Optical ACI — — A New Look

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ABSTRACT

This paper describes a program which has been underway to provide the railroad industry with methods for the improvement of its Optical Automatic Car Identification (OACI) system. The program involves studies of car presence detectors, performance and cost improvements to the OACI scanner system, an analysis of OACI label properties and label life, and a model to evaluate car identification enhancement from the railroads' advanced consist information. The major part of the effort addressed improvements to the scanner system. These improvements involved the use of advanced technology to design, build, and test pre-prototype hardware to develop a "firm" specification of the scanner system performance limit. The results to date from laboratory tests indicate that the scanner system readability accuracy with the existing labels can be increased at least 6% from its nominal value of 88% to 91%. This increase is obtainable through the use of charge-coupled devices and microprocessors which will also enable a 40% reduction in initial scanner system purchase costs and a 33% reduction in yearly maintenance costs. The program also resulted in an assessment of the underlying causes for label deterioration, a label life estimate of 17 years, and a users' guide for each railroad's determination of the effectiveness of its own OACI data enhancement policy.

INTRODUCTION

This paper presents the recent results of efforts on the part of the Federal Government to explore the upgrading of the Optical Automatic Car Identification (OACI) system. The efforts have been under the technical support of the Federal Railroad Administration (FRA) and are intended to specify the means for obtaining increased OACI system accuracy and wider application at lower costs. Although ACI is considered to be a major breakthrough for improving railroad service, operating efficiency, and car utilization, the nation's railroads have recently been reconsidering its continued use. Since its adoption on a national scale in 1967, the railroads have been faced with the problem of sustaining an effective maintenance program for the OACI system and the labels on 1.7 million freight cars. Depending on the operating life of the label and the levels of maintenance over the past five years, the OACI readability accuracy has varied from 78% to above 97%. While one railroad will contend that the lower accuracy can be greatly enhanced through correlations with their separately derived manual car identification records (advanced consist), another will argue that this degraded performance is unsatisfactory. The main reason for this difference lies in the way each railroad utilizes OACI in their management information system (MIS). Some railroads with their own maintenance program and fleets have derived signifi-

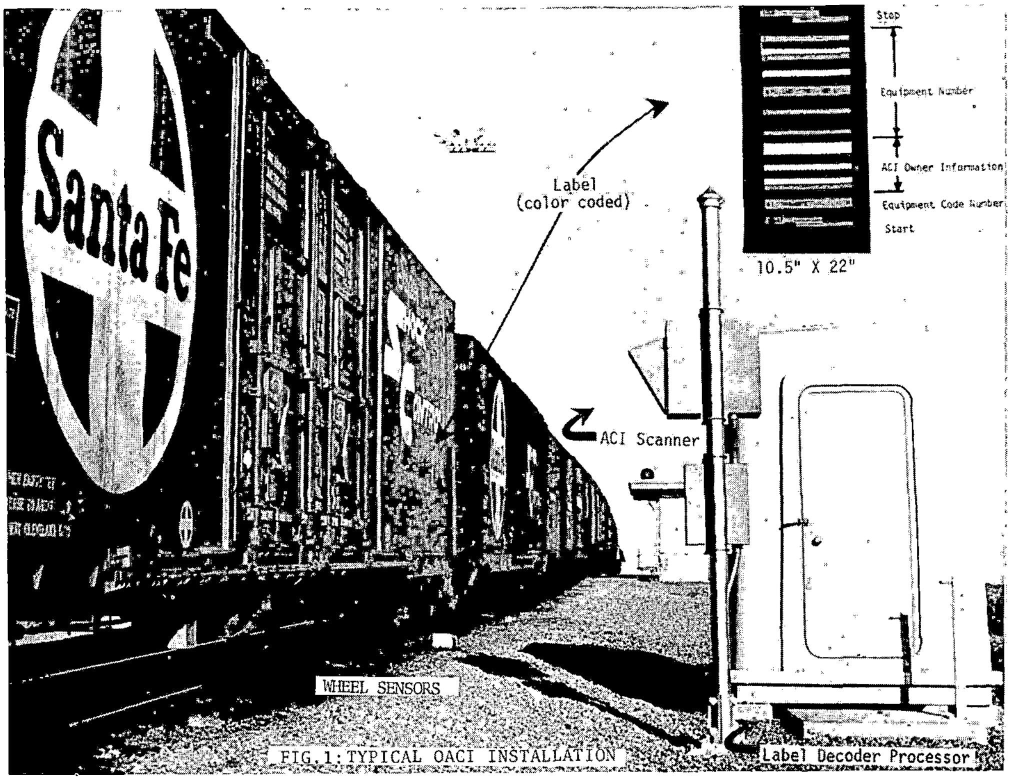


FIG. 1: TYPICAL OACI INSTALLATION

cant benefits from greater efficiencies in their waybill preparation, classification yard operation, and cargo identification. However, since the nationwide benefits of ACI requires the cooperation of all the railroads, its fullest potential cannot be realized until a convincing case is made for improved performance at lower operating and maintenance costs and an attractive return on investment is demonstrated.

BACKGROUND

Since 1890, when a patent was issued for a mechanical technique, the railroads have recognized a need for the automatic identification of the ownership and serial number of freight cars passing critical rail junction points. In 1967, the optical ACI was adopted as a viable technology after the Association of American Railroads (AAR) had developed specifications and tested the system in the field. Referring to Fig. 1, the OACI system was composed of three distinct elements: (1) Color-coded label ; (2) An optical trackside scanner system; and (3) Wheel sensors to determine train presence and direction. When the train first approaches, a high intensity light source is turned on and begins a rapid vertical scan of the trackside with a set of rotating mirrors. The wheel sensors then identify the passing of each rail car which has labels mounted on both of its sides. The labels consist of thirteen modules of retroreflective material like that used for markers illuminated by car headlights along the highways. Each of the thirteen modules has two stripes, which are colored white, red, blue, or black. The reflected light from these stripes is sensed slightly off the incident light axis and converted into electrical signals by photomultipliers. These signals are then decoded into three digits of car owner information and seven digits of the freight car/type number. If all of these digits and the fixed code of the label's "start" and "stop" modules are detected, this information is passed on to a label data processor for subsequent transmission to the railroad's local management information system computer. Validity for the ten identification digits is checked by the return from a modulo-eleven binary coded parity module.

