What is Anticipatory Maintenance?

Know what to replace before it breaks

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What does unplanned maintenance cost?

- Direct cost - $300K per year per airplane
  - Casebank Technologies Inc.
- Goodwill
  - Delayed passengers
  - On-time ratings
- Schedule disruptions
- Crew
  - Overtime costs
  - Underutilization

Outline

- What is Anticipatory Maintenance?
- How do you use the results of an Anticipatory Maintenance analysis?
- Fine tuning your analysis
- Case study

AM in a nutshell

- *Calculate probability of failure of specific parts based on an analysis of historical repair records, and use those probabilities to reduce unanticipated down-time and overall maintenance costs.*
- *Know what to replace before it breaks!*

Produce information from historical data

- What does the data look like?

100 rows from Table - Repairs

Unit ID	LocoType	Event Time	Repair Code	Repair Desc
108	2	3/10/2001	0445	Load, Not Loading, Load Limited
108	2	4/13/2001	3225	Handbrake Mechanism
108	2	6/19/2001	2920	Electronic Air Brake General - Knorr
108	2	8/24/2001	2933	PCU - BP Control (MVER, MV53, MVEM, PVEM)
108	2	8/24/2001	2785	FIWPS - Fuel Inj. Water Press. Sensor
108	2	8/24/2001	2926	CRU - Voltage Control Unit (VCU, SV, SVJ)
108	2	12/6/2001	1711	BATT - Battery (Locomotive Batteries)
108	2	12/15/2001	7351	Pump Assembly, Water - Eng
109	2	1/8/2001	4436	Brake Shoes - Truck

What do the rules look like?

Rules - SLOOP: Repairs.Repair-repair

LeftSide	RightSide	Expecte	Confide	Lift	Suppor
XEAB - Transducer Modules (EAB)	FPM - Fuel Transfer Pump Motor - Eng	29.82%	50.00%	1.68	0.88%
XAF - IFC Air Flow Transducer	ACS - Air Compressor Speed Sensor	1.75%	100.00%	57.00	0.88%
XAF - IFC Air Flow Transducer	Railroad Modification	3.51%	100.00%	28.50	0.88%

- Expected – Prior probability of RightSide
- Confidence – Probability that RightSide follows LeftSide
- Lift – Confidence / Expected (*surprise factor*)
- Support – Frequency of occurrence
- *The Fuel Transfer Pump Motor needs to be replaced in 50% of all cases following a Transducer Module replacement. This rate is 1.68 times higher than the normal 29.82% replacement rate.*

How can a failure in Part A predict a later failure in Part B?

- While Part A deteriorates, Part B experiences
  - Higher/lower temperature, pressure
  - Higher/lower voltage, current
  - Increased loads or usage
  - Vibration
  - Debris
- Repair of Part A disturbs Part B
  - Changes position
  - Releases debris or contamination

Causality

- Analysis does not determine causality
  - Finds correlations
  - Leads to discovery of causality
- Expert vetting of rules
  - Suspend rules that are hard to believe and/or have low level of support

How do you use the results of an Anticipatory Maintenance analysis?

- Identify parts likely to fail for
  - Immediate replacement
  - Scheduled replacement
- Use probabilities and costs to optimize
- Uncover hidden lore
- Improve repair procedures
- Re-engineer equipment

