CONF-960869--20 SAND--96-8222C

A Strap-on Monitoring System For Rail Car Applications

Jim Hogan, Dan Rey, Jim Mitchell and Roger Breeding; Sandia National Laboratories; Albuquerque, NM

R. Gordon McKeen; New Mexico Engineering Research Institute; Albuquerque, NM

Jim Brogan; University of New Mexico; Albuquerque, NM

Abstract

A joint Sandia National Laboratories, University of New Mexico, and New Mexico Engineering Research Institute project to investigate an architecture implementing real-time monitoring and tracking technologies in the railroad industry is presented. The work examines a strap-on sensor package, designed as a value-added component, integrated into existing industry systems and standards. As applied to freight trains, the sensors' primary purpose is to minimize operating costs by decreasing losses due to theft, and by reducing the number, severity, and consequence of hazardous materials incidents. Product requirements are based on a cost-benefit analysis of operating losses. Results of a concept validation experiment conducted on a revenue-generating train are reported.

Introduction

In April 1995, the New Mexico State Transportation Authority (STA) established a technology transfer project to help develop a real-time monitoring and notification product for railroads in North America [Ref. 1]. The goal was to assess the commercialization potential of electronic modules mounted on railcars to reduce operational costs by: (1) reporting in real time, events crucial to the safety and security of railcars or cargo, (2) alarming cars to reduce loss of revenue due to theft or vandalism, and (3) monitoring cargo to mitigate threats to public safety associated with incidents involving hazardous materials.

The concept, named the Green Box, consists of sensor modules which, under normal operating conditions, communicate to the railroad dispatchers via wayside reader stations or through the train's voice/data radio. In an emergency, the module would transmit a distress message identifying the location of the event, a description of the cargo, and the condition of the vehicle/container. To test the concept, a cellular phone was used to transmit data

Based on preliminary information gathered for the cost-benefit analysis, a system architecture that accommodates three different applications was developed. In the order of implementation, the three applications are security of cargo, safety of hazardous materials cargo, and a monitor of safety critical railcar components. For the initial application, only those cars transporting "high-value" cargo would be equipped.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Theft and Vandalism Alarm Operations

In this application, the Green Box would monitor high-value cargo transported by rail and send an alarm if someone attempts to steal or damage the protected items. The system would consist of two parts: a railcar-mounted sensor module and a central workstation to display the status of multiple modules. The workstation, located at the company headquarters or railroad dispatcher's office, would receive messages via modem, process the information, and sound the alarm. Two-way communication would permit the base station operator to remotely check the status of the sensors, activate and deactivate the alarm, set the timing interval and conditions for periodic status reports by the remote units, and communicate with the train operator.

The sensor modules would be mounted on the railcars or attached directly to the cargo containers. The modules would contain a power supply, transceiver, processor unit, global positioning system (GPS) receiver (optional), and intrusion sensors: door switches, area sensors, etc. The sensor module would be operational from point of origin to the delivery point and could be activated and deactivated by unique code control over the communications link or directly through an I/O connector. The processor unit would poll the sensors, resolve conflicts in sensor readings and report any changes to the base station via the communications channel. To conserve power, the transmitter could be placed in the sleep mode and be turned on only when an alarm condition was detected or a scheduled report was due. Low power consumption would permit the alarm system to function if the protected cargo/railcar were left at a railroad yard or siding for long periods of time. To minimize false alarm rates and maintain high system reliability, only high-probability events based on data fusion of all sensor inputs would trigger the alarm.

Hazmat Alarm Operations

This product could provide the railroad industry with a cost-effective way to monitor the material condition of hazardous cargo during shipment and to send immediate notification if containment of the cargo is in peril. The concept is to place an electronic sensor/tag, programmed to assess the vital signs of the cargo, on the hazardous material container. For example, one could monitor product in a tank car used to transport petrochemicals. Sensors could measure the liquid level in the tank, temperature, exhaust gas and container integrity. The processor could be loaded with a set of instructions defining the normal operating conditions and the protocol to follow in the event the that limits were exceeded. Additional information regarding the cargo type, class of hazard, handling cautions, emergency procedures, and point of contact for the response team might also be included. In the event that hazardous material leaked from the container or if an unsafe condition developed, the system would then transmit a message to the train conductor and/or dispatcher. Remedial action could then be initiated.

