ICARUS : Design and Deployment of a Case-Based Reasoning System for Locomotive Diagnostics

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Overview

- Introduction
- Problem definition
- Data
- Why CBR
- Solution Method
- Results
- Lessons Learned
- Future Work

Introduction

- GE
  - 12 Businesses, $100b
- GE Corporate Research Labs
  - 12 labs - 4-6 programs per lab. 10-25 people / program
  - $250M

- Information Technology Lab
  - ~100 people
  - Service Informatics program
  - Remote monitoring and diagnostics for service

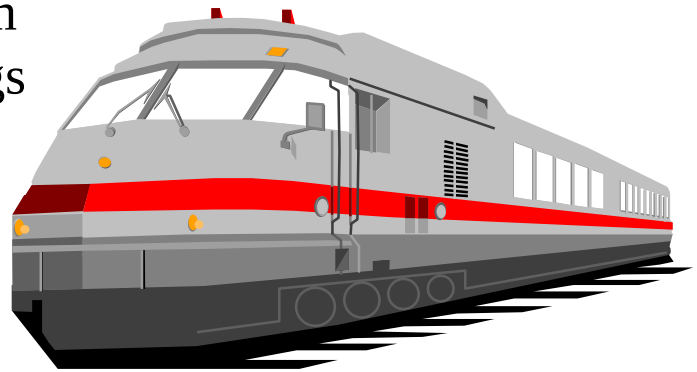
- Projects
  - Case Based Reasoning for Locomotive Diagnostics
  - GE Transportation systems

Problem Definition - 1

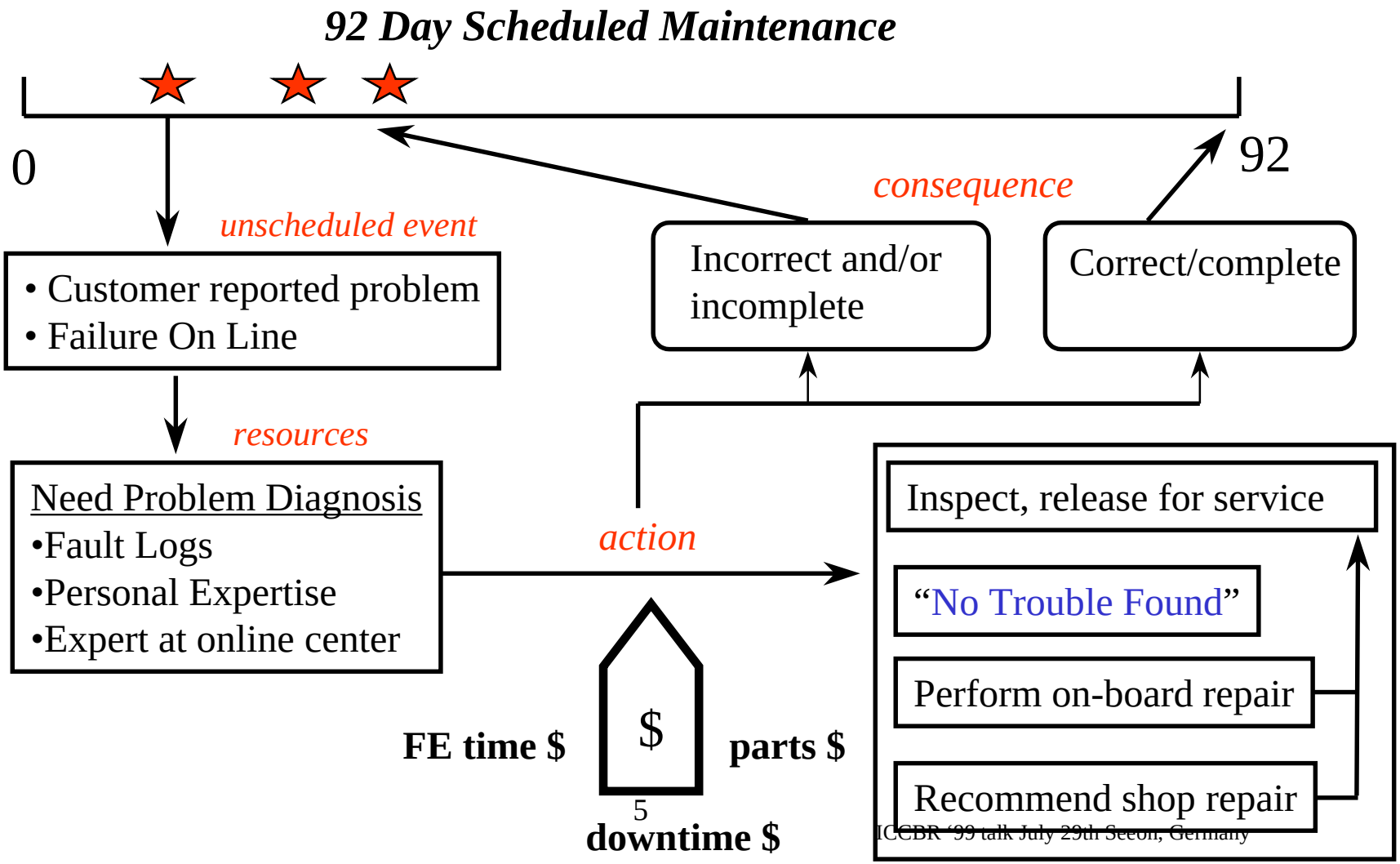
- Locomotives
  - Complex Electro-Mechanical Systems
  - Fault messages - corresponding fault codes e.g. 44AB
  - Fault codes can be reactive / predictive.

