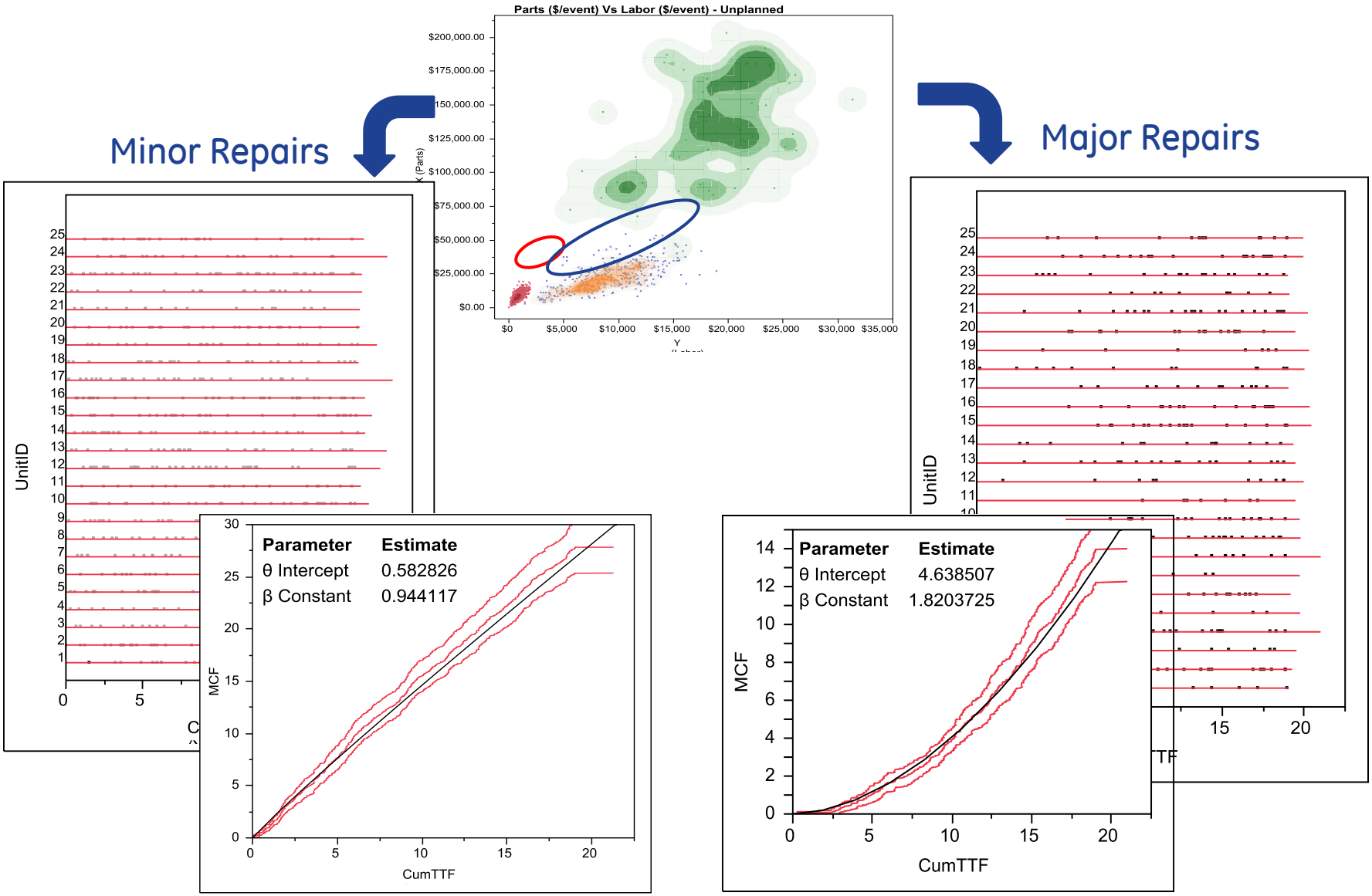
Predictive Models for Repairs (MCF-NHPP)



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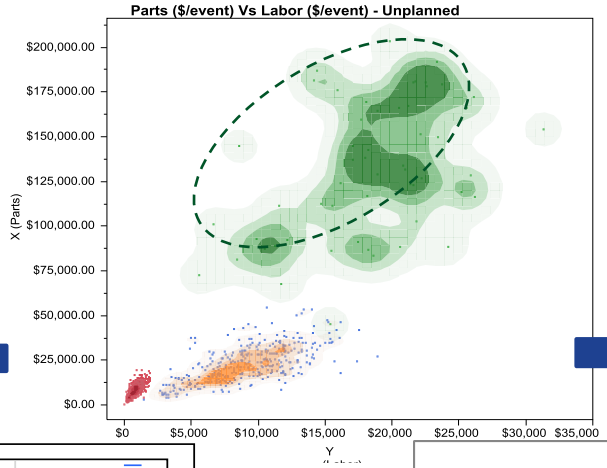
Predictive Models for Replacements (E.g. Weibull)