Fine tuning your analysis

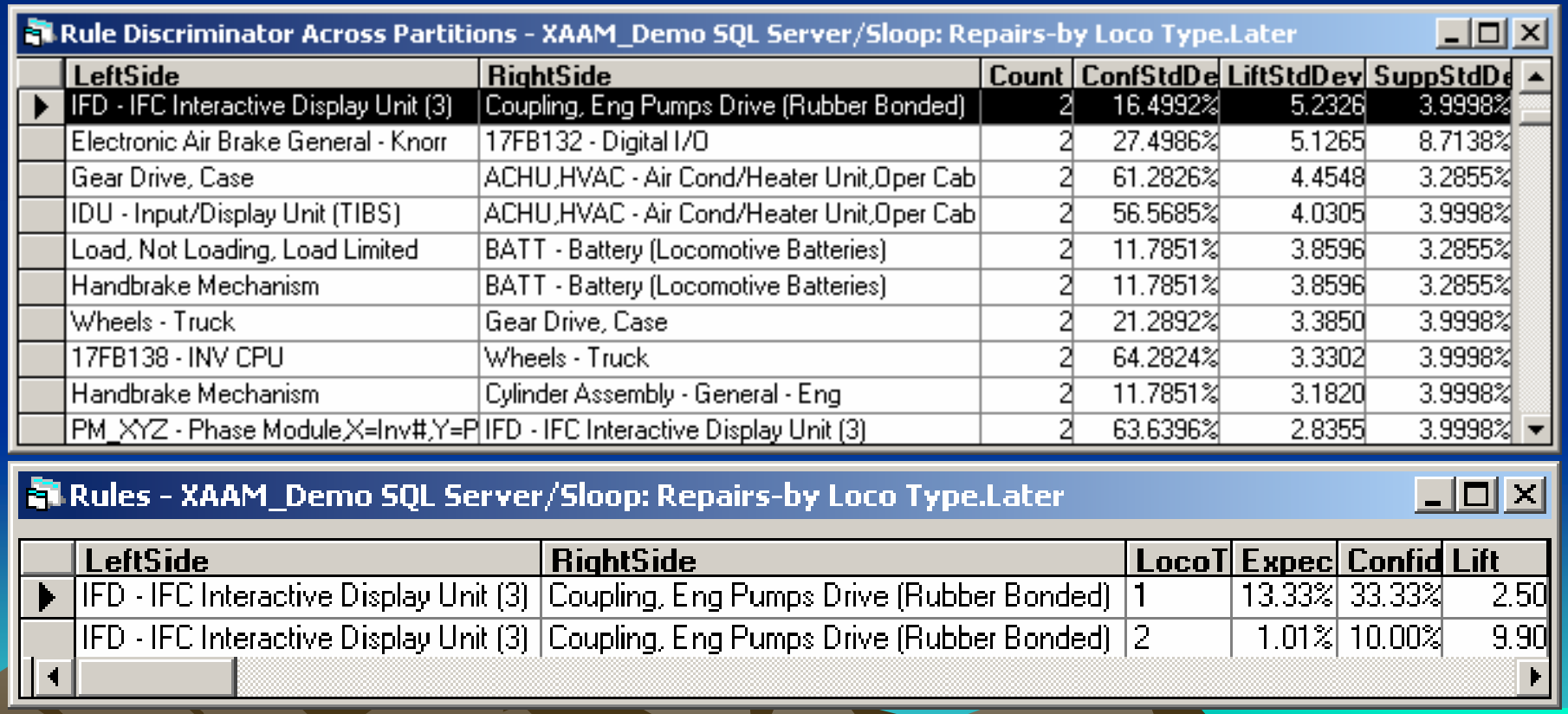
- Exploring latency effects
- Comparing across
  - repair facilities,
  - engineers,
  - sub contractors,
  - product versions,
  - day of the week

Exploring latency effects

- Any later time
- Specific time intervals
  - E.g., 0-5 hours
  - 1-3 months
  - Compare 0-4 weeks to 5-9 weeks
- Next failure

Comparing rules across another attribute

- Uses XAAM Partitioning & Discriminator
- E.g., compare across Loco Type



Rule Discriminator Across Partitions - XAAM_Demo SQL Server/Sloop: Repairs-by Loco Type.Later

LeftSide	RightSide	Count	ConfStdDe	LiftStdDev	SuppStdDe
IFD - IFC Interactive Display Unit (3)	Coupling, Eng Pumps Drive (Rubber Bonded)	2	16.4992%	5.2326	3.9998%
Electronic Air Brake General - Knorr	17FB132 - Digital I/O	2	27.4986%	5.1265	8.7138%
Gear Drive, Case	ACHU,HVAC - Air Cond/Heater Unit,Oper Cab	2	61.2826%	4.4548	3.2855%
IDU - Input/Display Unit (TIBS)	ACHU,HVAC - Air Cond/Heater Unit,Oper Cab	2	56.5685%	4.0305	3.9998%
Load, Not Loading, Load Limited	BATT - Battery (Locomotive Batteries)	2	11.7851%	3.8596	3.2855%
Handbrake Mechanism	BATT - Battery (Locomotive Batteries)	2	11.7851%	3.8596	3.2855%
Wheels - Truck	Gear Drive, Case	2	21.2892%	3.3850	3.9998%
17FB138 - INV CPU	Wheels - Truck	2	64.2824%	3.3302	3.9998%
Handbrake Mechanism	Cylinder Assembly - General - Eng	2	11.7851%	3.1820	3.9998%
PM_XYZ - Phase Module,X=Inv#,Y=P	IFD - IFC Interactive Display Unit (3)	2	63.6396%	2.8355	3.9998%