In the past, use of the OACI system's information has varied considerably depending on its size and the special needs of the railroad. One very large network, managed by the Chicago Railroad Terminal Information System, Inc. (CRTIS), was developed as a joint railroad effort to serve 28 users over 7,689 miles of track connecting 100 freight car classification and support yards. For the last five years, the FRA and twelve railroads have been involved in a cost-shared CRTIS demonstration of the benefits of OACI in reducing clerical costs, car detention times, misroutings, and classification errors. The results to date have had limited success due to: (1) a degradation in the quality of the labels; (2) a less than optimum scanner system performance;

and (3) limited data enhancement. In 1975, concern over the slowly deteriorating OACI readabilities led to an industry request for an FRA sponsored CRTIS field test program[1] which was conducted by the Department of Transportation's Transportation Systems Center (DOT/TSC). The tests showed that the readabilities could be increased from the national average of 80% to 91.3% through recent improvements to the OACI scanner system by the equipment manufacturers. Although the field test sample of over 6,000 cars was sufficiently large, this result was subject to considerable controversy. Some railroads believed that the test site was not representative of their own OACI experience. Others reported that readabilities of higher than 95%[2] were obtainable through a careful label washing program on their own captive fleets. The problem was further complicated when each railroad tried to assess the readability effect in terms of the costs and benefits of their own operations. Very little technical information was available on the effective life of the labels and the underlying causes for their deterioration. Readability improvements through advanced consist and multi-scanner correlations from both sides of a car had not been systematically defined in a form which could be interpreted by each individual railroad. These and other problems established a "wait-and-see" environment in which the static market for OACI systems precluded any major technological upgrading by the equipment manufacturers.

For the past year, the FRA has been working on four areas of the Optical ACI System to resolve its major issues and to provide a firm basis for the railroad industry's decision regarding its future use and deployment. These areas and their status are described as follows:

1. Car Presence Detector Studies have just recently been initiated to identify methods for improving the performance and reliability of the current wheel sensors and to investigate alternative techniques.

2. An analysis[3] of the optical properties of the existing labels has been underway for the past eleven months in order to estimate the label life and suggest methods for label improvement. Preliminary results of this work were presented to the industry in June 1977 and are summarized in later sections of this paper.

3. An extensive effort to improve the performance and cost of the scanner system has been conducted over the past ten months by DOT/TSC. The results of a first stage of fabrication and testing of newly designed pre-prototype hardware in this effort were also presented[4] to the industry in June 1977. The major portion of this paper describes the present accomplishments along with advanced designs which will lead to a July 1978 specification of the scanner system performance limit. The description contains an analysis of the current system, an identification of the levels of improvements, the results of laboratory testing and cost and sizing considerations.

4. An OACI System Alternatives Evaluation Model is being developed to *provide each railroad with a tool for* assessing their own approach to OACI. The model deals with the effectiveness of OACI enhancements from advanced consist information and multiplexed data from pairs of scanners. A user's guide for this model is being prepared and can be combined with an extensive Classification Yard Simulation Model[5] developed by ARINC Research Corp. for the AAR. The combination should provide a thorough assessment of ACI costs and benefits in the context of system enhancements, individual yard operations, yard configurations, and clerical requirements. A brief discussion of the major impact of the scanner system improvements on these models is contained in the last section of this paper.

PART I: SCANNER SYSTEM IMPROVEMENTS

CURRENT SYSTEM DESCRIPTION

The existing OACI Scanner System is composed of optics of good commercial quality and 1969 vintage electronics components. The system was originally designed to identify 99.5% of new or properly maintained labels with an unusually low false alarm rate of less than 1 part in 250,000. However, label degradation in the form of dirt, damage, and other causes has reduced the light returns from some of the labels to the point where they are obscured by the system noise. For the purpose of identifying readability improvements with the existing labels, the scanner system (Fig. 2) may be divided into four parts: an optics subsystem; front-end amplification electronics; a detector (called a "standardizer"); and a label data processor.

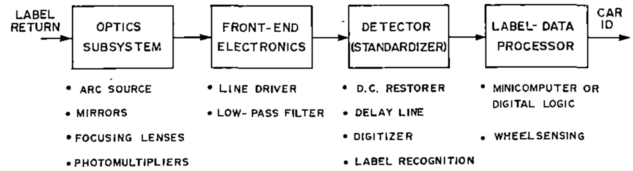


FIG. 2: SCANNER SYSTEM COMPONENTS

The detection of a label starts when its vertical edge first appears in the plane of the label scanning zone shown in Fig. 3. The label is illuminated in this zone by a 7.5 inch circular beam of collimated light from a Xenon arc lamp within the scanner head. This incident light is swept upwards by mirror faces mounted on a spin cube which rotates at a rate high enough to insure at least one scan of a label moving at 80 miles per hour. The rotating plane is tilted 7 degrees about the vertical axis to accent the labels retro-reflective properties over non-label specular reflections which are dominant on the normal to the car side. The labels contain very small glass beads mounted on a silvered surface which reflect light back within a small 2 degree cone centered on the axis of the incident beam. This effect may be seen by sighting a label with a flashlight at angles which can be as much as 45 degrees off the normal to the label.

