Cost of Quality: A Powerful Management Tool for Infrastructure Research

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An introduction to infrastructure research is presented in this paper. The railroad infrastructure includes the track, structure, and signal systems. An approach to improve the focus of research, enhancing the development of a high-quality railroad system, is presented. To that end, it is recommended that all railroads develop and deploy a total infrastructure quality-costs system. A similar approach successfully worked for the Union Pacific Railroad Company during the past 5 years and has contributed to the railroad's ability to maintain the lowest operating ratio among North American railroads. For the railroad industry, improvements are needed in the measures of effectiveness, predictability, and maintenance requirements of track, structure, and signal systems.

For the North American railroad industry to collectively meet the future needs of its customers, it must provide track, structure, and signal systems that are reliable, measurable and predictable, and maintainable.

The performance of the railroad infrastructure is controlled by many factors associated with rolling stock and the operating environment. Higher axle loads, for example, result in higher static and dynamic loads, creating more rapid deterioration of the components. Greater electrical resistance at the wheel-rail interface may cause signal systems to malfunction. Railroad professionals must understand which components are most sensitive to changes in these factors. The conditions vary over time, tonnage, from location to location on a given railroad, and between railroads. For Union Pacific, the transportation of coal has had a significant impact on the way the railroad thinks about the business and has resulted in changes to its operations. The materials that are installed and maintained must be of the highest possible quality to survive with this heavy unit train operation.

Requirement for Reliable Infrastructure

The customers' basic transportation needs are low-cost, highly reliable, new, and high value-added services. A new service is double-stack, which did not exist 15 years ago and has become an important part of the freight railroad business. Customers are demanding new technologies, and fixed facilities must rapidly be designed and constructed to support these changing customer requirements.

Union Pacific's rapid business growth has required continued capacity expansion. New construction technology, such as the track construction machine, allowed the railroad to respond quickly and build additional track at a reasonable cost. The railroad is continuing to search for new ways to improve capacity without the need for additional facilities.

The industry must improve physical plant quality to support these growing customer needs. At Union Pacific, the inability to meet customer needs is defined as an external failure, one of four categories in the railroad's quality-cost system. Using a similar approach, the industry could develop an understanding of its total freight railroad industry infrastructure quality costs. The quality-cost information could be used to pinpoint research efforts and dollars on the track, structures, and signal systems.

Development of Infrastructure Quality Costs

In 1987, Union Pacific began an effort to improve its business processes through a total quality management system (TQMS), a key component of which was the cost of quality program (*1*). Union Pacific quickly deployed and strengthened the successful application of TQMS and the use of quality costs as a key measure of performance. A similar approach could be used to describe the quality and performance of the entire railroad infrastructure.

Union Pacific has saved almost $2 billion since the cost of quality program was started in 1987. The program has been used as an effective management tool to enhance performance throughout the entire company. The process has enabled Union Pacific to

- Establish a cost of quality reduction objective,
- Cascade the objectives (top down) through the entire organization,
- Review and interpret trends, and
- Correlate the cost of quality with customer satisfaction.

The cost of quality program is an estimate of critical costs, not a new accounting system. The program's significant benefit is its monthly reporting system, which provides more up-to-date information than do comparable corporate financial statements. Corporate financial statements developed 30 days after the quarter contain some information that is more than 100 days old.

Union Pacific has learned that the cost of quality program

- Focuses attention on problems,
- Ranks problems to be solved in priority order,
- Supports justification of quality investments, and
- Measures effectiveness.

On the other hand, cost of quality numbers do not

- Solve quality problems,
- Recommend research,
- Suggest special actions,
- Clearly reflect improvements in the budget, or
- Clearly match effort and accomplishment.

Estimating the infrastructure cost of quality would require all U.S. Class 1 Railroads to communicate and share information through the Association of American Railroads (AAR). The savings from a cost of quality approach may take several years to develop.

