

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



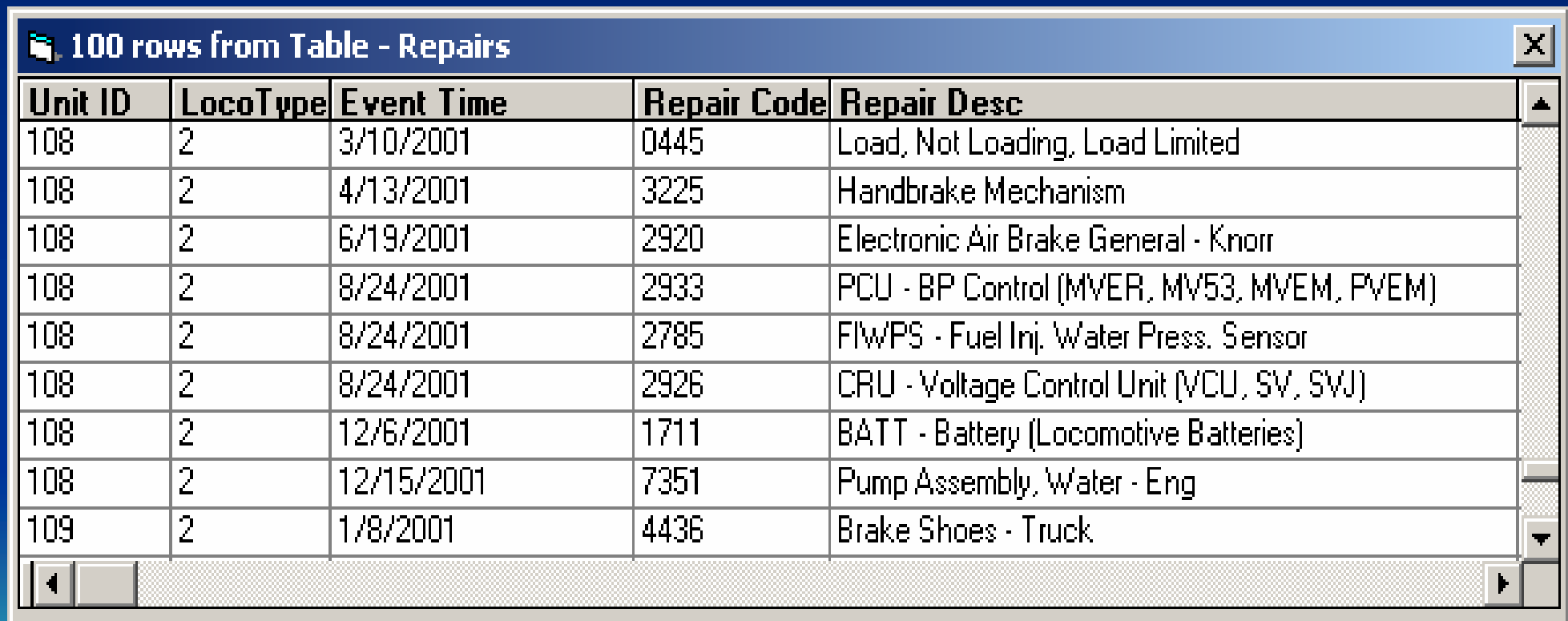
AM in a nutshell

- *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

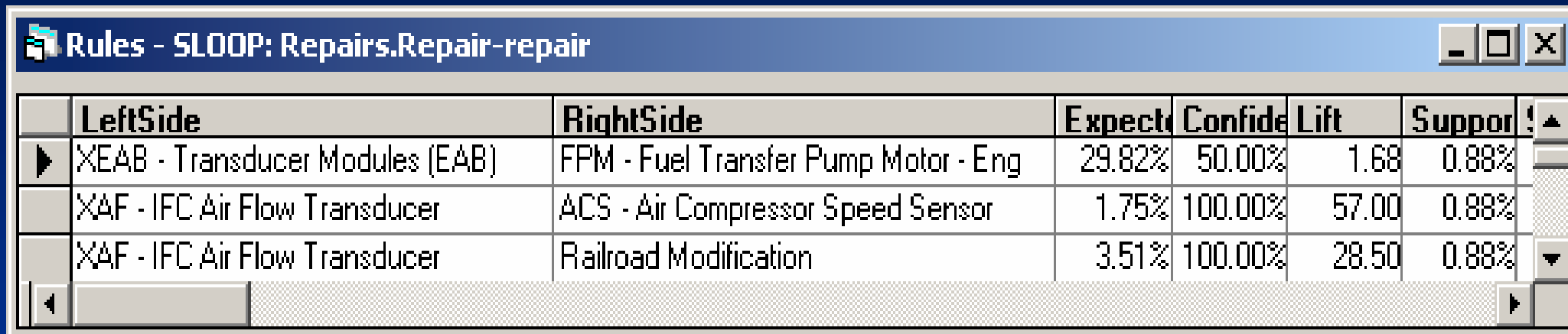
- What does the data look like?



The image shows a screenshot of a data table window titled "100 rows from Table - Repairs". The table contains the following data:

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 (MYER, 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?



	LeftSide	RightSide	Expect	Confide	Lift	Support	!
▶	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

Current repair: PSC - Propulsion System Controller

Show Costs

Proposed repairs by Propensity(DESC):

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
 - $100\% * \text{Cost}$
- Repair later
 - $(\text{Probability of failure}) * (\text{Future Cost})$



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:

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=1	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