Remote Diagnostic Tools and Services

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Volvo Group Trucks Technology & Halmstad University

Agenda

• Movie
• Scope
• Facts
• Execution
• Results
• Summary - Outcomes and Lessons Learned
Movie

- LINK

Scope

- All about increased "UPTIME" and related services
- Extract from project application:

  ....The aim with the project is to take two important next steps towards achieving the goal of increased up-time with fully predictive maintenance: combining the on-board fault detection with diagnostics tools; and exploring and designing the possible services that can be offered with such a tool.
Facts

- Original application April 2009 – Dec 2012
- Ends December 2013 (Extended one year)
- Budget 20 MSEK
  - Volvo 10MSEK
  - Vinnova 10MSEK
- Based upon "RDM – Remote Diagnostics and Maintenance" (FFI)
- Project consists of two parts

Execution

- Traditional approach for fault detection and diagnostics (forward loop approach, pre-specified problems)
- Our approach = “Data mining” approach (feedback loop approach, observed problems)
- Many faults are not frequent enough or have consequences that are sufficiently dire to warrant the design of a dedicated algorithm.
  - They can still be significant in terms of affecting transport efficiency
With a fleet of vehicles...

The image shows the distances between histograms for Engine Oil Temperature, for different vehicles and different times during a week in 2011. Each histogram is one day of data.

The plot is made using multidimensional scaling, which tries to maintain the distances while representing the points in a low dimensional space. It is not a perfectly faithful illustration of the distances.

When something is odd...

If a vehicle is consistently off from the group (eg. bus 378 in this picture) then this indicates a possible problem.
Bus 378 and Engine Oil Temperature

These numbers should be uniformly distributed between 0 and 1 if the vehicle is normal with respect to other vehicles.

What's going on in Q3 in 2011?

The lower plot shows the negative logarithm (base 10) for the p-value for the mean over a 20-day window (backwards in time) in the upper plot.

Volvo Group Trucks Technology
Bus 370 and Engine Oil Temperature

Note that the “normal” distribution of oil temperature in March is quite different from the “normal” in October.

Fault appears around Jan. 10.

Bus 454 and Engine Oil Temperature
**ECU problem**

- The bus 378 case with oil leaking into the ECU was the first ever on these buses (this fleet).
  - Might be a very unusual fault…
  - …but the same thing happened again 1½ years later…
  - …and a similar thing has been observed on another bus for a year
- A cooling fan that runs at full speed all the time leads to:
  - Higher energy consumption (consumes ~5-7%)
  - The fan’s power consumption goes like (speed)$^3$

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**Bus 70452**

*2009 model*

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coolant system leak</td>
<td>Dec 5</td>
<td></td>
</tr>
<tr>
<td>Tampering with EBS system (“sabotage”)</td>
<td>Feb 10</td>
<td>Volvo Action Service</td>
</tr>
<tr>
<td>Engine ‘knock’</td>
<td>Jul 2012</td>
<td>Cylinder 1 jams (skår) during annual inspection (Repair May 4)</td>
</tr>
<tr>
<td>Problems with alternator belt tensioner</td>
<td>Jul 2013</td>
<td></td>
</tr>
<tr>
<td>Gear box problems</td>
<td>Nov 28</td>
<td></td>
</tr>
<tr>
<td>Problems with Strocco heater</td>
<td>Mar 2012</td>
<td>(Dec 9 &amp; Jan 30)</td>
</tr>
<tr>
<td>Oil pressure problems</td>
<td>Mar 2012</td>
<td>(Mar 2)</td>
</tr>
<tr>
<td>Complaints that engine runs strangely</td>
<td>Apr 2012</td>
<td>Probable cause: CAC leak (Apr 12)</td>
</tr>
<tr>
<td>Service before annual inspection</td>
<td>Oct 2012</td>
<td>(inspection Apr 24)</td>
</tr>
<tr>
<td>Engine “knock”</td>
<td>Mar 2013</td>
<td></td>
</tr>
<tr>
<td>Gear box not working, replaced or repaired</td>
<td>Nov 2013</td>
<td>(Nov 26)</td>
</tr>
</tbody>
</table>

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Plots show deviations in Engine oil temperature and temperature upstream catalyst.
• The line marks engine renovation in beginning of May.