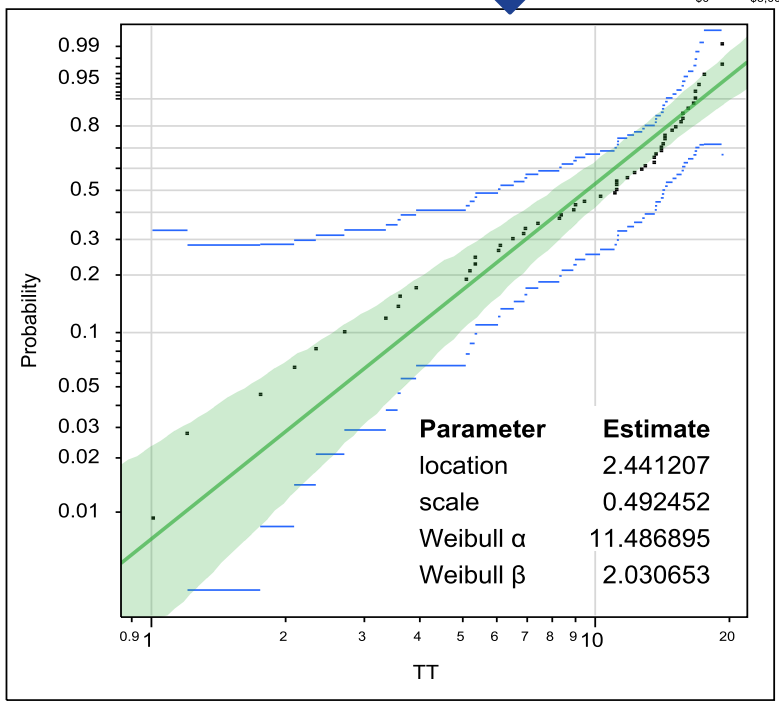
Survival Model for Replacements, F(t)

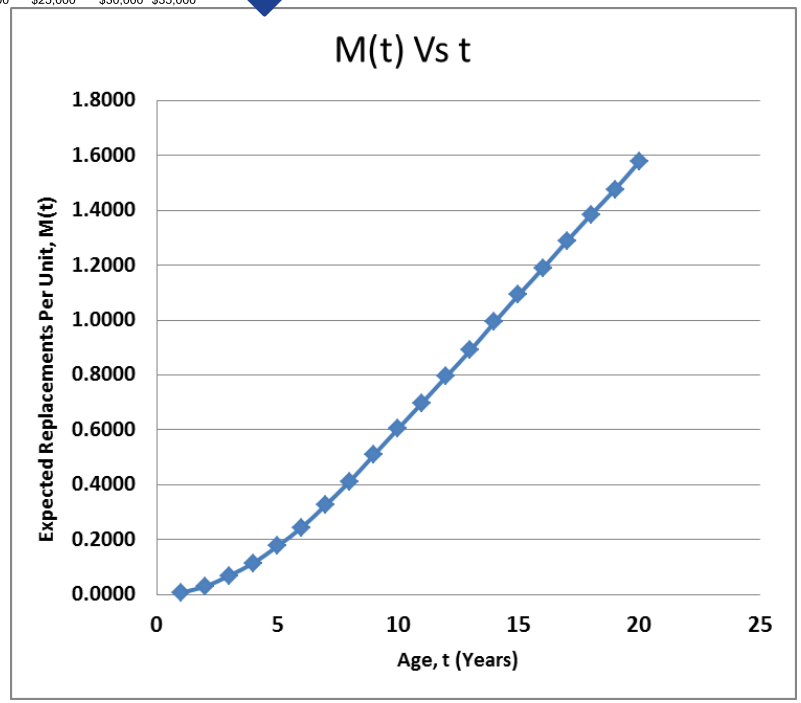
$$F(t) = 1 - exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right]$$



Renewal analysis from survival model, M(t)

