Locomotive asset management: integration of GPS, mobile telemetry, and GIS technologies

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Abstract

The paper discusses the prototype architecture and capabilities of a Locomotive Condition Monitoring System (LCMS) utilizing an open computing platform, public communications service and commercial software. Integration of locomotive originated data and existing data sets, along with proposed enhancements are also discussed. The treatise documents the use of computer technologies to aid and improve asset management in a railroad environment. Though deployed on a freight railroad, the LCMS application is readily transportable to a rail transit environment and can provide a “core” platform for the implementation of other applications requiring data from on-board a rail vehicle.

Introduction

The essentials of freight railroad operation are commodities to ship, trackage to transport these goods, the personnel to accomplish delivery, and reliable power (locomotives) to convey the shipment. Conrail's Locomotive Assets group, within the Operating Assets Department, is
responsible for the availability and optimal performance of Conrail's locomotive fleet, which consists of approximately 2100 units. Half of this fleet constitutes long-haul road service critical to serving Conrail's customers. While Conrail jurisdiction has a defined geographic footprint, a significant segment of its locomotive fleet is free ranging throughout North America. Regardless of the location, fleet performance status and utilization statistics are critical to overall operations: scheduling, optimal fleet size, and off-property charges. En route failures of the road fleet manifest themselves after the fact and contribute to bottleneck conditions on key routes. The logistics of diagnosing, servicing unscheduled shoppings, allocating new power, and returning the locomotive to service are resource intensive. The ability to predict incipient failures and suggest a most likely cause would greatly reduce cycle time and increase on-time performance.

Given the dynamics of freight transportation, locomotive fleet sizing has never been an exact science. Historically, possessing and maintaining a fleet in excess of demand addressed any potential shortages of locomotive power. It costs approximately $(US)1.3 million to replace a locomotive and an additional $(US)88,000 in annual maintenance. The average age of Conrail's locomotive fleet is 17 years with a life expectancy of 30 years. Conservatively this translates into roughly $(US)100 million annually in fleet turnover costs. With these significant numbers, is it necessary to maintain the current fleet size? What are the spatial and temporal patterns of "trains without power" to "locomotives without trains"? How much time does a locomotive spend waiting for a train to pull (utilization)? Can the disparities be reduced such that locomotive dwell time and "light engine moves" are reduced to the point that one can reduce the locomotive inventory? Tools, such as real-time Global Positioning System (GPS) tracking and Geographic Information Systems (GIS), are available at relatively low cost and have been employed with reported success by the competition. Real time location information would allow scheduling personnel to analyze power distribution and deficits, more effectively.

Objectives

Typical measurements undertaken to assess fleet performance include Mean-Time-Between-Failures (MTBF), Mean-Time-To Repair (MTTR), availability, utilization, and en route failures. The Operating Department of Conrail targeted goals for improvement of the fleet:
• MTBF to exceed scheduled maintenance cycle
• 50% reduction in MTTR
• 20% increase in utilization
• 4% increase in availability
• 50% reduction of en route failures, eliminating unnecessary shoppings

Additionally, maintenance should migrate from periodic or "run to failure" mode to "on condition" or usage-based repair -- from reactive to proactive.

Technology is available to raise current fleet utilization and lower maintenance costs, leading to modified maintenance policies and decreasing overall operating expenses. Advances in technology enable us to monitor, predict and react to adverse locomotive conditions in a real time environment, facilitating rapid and effective repairs while reducing inventory, and material handling costs. Increased availability translates into a lower number of maintained units and a smaller capital investment. Graphic presentation of the fleet's location and performance provides a "big picture" view to operations' personnel not currently available.

Benefits

Collecting useable, pristine data on-board a locomotive and relaying it, in real time, to a central site for immediate presentation and analysis is requisite to obtaining these goals. Decisions regarding proper sensor selection are necessary for effectively diagnosing a subsystem failure. All information collected may need to be interpreted by a qualified locomotive specialist in order to correctly troubleshoot the problem. Utilization of GIS capabilities for display and network analysis will clearly expedite the process. The development of an accurate, timely, comprehensive locomotive location and condition database to store and disseminate this data ensures expeditious repair while also providing a foundation for other corporate-wide users and applications, such as power distribution and train scheduling applications.