## Service Development

<table>
<thead>
<tr>
<th>Phase</th>
<th>Activities</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploration</td>
<td>Analysis of key stakeholders</td>
<td>A stakeholder map of Volvo buses business operations</td>
</tr>
<tr>
<td></td>
<td>Problem identification with stakeholders through case studies</td>
<td>A report on problems of Volvo dealer operated workshops, small customers with Gold contract, and mid-size companies with their own workshops</td>
</tr>
<tr>
<td></td>
<td>Future workshops with a potential customer having its own maintenance facilities</td>
<td>Co-created scenarios regarding future remote diagnostics services with a public bus operating company</td>
</tr>
<tr>
<td></td>
<td>Analysis of maintenance strategies</td>
<td>A report on pros and cons of corrective and preventive maintenance strategies</td>
</tr>
</tbody>
</table>
Service Development cont.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Activities</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptualization Phase</td>
<td>Customer needs analysis of RDS</td>
<td>A customer need model of public bus operating companies</td>
</tr>
<tr>
<td></td>
<td>Process mapping of bus operation and maintenance activities</td>
<td>Concepts of static and dynamic maintenance, Error reporting service concept</td>
</tr>
<tr>
<td></td>
<td>Business modelling</td>
<td>Business model canvas for RDS contract, Two RDS business model examples (Transactional BM and service contract BM)</td>
</tr>
<tr>
<td></td>
<td>Analysing return on investment for remote diagnostics services</td>
<td>A business case calculation method</td>
</tr>
</tbody>
</table>

Results

- Developed an On-board logger/analyzer (Volvo VACT system)
  - Have been logging data since September 2011
  - Collecting data on a bus fleet
  - Data from trucks
  - 550GB of quality data
Results cont.

- Using on-board data and our approach we are able to detect, in time, many infrequent but important problems that are relevant for improving transport efficiency (vehicle uptime, emission control and fuel consumption). Examples:
  - Cooling fan (3 cases in 19 buses over 1.5 years)
  - Jammed cylinder (1 case in 19 buses over 1.5 years)
  - Compressors (several cases – they all seem to need replacement after 5 years)
  - NOx sensors and emission control (several cases, they also seem to fail after 5 years) – separate patent application

Example: Two Business Models

<table>
<thead>
<tr>
<th></th>
<th>Transactional BM</th>
<th>Service Contract BM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Charge more at sales, sell add-on services or lose money</td>
<td>Increase profit through more efficient maintenance</td>
</tr>
<tr>
<td>Costs for Volvo</td>
<td>- Overhead (workshop, tools…)</td>
<td>- Spare parts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Technicians time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Overhead (workshop, tools…)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Downtime compensation</td>
</tr>
<tr>
<td>Revenues for Volvo</td>
<td>+ Spare parts</td>
<td>+ Monthly subscription fee</td>
</tr>
<tr>
<td></td>
<td>+ Technicians time</td>
<td></td>
</tr>
</tbody>
</table>

\[\textit{Future Work: To move along the phases of SGDP Model...}\]
Summary –
Outcomes and Lessons Learned

• HH decided to establish a research profile with intelligent vehicles as a particular direction (CAISR = Center for Applied Intelligent Systems). We have built up a competence in data mining around this project that has generated a lot of other projects. We are now looking at recruiting even more people.

• [http://www.hh.se/caisr](http://www.hh.se/caisr)

• MI-lab (Människa och Informationsteknologi) have decided to open a research direction in digital service design. This project was an important door-opener on this.

Summary –
Outcomes and Lessons Learned cont.

• Volvo
  – Several Spin-Off Projects started up
    • eg. InnoMerge (Vinnova)
    • eg. State of Vehicle Health (Volvo internal)
  – Input to ongoing diagnostics related projects
  – Self learning models leads to new businesses
  – A new “bird eye view approach” on diagnostics
  – Long projects can be difficult...
Summary – Outcomes


- Prytz Rune, Nowaczyk Sławomir, Rögnvaldsson Thorsteinn, Byttner Stefan (2013). Analysis of Truck Compressor Failures Based on Logged Vehicle Data. 9th International Conference on Data Mining, July 2013, Las Vegas, USA.


- Prytz Rune, Nowaczyk Sławomir, Byttner Stefan (2011). Towards relation discovery for diagnostics. 17th ACM SIGKDD Conference on Knowledge Discovery and Data Mining, August 2011, San Diego, USA.


- Submitted, under review or not yet presented


Summary – Outcomes


Questions?