Preventive Maintenance Operations

The concept for this product is to provide an after-market, strap-on electronics module to monitor the material condition of safety-critical components on railcars (e.g., wheel bearings, brakes, etc.), and to identify high-repair-cost items requiring maintenance or other high-consequence-event related items needing service. Under ideal conditions the warning would be early enough to permit orderly, scheduled repair of the out-of-spec item. For example, the onboard system might warn the engineer that a wheel had jumped the rail and was cutting ties, a condition, that unattended, might eventually lead to a derailment. The excessive vibration would be picked up by the Green Box and reported as an out of normal condition.

The Green Box would analyze signals from a suite of sensors and identify the characteristic signature of deteriorated performance and then transmit a message to the base station. The resulting information could then be used to schedule maintenance operations without affecting equipment operating in good condition. Problems would be identified under operating conditions and therefore better diagnosed. Also, repairs would likely be more effective in correcting the true cause of the deficiency and avoiding unwanted effects associated with the catastrophic failure of parts.

Cost-Benefit Analysis of Using the Green Box in the Railroad Industry

To assess the cost-benefit of the Green Box, one must estimate the cost of the accidents the Green Box might prevent, we therefore consulted the accident data compiled by the Federal Railroad Administration, U.S. Department of Transportation [Ref. 2]. Data in Tables 1 - 5 were extracted from this source. Our approach was as follows. First, we considered costs associated with accidents that could be avoided if all the cars in all freight trains were equipped with the Green Box. Second, we examined the case in which the Green Boxes would be attached only to tank cars carrying hazardous materials. Third, we considered the application in which the Green Box would be used solely to monitor shipments of high-value cargo.

Benefit of Equipping All Freight Cars

Reportable train accidents by cause are summarized in Table 1. The following tables include damage to railroad equipment (cars and locomotives) and track (rail, ties, switches, grade, bridges, signal systems, etc.). The ratio of equipment damage to track damage is approximately 3:1 for main line accidents and about 4:1 for yard accidents.

Table 1. Summary of Train Accidents by Cause (1994).

Cause of accident	Number	Damage (M$)
Track, Roadbed, and Structures	947	56.2
Equipment Failures - Locomotive	29	2.9
Equipment Failures - Car	264	28.9
Train Operation - Human Factors	911	44.3
Miscellaneous	518	48.3
Total	2,669	180.6

In Table 1, the "Track, Roadbed, and Structures" category of accident causes includes washouts, wide gauge, broken rails, damaged switches (not due to vandalism), and signal failures. "Train Operation - Human Factors" includes failure to use the brakes correctly, employee impairment due to drugs, alcohol, or sleep, communication failures, coupling at excessive speeds, and so on. The "Miscellaneous" category includes avalanches, landslides, floods, shifted loads, highway-rail grade crossing accidents, harmonic rock off, vandalism, and accidents under investigation. Of the five categories of accidents, the Green Box can affect those associated with car equipment failures directly and to a lesser extent those resulting from train operator error or miscellaneous causes. In the latter two cases, the Green Box could provide critical information, not otherwise available, that affects accident-avoidance decisions.

From Table 1 that slightly less than 10% of the accidents, and somewhat more than 15% of the damages, are due to car equipment failures. However, not all the car equipment failures would be preventable by using the Green Box. The major categories of car and locomotive equipment (mechanical and electrical) failures are shown in Table 2. Structural failure of doors, trailer/containers, or car body (sill, center plate, etc.) represent a small fraction of the accidents and are items probably not worth monitoring by the Green Box. Nonetheless, for structural members, the Green Box sensors could be used to measure the stresses in the material. Candidates for monitoring include coupler and draft gear failures and truck and wheel failures (which include broken wheels – broken flange, broken rim, etc. – damaged wheels, worn wheels, and thermal cracks). A vibration sensor in the Green Box might be able to eliminate some derailments caused by wheel failures.

Of the ten categories in Table 2, accidents listed in the "Brakes" and "Axles and Journal Bearings" categories appear preventable by application of the Green Box. Table 3 lists the specific causes of accidents in the "Brakes" and "Axles and Journal Bearings" categories. "Broken or Bent Axle" means broken or bent between the wheel seats; a broken or bent axle at the wheel seat is considered to be a journal or bearing failure. Seven accidents due to hand brake failures and nine locomotive axle and journal failures that are included in the figures in Table 2 are excluded from Table 3. (The hand brake failures caused $0.1M in damages and the locomotive axle and journal failures caused $1.4M in damages.)