Figure 1, which summarizes Union Pacific's cost of quality annual savings, shows the financial impact as a percent of revenue (*2*). Using this model and focusing only on the track, structure, and signal systems, a $300 million savings should be possible for the entire industry. If the North American rail industry adopted a total cost of quality approach similar to Union

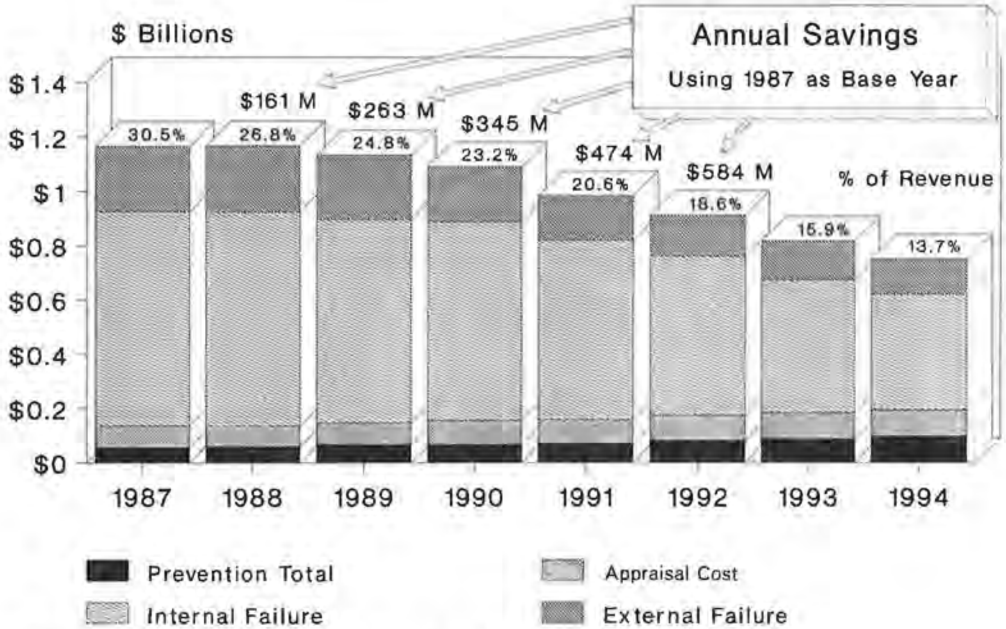

FIGURE 1 Cost of quality annual savings for Union Pacific Railroad.

Pacific's process, a savings of $3 billion to $5 billion would be possible during the next 5 to 10 years. Either approach would require the industry's top management to be dedicated to the process.

Total infrastructure quality costs are the sum of four key cost of quality measures: external failure costs (bad), internal failure costs (bad), appraisal costs (good), and prevention costs (good). These measures are described in the following paragraphs.

External failure costs measure the railroad's inability to meet customer requirements and the eventual lost business.

Internal failure costs are measures of problems that cause significant waste. These problems include broken rail, delays, some derailments, safety issues, environmental problems and the associated clean-up effort, unscheduled repair costs, fines, bridge failures, signal system failures, and so forth.

Appraisal costs include all track, bridge, and signal inspections, many of which are visual. Geometry car, rail profile, and ultrasonic rail inspection are part of the appraisal costs. Support of inspections made by qualified Federal Railroad Administration (FRA) or state inspectors are appraisal costs. Union Pacific wants FRA inspectors to pass on to Union Pacific employees what they consider important and to help them reduce the potential for accidents. Operation of the AAR Track Loading Vehicle (TLV) and the FRA Gage Restraint Measurement System are appraisal costs. Railroads worldwide use various appraisal techniques to evaluate facility conditions.

Prevention costs improve long-term safety and operational performance. Research is a critical prevention cost that reduces system failures and thus improves service. Training at all levels is considered a prevention cost, as are quality- and safety-improvement programs.

One prevention activity at Union Pacific, for example, is the development of improved turnouts. One test turnout near Odessa, Nebraska, uses concrete ties, elastic fasteners, and head-hardened rail. Costs over normal capital costs for this evaluation project are prevention costs. Maintenance cost data from this test is critical information that helps railroad professionals better understand and improve the performance of trackwork. Due to the line's heavy tonnage, failures occur fast, and the new technology's potential benefits can be evaluated quickly (*3*).

Early in the quality-cost process, Union Pacific observed that failure costs were many times greater than prevention plus appraisal costs. The railroad learned to leverage against appraisal and prevention costs to reduce failures. This continuing effort contributes to Union Pacific's low operating ratios.

To better understand the specific needs of freight railroad infrastructure research, AAR and FRA must develop an accurate estimate of the total rail industry's infrastructure quality costs. With this information, industry leaders can plan infrastructure research programs. This approach would indicate areas in which the industry (a) has been on the mark with past research, (b) needs to improve technology transfer to railroads, as in the case where research has shown benefits, but has not been implemented, and (c) needs research.