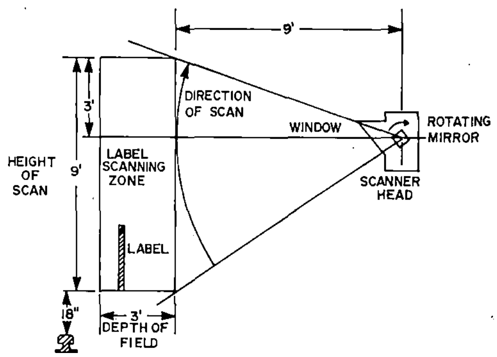


FIG. 3: LOCATION OF SCANNING ZONE

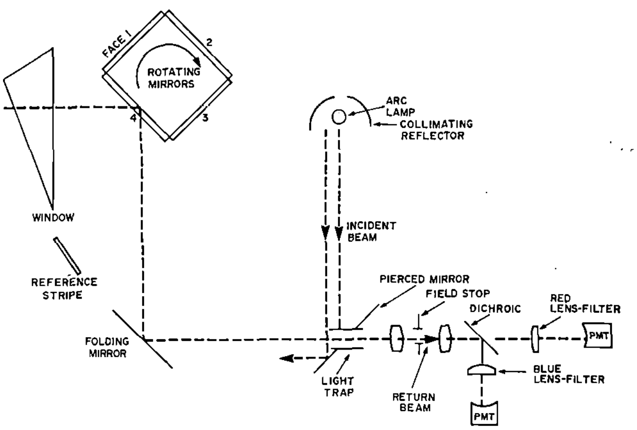


FIG 4: SCHEMATIC OF OPTICAL SUBSYSTEM

The optics subsystem is shown in Fig. 4 and contains a hole in the mirror which is also used to fold the incident light from the arc source on its way to the rotating mirrors. The hole admits the return light to a lens system which focuses it on the cathode of red and blue channel photomultipliers (PMT). Color separation is achieved by a dichroic mirror which passes the red band of light but reflects the blue band at 90 degrees. A white label module will therefore result in a PMT output on both channels. The red and blue filters are narrow-band matched to the spectral characteristics of the label colors. The effective received field of view is established by a field stop which admits a horizontal slit of the entire length of a module but only one quarter of its height. This causes a triangular PMT output for each half-module color and a trapezoidal output for full module colors. An example of these waveforms and the color code interpretation is shown in Fig. 5. The color combinations will produce sixteen possible logic states for each full module (four times four for each half module). Of these only ten are used because of the restrictions that no bottom stripe will be black and that the red/blue and blue/red modules are respectively reserved for the "start" and "stop" modules. The label background between and around both edges of the modules is composed of low reflectance black anodized material. A background-to-module spacing ratio of 6 to 5 provides a near-zero return between the signal pulses of adjacent modules.

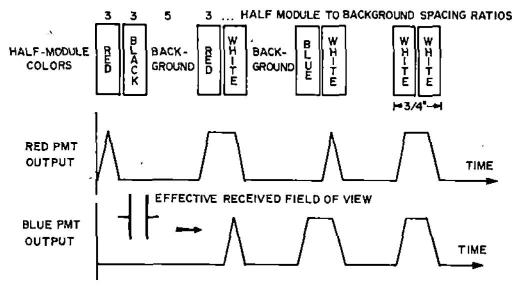


FIG. 5: COMBINED RED AND BLUE CHANNEL COLOR CODE INTERPRETATION

Recalling Fig. 2, the red and blue photomultiplier outputs are each fed to a separate line driver/400-khz low-pass filter combination with a dynamic range of 50 db. The line driver outputs present low impedance 30 mV to 10V label signals to the detector which is mounted in the air-conditioned Label Data Processor equipment hut. The hut also contains a power and signal interface box.

Since the purpose of the OACI system detector is to assure that only label analog signals result in an identification of a freight car, this device has been more appropriately called a standardizer. The standardizer eliminates false information from non-label reflections and assures the proper decoding of label signals through the use of DC Restorer circuitry, a delay line, a digitizer, and stripe/label recognition logic. As shown in Fig. 6, the triangular and trapezoidal photomultiplier signals arrive at the standardizer with rounded edges due to a non-ideal label reflectivity, optical and

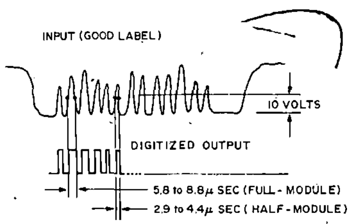


FIG.6: DETECTOR (STANDARDIZER) OPERATION

electronic bandwidth limitations, and system noise. DC Restorer circuitry first amplifies and level shifts the signal pulses so that they rise from a fixed DC reference level which is relatively independent of the slow variations in the outside ambient light. The ultimate objective is to convert these analog pulses into digital pulses with the same half or full module widths and relative spacing. This objective is realized through the use of a lumped constant transmission line which continuously tracks the instantaneous analog pulse amplitude over delayed time intervals. This delay line is shown in Fig. 7 and contains ten signal tap outputs with tap weight multipliers. The 9 microsecond "times-one" tap and the two 0.5 taps assure that a digital pulse is formed from the half-amplitude points of the analog label pulse regardless of its peak amplitude (the reflectivity strength) or waveform width (the label distance from the scanner). Other taps further away from the X1 center tap provide amplitude guardbands which inhibit a digital pulse when adjacent module peak amplitudes or spurious noise spikes are more than ten times greater than the center peak. The center tap voltage is also inhibited when it goes below a 50 millivolt DC threshold or when it falls below 0.2 times a "crosstalk" signal from the center-tap of the other channel. The crosstalk signal prevents a white color decision when one color produces a signal less than 1/5th of the others.

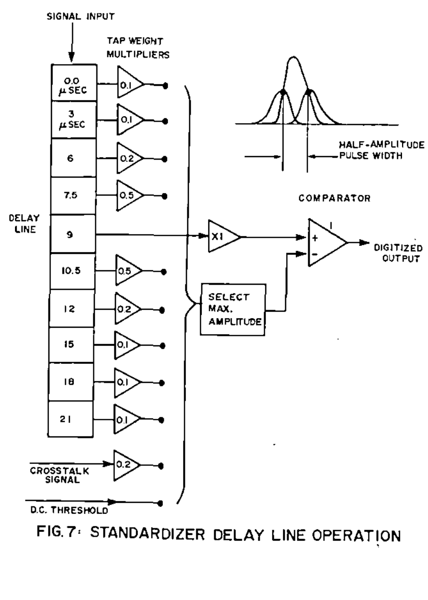


FIG.7: STANDARDIZER DELAY LINE OPERATION

The digitization of the red and blue label pulses is directly followed by two stages of Label Recognition Logic. The first stage examines the individual half-module pulse widths and determines the red and blue coincidence. These are assembled to arrive at a full-module numerical code which is checked for maximum pulse width and maximum distance from adjacent modules (which should always have at least one channel pulse in their first half module). If these conditions are not met, any preceding pulses are classified as noise and the circuitry is reset.

The second stage of label recognition checks more global information about the label, verifying that the pulse train consists of a "start" module followed by 10 numerical modules, a "stop" module, and a "parity" module. If any module is missing, all preceeding pulses are discarded as noise. If the pulse train satisfies all of the preceding conditions for a label, the label numerical codes are loaded into memory in the Label Data Processor.

The Label Data Processor verifies the label parity, checks for multiple scans of the same label, and uses the wheel sensor signals to identify each car and watch for cars with no labels. For each train, a list is then assembled and printed or transmitted to a remote computing site.

