CSXT FINDINGS & RESULTS FROM THE APPLICATION OF RIDE QUALITY MONITORING DEVICES FOR THE EVALUATION OF TRACK ANOMALIES AND DETERIORATION

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ABSTRACT

In March of 2001 CSX Transportation selected two companies to affix accelerometers to certain railcars in order to provide a continuous flow of ride quality information to our engineering headquarters. After a trial period of testing and review, SkyEye of Canada was chosen. With Amtrak’s assistance, SkyEye affixed Ride Quality Monitors (RQM) with battery and solar panel to eight autocarriers of Amtrak’s AutoTrain. CSX selected Amtrak cars so that CSX could correlate the raw data received to passenger ride quality and because the route of the AutoTrain is both repetitive and continuous.

The success of the AutoTrain information flow was so well received that we quickly expanded the application of accelerometers to 28 additional cars of the Tropicana orange juice fleet. Ride quality monitoring over these routes increased our mainline coverage to 2169 miles.

Each RQM device is equipped with three accelerometers that record vertical events, horizontal events, and longitudinal events. Devices are triggered when an excessive G force is measured in any of the three directions. Horizontal events of continuous duration and repetitive amplitude are indicative of truck hunting. CSX set the tolerances for each device in each of the three axes so that we would have an event level and an alert level. Both event and alert levels are transmitted immediately from the devices on the rail cars to a satellite and back to earth to a server in Canada. From Canada, the alert messages can be sent to a phone, a beeper, or a desktop computer. CSX chose to send the alerts via email to the computers of the responsible engineering line managers and the system headquarters.

Over the past year, CSX has had the benefit of having these devices running over 11% of our route miles on a daily basis. Even with geometry cars and split axle test cars, there is a significant benefit to having a daily process of monitoring the rail line at minimal costs. From a tactical standpoint, certain vertical and lateral alerts can be pinpointed immediately, thus reducing the time in track and the probability of a potential defect causing a derailment. Frequent hunting events with the same rail car can quickly identify troublesome rolling stock. The RQM can even identify low-speed longitudinal events that can exert high impacts on the rail car and damage the lading. Ride quality below the alert level can be compiled in a report form and used to determine where to focus the division maintenance resources.

The future looks bright for further application of the Ride Quality Monitoring process. From a strategic standpoint, track degradation models can be developed on routes by evaluating the frequency of lower level events as a function of time after major track rehabilitation from the System Production Gangs. Mechanical fleets can be evaluated by moving the RQM from car to car. Tropicana has already taken the use of GPS and Ride Quality Monitoring one step further with their new “Geo-Fence.” This is a process that automatically activates on-board refrigeration diagnostics when the empty train is within fifty miles of their processing plant. We are looking forward to see what the future holds for all departments with these exciting types of technologies for the rail industry.
1 PROJECT OVERVIEW

1.1 Goal

The combined development and interface of GPS technology, satellite communications, and improved sensors can provide a reliable and inexpensive method for the railroads to obtain a “near real-time” performance-based review of track and equipment. In our dedication to continuously improve safety and reduce derailments, CSX was looking for ways to enhance our existing automated measuring system that includes one geometry car, two gage restraint management system (GRMS) cars, and nine rail test cars. CSX engineers knew we could shorten the window that a possible defect stayed in the track through the daily recording and measuring of these events in this dynamic train environment. We began the process by examining the possibilities of measuring track and car anomalies using on-board accelerometers and then transmitting the information to central headquarters via satellites and email. The goal was the proper application and communication of reliable data to our frontline management of track maintenance for timely verification.

1.2 Train and Route Selection

After reviewing the key routes of the company and the trains that run on them, CSX Transportation chose Amtrak’s AutoTrain as the first train for this application. Our participation in the Amtrak/CSX Partners in Performance Team gave us a good foundation of cooperation and teamwork. Amtrak agreed to allow the fixation of the accelerometers to the upper side of the auto-carriers. Amtrak made sure that they selected rail cars which were not scheduled for rehabilitation or extensive time out of the pool from which the consists for passenger trains P052 and P053 come.

Amtrak cars were chosen in order to correlate the data received to passenger ride quality and because the route of the AutoTrain is both repetitive and continuous. The AutoTrain runs seven days per week between the cities of Lorton, Virginia and Sanford, Florida. This is a distance of 861 miles over 9 subdivisions and it comprises 4.4% of CSX route miles.

One goal of our evaluation period was to ensure repeatability of the event identification. In other words, “will each device identify the same spot and label it with the same severity?” In order to do this, we reviewed the data from trains that had three of the designated cars. Data analysis was necessary to make sure that multiple cars in the same train would record the track anomaly with the same GPS coordinates and intensity. Over the course of one month, these functions were tested and the GPS coordinates were within 300 ft and the amplitude differences were typically no more than 0.3 G. We found no loss in data quality when the device was mounted on the upper car body rather than on the frame.
1.3 Choosing a Vendor

The trial period for the selection of a suitable vendor began in November 2000. The task of each company was to affix Ride Quality Monitors (RQM) to certain railcars in order to provide a continuous flow of ride quality information to our engineering headquarters over select routes. Each Ride Quality Monitor contained accelerometers that record vertical events, horizontal events, and longitudinal events. It was critical that these companies be able to provide useful and appropriate reports that our engineers could use to identify and repair track problems as well as eventually develop new methods to balance maintenance demands.

After a trial period, both companies prepared reports for our senior engineering management. SkyEye of Canada was chosen. A significant factor in choosing this company was their ability to analyze the data and convey it in a useful form to us.

1.4 Initial Findings

The success of the AutoTrain information flow was so well received that we quickly expanded the application of accelerometers to 28 cars of the Tropicana fleet on October 25, 2001. The Tropicana Company is well known for its quality orange juice and other citrus products. They maintain a fleet of 504 cars at their Bradenton, Florida facility. These trains run daily from Florida to the northern cities of Cincinnati, Ohio and Jersey City, New Jersey. Ride quality monitoring over these routes increased our mainline coverage to 2169 miles. This number represents 11% of all CSX route miles and 26% of our “blue route” main lines.

![Amtrak and Tropicana Routes with RQM](image-url)
1.5 How the Ride Quality Monitoring Device Works

Each RQM device is equipped with three high-precision accelerometers, one for each of the X, Y, and Z axes. These directions represent longitudinal events, horizontal events, and vertical events.