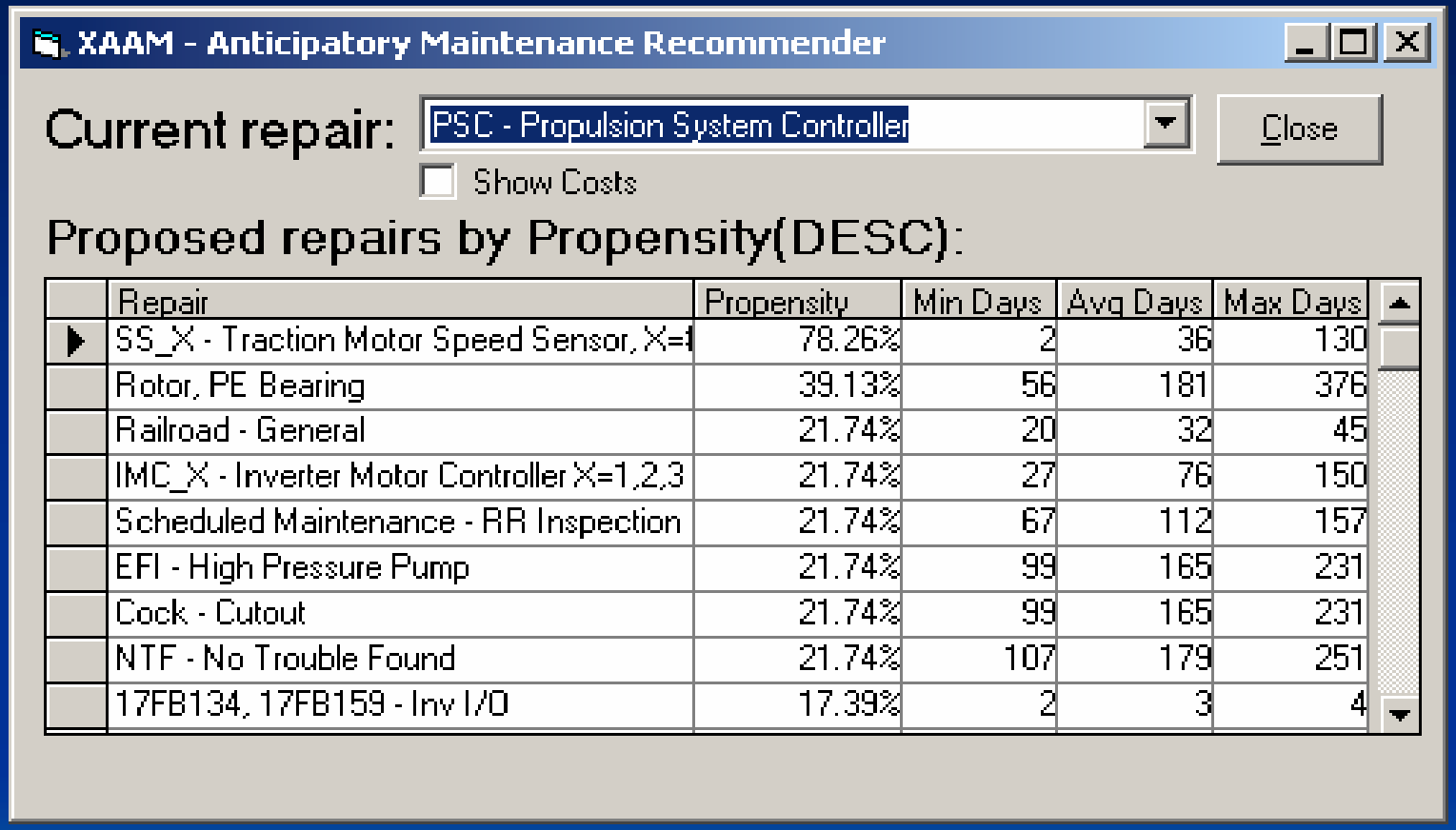
Rules - XAAM_Demo SQL Server/Sloop: Repairs-by Loco Type.Later