- Past Practice
  - Fix locomotive on customer demand.
  - Fault logs may be used to narrow problem
  - Few people qualified to interpret fault logs

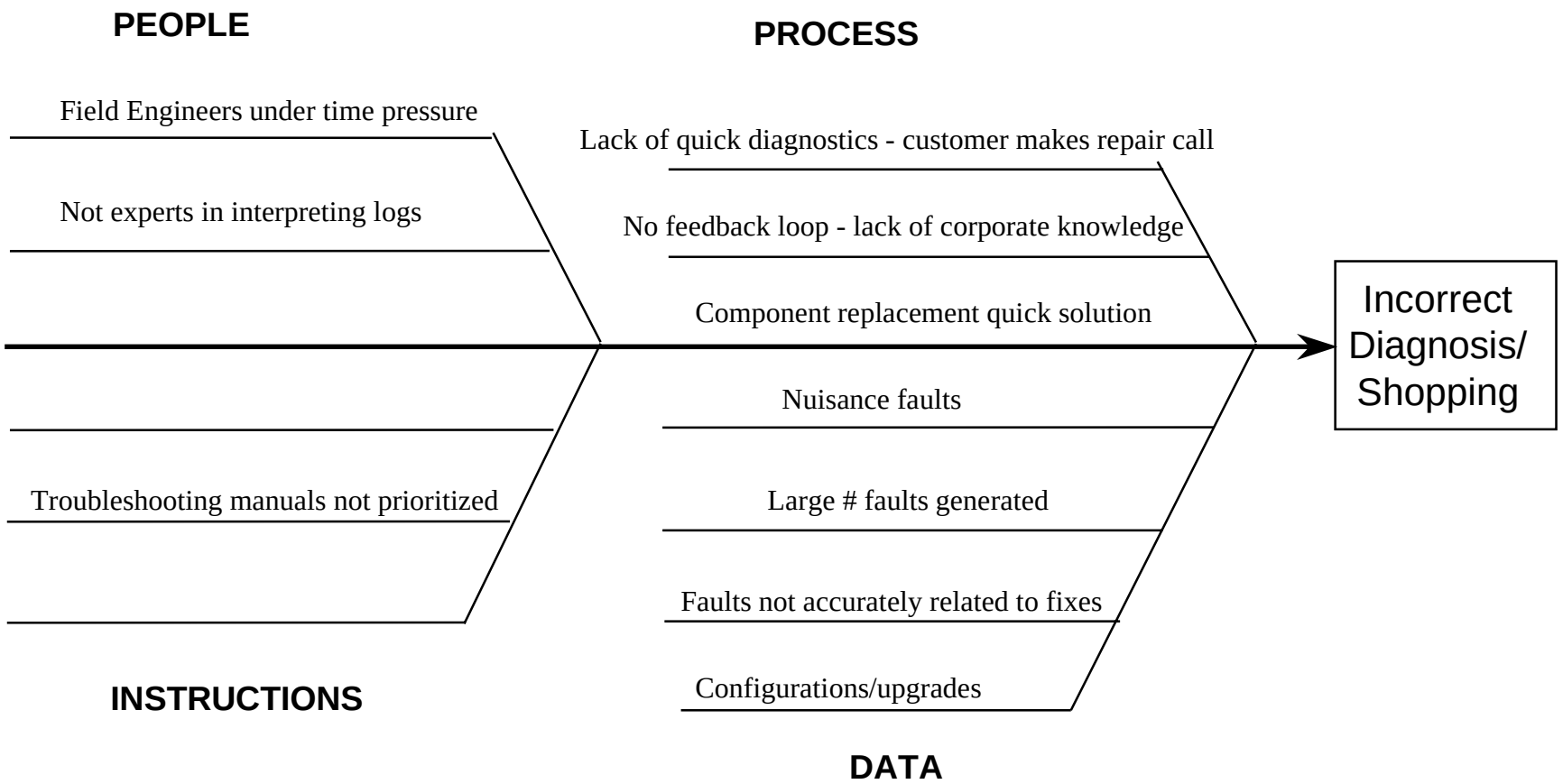
- Now
  - GE guarantees equipment performance
  - GE pays for service / downtime.