- **Vertical (Z axis)**
- **Longitudinal (X axis)**
- **Lateral / Horizontal (Y axis)**

Devices are triggered when an excessive G force is measured. CSX set the tolerances for each device in each axis so that we would have an event level and an alert level. Both event and alert levels are transmitted immediately from the devices on the rail cars to a satellite and back to earth to a server in Canada. From Canada, the alert messages can be sent to a phone, a beeper, or a desktop computer. CSX chose to send the alerts to the computers of the responsible engineering line managers and the system headquarters.

Once this information has been received, the information must filter down to the workplace. For vertical events, this means finding the track location and fixing it if necessary. CSX purchased 85 Garmin GPS hand-held units so those track inspectors could find the track locations. The hand-held units can also be mounted on the dashboard of the hi-rail truck. We trained our employees with these devices and worked through the learning curve of finding the RQM event location.

The hunting events were evaluated statistically and it was determined that certain older rail cars exhibited severe truck-hunting much more than others. With a fleet of over 500 Tropicana cars, CSX and Tropicana engineers reviewed the data and quickly discovered that the top car on the truck-hunting list was also
known to both companies as the car with the poorest shipping record. In other words, this car sometimes had a shifted or damaged pallet of orange juice in it when the car was opened. Tropicana swiftly assembled a team of rail-car experts at their Bradenton, Florida car shop. The Tropicana car maintenance crew dismantled this car in view of the expert team. After studying all the moving parts in the car, the group decided to replace the split wedge on the trucks. When the car was returned to the field, the violent truck hunting behavior was eliminated and thus eliminated the shifting of the pallets of orange juice inside.

Longitudinal events were infrequent at the higher alert levels, but we acted when we saw them. They typically occurred at slow speeds and in yards. These events were forwarded to the local road foreman.

1.6 Benefits

Since the start of the project, CSX Engineering has gained great insight into the utility of the process of using GPS and related technologies to alert us of unusual G forces. The benefits have spread from the engineering department to the mechanical, operating, sales, and damage prevention departments. A further spin-off of this process resulted in the development of the Geo-fence for the Tropicana shipping department in Bradenton, Florida. When one of their enroute empty rail cars approaches within fifty miles of the shipping dock, the RQM device automatically turns on and performs a 128 spec diagnostic test and relays its readiness to the Tropicana offices.

Future use of this unique real-time monitor will require a greater focus on the statistical database so that we can expand beyond the tactical benefits of the alert messages. We look forward to the day when we can monitor the track degradation on a weekly basis and direct our floating maintenance forces to the right spots. In addition, this same methodology can be used for both future production maintenance planning and car repair.

2 RIDE QUALITY MONITORING

2.1 What is GPS

The Global Positioning System (GPS) is a worldwide radio-navigation system built by the United States Department of Defense at the cost of $12 billion. This navigation system is formed from a constellation of 24 satellites with matching ground stations. The GPS uses these satellites as reference points to calculate positions that are accurate to a matter of meters for commercial use. A few years ago this technology became accessible to many users when the construction of the GPS receiver was reduced to just a few small integrated circuits. As a result, the hand-held unit has been used in thousands of applications, including real estate, construction, film, marine uses, farming, camping, and many other recreational uses.

The 24 satellites orbit the earth at 11,000 miles. Each satellite has a unique Pseudo Random Code (PRC). A PRC is a very complex digital code that is made up of a complicated sequence of “on” and “off” pulses.
The code is amplified so that the hand-held receivers do not need big satellite dishes to receive the GPS signal.

GPS satellites use atomic clocks for high accuracy, but the handheld units do not have sophisticated timing mechanisms in them. Instead they rely on referencing an additional fourth satellite to provide a range measurement that removes errors. The timing measurement is very short. If the satellite is directly overhead (in high orbit) then the travel time is only 0.06 seconds using the speed of light as the velocity. The four satellites use triangulation to calculate distance from the travel time of the radio signals. GPS provided us with the time of the event/alert, location, velocity and direction of the railcar being monitored.

2.2 Hardware Description

The Sky Eye Ride Quality Monitoring (RQM) unit consists of an Orbcomm satellite communicator with an integrated GPS receiver, VHF and GPS antennae, microprocessor board, ride quality module and application software, batteries and solar panel, all in a self-contained factory sealed housing. The GPS receiver provides event or alert location, velocity, and accurate time. Each RQM is equipped with three high-precision accelerometers, one for each axis.

As soon as acceleration is recorded, the RQM communicates with the GPS satellite for location and time. This is followed by a message from the RQM to the Orbcomm satellite. The data advances to the subscriber’s Data Management Center (DMC) for filtering. The RQM’s message profile (frequency and type of message) can be programmed to suit customer requirements. The following two pages diagram the GPS unit-Train-ORBCOMM satellite followed by a diagram of a typical mounting of the RQM on a railcar.
CSX RIDE QUALITY COMMUNICATION NETWORK

GPS (one of four)

ORBCOMM

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CSX

ORBCOMM

GPS

Computer

Canadian Flag
TYPICAL RAILCAR MOUNTING

CLOSE UP VIEW
SATIN FAIRFA

POST # 9

BASE Matte SHEET THICK STEEL (POST # 9)
1' END OF CAR

ANTenna CONNECTOR

7" (+/- 1")

SWILL HERE BOTH SIDES

DRILL HERE BOTTOM CTR.

POST

SHAFT BAR(S)

RIVETS

WASHERS

Installation details
2.3 Event Descriptions

Events occur in the X, Y, and Z-axis. A longitudinal event (measured in G’s) is defined as the absolute value of the maximum peak between consecutive zero crossings of the acceleration signal from the X-axis. For every longitudinal event, the Delta V is computed by the RQM. The Delta V value provides a better indication of the potential for a shock to cause damage than the peak value by taking time into account. For instance, a high peak acceleration of very short duration is not likely to displace the load. It would have a low Delta V.

The Delta V is the “net area” under the curve of the oscillogram of a shock for a period of one second. One can visualize this sort of oscillogram as a decaying sinusoid, and the areas of interest are those limited by the oscillogram curve and the time axis for both the positive and negative swings, for the first second of the shock wave. The areas under the time axis are subtracted from the areas above the axis, hence the expression “net area”. Longitudinal events greater than 1.0 G (selectable setting) are called alert events and they initiate a transmission to the Data Center. For more information on the Physics of Railcar Impacts, please see Appendix I.