Table 2. Accidents Resulting from Car and Locomotive Equipment Failures.

Cause of accident	Number	Damage (M$)
Brakes	26	5.5
Trailer or Container on Flat Car	2	0.1
Body (Structural)	18	0.6
Coupler and Draft System	34	2.0
Truck Components	75	5.6
Axles and Journal Bearings	59	8.6
Wheels	46	7.6
Locomotives	9	1.2
Doors	7	0.2
General (Other)	17	0.5
Total	293	31.7

Table 3. Accidents Resulting from Brake and Axle and Journal Bearing Failures.

Cause of accident	Number	Damage (M$)
Air Hose Uncoupled or Burst	2	0.06
Obstructed Brake Pipe	1	4.0
Brake Valve	3	0.6
Other Brake Components	1	0.3
Brake Rigging Down or Dragging	8	0.3
Other Brake Failures	4	0.08
Broken or Bent Axle	4	0.3
Plain Journal Overheating Failure	5	0.2
Roller Bearing Overheating Failure	40	6.6
Other Axle and Journal Failures	1	0.02
Total	69	12.5

Nineteen brake failures and 50 axle and journal failures are listed in Table 3, and the average damages of these accidents is $181K. Table 3 has divided the accidents for one year so finely that the results may be skewed by one or two accidents. In particular, note that the one accident due to an obstructed brake pipe resulted in almost 75% of the damages for all 19 accidents caused by air brake failures. This particular failure resulted in a collision; 15 of the 19 air brake failures resulted in derailments; and 3 caused "other" accidents. Of the 50 accidents due to railcar axle and journal bearing failures, all but 2 were derailments. As a comparison, the average equipment and track damages for six years are shown in Table 4. Note that variations occur from year to year for all three categories for the number of accidents, damage, and average damage.

Table 4. Summary of Train Accidents by Type (1989 - 1994).

Year	Total number of accidents	Total damage (M$)	Average damage (K$)	Number of collisions	Collision damage (M$)	Collision average damage (K$)	Number of derailments	Derailment damage (M$)	Derailment average damage (K$)
1989	3,081	212.0	68.8	305	22.8	74.7	2,129	152.7	71.7
1990	3,045	211.8	69.6	315	27.8	88.3	2,146	159.3	74.2
1991	2,814	222.9	79.2	261	37.9	145.3	1,936	153.1	79.1
1992	2,531	127.0	50.2	207	14.0	67.6	1,734	91.5	52.8
1993	2,785	190.9	68.5	205	26.2	127.6	1,930	139.8	72.4
1994	2,669	180.6	67.6	240	30.7	127.8	1,825	125.2	68.6
Total	16,925	1,145.1	403.9	1,533	159.4	631.3	11,700	821.6	418.8
Ave	2,821	190.9	67.3	255.5	26.6	105.2	1,950	136.9	69.8

The average equipment and track damage for an accident caused by equipment failures for the years 1989 - 1994 is $98K, and the average annual equipment and track damages due to all accidents caused by equipment failures is $38M. (All highway-rail crossing accidents are excluded from the data, even if they were due to equipment failure.)

Costs Averted if All Railcars are Equipped

The data presented in the previous section allows us to estimate the annual equipment and track damages that might be avoided if the Green Box were installed on all railcars. To bound the damage avoided, we will assume that accidents due to all causes listed in Table 3 (compiled for calendar year 1994) can be prevented by the Green Box. There are several ways of computing costs, estimates of averted costs range from $4.7M to $12.5 depending what basic assumptions are made. There are additional costs such as environmental restoration and penalties, medical and death benefits, overtime for operating crews, fees paid to other railroads for detours, damages paid to evacuees, penalties paid to shippers for lost and delayed cargoes, etc. These costs can be substantial. In the case of the July 1991 derailment near Dunsmuir, California, for example, Southern Pacific Railroad reported a cost of $50M. Nonetheless, equipment and track losses provides the basis for an estimate of the range for total costs. Using the higher damage figures for calendar year 1994 from Table 3 of $12.5M and a factor of four, to account for environmental and other costs, we argue that $50M is a reasonable upper bound for all annual averted costs due to equipment failures that the Green Box could prevent if installed on all railcars. The nominal estimate of annual averted costs is approximately $25M.