The underlying communications infrastructure necessary to support message and data transfer between a locomotive and a central server can also provide a company-wide solution for extending its information network into the mobile environment. The combination of a multitasking computing environment aboard a locomotive, coupled with a reliable communications framework, would enable a variety of applications to be
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developed that require real time train information.

Background

Conrail personnel conducted a fifteen month study through 1994 and 1995 collecting and collating historical data on locomotive utilization, failures, and repairs. The study covered over 6,000 locomotive incidents -- anomalies that required shopping or dispatch of field service personnel. Analysis of this data yielded MTTR, number of en route failures, failure classification, average transit time to repair figures, resulting in actual utilization and availability statistics. Among the recommendations cited was the need for an intelligent on-board monitoring system with a near real-time delivery mechanism and central repository.

Current Systems

Locomotive Assets currently monitors and reports Conrail's' locomotive performance and availability using data reported through the Locomotive Information System (LIS) and the Locomotive Distribution System (LDS) -- both of which are mainframe based. In all instances, knowledge of locomotive failure is after the fact. These systems derive information from a variety of manual data collection processes at system and local levels. As the locomotive data becomes available, a subset is downloaded into a Windows-based relational database for analysis.

Over 40% of the shoppings resulted in “no defects found.” The combination of inadequate information about a reported failure with no defect identified, coupled with no information prior to the failure clearly indicates the need for pre-failure locomotive operating conditions to assist in identifying the underlying cause of perceived failures. Present systems are highly reliant on oral exchange of information, manual data entry, and faxing of reports. The information may pass through several hands and reporting mechanisms prior to reaching shop personnel and are susceptible to errors, loss of information, and high data latency.

A cross departmental team evaluated commercially available systems and their use at other railroads. More than fifteen potential providers and system integrators proposed solutions. The result of this effort revealed inherent design and compatibility flaws in these condition monitoring systems:

• closed architecture -- available systems not compatible across
locomotive builder classes

- proprietary communications protocols or single network provider
- restricted scalability -- Conrail cannot enhance system to monitor additional subsystems
- limited configuration ability -- manufacturer defined functionality
- fixed outbound messaging -- manufacturer defined fault monitoring and reporting
- one-way communications -- non-interactive and predetermined

The most prominent drawback of all systems reviewed is their inability to be deployed across the entire fleet, which consists of a variety of makes and models. Some locomotives are equipped with sensors and processors to collect certain types of locomotive statistics. Additional moneys are required to move this data off board. Older models are not instrumented and therefore need to be retrofitted with an entire LCMS.

These deficiencies reinforced the LCMS Team's recommendation that Conrail design and specify a locomotive condition monitoring system compatible to both present and future locomotive fleets. The team was chartered to field test a prototype and draft system specifications. Subsequent to testing and approval, the specification would be circulated to potential LCMS builders for construction. Conrail could then test their products in a real-time, working environment with the prototype functioning as a control.

**Design Strategy and Approach**

Conrail's intention is to incrementally equip the road service locomotive fleet with a health and welfare monitoring system based upon open architecture/open systems principles. The system will incorporate the monitoring of significant locomotive subsystem parameters; convey that information to a central site, and display that information in a manner expediting troubleshooting by qualified Locomotive Assets personnel. There should be continuous performance monitoring of:

- Geographic location (global coordinates and rail line referencing system)
- Diesel engine and its support systems (combustion air, fuel, lubrication, cooling)
- Electric controls, including propulsion system
- Excitation system (speed, horsepower, braking)

Communication with the locomotives will be bi-directional in near real-time. Continuous railroad-wide data communications will be
necessary for:

- Routine message and data reports
- Immediate anomaly reports
- Periodic data requests initiated by Locomotive Assets personnel at the central site

A database server at the central site will function as a data storage mechanism providing a feed to the LCMS display module and other client applications. Examples of client applications include existing mainframe applications (LIS and LDS) as well as potential applications for Shop facilities and service dispatch. This extended functionality will permit "closing the loop" on locomotive status, availability, and repair history.