SCANNER SYSTEM IMPROVEMENTS

In its simplest form, the improvement of a scanner system to read more labels which have become degraded involves two tasks: (1) The dynamic range must be extended downward to read smaller optical returns; and (2) The effects of noise, either on the label or internally to the scanner must be reduced. That is, the system gains for new labels are maintained while improvements are made to identify very small signals from degraded labels in the presence of noise from three sources: (1) background noise from the label; (2) noise from the scattering of internal light; and (3) electronic noise. With this in mind, two stages of modifications to the scanner optics, electronics, and label detection subsystem were identified:

1. A <u>First Stage</u>, involved: (1) optics improvements; (2) wider dynamic range of the front end line driver; and (3) more stable thresholds for the existing standardizer. These modifications were intended to be an early package which could eventually be retrofitted in the field by the manufacturer at a cost of $4500 (approximately 10% of the initial purchase price of the

scanner system). The first stage hardware has been designed, fabricated, and tested in the DOT/TSC laboratory. The tests simulated the key aspects of the conditions in the field and were performed with a label population which was a representative selection of marginal and non-read labels provided by the railroads. These modifications were installed in a scanner system and directly compared to another scanner which had the manufacturer's latest improvements and a known readability of 91.3% established from field tests.[1] The comparison revealed that the modifications produced a readability improvement[4] of over 4%.

2. Final Modifications are now being designed to replace the standardizer and the Label Data Processor minicomputer with a new detector and multi-scan correlation in a microprocessor. These modifications will build on the optics and line driver improvements of the First Stage and will take advantage of recent advances in signal detection techniques and integrated circuit technology. These modifications have been verified as feasible and, from the results of a detailed analysis, will produce an additional 2 to 2.5% increase in readability. They will also involve a major reconfiguration of the present four-box system with its air-conditioned hut into a two-box system mounted entirely on the scanner wayside pole. This and the use of integrated circuits will reduce the initial costs of the scanner system from the present $40,000 to $54,000 range down to an estimated price of $27,000. The system reliability and maintainability will also be improved, reducing the scanner maintenance costs from $5100 to an estimated cost of $3400 per year.

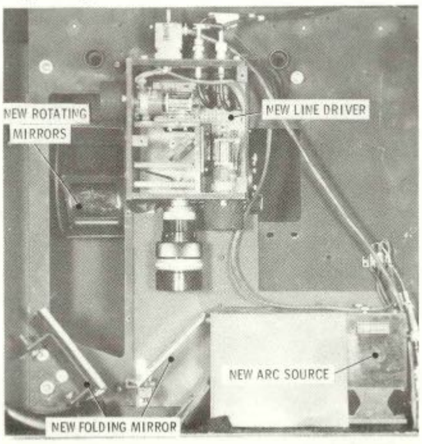


FIG.8· FIRST-STAGE OPTICS & LINE DRIVER MODS

The optics modifications and the line driver modifications are shown in Fig. 8 and are described as follows:

1. Optics Modifications

A. A new arc source manufactured by Varian, Inc., has been substituted to obtain a brighter rectangular beam of light on the label. The beam height has been reduced by a factor of two while maintaining an optical collecting and focusing system of the same F number as that currently used. The lamp assembly contains a secondary optical system with a well-defined illumination beam which results in less internal light scattering. Although the new source is more expensive ($475 vs. $375), it has a 60% longer lamp life and can be much more quickly replaced without any of the present requirements for special alignment time and skill.

B. A half-silvered mirror has been installed in place of the present pierced mirror. The new mirror and a larger, more expensive lens ($260 vs. $60) increase the light returns on the photomultipliers.

C. Flatter folding and rotating mirrors have been installed (at negligible additional costs) to obtain better resolution and more repeatable scan-to-scan module pulse times from the label. These mirrors also operate in conjunction with a small lens to obtain a synchronization pulse with a .05 microsecond stability for the advanced detection processor applications. The sync pulse is obtained from a reference module placed inside the scanner and slightly below the bottom of its viewing window. This module can also be used for optical thru put checks and photomultiplier gain stabilization similar to that already provided in the present scanner.

2. Line Driver Modifications

The new line driver has an increased dynamic range of 80 db which should be sufficient for the weakest (1 millivolt) returns from very degraded labels. The driver has integrated circuit operational amplifiers in place of transistors to achieve a higher immunity to temperature and power supply variations. The optics modifications and the new line driver have resulted in a 3% readability increase and have reduced the internal light scattering to the point where the dominant noise (of approximately 3 millivolts) is from the background material and deterioration of the label itself. An additional 1% improvement was obtained through modifications to the existing standardizer at an incremental cost of $1250.

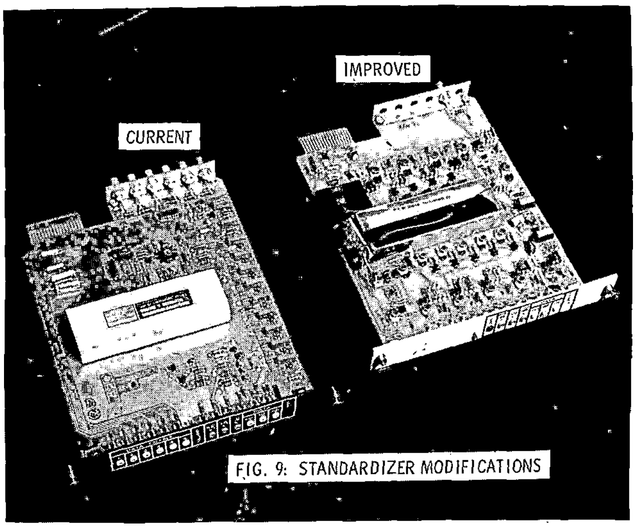


FIG. 9: STANDARDIZER MODIFICATIONS

The new standardizer is shown along with the present one in Fig. 9 to indicate that the breadboard electronics were well constructed and are direct plug-in replacements for the existing circuitry. The purpose of the modifications was to increase the dynamic range by a factor of 3 (from 46 db to 56 db) and to provide a stable threshold for degraded label signals in the region of 5 millivolts. The stability was obtained through the substitution of integrated circuit operational amplifiers for the transistor summers used in the tap weight multipliers (see Fig. 7). This substitution reduced the threshold temperature sensitivity by a factor ofthree (from 12 mv to 4 mv, 0 to 50°C) and resulted in a better immunity to power supply variations (from 15 mV/V to 1 mV/V). Signal reflections in the delay line were also reduced through high impedance buffering at the inputs to the tap weight multipliers.