There are approximately 1.2 million railcars in North America. Thus, our range of averted costs is from $4 to $40 per railcar per year plus annual operating costs associated with the Green Box. This compares to the cost of a standard railcar of $50K to $80K, tank cars of $50K to $100K, and specialized cars from $150K to $250K each.

Benefit of Equipping Only Hazmat Tank Cars

If putting the Green Box on railcars is difficult to justify on the basis of equipment and track damages averted, what additional benefit can be realized if one considers the higher losses if hazmat cars are involved in an accident? Alternatively one might consider the benefit if only hazmat cars were monitored. Table 5 presents hazmat accident data for calendar year 1994 by type of accident. There were 537 accidents involving 558 consists (trains) that included hazmat cars. Table 5 shows that 680 of the 4,377 hazmat cars in these consists were damaged and only 43 cars released hazardous material. Note: as a precaution, since the integrity of the tank car is unknown, evacuations may occur even if hazardous material is not released.

Table 5. Summary of Accidents Involving Trains with Cars Containing Hazardous Materials by Type (1994).

Accident	Number of consists	Cars in the consists	Cars containing hazmat	Damaged cars containing hazmat	Damaged cars releasing hazmat	People evacuated	Equip-ment damage ($M)
Derailment	395	24,020	3,339	571	37	5,336	22.4
Collision	74	3,740	495	53	2	10,000	11.9
Hwy-Rail	26	1,621	217	4	3	12	3.9
Other	63	2,440	326	52	1	0	0.9
Total	558	31,821	4,377	680	43	15,348	39.2

The data shows that accidents were due to equipment (mechanical and electrical) failures in eighty-five of the 558 consists having one or more hazmat cars. And of these, the Green Box might be expected to avert only 32 consist accidents due to brake and axle and journal failures. These accidents accounted for $4.2M of the $39M in equipment damage. We again exclude structural failures, coupler and draft gear failures, etc., from failures the Green Box could detect in time to prevent an accident.

Table 5 shows that slightly less than 14% of the cars in the trains carrying hazardous materials that were involved in accidents actually contained hazardous materials. It is not clear from *Bulletin 163* whether the cars listed as containing hazmat includes all cars that might contain hazmat, loaded or empty, or just cars that were actually loaded with hazmat at the time of the accident. We will assume the latter since an empty car that is used to transport hazmat would not pose a danger of a hazmat release, and the shipper would not notify the railroad of a hazmat shipment for an "empty" car. (A procedure perhaps worth reviewing in the wake of the May 1996 Value Jet accident where "empty" oxygen canisters were transported in a passenger liner storage compartment.)

Costs Averted if Only Hazmat Railcars are Equipped

Nominal values for the equipment and track damages averted by the Green Box in hazmat accidents are based on 1994 data. To bound the total costs we will rely on subjective cost multipliers based on best engineering judgment. The derailment of a hazmat car might be caused by a brake, axle, or journal failure on the hazmat car itself, or some other car ahead of the hazmat car in the train.

Based on the above analysis, one can expect 28% of the equipment and track equipment losses in accidents involving hazmat-carrying trains can be averted by using Green Boxes on hazmat tank cars. This amounts to about $1.2M and assumes that all accidents due to the causes listed in Table 3 are indeed prevented by the Green Box. (Hazardous material carried in tank cars constitutes a substantial portion of the hazmat shipped by rail. Petrochemicals, flammable gases, and molten metals, for example, are transported in tank cars. We estimate that there are ~ 60,000 tank cars in North America.) We conclude that equipping 60,000 hazmat tank cars with the Green Box will avert $1.2M of equipment and track damage every year. This works out to about $20 of averted equipment and track damage per year per car equipped with the Green Box.

To determine the total costs that might be averted by placing the Green Box on hazmat tank cars, we need to estimate the accident costs other than damage to the railcars, locomotives, track, and related railway structures. These costs include: loss of the cargo, property damage, highway closings, local emergency services, traffic delays, loss of wages to residents and businesses, public evacuations, cleanup and remediation of hazmat, casualties, fines, litigation, etc. We know that some hazmat railroad accidents run up tens of millions of dollars and higher in environmental costs. A study conducted in 1991 for the National Transportation Research Board [Ref. 3] looked at 45 hazmat rail accidents that occurred between March 1988 and February 1989 and estimated the per year costs based on 25 - 50 incidents per year. The results by category were: property damage – $50M - $100M; highway closing – $20M - 40M and public evacuation – $25M - $50M.