Since the data is primarily spatial in nature, a geographic-based interface is appropriate. For temporal trending and identification of recurring problems, the collected data needs to be integrated with other data sources -- another task well suited for GIS. Operator-selectable displays must be available to analyze and sort through all routine messages and anomaly reports. The system must support links to expert systems and other modeling tools.

The Association of the American Railroads (AAR) establishes recommendations for the industry, which members often codify into standards and scope specifications. Applicable AAR specifications include Locomotive System Integration (LSI)\(^1\) and Advanced Train Control Specifications (ATCS)\(^2\), the predecessor of Positive Train Separation (PTS). The former encompasses environmental criteria, interoperability and communications between devices, component and subassembly MTBF, and test parameters. The latter defines vehicle movement authority and enforcement, with heavy emphasis on communications protocol and messaging. Cognizant of these industry recommendations, the team deliberated over full versus selective compliance. Of greatest concern were the environmental aspects of the LSI specification. As to the ATCS specification, messaging regarding locomotive condition monitoring was incomplete.

ArcView, certified as the corporate desktop GIS, was utilized as the integration mechanism and data visualization tool. Incorporating GIS resources not only aided rapid prototype development, but provided immediate access to data in the corporate spatial database. General reference information (political boundaries, streets), railroad industry (ownership), and Conrail-specific data (route structure, facilities) are all available to the LCMS operator. By knowing the locomotive's location in real time and the specific condition prior to dispatching repair personnel,
the LCMS can improve the efficiency of locomotive repair.

Since the final end-to-end system consisted of many subsystems, the team implemented a modular proof-of-concept system. The major benefits of a well-constructed modular architecture are that it provides expandability, avoids obsolescence, and prevents high costs associated with major code rewrites. Conrail plans to install components, both hardware and software, of various manufacturers so as to reduce the company's dependence on any one supplier or manufacturer. As technology, and more importantly, the user's needs change, Conrail staff should be able to take advantage of a competitive marketplace for improving the Locomotive Condition Monitoring System.

Prototype Design and Process

There are three functional subsystems within the LCMS prototype: the On-Board Computer (OBC), the Trouble Desk, and the Communication Subsystem.

The **On-Board Computer (OBC)** collects information about locomotive condition and location, stores the data, reports the status at predetermined intervals, detects and forwards anomaly conditions and supporting information, and responds to Trouble Desk initiated requests. Under existing processes, locomotive failures are manually classified by symptom codes. Within the LCMS OBC, "self-diagnosis" occurs as sensor values are associated with symptom codes on-board. Physical components of the on-board equipment include the locomotive subsystem sensors (both analog and digital), a GPS receiver, an on-board processor, and communications transceivers.

The **Trouble Desk** can be further broken down into two components: a data storage, management, and distribution subsystem and a presentation and analysis subsystem. The data management subsystem receives messages from the locomotives (via the communication subsystem) or the trouble desk operator, logs them in a relational database, and notifies either the presentation subsystem or the locomotive that a new message has arrived. The presentation subsystem is a map-based interface displaying requested information in a "railroad-centric" perspective. When an incoming message is received by the presentation subsystem, the locomotive's position is updated on the map. If the message contains an anomaly, the trouble desk operator is notified by:

- a change of the locomotive symbol on the map. and
a dialog box containing the locomotive unit number, a symptom
code, and an English language description of the problem.
The underlying data values used by the OBC to generate the symptom
code are also available for immediate viewing, should the operator need
to confirm the diagnosis or explore alternatives. This speeds
troubleshooting and provides an immediate entry point into the log files.

The **Communications Subsystem** is the interface between the OBC
and the Trouble Desk. It receives messages from the OBC or Trouble
Desk subsystem, establishes and maintains the communication link, and
transmits the packets to the target subsystem. Since continuous coverage
is required, multiple communication channels require support. While a
satellite communication link provides ubiquitous coverage, it is
expensive and not suited to large file transfers. Cellular technology and
packet data radio are cheaper and provide increased throughput, but tend
to cover only local service areas. Our solution was to isolate the
communication links from the OBC and Trouble Desk subsystems and
adopt an application programming interface (API) between these
modules. This API would allow the OBC and Trouble Desk to write
messages independent of the communication link. The communication
subsystem prepares messages for transport and ensures delivery.