A lateral event (measured in G’s) is defined as the absolute value of the maximum peak between consecutive zero crossings of the acceleration signal from the Y-axis. Lateral events greater than 0.75 G are called alert events and they initiate a transmission to the Data Center.

In addition to generating the lateral events as described above, the Y-axis accelerometer is also used to detect car truck hunting. A hunting event is defined as 5 or more sequential and oscillating lateral peaks equal to or exceeding 0.50 G within a short defined time window (default: 3 seconds). Both positive and negative peaks are included in this count of 5. The detection of a hunting event initiates some on-board data collection, and the end of the event triggers the transmission of a message to the Data Center. A hunting alert must exceed a duration of 120 seconds.

A vertical event (measured in G’s) is defined as the absolute value of the maximum peak between consecutive zero crossings of the acceleration signal from the Z-axis. Vertical events greater than 1.5 G are called alert events and they initiate a transmission to the Data Center.

2.4 The Alert Message

The RQM unit model CO1 that was used has a messaging profile that is programmable. For this particular application, the RQM unit will transmit the following message types:

- Daily unit health status message (GPS and internal unit parameters).
- Event messages above the customer-determined thresholds (alert type, GPS position and severity in G’s) transmitted on occurrence.
Automatic e-mail notification of alert level events in near real time is the recommended method of notification. Alert level thresholds are customer defined and may be equal or higher than the default event threshold settings.

Default alert threshold settings for CSX Transportation are:

- Longitudinal: 1 G and $\Delta V$ of 4 mph
- Vertical: 1.5 G
- Lateral: 0.75 G
- Hunting: peak lateral accelerations above 0.5 G for more than 120 seconds

2.4.1 Sample Alert Message

Alert messages at CSX are transmitted from a server in Canada via email. Below is a copy of the information contained in an alert message.

<table>
<thead>
<tr>
<th>Alert Number</th>
<th>RZ003080-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAILCAR DETAILS</td>
<td></td>
</tr>
<tr>
<td>Railcar Owner</td>
<td>CSXT</td>
</tr>
<tr>
<td>Car Number</td>
<td>TPIX3011</td>
</tr>
<tr>
<td>Fleet/Category</td>
<td>Box railcar / N/A</td>
</tr>
<tr>
<td>VERTICAL EVENT DETAILS</td>
<td></td>
</tr>
<tr>
<td>Peak + : 1.60 G</td>
<td></td>
</tr>
<tr>
<td>Peak - : 1.10 G</td>
<td></td>
</tr>
<tr>
<td>GPS Speed : 60.8 mph</td>
<td></td>
</tr>
<tr>
<td>GPS Heading : 202 degrees</td>
<td></td>
</tr>
<tr>
<td>GPS Event Time : 2002/07/01 04:49:47 GMT</td>
<td></td>
</tr>
<tr>
<td>GPS Event Location : 6.12 mi SSW of Ridgeland, SC</td>
<td></td>
</tr>
<tr>
<td>GPS Event Mile Post Location : 0.49 mi WSW of crossing A465.1</td>
<td></td>
</tr>
<tr>
<td>GPS Event Latitude : 32.4000</td>
<td></td>
</tr>
<tr>
<td>GPS Event Longitude : -81.0279</td>
<td></td>
</tr>
<tr>
<td>Track Owner : CSXT</td>
<td></td>
</tr>
</tbody>
</table>

When GPS is used to pinpoint a location of a stationary object, the precision can be within six feet or less. Measuring the GPS location of a moving object with precision is another challenge altogether. At 60 mph, our latitudes were typically accurate within 300 feet. Most are significantly closer. This certainly allowed our track inspectors to find a problem area if one existed. The technique used to calculate the precise location relies on a backsight calculation using the velocity and time to find a more accurate location. This is due to a time lag between the correlation of the event and the time recording from the GPS coordinates. The assumption is that the acceleration is zero during the GPS transmission and the track is tangent. Since
the railroad is on a fixed guidance system, we rely only the latitude on north-south routes and the longitude on east-west routes. The track takes us to that intersection because railroads are a fixed position system.

Our study indicated most of the alert message information is accurate. Below are the components with which we struggled to verify. Please refer to the Sample Alert Message.

**GPS Event Location.**

The locating system set up by our vendor established certain nodal points or cities. These nodal points were called proximity stations. Like any city, the proximity stations were varying distances from each other. When the alert was measured from the city in hundredths of a mile, we really did not know the starting point of the proximity station. Therefore, the benefit of using one-hundredths of a mile did not account for any accuracy. The event location gave us a general idea where to look as compared to specific location given by the GPS coordinates.

**GPS Event Milepost Location**

The mileposts were not always accurate. Since the beginning of the ride quality project we have made an accurate GPS assessment of our mileposts, but this accurate data was not available for most of our study period.

### 2.5 Training

At the beginning of this study in 2001, the Alert messages were coordinated with certain mileposts and GPS coordinates. Since our workforce was not equipped with GPS receivers, we relied solely on the locations as designated by the mileposts listed on the alert message. We soon found out that the vendor’s GPS database for CSX mileposts was inaccurate and we abandoned that practice. This caused us to rely solely on the GPS coordinates and in order to do that, we equipped every track inspector over these routes with a hand-held GPS receiver. These units were installed in the hi-rail car on a mounting bracket on the dashboard.

Our assignment of this new device was unconventional because we encouraged our employees to use these tools for work and for pleasure. This was clearly one way to improve on the learning curve and obtain the immediate benefit of locating the events found by the RQM units on the Amtrak cars. In addition, we found that one of our track inspectors had plenty of experience with GPS and so he was assigned the special duty of training his fellow track inspectors with the tools of the GPS trade. Our records indicate that the training was beneficial. In the first three months of use, the “find rate” of the alerts was 63%. In the most recent three-month period, this “find rate” has climbed to 83% of reported alerts.
3 RIDE QUALITY MONITOR (RQM) COMPONENTS

The Sky Eye Ride Quality Module (RQM) Unit consists of an ORBCOMM satellite communicator with an integrated GPS receiver, VHF and GPS antennae, microprocessor board, ride quality module board (3 axes accelerometer board), and application software, batteries and solar panel, all in a self-contained factory sealed housing. The ride quality module determines accelerations in the three axes thus detecting over-speed impacts, vertical and lateral shock events, truck hunting, railcar mechanical characteristics and potential track defects.
3.1 Product Description

The Sky Eye America RQM Sensor Package, hereafter referred to as the unit, is a smart triaxial shock sensor that can sense, classify, and report shock events. The unit is composed of 3 single axis accelerometers, 3 signal Conditioning ASICs (EDM700), a microcontroller (µC), and other support components. The unit monitors the accelerometers for predefined shock and vibration events, performs event characterization and parameterization, and reports the event to a satellite transceiver via a serial communications protocol defined in this specification.