Locomotive Fault Isolation



Problem Definition - 3



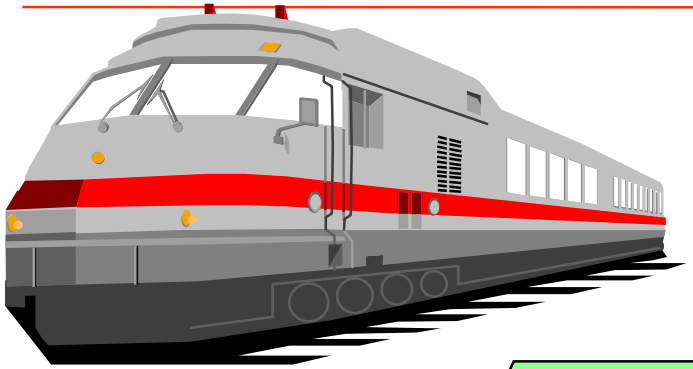
Sample Fault Log


```
AB 2004 12-oct-1997 176B 52.93 52.95 X X X X X X Oil Problem
AB 2004 12-oct-1997 142E 52.95 53.00 X X X X X X Fault Reset
AB 2004 14-oct-1997 170F 36.91 36.99 X X X X X X Loading Limited
AB 2004 14-oct-1997 142E 36.96 75.81 X X X X X X Fault Reset
AB 2004 17-oct-1997 172B 15.63 15.63 X X X X X X High Current Problem
AB 2004 17-oct-1997 172A 15.63 15.63 X X X X X X Motor problem
AB 2004 17-oct-1997 172B 15.63 15.65 X X X X X X High Current Problem
AB 2004 17-oct-1997 1737 15.63 15.67 X X X X X X Low Current Problem
AB 2004 17-oct-1997 1736 15.63 15.65 X X X X X X Low Current Problem
AB 2004 17-oct-1997 1749 15.63 15.65 X X X X X X High Temp Problem
```

Total Number of Faults : > 600
Total Number of Repairs : > 600

Case-Based Diagnosis for Locomotives

GE Corporate Research and Development



Railroad Data

GETS Data

Loco-History

Dasher

Dash*Star™

Current Case

Match log with case base

CASE 4:
CASE 3:
CASE 2:
CASE 1:
452A TM #1
Stalled
(High Cur

Case-Base

Filter and parse logs
Extract Features

```
AB   1101   02-jul-1997 956B Shutdown: Low Oil Press
AB   1101   02-jul-1997 492E Fault Reset While In Le
AB   1101   14-sep-1997 850F Load Limited:         L
AB   1101   14-sep-1997 222E Fault Reset While In Le
AB   1101   17-oct-1997 952B TM #2 Stalled (High Cur
AB   1101   17-oct-1997 444A TM #1 Stalled (High Cur
```