With the architecture divided into separate processing subsystems,
various messaging formats were defined for requesting and delivering
data. A *snapshot request* -- sent by the Trouble Desk to the OBC --
would return one reading for all selected subsystem parameters. The
*snapshot response* from the locomotive would represent the latest values
recorded by the OBC. In contrast, when the OBC received a *buffer
request*, it would return to the Trouble Desk all values recorded for a ten-
minute period prior to an anomaly report with the last values
representing the triggering event. *Status* messages are sent by the OBC at
periodic intervals to the Trouble Desk. The frequency of status messages
sent is a user-defined parameter and can vary between locomotives.
Anomalies manifest themselves as *Alert* and *Alarm* messages. An *Alert* is
a reading outside of limits, but with no immediate failure pending. An
example of this could be elevated engine temperature while the
locomotive is pulling up a steep grade -- while the value is out of range,
it can be expected to return to normal once even grade is reached. An
*Alarm* is a value out of range with imminent failure. This may require
shopping the locomotive or dispatching a repair crew immediately.
Findings and Conclusions

The LCMS prototype has been functional since April 1996. Since its installation, the system has logged thousands of messages, including alarm conditions. Alarm messages appeared in June 1997 for a fan controller sensor. (The fan controllers start fans to help regulate engine temperature.) The condition was not persistent, and did not warrant immediate action, yet a review of the location, time, and activity associated with each anomaly report revealed that the locomotive's fans were not firing properly. In each instance, Locomotive 6724 was pulling a heavy consist and was therefore required to work harder -- and hotter. In these situations, all fans are needed to regulate engine temperature. The LCMS reported that fan controller #2 had stopped working. Upon subsequent shop inspection, the fuse for fan controller #2 was found to be blown. Success! While not a show stopper, if unknown, this condition would contribute to unnecessary engine stress and decreased life expectancy. Further, possessing this information beforehand precluded an en route failure.

With the successful performance of the prototype, and a functional specification completed, the team was ready to test and evaluate systems. Next steps included:

- Equipping more of the fleet with Locomotive Condition Monitoring Systems
- Increasing the number of available channels/sensors for on-board processing
- Implementing dynamic parameter configuration
- Enhancing on-board decision making capabilities
- Supporting additional communications links with priority messaging
- Modification of structure to accommodate additional message types:
  - System maintenance utilities
  - Application-specific messages (OBC/TD running multiple applications)
- Remote system troubleshooting
- OBC software upgrades

The complexity imposed on the present system by these enhancements extends the functionality of, and reliance on, middleware and APIs. The isolation of application software from transport mechanisms and supporting infrastructure is critical. The logistics of capturing a 100+ ton moving target to tweak software or switch communication networks are diametrically opposed to the goals of
increased efficiency and asset utilization.

Obviously, as the number of outfitted locomotives and sensors increases, there will be a dramatic increase in the amount of data collected and reported back to the central site. Further data modeling, data warehousing, and data "mining" techniques must be employed to guarantee fast and easy access to this data. Automated trending tools will assist users in correlating anomalies and suggest previously unforeseen relationships within classes of locomotives and/or across the fleet. The use of ESRI's Spatial Database Engine (SDE) would ensure immediate access to comprehensive geographic datasets while an Oracle-based Locomotive Maintenance Database would provide a flexible repository and delivery mechanism capable of satisfying many different users. Future expansions, based on a full-scale production LCMS platform, include establishing terminal and shop diagnostic workstations, interfacing with train inspection devices, performing train consist reconciliation, and assisting power and train scheduling.

No longer an isolated technology reserved for "closet" or "behind-the-scenes" mapping, GIS is coming into its own supporting mission critical operations. Recent advances in GIS and related technologies, coupled with wider political acceptance, has promoted utilization of GIS throughout multiple application domains. Whether for asset or shipment tracking, commodity flow, crew dispatch, or vehicle/locomotive repair, GIS and GPS technologies are playing an increasing role throughout the transportation industry.

References