A study by Wizig and Shillen in 1987 [Ref. 4] estimated the cost of evacuation (accounting for direct evacuation costs and lost wages and earnings by residents and business) to be $600 - $1,000 per evacuee. From 1980 - 1989, the railroad industry spent $100M on cleanup and remediation for major hazmat spills. Hazmat incident reports collected by the State of California and the State of Illinois suggest that between $12.5M and $25M may be related to transportation (this includes both trucks and railroad). Since we lack detailed information about these expenses, we will account for these costs by use of a multiplier on the equipment and track damages.

Although some railroad hazmat accidents are very expensive, Table 5 indicates that only about 1% of the hazmat cars in trains containing hazmat cargo that are involved in accidents actually release their cargo. Thus, while a multiplier of 100 on equipment and track damage to account for environmental and other costs may be reasonable for a few specific accidents, a multiplier that large is not appropriate for all accidents involving trains with hazmat cars. For all accidents involving trains with hazmat cars, a factor of 10 on equipment damage to account for environmental and other damage is a reasonable upper bound. A lower bound would be a multiplier of 1; achieved if half of the accidents due to brake and axle and journal failures on a car equipped with the Green Box were eliminated and the environmental multiplier were 2.

The implication of an environmental damage multiplier of 100 is that there would have been environmental costs of about $360M from the 537 accidents involving trains with loaded hazmat cars in calendar year 1994 (which caused about $40M in equipment and track damage). This is twice the equipment and track damages for <u>all</u> accidents ($180M, Table 1). This may be compared to a total of about $100M for all freight loss and damage payments for an entire year due to all causes. We conclude that an estimate of the average annual hazmat environmental (and other) costs on the order of $400M are not reasonable, although the costs might run that high for one exceptional year.

With these bounds on the multiplier to account for environmental and other costs, it appears the Green Box might be expected to avert between $20 and $200 of accident costs per car per year. This value assumes that all the hazmat cars in the U.S. and Canada are equipped with Green Boxes. It is technically feasible to equip just a small fraction of the hazmat tank cars with the Green Box, but then fixed costs would be spread over a smaller number of cars. Still, placing Green Boxes on a small number of hazmat tank cars might be feasible where specific routes are involved.

<u>Benefit of Equipping Railcars with High-Value Cargo</u>

As much as one-third of goods lost in the wholesale industry are lost during the transportation phase. The security of merchandise is particularly acute in the high-tech and automotive industry. Automobiles, once shipped by rail on open flat cars, are now transported in closed containers. Containerized cargo, which now replaces truck-trailers as the preferred form of inter-modal packaging, is being equipped with sensor systems to counter theft and vandalism losses. The estimated annual cost of robbery, theft and pilferage from and damage to specialty railcars used to ship automobiles and automotive parts alone, for example, is $10 million. The size of this fleet is ~ 100,000 cars. As a result, equipping these cars alone can be justified on the basis of cost avoidance of $100 per car per year.

In summary, the benefits of Green Box railway applications are primarily the costs of events avoided: thefts, hazmat incidents, and accidents (in that order). Additional benefits may be found in the areas of reduced railcar maintenance costs and improved accident response. The first product should target the security market for protecting high-value cargo from theft and vandalism. To be cost effective, the units should be in the few hundred dollar range. When only tank cars that carry hazardous material are considered, the next most attractive application of the Green Box is to monitor hazmat shipments. The accident costs averted by placing Green Boxes on all hazmat cars appears to be in the $20 to $200 range per tank car per year. It appears to be very difficult to justify placing a

Green Box on every car in the North American railcar fleet on the basis of annual accident costs averted. Using the highest estimates the averted accident costs are only on the order of $100 per railcar per year.

System Design and Validation

The system design effort for the Green Box is based on a strategy suggested by the market research and the cost-benefit studies. The idea is to introduce a product with modest capabilities, establish a performance record with the customers, and later expand to additional capabilities. As a result, the technical goal was to design a system architecture for the first product with built-in expansion capability. We propose to develop a common system architecture for the three applications in a single, software and hardware reconfigurable module. Based on this approach, the security application will be specified to the chip sets level. The resulting design will be delivered to our commercial partner for resolving product realization issues and estimating production cost.

The Green Box system consists of two parts: a remote unit (strap-on module) mounted on a train car and a base station located at company headquarters. We have assumed that the base station can be assembled from commercial hardware: personal computers (PCs) and modems common in business offices today and Green Box-specific software, compatible with PC operating systems. Validating these crucial assumptions is discussed at the end of this section. We will first concentrate on the unique features of the strap-on module.