3.2 Sensors

There are two main sensor sections: Triaxial accelerometer (consisting of three piezoresistive accelerometers) and a temperature sensor. The temperature sensing is built into the EDM700.

3.2.1 Signal Conditioning

The signal conditioning is performed by 3 EDM700s and the µC. The EDM700s are digitally controlled analog circuits that perform the functions of offset correction, sensitivity correction, low pass filtering, Analog to Digital Conversion (ADC), and temperature sensing. The filter f_{\text{db}}, the ADC sampling rate, and the acceleration sensitivity are all adjustable over the communications interface. The temperature sensor
used for accelerometer temperature compensation, as well as temperature reporting, is located in the X-axis EDM700.

3.3 Signal Processing

The signal processing is performed by a Microchip PIC16C6X microcontroller (μC). The μC performs the following signal processing functions: calibration of the sensor, detection of events, parameterization of events, and histogramming of acceleration values.

3.3.1 Sensor Calibration

The calibration of the sensor is accomplished with calibration data stored in lookup tables for controlling the EDM700s to achieve the desired sensor accuracy. The offset correction of the sensors is performed by an auto zero function implemented as a single pole digital high pass filter with a 409.6 s time constant.

3.3.2 Event Detection

The detection of events is performed on each axis independently by monitoring the incoming acceleration sensor data and looking for a value to exceed the user defined threshold. The acceleration sensor data is absolute valued and then compared against the preset threshold. If it is greater than the threshold then an Event is considered to have been detected. The event detection starts a user-defined time window during which all sensor data on that axis is considered to have been due to a single railway activity. The threshold setting and event window time will be adjustable over the communications interface. When hunting has been detected and a “Hunting Start” message has been sent, Y axis event processing and reporting will be disabled and Z axis events will be counted instead of being individually reported. The Z axis event count will be reported with the “Hunting Stop” message. When hunting has stopped and the “Hunting Stop” message has been sent, the Y and Z axis event detection will return to its pre-hunting state.

4 DATA ANALYSIS

The Ride Quality Monitoring study began with the application of eight (8) RQM devices on the AutoTrain on March 14, 2001. There were an additional twenty-eight (28) RQM devices added to Tropicana cars beginning in September and completed in November 2001. When we started this study, we were naturally focused on the controls of the RQM process.

- Repeatability of event from one vendor’s device to another
- Repeatability of event from RQM unit placement on car
- Repeatability of event from multiple cars in same train

Most of these concerns were addressed during the vendor trial period, although we continue to deal with the repeatability of events from one car to another mostly because of car type. Our informational database
grew quickly as the RQM’s started generating over one thousand events per month. By June 2001 we were ready to address the alert levels from a statistical basis. Early data indicated the AutoTrain experienced 99% vertical events. Nearly 60% of all events were in the northbound direction. Amtrak attributed this seasonal tendency of the loads versus empties. Since the data provided by SkyEye showed that nearly all of the early detection from the AutoTrain was in the vertical axis, we naturally focused on the track and set 1.9 G as the vertical alert threshold.

The first step in analyzing the alerts was to identify the uniqueness of the events. In other words, we noticed many cars were reporting the same event location. Timely field identification and track maintenance at the alert location could minimize reoccurrence of future “hits”. One way to compare track quality is to use the measure of “events per car trip per mile”. In our fieldwork we found the table below helpful. Setting 300 feet as our threshold, we used 0.001 as the tolerance to separate unique events.

### Typical Distance Comparisons for Latitudes in Southeast USA

<table>
<thead>
<tr>
<th>Degrees of Latitude:</th>
<th>Distance</th>
<th>English Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>69.17</td>
<td>miles</td>
</tr>
<tr>
<td>0.1</td>
<td>6.92</td>
<td>miles</td>
</tr>
<tr>
<td>0.01</td>
<td>0.69</td>
<td>miles</td>
</tr>
<tr>
<td>0.001</td>
<td>365.2</td>
<td>feet</td>
</tr>
<tr>
<td>0.0001</td>
<td>36.5</td>
<td>feet</td>
</tr>
<tr>
<td>0.00001</td>
<td>3.7</td>
<td>feet</td>
</tr>
<tr>
<td>0.000001</td>
<td>4 3/8</td>
<td>inches</td>
</tr>
<tr>
<td>0.0000001</td>
<td>7/16</td>
<td>inches</td>
</tr>
</tbody>
</table>

It is at this point that we began our on-site inspection of vertical events at the “alert” level. We endured some trouble with locating the alert sites without the benefit of our track inspectors having the GPS receiver equipment. The database after 8 months of Amtrak and before the use of GPS receivers revealed that 269 alerts took place out of a vertical event pool of 11,164 for an average “alert” level of 2.4%.

GPS receivers were purchased in December 2001 and distributed immediately. During this time we progressively turned down our alert vertical alert level to 1.8, then to 1.7 and finally to 1.5 by March of 2002. By this time all of our track inspectors on the RQM routes were properly equipped and trained. We were able to document feedback from the field starting in November 2001 and continuing to the present. The following table shows the total of all events during the CSX Ride Quality Monitoring study.