Requirement for Measurable Infrastructure

The industry must accurately and quantitatively assess the ability of infrastructure components to perform their intended functions and the influence of these components on maintenance requirements. Some necessary measurement systems already exist and are used to varying degrees of success, but other measurement systems need to be developed. In other cases, a single system may provide many of the required measurements. A listing of major track, structure, and signal system components to be measured is presented in the appendix to this paper.

Measurement Issues

Infrastructure components and their condition affect railroad safety and the ability to provide good customer service. AAR should develop measurement systems to determine the condition of high-cost components. Total-system reliability is a function of component reliability. Technology must measure the greatest number of the sensitive component conditions.

Critical areas include the following:

- Impact of each component on the customers' needs,
- Interactions between components,
- Accuracy of the measurement system, and
- Impact that cluster or repeatable defects have on reliability.

Among the questions to be answered are the following:

- In the event of one component's failure, can the load be transferred, and for how long will adjacent components carry the load?
- Can the fatigue that results in a reduction in reliability of the component be modeled?
- If visual inspection is the standard, what improvements in training and technology will optimize the inspection process?

Requirement for Predictable Infrastructure

Developing a predictable infrastructure is part of prevention costs. Important issues for the freight industry are discussed in the following paragraphs.

Influence of Heavy Axle Loads

The influence of heavy axle loads on the infrastructure must be precisely understood. The Heavy Axle Load Program under way at AAR, and partially funded by FRA, has provided excellent feedback to the industry, supporting decisions regarding heavy axle loads. One area requiring more data is track tonnage history; these data are necessary to aid fatigue analysis, especially on structures.

Influence and Interactions Between Vehicle and Track

The influence and interactions between the vehicle and track systems must be understood. The AAR Vehicle Track Systems Program is a key to understanding this interaction. A change in the freight, the car body, suspension system, and wheels will change the load on the rails, ties, and ballast. Changes in the track will likewise affect cars and freight. Union Pacific trackwork manufacturers are being asked to purchase the AAR-NUCARS (New and Untried Car Analytic Regime Simulation) model to help analyze the trackwork. Union Pacific wants its premium trackwork to be checked with the NUCARS model to accurately estimate lateral and vertical accelerations. This will improve performance and reduce trackwork life-cycle cost.

Through investigation of wheel-impact issues, Union Pacific found wheels creating 140,000-lb, static plus dynamic loads. During normal inspection, a wheel causing this load was not considered condemnable by AAR. This defect, probably due to an out-of-round wheel, imparts significantly greater energy into the track than some defects that are AAR-condemnable. Information provided during the Fifth International Heavy-Haul Railway Conference suggests that high-impact loads may have a greater impact on some steel bridges than previously thought (*4*). The basic need is to decrease the dynamic load on the entire structure.

Predictive Maintenance Models

Predictive infrastructure maintenance models must be developed and implemented. Questions to be answered include the following:

- How long will the component last?
- How fast is the component deteriorating?
- What impact will fatigue have on the life of the component?
- When should the particular component be maintained, treated, or replaced?
- What is the influence of heavy axle loads?
- How should maintenance or replacement of the component be prioritized?
- Should the component be redesigned?
- Are performance standards appropriate?

For example, it appears that the standard railbound manganese frogs will last 25 percent as long as the best movable-point frog in the same load environment. It also appears that concrete ties may help reduce the life-cycle cost of turnouts. Because of service issues associated with limiting speed through the trackwork, Union Pacific developed No. 30 turnouts. The No. 30 turnouts will allow operation through the divergent route at 60 mph, 20 mph faster than existing turnouts allow, and thus provide better service and boost track capacity.

Improved Analysis

Improved analysis techniques for evaluation of the components' performance must be used. Improved analysis techniques include mean time between failures predictions, finite element analysis, and multiple environment overstress testing (MEOST). Union Pacific successfully used MEOST in the development of its new ballast car fleet. AAR should develop expertise in these areas and transfer this technology to the railroad industry.