The final stage of modifications began with an assessment of the capabilities of the present standardizer and Label Recognition Logic. These subsystems were well designed to identify labels which had signal returns as low as 1% of those from a new label. However, a significant number of the degraded test labels received from the railroads had pulses more than ten times lower (5 millivolts) than this threshold and, in some cases, were barely distinguishable from the background noise. In addition to the threshold limitation, the unusually strict requirement on false alarm rates had led to a design where partial label reads were discarded during each scan with no provision for scan-to-scan correlation. This situation, and recent advances in microcircuit technology, dictated a major modification of the system detector based on gated integrator or matched filter techniques. The new design started with the requirement for an accurate location of the label from which the signal energy could be accurately gated into an averaging circuit. The averaging circuit would be followed by a matched filter for module decoding which operated from an instantaneous estimate of the label's width and position in time. This design was complicated by three problems:

1. The pulse widths vary as the arc tangent of the ratio of the label height to its horizontal distance from the scanner.
2. The pulses have a wide variation in amplitude from module to module.
3. Vertical motion of the railroad car can cause a continuous shift in pulse location by as much as one-sixth of a pulse width during each successive scan.

These problems were solved with the following designs:

1. A Voltage-Controlled Oscillator (VCO) with a secant-squared function is used to vary the system clock rates. This results in the detection of pulse trains with an even spacing and width which is independent of vertical position.

2. A Label Locator is used to take advantage of the fact that the 13 regularly spaced label modules are a unique pattern on the railroad car side. The input to this locator is a fixed-level digital pulse obtained from an adjustable threshold detection of the analog label signals. The output of the locator is the label location time, pulse widths, and an indication of the confidence in these two measurements.

3. A Signal Processor and Module Decoder uses the label locator output from the previous scan to perform a matched filter averaging of each module's pulse energy during the current scan. This information is then fed into a tapped delay line where the half-module and intermodule spacings are stored. The module is then decoded and finally assembled into a label identification and a confidence indication on each module's detected digit value.

4. A Microprocessor is used for multiscan correlation of the large number of label identifications and confidence indications obtained on each scan from the module decoder. For the train speeds usually encountered (speeds above 40 miles per hour are extremely rare) at least ten identifications are available. The most likely identification and the confidence on each module

are then stored as the car identification.

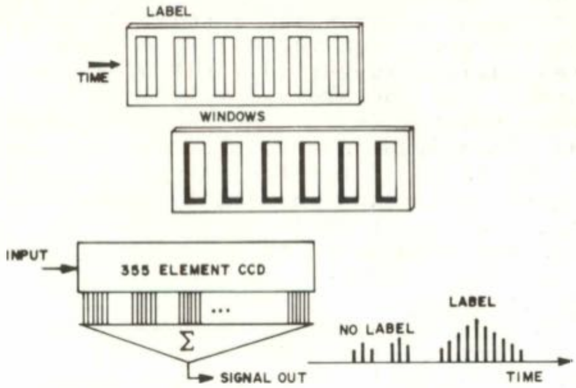


FIG. 10 · CHARGE-COUPLED DEVICE LABEL LOCATOR

Figure 10 illustrates the method for locating a label with tapped analog delay lines made from charge-coupled devices[6] (CCD's). As the label's combined red and blue signals pass by in time, a set of windows matched to the label pattern are observed for the sum of colors in all windows. The sum has a triangular form which peaks when the label is exactly aligned with the windows. This analog label location technique requires an array of eight such windows of successively smaller length and window size in order to match labels in the range of horizontal distances from the scanner. A breadboard version of a single array has been constructed and has located very degraded labels with pulses as low as 5 millivolts. The location accuracy was within one-sixth of a module width. As a backup measure, a second all-digital label locator utilizing the pulse symmetry was constructed and tested. This locator had the same accuracy as the analog version and could locate a significant number of the laboratory test labels which were not read by the scanner.

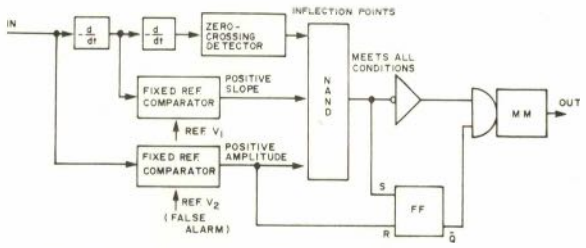


FIG. 11 · ADJUSTABLE THRESHOLD DETECTOR

The principle of adaptive threshold detection[7] is illustrated in Fig. 11. Half-amplitude leading edge detection independent of the pulse amplitude is obtained through an "anding" operation of the signal amplitude, the sign of its slope, and its inflection points. All of these conditions will be met for band-limited signals at the half-amplitude point. The detector also has a threshold setting to reduce false alarms and contains a gated delay to suppress noise spikes.

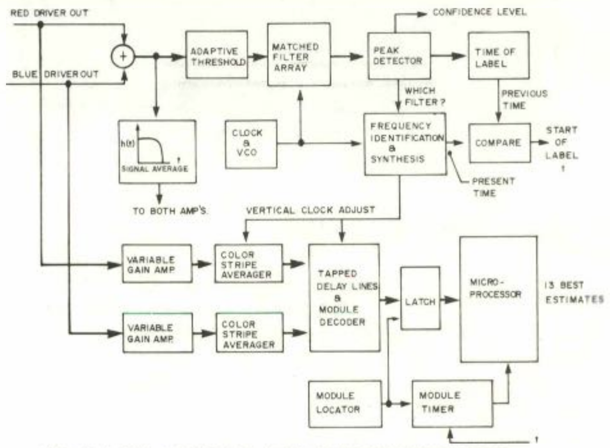


FIG. 12 · LABEL LOCATOR & POST DETECTION PROCESSOR

The full system block diagram for the label locator and the detection processing is shown in Fig. 12. The label locator is indicated on the top part of the figure where the combined red and blue channel digitized pulses are fed into the array of eight matched filters. The highest amplitude of all of these filters is identified by a very fast (5 MHz) peak detector which has been designed and tested. The detection processor is shown in the bottom part of the figure and contains the signal averager with an h(t) impulse response which varies as the label length. The signal average dynamically varies the gains in the separate red and blue channels. The resulting signal is then passed on to the module detector which identifies each module and its associated detection confidence level.

The microprocessor is commercially available in a "Mil.Spec." version with a 0.5 microsecond clock cycle time. The input data is 16 eight-bit words per scan which includes 11 words for the car identification and the parity digit. Four thousand words of Random-Access-Memory (RAM) are required for the I/O buffers and 64 scans of data storage. The software program will occupy 4000 words of Erasable Read-Only-Memory.