### SUMMARY OF ALL EVENTS – March 2001 to June 2002

<table>
<thead>
<tr>
<th></th>
<th>Amtrak</th>
<th>%</th>
<th>Tropicana</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hunting Events</td>
<td>1</td>
<td>0%</td>
<td>2,855</td>
<td>32%</td>
</tr>
<tr>
<td>Lateral Events</td>
<td>80</td>
<td>1%</td>
<td>1,737</td>
<td>19%</td>
</tr>
<tr>
<td>Longitudinal Events</td>
<td>1</td>
<td>0%</td>
<td>93</td>
<td>1%</td>
</tr>
<tr>
<td>Vertical Events</td>
<td>14,935</td>
<td>99%</td>
<td>4,302</td>
<td>48%</td>
</tr>
<tr>
<td>Total Events</td>
<td>15,017</td>
<td>100%</td>
<td>8,987</td>
<td>100%</td>
</tr>
</tbody>
</table>
4.1.1 Vertical Data

With the AutoTrain data leaning heavily towards vertical events, we categorized their distribution during the first eight months as follows:

**G force Intensity vs. # of events**

<table>
<thead>
<tr>
<th>ABS</th>
<th>Total</th>
<th>Pct of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5799</td>
<td>51.94%</td>
</tr>
<tr>
<td>1.1</td>
<td>2906</td>
<td>26.03%</td>
</tr>
<tr>
<td>1.2</td>
<td>1277</td>
<td>11.44%</td>
</tr>
<tr>
<td>1.3</td>
<td>599</td>
<td>5.37%</td>
</tr>
<tr>
<td>1.4</td>
<td>314</td>
<td>2.81%</td>
</tr>
<tr>
<td>1.5</td>
<td>164</td>
<td>1.47%</td>
</tr>
<tr>
<td>1.6</td>
<td>56</td>
<td>0.50%</td>
</tr>
<tr>
<td>1.7</td>
<td>38</td>
<td>0.34%</td>
</tr>
<tr>
<td>1.8</td>
<td>8</td>
<td>0.07%</td>
</tr>
<tr>
<td>1.9</td>
<td>2</td>
<td>0.02%</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0.01%</td>
</tr>
<tr>
<td>Grand Total</td>
<td>11164</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

Recently Amtrak engineers sent CSX a list of data from an accelerometer that they placed on AutoTrain on June 19. We compared our vertical RQM reports and with Amtrak’s and found our figures to be significantly higher than theirs for the same GPS coordinates taken one day prior to the Amtrak test. The placement of RQM device and the type of car cause this variance. Our RQM reading for this event was taken from a Tropicana car on a device fastened to the upper corner of the car body. By comparison, Amtrak’s device was placed on the floor of a cushioned passenger car.

4.1.2 Lateral (Horizontal) Data

The following graph demonstrates how lateral events on AutoTrain focused on one car

![AutoTrain Lateral Events March-Nov 2001](image)

The data above indicates that a RQM device is helpful in identification of car behavior. This was also evident with the Tropicana cars. The following tables and charts in this section will provide reasons for this statistical behavior and other deductions concerning Ride Quality Monitoring.
LORTON, VA - SANFORD, FL
AVERAGE VERTICAL EVENTS/CAR TRIP BY ASSET
MARCH 14, 2001 TO JANUARY 14, 2002

<table>
<thead>
<tr>
<th>ASSET ID</th>
<th>EVENTS/CAR TRIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMTR9010</td>
<td>15.3</td>
</tr>
<tr>
<td>AMTR9028</td>
<td>11.2</td>
</tr>
<tr>
<td>AMTR9004</td>
<td>10.9</td>
</tr>
<tr>
<td>AMTR9011</td>
<td>10.3</td>
</tr>
<tr>
<td>AMTR9031</td>
<td>9.6</td>
</tr>
<tr>
<td>AMTR9015</td>
<td>8.2</td>
</tr>
<tr>
<td>AMTR9100</td>
<td>8.1</td>
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<tr>
<td>AMTR9092</td>
<td>2.8</td>
</tr>
<tr>
<td>TOTAL</td>
<td>8.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ASSET ID</th>
<th>EVENTS</th>
<th>CAR TRIPS</th>
<th>EVENTS/CAR TRIP</th>
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<td>AMTR9010</td>
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<td>145</td>
<td>15.3</td>
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<tr>
<td>AMTR9028</td>
<td>1157</td>
<td>103</td>
<td>11.2</td>
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<tr>
<td>AMTR9004</td>
<td>1749</td>
<td>160</td>
<td>10.9</td>
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<tr>
<td>AMTR9011</td>
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<td>10.3</td>
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<td>203</td>
<td>8.2</td>
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<td>AMTR9100</td>
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<td>848</td>
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</tr>
<tr>
<td>TOTAL</td>
<td>848</td>
<td>300</td>
<td>8.7</td>
</tr>
</tbody>
</table>
LORTON, VA - SANFORD, FL
VERTICAL EVENTS BY INTENSITY
MARCH 14, 2001 TO JANUARY 14, 2002

<table>
<thead>
<tr>
<th>INTENSITY (G's)</th>
<th>1.0</th>
<th>1.1</th>
<th>1.2</th>
<th>1.3</th>
<th>1.4</th>
<th>1.5</th>
<th>1.6</th>
<th>1.7</th>
<th>1.8</th>
<th>1.9</th>
<th>2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>count</td>
<td>6494</td>
<td>3234</td>
<td>1403</td>
<td>645</td>
<td>344</td>
<td>169</td>
<td>59</td>
<td>39</td>
<td>8</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>% of total</td>
<td>52.38%</td>
<td>26.08%</td>
<td>11.32%</td>
<td>5.20%</td>
<td>2.77%</td>
<td>1.36%</td>
<td>0.48%</td>
<td>0.31%</td>
<td>0.06%</td>
<td>0.02%</td>
<td>0.01%</td>
</tr>
<tr>
<td>cum. % of total</td>
<td>52.38%</td>
<td>78.46%</td>
<td>89.78%</td>
<td>94.98%</td>
<td>97.76%</td>
<td>99.12%</td>
<td>99.60%</td>
<td>99.91%</td>
<td>99.98%</td>
<td>99.99%</td>
<td>100.00%</td>
</tr>
</tbody>
</table>
**VERTICAL EVENTS BY SPEED**