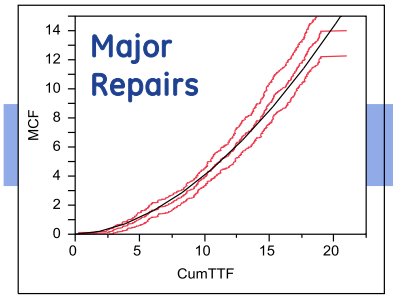
$$M(t) = F(t) + \int_{u=0}^{u=t} F(t-u)dF(u)$$

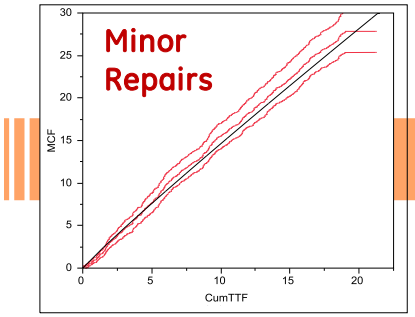


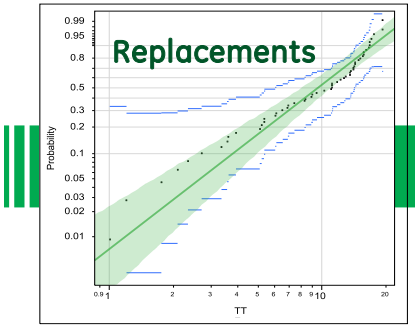


Predicting Costs via Simulation

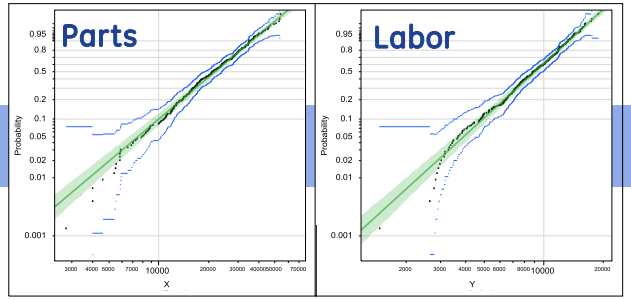
Event Models

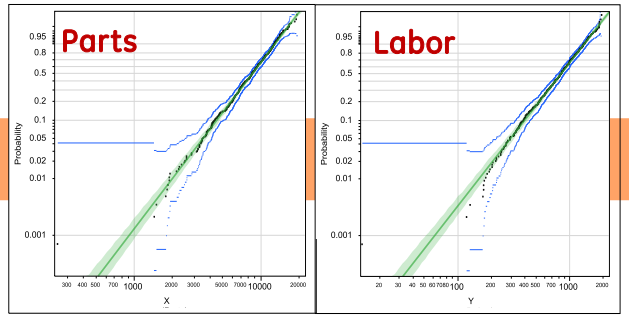


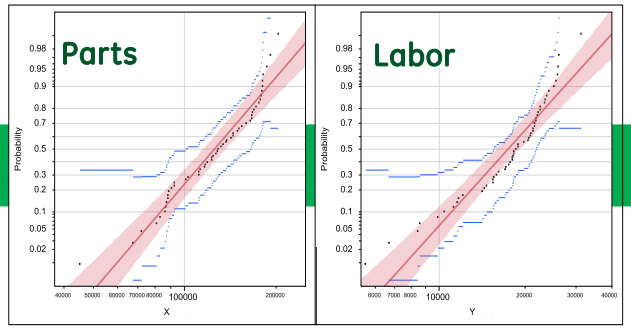




Part & Labor Cost Distributions





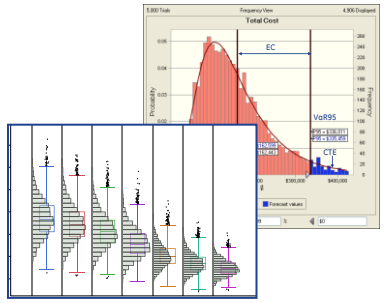


Monte-Carlo Simulation Engine

O&M Capabilities

Scheduled Maintenance
Inspection Capability
Repair Effectiveness
Crew availability
Crane availability
Spare Pools
Condition Monitoring

Results



Risk & Confidence Bounds
Cost Distributions
Availability Distributions
Optimal CBM/PHM design,
Optimal schedules for logistics, inspection & maintenance, spares etc.

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Conclusions

Analytics for Physical Asset Management can be applied to existing maintenance, cost & condition monitoring data to build predictive models that optimize wind farm O&M costs

This goes beyond "classical reliability" (E.g. Weibull's) and includes a range of data-mining and actuarial analysis techniques

This methodology is a low-risk, low-cost approach to systematically exploit your data and drive productivity into your wind farm operations.

Please contact us for more information if interested

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tracy.ford@ge.com

Thank You !