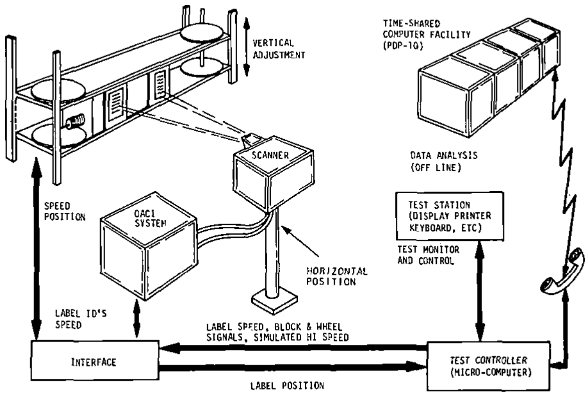


FIG. 13: SYSTEM TEST FACILITY

SCANNER SYSTEM TESTING

Fig. 13 illustrates the DOT/TSC laboratory test facility where the readability improvements were measured (a photograph of this facility is contained in an earlier paper P.5). A label motion generator holding up to ten railroad labels was constructed to simulate horizontal label motion past the scanner system. Speeds up to five miles per hour were obtained from a chain-driver carrier. An extensive hardware interface and a microprocessor system were also developed for a test control and monitoring capability. These included an operator display and keyboard, control of label speed, and recording of the label read status on a printer and cassette tape. The freight car wheel sensor signals and speeds higher than 5 miles per hour were simulated. Off-line data analysis, comparing the scanner read values with the actual label identification, was performed on a large time-shared computer facility.

A test label population of 54 labels was carefully selected[4] from 129 degraded labels supplied by the railroads. The selection process involved the identification of the non-read and marginal read labels and a matching of the percent of non-read error causes (damage, dirt, bent backing plate, etc.) with the distribution of error causes in the field.[1] An analysis revealed that the error causes were independent of car type (box car, hopper, etc.). This enabled the tests to be performed at a fixed distance which was representative of the distances of car types in the national fleet. Representative speeds were also obtained from field data.[4]

The measurement of improvements in readability over the known 91.3% readability of the manufacturer's reference scanner system were based on a newly developed readability criteria called a Figure of Merit (FM). The FM was created from a close examination of the standardizer input signals and a knowledge of its central detection mechanisms. These examinations suggested a ratio of two terms: (1) The average value of the pulse heights in the red and blue channel; and (2) A denominator which was the sum of the ratio of the largest to smallest signal amplitudes in each channel. This Figure of Merit ratio represented the combined effects of thresholding and delay line reflectivity constraints in the standardizer. A functional relationship between values of the FM and known field readabilities was then established for the 54 test labels and was closely approximated by:

$$\text{Readability} = 1 - (\text{Figure of Merit}) \quad (1)$$

A rank-ordered correlation of the read and non-read status of the 54 test labels in decreasing values of the FM showed significant results. A correlation of 0.97 was obtained in the determination of the readability of a single label from its reference scanner FM value. Moreover, the FM value for labels read by the reference scanner always established its readability at 91% regardless of their distance within the scanning region. This result enabled the increased readabilities of an improved scanner to be directly derived from the increase in the number of labels it read over the reference scanner. The increased readability established by Equation 1 was easily obtained from a table look-up of the corresponding FM value for the improved number of reads.

PART II: OACI LABEL PROPERTIES

The Scotchlite engineering grade (commonly used on the highways) is used as the basic material in the manufacturing of OACI modules and consists of a superposition of 8 layers with different physical properties. Fig. 14 shows a schematic cross section of a standard module. The removable cover sheet (1), when peeled off, exposes a self-adhesive layer (2). The second layer (3) is a moldable cushioning coating. The reflector coating (4) includes metallic flake pigment particles; (5) contains a transparent color pigment; (6) contains transparent color pigment in which is partially embedded a single surface layer of glass beads (7), which give retroreflective properties when illuminated. There are upwards of 1550 beads per cm^2. The transparent coating (8) over the layer of glass beads bonds to and conforms to the exposed front surfaces of the beads and the binder coating (6).

Finally, the silk screened (9) color-coded layer receives the protective coating (10).

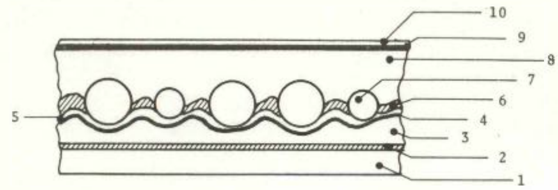


FIGURE 14: SCHEMATIC CROSS SECTION OF A STANDARD OACI MODULE

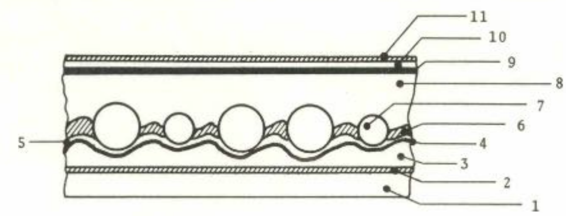


FIGURE 15: SCHEMATIC CROSS SECTION OF AN IST OACI MODULE

Fig. 15 shows a schematic cross section of an Improved Surface Treatment (IST) module which is similar to the standard with the addition of a layer of fluorinated ethylene-propylene (FEP) Teflon 2 mils thick film (11) put on a layer (9) with a self-adhesive (10). The Teflon layer provides an inert surface which does not collect nearly as much dirt as the standard label, therefore considerably extending its life in the railroad environment.

To evaluate the optical properties of the OACI modules (blue, red and white), four parameters should be measured: (1) the wavelength λ max, for maximum retroflectance; (2) the bandwidth, between the 10% points; (3) the retroreflected full beamwidth angle, A; and (4) the optical retroreflectance, G. The primary parameter of interest is the retroreflectance, G, which is proportional to the signal voltages at the detector input.

LABEL LIFE ESTIMATES

Previous estimates of label life have been made from visual judgments of label quality. The judgments have proven unreliable since the human eye does not see the labels in the same way the scanner system views them.[4] The estimates of the operational life expectancy in this paper have been based on field data from the Canadian National Railways and on weathering data supplied by the 3M Company at fixed test installations for Scotchlite modules which were exposed in a south-facing direction. The complexity in the estimation of the OACI label operational life expectancy is complicated by the fact that a definition of operational life has not been formulated and that labels are: (1) installed with different degrees of quality control (especially substrate preparation); (2) exposed to different kinds of natural environment (i.e., solar radiation, rain, snow, etc.); (3) subjected to different railroad environments strongly dependent on type of car and cargo; and (4) subjected to different levels of maintenance. In order to properly assess[3,8] the field Scotchlite weathering and OACI label data and translate it into operational life expectancy terms, an understanding is required of the causes and/or mechanisms which affect label operational life for different label structures (i.e., standard, IST and standard overlayed).