**MARCH 14, 2001 - JANUARY 14, 2002**

**Avg. AutoTrain Speed during Event = 67 MPH**

<table>
<thead>
<tr>
<th>mph</th>
<th>&lt;10</th>
<th>10-20</th>
<th>20-30</th>
<th>30-40</th>
<th>40-50</th>
<th>50-55</th>
<th>55-60</th>
<th>60-65</th>
<th>65-71</th>
<th>71+</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td># of events</td>
<td>24</td>
<td>129</td>
<td>410</td>
<td>581</td>
<td>743</td>
<td>509</td>
<td>1074</td>
<td>1187</td>
<td>7118</td>
<td>623</td>
<td>12398</td>
</tr>
<tr>
<td>% of total</td>
<td>0%</td>
<td>1%</td>
<td>3%</td>
<td>5%</td>
<td>6%</td>
<td>4%</td>
<td>9%</td>
<td>10%</td>
<td>57%</td>
<td>5%</td>
<td>100%</td>
</tr>
<tr>
<td>cum # of events</td>
<td>24</td>
<td>153</td>
<td>563</td>
<td>1144</td>
<td>1887</td>
<td>2396</td>
<td>3470</td>
<td>4657</td>
<td>11775</td>
<td>12398</td>
<td></td>
</tr>
<tr>
<td>cum % of total</td>
<td>0%</td>
<td>1%</td>
<td>5%</td>
<td>9%</td>
<td>15%</td>
<td>19%</td>
<td>28%</td>
<td>38%</td>
<td>95%</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>
LAKE CITY

Event Activity over 850 miles of main line prior to 2001
Production Gang work in Lake City, S.C.
Event activity at proximity station Lake City after Production Gang work. Note ten weeks virtually event (1.0G) free, followed by gradual track degradation. Spot surfacing or crossing replacement could be the improvement in weeks 39-41.
Comparison of Event type- Amtrak & Tropicana

These pie charts show the RQM event distribution on two types of rail equipment. The Amtrak equipment is comprised of auto-trailers with premium passenger trucks. These trucks experienced no truck hunting and the Amtrak AutoTrain only had one longitudinal event. Most of the lateral events were from only one car.

By comparison, the Tropicana fleets are boxcars with standard trucks of varying age. There was a correlation to the hunting behavior based on age of the car.

The reason there are many more events for Amtrak Autotrain is because their cars were under study for a longer period of time and they operate at significantly higher speeds. Data includes entire study period.
Vertical Events were more frequent with Amtrak AutoTrain because they operate at higher speeds and the cars were in the RQM study for a longer period.

Tropicana’s higher percentage of Alerts is directly related to their load vs. empty ratio. Tropicana runs empty 50% of the time as the train returns to the south for reloading.
The distribution of event type by asset clearly indicates that the most modern cars (3000 series) exhibit no hunting. As the direct result of this graph, Tropicana swiftly dismantled two railcars and replaced truck parts, virtually eliminating hunting in both of them.
**TROPICANA EVENTS BY TYPE - EMPTY VS LOADED**  
**SEPTEMBER 25, 2001 - JANUARY 14, 2002**

<table>
<thead>
<tr>
<th>EVENT TYPE</th>
<th>EMPTY</th>
<th>LOADED</th>
<th>TOTAL</th>
<th>L/TOTAL EVENT %</th>
</tr>
</thead>
<tbody>
<tr>
<td>LONGITUDINAL</td>
<td>67</td>
<td>2</td>
<td>69</td>
<td>3%</td>
</tr>
<tr>
<td>VERTICAL</td>
<td>1110</td>
<td>185</td>
<td>1295</td>
<td>14%</td>
</tr>
<tr>
<td>HUNTING</td>
<td>974</td>
<td>1</td>
<td>975</td>
<td>0%</td>
</tr>
<tr>
<td>LATERAL</td>
<td>525</td>
<td>3</td>
<td>528</td>
<td>1%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2676</td>
<td>191</td>
<td>2867</td>
<td>7%</td>
</tr>
</tbody>
</table>

This slide indicated to us that the greater activity was with empty cars.
The chart above shows the Nahunta Georgia subdivision before and after the Tie and Surfacing Production gang. The Track degradation slope is a future maintenance planning tool using RQM technology.
4.2 TROPICANA Data

Tropicana orange juice is shipped fresh in palletized containers which are shrink-wrapped and double stacked in the refrigerated boxcar. Each week approximately 200 cars head for Jersey City and 90 cars for Cincinnati at a maximum authorized speed of 60 MPH. As with AutoTrain, the Tropicana business is guaranteed, runs on a repetitive route, and operates with regularity.

When 28 Tropicana cars were added to the study in September 2001, they gave us additional insight into the behavior of their fleet and our tracks. Instead of just 861 miles, we were able to traverse an additional 1308 miles plus the Fort Pierce to Jacksonville mileage on the Florida East Coast Railway (FEC). These cars traveled on subdivisions not used by passenger trains, including Folkston, GA to Cincinnati, OH via Atlanta and the northern leg from Washington, DC to Jersey City, NJ. Early Tropicana data revealed the following:

- Out of 980 events, there were 29% hunting events.
- All hunting events occurred in empty cars.
- Vertical events comprised 56% of the events.
- 80% of the vertical events occurred in empty cars.

As we responded to the alert level events, the statistics changed slightly. By January 2002, the percentage of vertical events decreased.
4.2.1 Event Evaluation

Vertical events comprised 48% of all events for Tropicana cars. Four percent of those events were at the alert level, or 1.5 G. This compared to 2% at the alert level for Amtrak. With the combined pool of railcars at 36, we really started to benefit from the information. On December 12, Tropicana car TPIX3020 indicated a vertical alert at 1.7 G on an open deck bridge near Folkston, Georgia. Initial field investigation did not identify a track problem until they examined the bridge timbers and found a crushed timber cap. This defect was not evident in the rail profile. A typical vertical alert-level event was track profile in the range of ½ inch to 1 inch with or without mud or weakened ties. These were commonly found near road crossings or ends of bridges. It was especially beneficial for us to identify the areas with repeat alerts. Any railway maintenance engineer understands the benefits of finding the underlying cause of the track anomaly and fixing it.

The most enlightening information on the Tropicana fleet was not with the number of vertical events but with the measure of “events per car trip” for each Tropicana railcar. The statistics clearly indicated that 48 percent of all recorded hunting events came from only two cars of the 28 RQM cars. Further, there were no lateral events from the newest 3000 series of the Tropicana cars. This type of lateral and hunting data led the CSX/Tropicana team to focus on the car types and their conditions. Tropicana management removed two cars from service as the result of this report. One of the cars was the TPIX2066. It is an older boxcar that was modified for the 286,000 pound service at Tropicana. The trucks were completely disassembled by the Tropicana car maintenance team. After hours of measurement of the truck parts, it was decided that they would replace the resilient (polymer) friction wedges with an all-metal split wedge. This necessitated some welding of the bolster, but the car was back on line in two weeks. After this $1000 modification, the stiffened trucks provided the proper support and the truck hunting on this car virtually disappeared.