Requirement for Maintainable Infrastructure

The industry must develop a more maintainable infrastructure. Similar life-cycle models could apply to track, signals, or structures. Long- and short-range plans are developed as an annual program to establish when and where track material replacement is to occur. The program is then executed, with material being ordered, manufactured, built, and eventually installed. This is a moderately expensive portion of the life-cycle cost of the trackwork. During operations, there are the usual minor start-up troubles, as a program of low-risk usage that requires minimal maintenance is introduced. Performance results during low-risk usage, especially for new technology components of which only a few may be in place, can be quickly fed back to material design and reduce risk of failure. This low-risk usage is followed by medium-risk usage, with wear or fatigue becoming issues. Measurement and testing are critical at this stage. Results are then fed back to the long-term, 5-year plan for major renewals. At the end of the life-cycle, high-risk usage, which results in slow orders, should be avoided as much as possible.

Infrastructure maintenance goals include the following:

- Avoid over-maintenance, which is expensive;
- Avoid under-maintenance, which results in high risk; and
- Improve the quality of the total maintenance function.

In many areas, heavy-haul railroads operate quite efficiently; however, on certain heavy-haul lines in other countries, a tendency to over-maintain has been observed. Railroad professionals in those other countries, seeking ways to reduce the costs of over-maintenance, have begun to observe the maintenance practices of North American railroads.

Short-term maintenance needs include the following:

- Improve the prediction of service and material life;
- Improve defect-location information;
- Improve inspection skills, techniques, tools, equipment, and information;
- Improve maintenance skills, techniques, tools, equipment, and information;
- Improve inspectors' and maintenance workers' feedback and involvement in decisions;
- Improve control of maximum defect size, defect growth, and defect distribution, particularly in metal components; and
- Determine the optimum maintenance and replacement strategy.

Changes in the feedback system can result in performance improvements, as Union Pacific learned in a study of maintenance practices. Project Cheyenne is Union Pacific's name for a Management Effectiveness and Employee Empowerment System, developed and deployed with the help of General Systems Company. Through this employee-involvement project, the railroad is able to use ideas from the best employees, especially those closest to the work, and create teams to help improve the maintenance function's performance. A product of one team was improved training for track-buckling preventive maintenance.

Long-term maintenance strategies include the following:

- Understand and optimize the entire operating environment. Tradeoffs are the rule: if a change is made in one area, it will without question affect another area.
- Minimize variability in the infrastructure. Better information on conditions, materials, manufacturing processes, and the load environment will contribute to reduced system variability.
- Develop self-diagnostics for track, signals, and structures. Much work still needs to be done in this area. Union Pacific experimented with real-time performance monitors on tampers, which allowed machine operators to report reasons for specific delays and create a production record. In addition, the operators prefer this to a written or verbal report. Another important need is in the prediction of track buckles, which are truly a worldwide problem.
- Improve safety, ergonomics, and work conditions for maintenance employees. Significant effort is being made at Union Pacific to help improve these conditions for all employees. One

example is the development of a wheel-throw switch stand that reduces the load on the operator's back when the switch is thrown. Although this stand is not the solution to all back-injury problems, it appears to be a reasonable alternative on some turnouts.

• Minimize the environmental impact of the infrastructure. Recycling is a concept with which most railroad maintenance people are familiar. Collection technology to pick up grease, lubricants, and the like along the right-of-way is new and needs to be expanded.

• Develop independent maintenance practices. Devices are needed to help maintenance personnel find the exact location of a defect. For example, the geometry car could download data to a small hand-held geo-positioning system to advise those responsible for making the repair where that defect is located. A track crew would direct maintenance efforts to the precise location.

Another major issue is coordination between the inspection and maintenance functions. Information flow is critical, and once an inspector or inspection device finds a severe defect, this information must immediately go to the maintenance personnel for correction. In the case of wheel defects, Union Pacific provides its car department a picture of the car that shows the exact wheel that is defective.

• Develop performance measurements. The TLV was developed to help provide performance measurements for the track and equipment. This is an excellent device, and its use needs to be expanded. Opportunities exist for using this vehicle to measure track performance, including predicting the performance of a variety of components simultaneously.

• Consider the impact of the Federal Employers' Liability Act and the Research and Development Tax Credit on research.

• Keep an open mind to the many ideas that are being developed in railroads around the world.

Conclusion

The railroad industry can improve performance through the use of research in many areas. A cost of quality strategy will improve the focus of the railroad industry's infrastructure research. Several hundred million dollars in potential savings is possible. As a result of these improvements, the industry as a whole will be able to provide better customer service. This approach will support many of the quality improvement programs already under way within each railroad.

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