The primary functions of the Green Box system are acquisition, processing, communication, and display of data. The computing power of the controller establishes a robust system in which changes are easily made in software. The system is both software and hardware modular. The sensor suite, the alarm threshold conditions, the specific response algorithm, power supply technology, and communication system are all selectable. Components can be matched to the specific application from a pre-approved/qualified list.

Sensor issues: Based on two, two-axle trucks and one strap-on unit per railcar, we estimate eight data channels are required to provide information on each bearing. If we consider the applications for monitoring either the security of cargo or state-of-health of hazmat, eight channels also appear adequate. For a tank car transporting hazardous material, eight sensors channels could provide information on the temperature of the product, fluid level, orientation and acceleration of the car in 3-axes. Based on these considerations, we set the requirement for an eight-channel, eight-bit analog-to-digital converter.

Communication issues: Reporting real-time events identified by the strap-on unit is essential to realizing improvements in operational performance and operating cost. In order to accommodate a variety of communications devices including RF, IR, and acoustic, the Green Box module will be configured with a serial port. Information about the status of the car and cargo could be reported through existing wayside monitor stations. In situations requiring immediate response (e.g. failed bearing, broken axles) direct communication with the engineer or dispatcher could be accommodated by the railroad's voice/data radio. To validate the communication strategy, we selected the cellular telephone technology to test the essential features.

Power issues: When the electric-controlled braking system is fielded, a source of power for the Green Box will be available. In the meantime, the strap-on module must be stand-alone on most freight cars. Based on system reliability, safety, maintainability and cost of implementation we selected a battery-operated design with the goal of three months independent operation.

Controller and Processor issues: Processing the data collected by the sensors and extracting the information is the essence of the Green Box concept. The processor would calibrate sensor signal values and interpret the corresponding measurement in a look-up table. To hold conversion tables and scratch pad information for the specific applications, we augmented the processor with a memory chip. To reduce power consumption, the system would be designed to report "by-exception". To minimize false alarms (limits to be established by the customer), polling techniques and signal averaging should be employed.

Packaging issues: The packaging must provide protection for the strap-on module when exposed to environmental conditions: -40°C to +80°C, humidity 0 to 100%, shock (5% min-max absolute shock bounded between 20 and 100 g's over the frequency range 10 to 1,000 Hz), and vibration (bounded between 0.01 and 0.1 g^2/Hz over the frequency range 10 to 1,000 Hz). If post-accident survival is required, these specifications could be supplemented with immersion in a fuel fire (~ a few minutes) and static crush load (~ 1000 lbs).

Location issues: In some instances the customer may desire location information. If hazmat is being monitored or the railcar is serving as temporary storage on a siding, independent location information might be useful. In the case of certain shipments (e.g., containerized cargo) the tags are not always on the railcar and in other cases the tank cars are owned by the shipper or car leasing companies (e.g., the phosphorous producers). The GPS receiver is therefore included as an option.

Display issues: The information collected by the strap-on unit can be displayed on a standard personal computer found in today's business office. If augmented with modem capability and configured with a minimum of 8 Meg RAM and 80 Meg disk space, the office PC can run a compiled version of the Green Box display system software.

Validating the System Design Assumptions: A prototype strap-on unit was assembled from commercial parts and base station software was installed on a Gateway 2000 computer. With this equipment, temperature and position data was transmitted from a railcar on the Santa Fe Southern Railroad during a round trip run from Santa Fe to Lamy, New Mexico. The data was sent via cellular telephone to the base station in Livermore, California. The test validated the assumption that commercial hardware and software could be used to configure a typical office computer to receive and display the information transmitted from the Green Box using a commercial communication system. Two-way communication was also demonstrated. As a result, we concluded that a major cost of implementing the Green Box system, i.e. the cost of a communication system, can averted. Independent assessment of similar communication strategies used by other projects at the laboratory reinforced this conclusion.

Manufacturing issues: The system requirements reflect the desire to produce a reliable product for both a reasonable purchase price and with a low life-cycle cost (serviceability, reparability). To keep production costs low, commercial parts and standard production processes must be specified. Based on the benefits analysis we established a cost target of $500 per unit for the strap-on module produced in lots of 1,000.