4.3 AutoTrain and Tropicana Summary

The study of the Amtrak AutoTrain was six months in progress before the gradual addition of the Tropicana fleet in the fall of 2001. When we started this study our “find-rate” of vertical alert messages was only fifty percent. By January 2002, this rate had climbed to 64%. After the GPS training our “find-rate” climbed to the present rate of 83% in June 2002. It is imperative that the inspectors are trained so alerts can be verified.

As the study continued into this year, we became concerned with the durability, downtime, and RQM asset attrition. Since the start of the study in the spring of 2001, we lost one AutoTrain RQM unit at three months, a second one at six months, and an additional four AutoTrain units since then. Only cars AMTR9092 and AMTR9011 are transmitting at this time. The ability of the vendor to perform the electronic “health-status” check is as important as the maintenance contract to repair the defective units. Certainly any study that is monitoring track performance needs to know how many units are on line. This is
why the category of “events per car trip” is a critical measure for any RQM process. You only need one reliable unit on a regular schedule to receive the data.

On the other hand, the Tropicana cars have fared better. Nearly nine months into the study we still have 26 units performing regularly. It is necessary that the railroad be free of brush and trees because the side-mounting of the RQM device subjects the satellite antenna to damage. When an event signal is sent to the ORBCOMM satellite with no reported location, you can infer that the GPS receiver antenna is damaged or missing.

During the period of this study, we recorded 19,237 vertical events from AutoTrain and Tropicana equipment. On November 18, 2002 CSX engineering started to document the findings from the alert-level vertical events even though we did not yet have the benefit of the GPS receivers for the track inspectors. Between November, 2001 and June 2002 we investigated 95 vertical “hits” exceeding 1.5 G. Our track inspectors were able to find the locations on 75% of them. This follow-up documentation was an important part of the study. Alert inspections were sent via email from the Roadmaster to system engineering headquarters. Two-thirds of the responses provided detailed quantifiable data.

There was no specific signature to the events exceeding our thresholds. A “typical” vertical event over 1.5G was a profile spot of just under 1-inch measured in a 62-foot chord. It was interesting to us that we did not find alerts at rail crossing diamonds or the frogs in turnouts. CSX Engineering tallied this information and found a range of track anomalies causing the alerts:

- profile of ¾ inch (typical)
- engine burns creating short profile spots
- low welds
- crushed rail plugs
- battered end joints
- bridge cap failure (1 event)

In this study we did not use scientific precision for documenting the amount of profile. The investigators of the alerts were not scientists, but experienced track inspectors and management. They used the same tools that are used in daily track inspection, i.e., a tape measure, a level board and a string. We were able to identify a correlation between the severity of the profile spots and the amplitude of G force.

There was correlation between loads and empties. The empty cars tended to have more “alert” level events. Also, speed was a factor. The median speed of a vertical event with AutoTrain occurred at 67 mph and the median speed with Tropicana was 54.1 mph. Very few vertical alerts occurred at speeds under 40 mph.
5 CONCLUSIONS

CSX Transportation has benefited from GPS satellite communication and the RQM ability to provide near-real time data about our tracks and railcars. This data has given our engineering team a frequent measure of the track structure in a loaded condition as compared to the twice weekly track inspections in the unloaded state. The RQM augments, but does not supplant, normal visual track inspection or electronic track inspection by geometry cars.

The vertical alert messages provided us with an additional tool for our visual track inspection. The vertical event trend lines help us to assess the track condition and monitor track degradation after completed work. The lateral and hunting information gave insights to equipment condition and behavior. The longitudinal events provided for increased awareness of train handling and switching operations.

During the study period, we experienced a reduction in vertical alerts by fifty percent. We have learned where our repeated alerts occur and we are addressing them with our maintenance forces. Our engineering team is excited about the future development of this tool to provide trend line information for our track maintenance needs and equipment upgrades. This effort will include both the expansion of coverage areas, as well as the evolutionary replacement and upgrade in equipment and processes.

- CSX presently covers 11% of its route miles with the GPS/RQM equipment. During the next year we intend to expand this coverage to 18% through the inclusion of routes between Jacksonville, FL-New Orleans, LA, and Boston, MA-Cleveland, OH.
- Equipment Improvement – Future improvements to upgrade system availability, the computing (both CPU and memory), communications (available message size), and power generation capabilities of the RQM units are being researched and evaluated. These improvements would provide greater and more flexible alert/event generation and reporting, more detailed information processing, and a more reliable GPS/RQM device.
- As a result of the equipment improvements that should generate more and better data, CSXT intends to provide dedicated resources to review and evaluate trends. This effort also includes the gathering and evaluation of data related to “Delta V” (the change in velocity over time) for alarms. This would allow us to possibly characterize alerts to specific traffic anomalies. This would provide valuable data to track inspectors as the search for alerts.
- CSXT has instituted processes and procedures for investigating and tracking alerts. Needless to say, these efforts are very manpower intensive. Improvements based on training and providing track inspectors with hand-held GPS devices resulted in a quantum improvement in our ability to locate and identify track anomalies. Further refinement of our ability to accurately identify a location, and automation of the collection and evaluation of data are under investigation.

Based on the excellent benefits to date from the use of the GPS & RQM technologies, it is CSXT’s intent to continue its program in the research and application of this type equipment and capability.
6 ACKNOWLEDGEMENTS

The authors would like to acknowledge the following organizations for support of this project:

**CSX Transportation:** Tom Schmidt, Vice President
Larry Romaine, Chief Regional Engineer  Ron Foster- Regional Engineer-Track
Michelle Dennis, Intern, North Carolina State University

**Amtrak AutoTrain**
Bob Layne, Service Manager
Tom Farr, Mechanical Supervisor

7 APPENDIX 1 – THE PHYSICS OF RAILCAR IMPACTS

7.1 General

In normal railroad operations, railcar impacts and shocks commonly occur. When the locomotive speeds up; the accelerative forces are transferred from car to car one at a time as the slack is taken up between each railcar. Due to the whip effect of all the cumulative slack being taken up and the resulting velocity differences between the locomotive and the last railcars, the trailing railcars of a train can sometimes experience high accelerations and sudden changes in speed. The same thing happens during braking. In yards, impacts between railcars are commonplace and necessary. There are minimum levels of impact required to properly lock the two couplers together, this normal speed for positive coupling operations is 4 mph. Unfortunately, yard impacts sometimes occur at much higher speeds which can cause damage to the railcars and the goods being shipped.