For the OACI label operational life, the following definition applies: OACI label operational life is the time, T, required in a given environmental and maintenance condition to reduce the original retroreflectance, G, of any of the 13 modules to 5% of its original value. (This value is consistent with the present and improved 1% minimum system voltage for the scanner system). Since the reduction in retroreflectance is affected by the environment, operational conditions, and/or level of label maintenance, it is important to qualify this definition with these factors.

The first source of data for the label life estimate was based on data from the 3M Company. 3M has conducted, over the years, weathering tests at their different test sites of the Scotchlite and OACI modules (standard and IST). These tests consisted of the measured G, along with spectral retroreflectances and chromaticity coordinates.

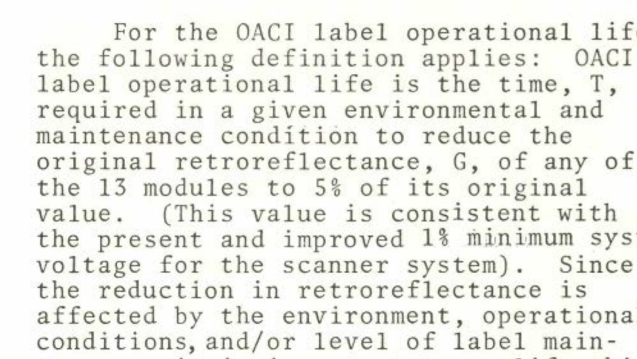


FIG. 16: SCOTCHLITE RELATIVE OPTICAL RETROREFLECTANCE, G, VS. WEATHERING TIME AT: (a) TEXAS, SAMPLES ORIENTED VERTICALLY; (b) FLORIDA, SAMPLES ORIENTED 45° TO THE HORIZONTAL

Fig. 16 gives the results of tests at Texas (a) and Florida (b) for Scotchlite. The data consists of approximately 100 data points per year from 20 samples of each of the following colors: blue, green, red, silver, and yellow. An evaluation of the average solar insolation[9] at ground level at both sites and, taking into account the different orientations (vertical and slanted at 45°), led to the conclusion that the ratio of total integrated solar radiation on the samples tested in Florida and Texas is approximately two. Field tests for standard OACI modules rendered similar results to the field tests of the Scotchlite material. By observation of the data given in Fig. 16, it is clear that to reach a given G in the Florida samples, it will take one-half of the time that it took in Texas. This suggests that the difference in solar radiation input is the cause. Further analysis of the Scotchlite also suggests that the reduction of G appears to be mainly due to changes in the bulk of layer #8 due to polymerization and on the surface of layer #10 (see Fig. 15) due to loss of gloss.

Based on the limited data (9 samples over 20 months exposure) available, it appears that the IST modules do not weather any differently than the standard modules. That is, the Teflon material does not provide any protection against solar radiation.

The second source of data for life estimates was obtained from the CNR in-service evaluation of IST labels.[10] In February 1970, one IST and two standard labels were applied to each side of twenty "Dane Ore" captive fleet cars in service between Hamilton, Ontario, and the iron mines in Northern Ontario. These cars are exposed to a severe environment in passing through the mine and the steel plant to automatic ore loading and unloading procedures. As a result of CNR laboratory measurements on some of these labels, and after 5 and 7 years in-service, reductions in retroreflectance of 3.3% per year and 2.2% per year (a mean of -2.8% per year) were respectively obtained. The ratio of this value to the -4% per year observed by the 3M Company (Fig. 16a) for the Texas test site is 0.7, which is the estimated ratio of the yearly solar exposure on a vertical surface facing south in Texas to the region where CNR conducted the tests.

Since the tested CNR labels are 7 years old, the 2.8% per year (4% per year x 0.7) adjusted rate from the 3M Company tests (Fig. 16) is applicable and is the same value obtained by the CNR. Based on the 3M data in Figure 16 and yearly solar exposure adjustments, the IST CNR labels decay will increase up to 7.7% per year after a 10 to 11 year period. Allowing for an uncertainty on the order of 15%, the estimated operational life of the IST CNR labels will be approximately 17 years. This estimate is based only on module performance and not on other overriding mechanisms such as damage and deterioration of the background surface.

Simultaneously with the IST label evaluation, the CNR carried out the evaluation of overlays on in-service labels from the "Dane Ore" captive fleet. The experiment indicates that the self-adhesive on the Teflon has improved the standard label surface conditions and that Teflon improved the label life to the point where it had the IST performance.

LABEL ALTERNATIVES

Review of available OACI label operational data obtained by railroads and test data obtained by the 3M Company on the two different types of material (standard and IST) shows a wide range of railroad reports on label operational lifetimes. This apparent disparity can be explained on the basis of three factors:

1. Different definitions of OACI label operational lifetimes,

2. Non-uniform quality control on label assembly by different assemblers, and

3. Different characterizations of the label population and the railroad environment.

In cases where the IST label does not satisfy the operational needs, label alternatives can be suggested. These alternatives could be applicable for different car and service types as well as for given operational life expectancies.

The main concepts developed in the FRA's OACI program and used in one of the new label designs are:

1. Use of materials practically not affected by solar radiation over a 15-year period;

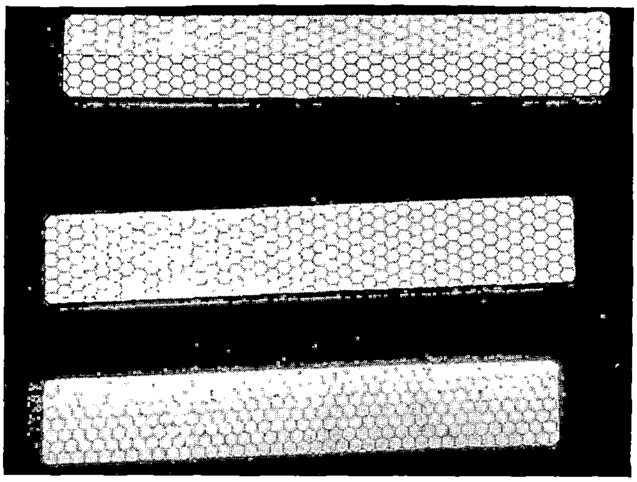
2. Substituting automatic means of label construction for the present manual assembly methods;