Circuit Implementation

The Green Box circuit implementation is a low-cost, low-power, flexible design which permits a wide variety of potential applications. At the heart of the Green Box is the 8-bit Motorola MC68HC811E2 microcontroller. The microcontroller is a fully static design that allows operation at frequencies down to DC. In addition to its low-power stop mode function, the processor can be operated at lower frequencies to reduce power consumption. An eight-bit, eight-channel analog-to-digital (A/D) converter is included on-chip. The processor can be programmed to run in a “pulsed” mode, whereby a sensor can be checked for possible alarm condition once per second with only a 1% duty cycle.

Sensor Inputs

The sensor interface includes eight differential inputs that can accept single-ended inputs by grounding the inverting (or non-inverting) input pin. The input amplifiers can be configured for gain and anti-aliasing filters. A differential input interface accommodates both single-ended or differential sensor outputs.

GPS Receiver Interface

The Green Box uses a Motorola *VP Encore* GPS receiver. The unit is purchased as a fully assembled, 2.00" in. x 3.25" in. x 0.64" printed circuit board. The GPS serial communications has a TTL level interface. Also included with the receiver module is an on-board keep-alive battery and an active antenna.

Communications Interface

Communications system specifications will be determined by the needs of each application. We therefore designed the communications interface to accommodate several options. For the purpose of this design/study, we investigated using an FCC part 15 spread spectrum, 1/3-watt radio. The radio includes a 32-bit CRC error detection with retransmission capability. The I/O port is an asynchronous RS232 interface. The spread spectrum transceivers are capable of data rates of 115.2 kBaud over distances of 20 miles. Used in conjunction with other data links such as the Internet, it is possible to combine wireless and wireline data communications, essentially making remote data available world wide.

Power Supply

A 7-volt dual-cell, 1.6 ampere-hour lithium battery provides the power for the entire Green Box processor board. A 5-volt output DC/DC converter provides power regulation to all circuits, including analog signal conditioning, RS232 transceiver, and digital devices. To conserve power, the Green Box has a sleep mode of operation for prolonging battery life.

Product Realization

To provide a reliable product at a reasonable cost the emphasis was placed on using standard parts and commercial processes to transform the concept into a market product. For this application, Delta Group Inc. of Albuquerque, New Mexico suggested a single printed circuit board to contain all Green Box data processing electronics. The processor, GPS receiver and communications transceiver are on separate boards. All three boards can be stacked inside the Green Box enclosure. To keep costs low, commercial surface-mount parts were used where possible. Printed circuit board fabrication costs are proportional to the quantity of hole drilling needed to produce the boards. To reduce labor and wiring costs, as many functions as possible were consolidated into a single container. CMOS technology was used to keep power consumption low.

Market Potential

A marketing study was conducted for the Green Box project by the School of Business and Economics, California State University, Hayward [Ref. 5]. The study concluded that three issues are important for the successful marketing of the Green Box: industry awareness of the product capabilities, the existence of a broad customer base, and the cost of the product. Of these the cost is paramount -- "Cost should be kept low."

Conclusion

The Green Box strap-on sensor package has the potential for providing significant savings for the railroad companies or for individual shippers of high-value or hazardous material cargo. The initial application provides security of the cargo and tracking capability at a reasonable price. Future applications can extend benefits to include emergency transmissions during a hazardous material transport incident and railcar preventive maintenance operations. The decision to implement a Green Box system will depend on a comparison of the costs averted with the original cost of the Green Box itself, the annual maintenance costs, and the apportioned per car costs for providing monitoring and communications equipment.

References

1. Rey, D., R. Breeding, J. Hogan, J. Mitchell, R. Gordon McKeen and J. Brogan, "Development of Green Box Sensor Module Technologies for Rail Applications", Sandia National Laboratories Report, SAND 96-1185, April 1996.

2. Federal Railroad Administration, U.S. Department of Transportation, Accident/Incident Bulletin No. 163, Calendar Year 1994.

3. National Research Council, Transportation Research Board, Special Report 239, "Hazardous Materials Shipment Information for Emergency Response," 1993.

4. Witzig, W. F., and J. K. Shillen. 1987. "Evaluation of Protective Action Risks", Report NUREG/CR-4726. U.S. Nuclear Regulatory Commission.

5. Christina, J. D., D. Carmichael, H. Gilman, M. Lewis, M. Beeby, and S. Fernandez, "The Green Box Marketing Feasibility Study," New Ventures Research Project Report, Fall Quarter 1994, California State University, Hayward.