The railroad industry pays close attention to its shipping environment by monitoring their ride quality through the use of services such as Sky Eye. Knowing where, how often and how bad the events are can help improve railcar handling, ride quality and reduce damage claims. The two indicators commonly used to measure ride quality are ‘G’ and delta V. This document has been written to help understand these two subjects. First, we’ll start with basic physics:

7.2 Newton’s Physical Laws of Motion

Isaac Newton is best known for his 3 laws of motion. These laws were used to create the famous formula: ‘\( F=ma \)’. ‘\( F \)’ is the total constant force applied to an object, ‘\( m \)’ is mass of the object and ‘\( A \)’ is the resulting constant acceleration of the object caused by the force and is always in the same direction as the force. Acceleration is a physical measure of the rate of change of speed. Newton used this formula to determine the gravitational force of the Earth (the apple dropping on his head…). The Earth’s mass pulls all nearby masses constantly; this force of attraction is the weight or the gravitational force that you have to overcome when you pick up an object. It is this same force that accelerates an object towards the center of the Earth when you drop it. The greater the object’s mass, the greater the gravitational force acting on it.
7.3 What is ‘G’?

The acceleration of an object subjected to the force of gravity is constant on or near the Earth’s surface. This is due to another law of physics concerning gravitational forces between two masses (too complex for this document). This constant rate of acceleration is equal to 9.8 meters per second per second (m/ss) or 32.2 feet per second per second (f/ss). This rate is used as a unit of measure for acceleration and is referred to as one ‘G’ (for Gravity). It can also be used as a force measurement. A force causing an object to accelerate at 1 ‘G’ is equal to the force exerted on that object by the Earth’s gravitational pull. An acceleration of 1 ‘G’ means that a body is changing its speed at a rate of 9.8 m/ss (21.9 MPH per second).

For example, a force accelerating an object at 2 ‘G’ means that the object is actually accelerating at 2 times 9.8 m/ss, or 19.6 m/ss (64.4 f/ss). In this case, the force accelerating the object is also 2 times the force of gravity on that object. ‘G’ is often used as a reference for force and acceleration levels by fighter pilots; they encounter multiple ‘G’ forces pulling on their bodies as a result of maneuvering their aircraft through the sky. Astronauts also refer to ‘G’ levels. While in space, they encounter a condition known as “zero Gs”; meaning there are no forces pulling at them so they just float around, with no acceleration at all.

7.4 Railcar Impacts and ‘Gs’

In terms of ride quality monitoring, ‘G’ is used as a measure of acceleration. Accelerations can be positive or negative (deceleration) depending on your frame of reference. A railcar moving in a train will accelerate and decelerate continuously during the normal course of a trip. Looking at this acceleration signal; it would rise to some value on the positive side and then quickly descend to an equal value on the negative side and so on. These accelerations can be large in both directions and still not be very rough on the railcar or load. That’s because the forces causing these accelerations mostly cancel one another out and are of very short duration (milliseconds). A railcar’s speed changes when the cumulative forces on the railcar cause it to accelerate more in one direction than the other. This is commonplace and not usually severe, so long as the acceleration and speed change is relatively gradual.

Railcar impacts are short, complex events, usually over in a matter of seconds and involving very large forces and important changes in momentum and energy. Impact forces have many components over a range of frequencies. The higher frequency force components cause high frequency vibratory accelerations and noise; but generally have little effect on the lading. Ride quality is primarily affected by the lower frequency force components (usually 10 Hz and below) and their resulting accelerations.

Fortunately, railcars and their lading are not exposed to the full force of impacts. End of car cushions and draft gear protect railcars and their loads by absorbing impact forces and dissipating some of the impact energy. The forces not absorbed by the cushion gear, are used to slow down or speed up the railcar (and it’s lading), and are transferred to the next railcar in the string. The force distribution, momentum and energy changes caused by impacts are complex events which vary from event to event and from car to car.
The change in momentum of a mass is proportional to its velocity change (another law of physics...).

Severe railcar impacts result in large and sudden changes in speed and are key to understanding ride quality. If the speed change is more gradual, the event is less severe. Think of the comparison between an automobile rolling at 10 mph, the driver applying the brakes and coming to a full stop at a light; then think of the same automobile suddenly hitting a brick wall at 10 mph. The total change in speed is the same, but one event lasts longer than the other, and therefore isn’t as harsh. That’s where measuring delta V comes in.

7.5 What’s delta V and what does it represent?

With respect to ride quality, delta V represents change in velocity over a fixed period of time (about 1 second). Impacts between railcars are of a relatively short duration. The most important (and sudden) changes in velocity usually occur during the first second of the event. That part determines the severity of the impact. To measure the delta V of a railcar during an impact, the acceleration signal of the impact is analyzed during the first second or so of the impact. Refer to the simplified plot below:

Acceleration is a measure of the rate of change of speed. Looking at the simplified curve above, you can see both positive and negative accelerations occurring during the impact. To calculate the total amount of velocity change over the sample period, the total area between the acceleration curve and the axis is added up. The area indicated in gray is equal to the delta V for that time period (in this case 1 second). Note that further on in time there are still blips of acceleration, but they are not severe and are more stretched out. These blips have little effect on the ride quality or severity of the event.

Rarely is delta V equal to the actual impact speed. Impact speed is the speed at which the railcar is actually rolling before it impacts the anvil railcars. As explained before, end of car cushions and draft gear, friction between wheels and brakes can dissipate some of the impact energy and the rest is distributed, some to slow down the impacting railcar and some to speed up the stationary ones. In the end, all the energy is either dissipated or transferred, none is lost. Understanding what G and delta V represent is important to railroad professionals responsible for the safe and damage free transportation of goods by rail.

1-“Physics of Railcar Impacts –About G and Delta V“ provided by SkyEye Corporation.