Fault Log

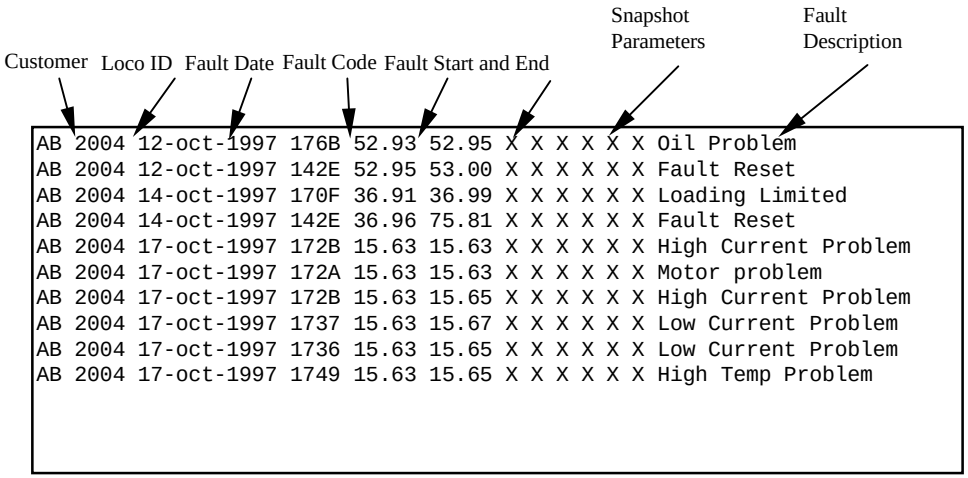
Diagnosis Results

• No control air pressure to WTS	0.75
• Welded power contacts on WTS.	0.66
• Defective WTS magnet valve (stuck open).	0.50
• Defective WTS Interlock or associated wiring.	0.25

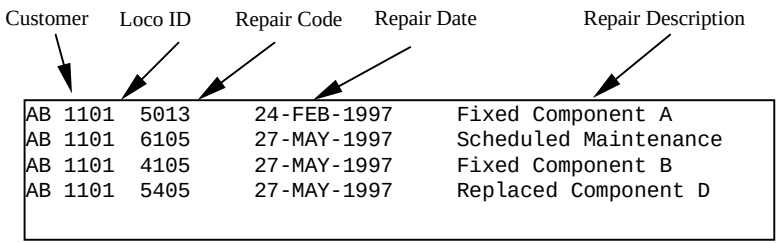
Why CBR

- Complex systems must be diagnosed under time constraints
- Frequent hardware / software upgrades and modifications
- Multiple generation of locomotives
- Experts able to accurately diagnose using fault logs
- Maintenance problem with rule-based systems, BBNs.
- Impossible to accurately express a nearly complete set of rules
- Extensive data from which cases could be mined
- Manual effort not feasible for case construction or rule generation