3. Physically separating the addition of the label color from the retroreflective material; that is, the colors are added as a separate layer during construction;

4. Introduction of rugged modules which can be easily handled and inserted in the field; and

5. An outer layer of 5 mil thick abherent film (e.g., Teflon FEP) to protect the module surface.

FIG. 17: ALTERNATIVE MODULE DESIGN



An alternative module design shown in Fig. 17 consists of a Plexiglass back plate with a cavity to receive the silver Scotchlite High Intensity Grade module covered by a front plate which is made of the same material used for the blue and red filters in the scanners. The front and back plates are sealed to completely isolate the Scotchlite from the elements. A 5 mil thick Teflon FEP layer is applied for surface protection. The modules are dropped into cavities made in an aluminum back plate. Prototype modules of this design have been successfully made and photometrically tested. The retroreflectance is equal to the IST modules and the color match of the red and blue modules with the spectral transmittance of the respective scanner channels is perfect and does not change with time.

PART III: OACI SYSTEM ENHANCEMENTS

The OACI scanner system improvements offer a number of new capabilities which can be used by the railroads in their OACI maintenance program and their management information system. These new capabilities can be summarized as follows:

1. Confidence levels on all digits of the car identification can be automatically correlated with "advanced consist" car identifications lists; even in cases where only a few digits are available from a very degraded label.

2. The scanner system can provide train speed and direction data previously obtained from the wheel sensors. The speeds can be derived from the number of label locator outputs and the known synchronous speed of the scanner rotating mirror. Train direction can be obtained from the assymetrical structure of the label "start" and "stop" modules.

3. A communications microprocessor can be installed in the scanner to permit multiple scanner polling by the management information system computer. The polling will enable a serial connection of large numbers of scanners systems at a reduced cost for communication lines.

4. Thorough system error and status checks of the scanner system and labels can be performed for maintenance purposes. This includes intercomparisons of scanner readabilities, the early identification of labels needing repair or washing, and more elaborate thruput checks on each scanner's operating condition.

The cost-effectiveness of these enhanced capabilities should be evaluated in the context of each individual railroad's operations. Quantitative information for this evaluation can be obtained by including the capabilities in the System Alternatives Evaluation and Classification Yard Simulation[5] models.

CONCLUSIONS

This paper clearly indicates that significant improvements in OACI scanner system performance and costs are achievable. The extent of these improvements are summarized in Table 1 where the Final and First Stage of modifications are respectively listed as items 1 and 2 of the scanner system options. The table indicates the range of readability accuracies for each option and identifies one-unit and 500-unit initial purchase costs, field retrofit costs, and yearly maintenance costs. The final modifications will increase the scanner readability to 94%-97% enabling a reduction in initial purchase costs from the range of $40,000 to $54,000 down to $27,000. The scanner system yearly maintenance costs would also be reduced by $1700 per year, yielding a $3400 yearly cost after the wheel sensor maintenance is included. Alternatively, a scanner system performance of 92% to 95% is achievable through a $4500 field retrofit cost for the first stage of modifications.

TABLE 1: OACI SCANNER SYSTEM READABILITY AND COSTS

SCANNER SYSTEM OPTIONS	READABILITY[1]	NEW SYSTEM[2] CAPITAL COSTS		FIELD[3] RETROFIT COSTS		YEARLY MAINTENANCE COSTS[4]	
		ONE UNIT	500 UNITS	ONE UNIT	500 UNITS	ONE UNIT	500 UNITS
1. FULLY MODIFIED SCANNER	94-97% [5]	$27K	$14M	$17K	$9M	$3.4K	$1.7M
2. PARTIALLY MODIFIED SCANNER	92-95%	$49K	$25M	$4.5K	$2.3M	$5.1K	$2.6M
3. MANUFACTURERS' LATEST MODIFICATIONS	88-91%	$47K	$25M	-	-	$5.1K	$2.6M
4. TYPICAL EXISTING SYSTEM	78-86%	$47K	$25M	-	-	$5.1K	$2.6M

NOTES

1. LOWER LIMITS INCLUDE WHEEL SENSOR AND MAINTENANCE PROBLEMS (ESTIMATED LOSS 3%); UPPER LIMIT IS FOR SCANNER SYSTEM ALONE
2. ONE-HUNDRED LOT BUYS
3. COSTS TO UPGRADE EXISTING SCANNERS IN THE FIELD
4. COSTS INCLUDE 40% MONTHLY WHEEL SENSOR MAINTENANCE AND 60% SCANNER MAINTENANCE
5. PERCENT READABILITIES EXCLUDE CARS WITHOUT LABELS AND MISAPPLIED LABELS

In the OACI label area, a number of significant conclusions are made. These are:

1. The main non-reversible cause of OACI module degradation over the years is the change in physical properties of the upper layer of Scotchlite due to solar radiation.

2. A reversible cause of OACI standard module degradation is loss of gloss of the module surface due to the natural environment or to abrasion. This loss of gloss can be corrected by maintenance or module redesign.

3. Data from two sources (the label material manufacturer and the Canadian National Railways) leads to a 17-year estimate for the label's operational life.

4. Teflon overlay on the modules has been completely effective in protecting the Scotchlite base material and extending its life.

5. Labels of new design using materials not affected by solar radiation and optically matched to the scanner can be developed.

In closing, the railroad industry has a large prior investment in the OACI system. It is believed that the improvement effort and enhancements reported will assist the industry in making it's decision on any future investment in automatic car identification.

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OVERVIEW OF FREIGHT SYSTEMS
R&D REPORT NO FRA/ORD-77/58
OCTOBER 1977

ERRATA

"Rail Dynamics Laboratory Requirements and Hardware Configurations"

Page 90 first sentence under Fig. 6, Vibration Test Unit should read as follows:

"The vertical excitation modules (each under independent servo control) are designed around a 60,000 lb (27,216 kg) hydraulic actuator, equipped with a 200 gpm (.0126 m^3/s) high performance servo-valve."

Page 90 first sentence of second major paragraph from bottom starting "The hydraulic flow demands ..." should be changed to read as follows:

"The hydraulic flow demands of the various excitation modules and hydrostatic bearing elements at peak excitation levels can be as high as 1000 gpm (.0631 m^3/s) @ 3,000 psi (20,684,271 N/m^2). This has been provided for via three 360 gpm (.0227 m^3/s) variable volume pumping systems each capable of delivering the rated flow at 3,000 psi (20,684,271 N/m^2)."