LeftSide	RightSide	LocoT	Expec	Confid	Lift
IFD - IFC Interactive Display Unit (3)	Coupling, Eng Pumps Drive (Rubber Bonded)	1	13.33%	33.33%	2.50
IFD - IFC Interactive Display Unit (3)	Coupling, Eng Pumps Drive (Rubber Bonded)	2	1.01%	10.00%	9.90

Deployment at the repair facility

- XAAM Deployment Tool
  - Links to rule warehouse
  - Select part being replaced
  - XAAM suggests other parts to replace by
    - Probability of failure
    - Earliest failure
    - Maximum savings
- Integration with maintenance management software

XAAM Deployment Tool



Repair	Propensity	Min Days	Avg Days	Max Days
SS_X - Traction Motor Speed Sensor, X=1	78.26%	2	36	130
Rotor, PE Bearing	39.13%	56	181	376
Railroad - General	21.74%	20	32	45
IMC_X - Inverter Motor Controller X=1,2,3	21.74%	27	76	150
Scheduled Maintenance - RR Inspection	21.74%	67	112	157
EFI - High Pressure Pump	21.74%	99	165	231
Cock - Cutout	21.74%	99	165	231
NTF - No Trouble Found	21.74%	107	179	251
17FB134, 17FB159 - Inv I/O	17.39%	2	3	4

- Immediate – SS_X Traction Motor Speed Sensor
- Schedule – IMC_X Invert Motor Controller & PE Bearing Rotor

Cost Components

- Direct cost
  - Part cost
  - Labor cost
- Unplanned maintenance costs
  - Service interruption
  - Co-locate parts, equipment, engineers
  - Under utilization of equipment, personnel

Costs – Now vs. Later

- Repair now
  - Direct cost, plus
  - Cost of additional downtime
- Repair later
  - Direct cost, plus
  - Unplanned maintenance costs

Using Probabilities to Compute Expected Cost

- Repair now
  - 100% * Cost
- Repair later
  - (Probability of failure) * (Future Cost)

Example – Two Candidates

- SS_X Traction Motor Speed Sensor
  - 78.26% Propensity to fail
  - Repair now – $157
  - Repair later – $1,688
    - 0.786 * ($157 + $2,000)
  - Savings from AM: $1,531
- IMC_X Inverter Motor Controller
  - 21.74% Propensity to fail
  - Repair now – $896
  - Repair later – $412
    - 0.2174 * ($896 + $1,000)
  - Wait till it breaks

Example (cont'd)

XAAM - Anticipatory Maintenance Recommender

Current repair: PSC - Propulsion System Controller [Close]

Show Costs

Proposed repairs by Propensity(DESC):

Repair	Propensity	Min Days	Avg Days	Max Days	RepairCost	UnSchedCost	ExpectedCost	Savings
SS_X - Traction Motor Speed Sensor, X=	78.26%	2	36	130	$157	$2,000	$1,688	$1,531
Rotor, PE Bearing	39.13%	56	181	376	$157	$1,000	$453	$296
Cock - Cutout	21.74%	99	165	231	$382	$1,000	$300	-$82
Railroad - General	21.74%	20	32	45	$226	$0	$49	-$177
NTF - No Trouble Found	21.74%	107	179	251	$638	$1,000	$356	-$282
IMC_X - Inverter Motor Controller X=1,2,3	21.74%	27	76	150	$896	$1,000	$412	-$484
EFI - High Pressure Pump	21.74%	99	165	231	$780	$0	$170	-$610
Scheduled Maintenance - RR Inspection	21.74%	67	112	157	$1,480	$1,000	$539	-$941

AM Compared to PM and CM

- PM – Preventative Maintenance
  - Scheduled lubrication and cleaning
  - Replace parts based on estimated life
- CM – Condition Monitoring
  - Use sensor data, anomalies to predict failure
  - Requires engineering knowledge to correlate data with predicted failures
- AM is like CM in that it predicts failure
  - Does not require sensor data
  - Uses data mining to correlate historical failure patterns

What is the value of Anticipatory Maintenance?

- Reduce unscheduled service interruptions
- Reduce need to bring equipment to maintenance depot, or
- Reduce need to bring repair crew to failed equipment
- Reduce time waiting for parts to arrive
- Increase safety

Case study

- Demonstration of XAAM
  - Data
  - Rule generation
  - Deployment