Data Sources

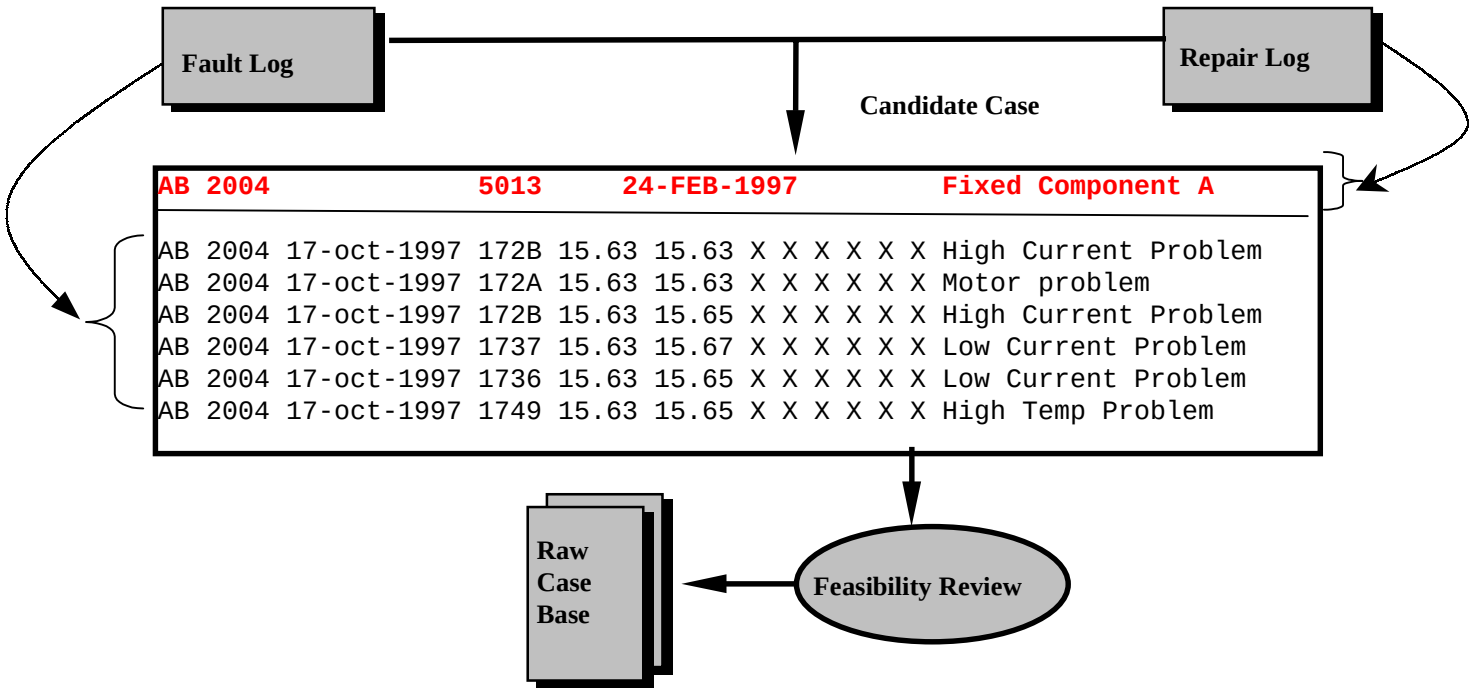


Fault Log Database



Maintenance Database

Automated Case Creation



Sources of Error in Data

- Missing Fault Log data
- Multiple repairs on same day
- Overlapping repairs
- Incorrect Repairs - locomotive failed again within 24 hrs.
- No Trouble Found
- Date of Repair incorrect
- Consider fault log of how many days before repair ?

What to use as Case Features?

- N day fault log window could contain from 0 to X number of occurrences of each fault code
- Fault code frequency
- Combinations of fault codes
- Trends in fault code occurrences
- Anomalous behavior in parameter data
- Sequence information in fault codes

Fault codes - singly and in combination are used as features.

CASE 1	Repair 1	A , B , AB
CASE 2	Repair 1	A , B , C , AB , AC , BC , ABC
CASE 3	Repair 2	B , D , F , BD , BF , DF , BDF

Learn to Identify Fault Patterns

•Fault combinations as indicators.

•If fault/combo occurs evenly before multiple repairs => low weight

•Majority of times fault/combo happens is before same repair => weight is high

•Must see a fault/fault combo occur N times before we assign non-zero weights.

•Individual faults are weak indicators but occur more often. (lower avg. weight)

•Fault combinations that repeat are relatively rare but when they happen, are strong indicators. (Higher avg. weight)

• Fault/fault combinations with weights below a threshold are ignored.

Case Matching

Case 1

```
AB 9090 08-FEB-1999 22-
FEB-1999 16
222F
444F
123F              0.15
1234              0.50
2345              0.55
5558
3456              0.33
666B
4567              0.50
74AB              0.22
6789              0.31
777B
888D
4455              0.40
999B
111F
Speed Sensor #1
```

Case 2

```
AB 4345 14-APR-1999 28-APR-1999 6
730F
444F
1234        0.50
2345        0.55
4567        0.50
4455        0.40
Speed Sensor #1
```

The codes colored red are ignored by the system due to low weights

$$\text{Match} = \frac{(0.5+0.55+0.5+0.4)^2}{(0.5+0.55+0.5+0.4)(0.15+0.5+0.55+0.33+0.5+0.22+0.31+0.4)} = 1.95 / 2.96 = 0.66$$

Case Validation

Leave one out testing

- Remove one case from casebase
- Learn weights over remaining casebase
- Match hold-out case
- If matches with same diagnosis in top 3 results then success

Repair Code	Diagnosis	#cases correctly diagnosed	Total # cases	% diagnosed
1	Cylinder	15	36	0.42
2	Controller Panel	2	15	**0.13**
3	Cab Interface	15	38	**0.40**
4	Traction Motor (AC)	14	18	0.78

- Revisit low yield repair code cases
- Hand verify
- Is repair diagnosable from fault log?
- Not enough cases - many repairs bundled under one code

Reasons:

XXXX- not enough info in Dash*Star fault log

- change light bulb

-from IFC, not in fault log

-nothing in fault log would indicate this

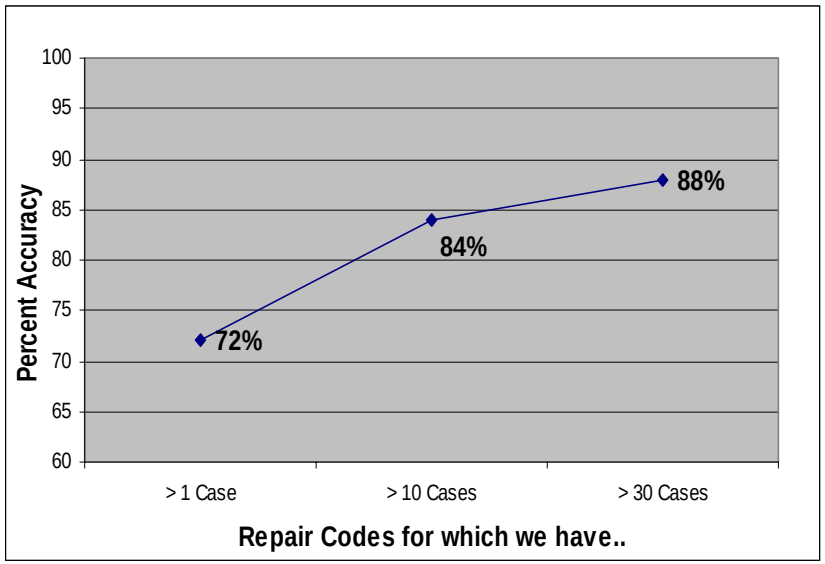
- oil change

- in IFC, couldn’t cause fault

- change wheels, no faults would be logged

- radio, no log

Some Results



	All Cases	Repair codes with > 10 cases each	Repair Codes with > 30 cases each
Number of Repair Codes diagnosed	80	16	5
Total % of yearly problems caused by this set of repair codes	75%	50%	32%

Results

- Design to deployment - 14 months, $250 k overall
- > 70% accuracy over about 75% of repairs
- 600+ locomotives in ‘99
- Different Fleets :
- Different Locomotive Models :
- Savings estimate : few thousand $ per locomotive per year.
  ~ $ 5m./year overall.
- Lots of locos and bad diagnosis is expensive.

Lessons Learned

- High quality cases are hard to come by
- ‘Mine’ data to create casebase
- Iteratively improve quality
- Focus attention on high importance/worst quality cases
- Quick deployment with low performance better than no deployment
- CBR ability to improve with time a big plus with management
- Upfront emphasis on case validation can alienate experts
- Value is often relative - helping users understand how cbr works made them get involved with the process

Ongoing Work

- Added features based on time-related info
- Defined anomalies on snapshot parameters
- use ‘good quality’ information collected in Case Base to jumpstart other analyses
  - time to failure
  - prioritizing effort on to areas CBR could not cover

Summary and Conclusions

- Propose and Verify approach to case collection
- CBR attributes attractive to management
  - Low maintenance
  - Learn with time
  - All effort need not be up-front
  - Keep up with changing nature of data

- CBR attributes attractive to users
  - Not required to commit 100% to case quality
  - Easy for them to understand CBR's shortcomings
  - Did not have to learn new knowledge representation
  - Lowers workload, does not replace expert opinion.