at 141 million Mg (155 million tons)], a few elastic-clip plates began to fail. These bending failures occurred at the lead edge of the plates where the outside of the rail edge contacted the plate (see Figures 9 and 10). As data given in Table 2 show, 65 of these failures occurred out of a sample population of 732 plates. Forty-one of the failures occurred in cut-spike segments 4 and 8. These were the original plates from the first test. By the time the second test was terminated, they had almost 12 million load cycles on them. There were not enough failures to determine a characteristic curve on the plate but, in contrast, over an accumulation of 213 million Mg (235 million tons), 38 AREA tie plates out of a lot of 22 120 failed.

It is not known whether or not these failures have occurred at all in revenue service and, since the choice of the hold-down fastener may have contributed to the failures, it is difficult to say whether or not this would occur outside of FAST. However, the manufacturer has since redesigned the plate to considerably increase the cross-sectional area in which the fractures occurred. These new plates should perform substantially better.

Beginning at 36 million Mg (40 million tons), the hold-down fasteners in elastic-clip segments 3, 4, 5, 7, 8, and 9 began either to work out of the tie or to fail. A complete tabulation of these problems is given in Table 2. These problems were most pronounced in screw-spike segments 3 and 7. In a period of 127 million Mg (140 million tons), 173 of 484 spikes in these segments either failed (see Figure 11) or came out of the tie more than 2.5 cm (1 in) (see Figure 12). A plot of the failure rate is shown in Figure 13. At about 118 million Mg (130 million tons), the failure rate began to escalate, eventually causing the test to be terminated at 128 million Mg (141.1 million tons).

The majority of the fractured screw spikes, drive spikes, and cut spikes failed in bending about 5-7.6 cm (2-3 in) below the head of the spike. When these failures occurred, the stub end of the spike was driven through the tie and a resin tie filler was used to fill the hole as a new spike.

The result was a deterioration in track gage. Figure 14 clearly shows that, except for segment 7, there was a rapid deterioration in gage after about 73 million Mg (80 million tons) of traffic [200 million Mg (220 million tons) overall]. The dynamic gage widening was also becoming severe, as shown in Figure 15.

The other problem of note in section 7 is elastic-clip fallouts, which are listed in Table 2. These are addressed in another FAST report and will not be discussed here.

It was evident from the results of the second test that the number and type of hold-down fasteners needed to be changed. Consequently, the number of screw and drive spikes was increased to four, and the cut spikes were replaced by lock spikes. In addition, a segment of hardwood ties with screw-spike fasteners was added to duplicate a similar test in revenue service.

Early data taken in section 7 on railhead deflections (see Figure 16) and comparisons of rail fastener stiffness [L/(H-B)] (see Figure 17) indicate a substantial difference in the responses of cut spikes and one kind of elastic clip. Relative railhead movement is much greater with the cut spike, which results in more gage widening, as Figure 15 shows. However, the rigidity of the elastic clip puts a premium on providing adequate hold-down capacity between the tie plate and the tie. In the second test, it was obvious that there were not enough fasteners of this type.

SUMMARY

The results of wood-tie-fastener testing at FAST to date have shown that the alternative elastic clip or compression clip has not performed better than a conventional cut-spike fastener. The dynamic effects of traffic on each system are much different, which indicates that different design considerations must be taken into account. The elastic clip puts a premium on the type and number of hold-down fasteners used to hold the tie plate to the tie, whereas the cut spike allows so much rail movement that there is a greater probability of gage widening and, as has been demonstrated in revenue service, a likelihood of spike-killed ties. Given these basic conditions and the results of the second test, the current test is much more likely than the second test to result in an adequate design alternative to the cut spike.

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Development of an Analytical Approach to Track Maintenance Planning

A. E. Fazio and Robert Prybella

Current research being conducted in a joint effort by the Consolidated Rail Corporation and the Federal Railroad Administration to develop an integrated maintenance-of-way planning model is reported. To develop a rational plan for maintenance-of-way expenditures, it is necessary to predict the effect of increased "basic" track maintenance on the requirement for "discretionary" maintenance. Basic (routine) track maintenance is performed by small, labor-intensive section and subdivision gangs. Discretionary track rehabilitation is performed by large, mechanized track maintenance gangs that move about the track system. Basic-maintenance gangs generally complete a particular task at a higher unit cost than discretionary-maintenance gangs. The frequency of the discretionary-maintenance cycle varies as some function of the level of basic maintenance—i.e., as the level of basic maintenance is reduced, the interval between discretionary-maintenance cycles is shortened. The limiting case, in which basic track maintenance is restricted to complying with safety requirements, requires the most frequent performance of discretionary maintenance. For various reasons, it is generally desirable to fund basic maintenance at a level greater than this minimum.

One of the most serious problems currently facing America's railroads is the deteriorated track structure. For many years, as profit margins decreased, railroads reduced their operating costs by a somewhat subjective program of deferred maintenance. The absence of an analytically based planning methodology made it difficult to identify much of this deferred maintenance at the time at which it occurred, and this made the overall financial situation of the railroads appear to be better than it actually was. In the recent rail renaissance, there has been an intensive effort by railroads to rehabilitate their physical plant, particularly the track structure.

Total maintenance-of-way expenditures for class 1 railroads in the United States in 1978 exceeded $3.4 billion (1). The apportionment of these funds between "discretionary" and "basic" maintenance was generally not accomplished by using a standard planning model; instead, money was budgeted and spent on the basis of subjective techniques that varied from railroad to railroad. Once this upgrading is completed, it will be necessary to apply a maintenance-of-way planning methodology that will normalize track maintenance cycles and clearly and objectively identify incidences of deferred maintenance.

An analytical planning technique that is capable of fulfilling these needs is currently being developed in a joint effort by the Federal Railroad Administration (FRA) and the Consolidated Rail Corporation (Conrail). Because the model is currently under development, its theoretical basis and the specific tasks prerequisite to the formulation of a working model are presented here by using hypothetical data, where required, for illustrative purposes.

CURRENT PRACTICE IN TRACK MAINTENANCE

Track maintenance is generally grouped into two broad categories: (a) rehabilitation, or discretionary maintenance, and (b) routine, or basic, maintenance.

The basic-maintenance track gang evolved from the "section gang", which, in its original form, is nearly extinct in the United States. The section gang predated the development of sophisticated machinery for track renewal and repair and consisted of a dozen, or fewer, men who were assigned to perform all required maintenance on a specific, limited [approximately 50-km (30-mile)] section of track. Contemporary basic-maintenance forces were created by placing section gangs in trucks and enlarging and combining their territory of responsibility. The development of mechanized rehabilitation gangs changed the role of these basic-maintenance forces.

Consider, for example, tie renewal. Before the advent of the mechanized tie gang, subdivision gangs were required to replace all deteriorated ties in their territory. They would therefore replace all ties in their territory over the life cycle of the ties. Now, however, with a periodic visitation by a mechanized tie gang, the section gang need only replace a portion of the ties that deteriorate and could even totally abstain from spot replacement of ties. Since mechanized gangs replace ties at a lower unit cost than do subdivision gangs, it might appear to be preferable not to use subdivision forces at all to replace ties. But other factors, including (a) the fact that the rate of deterioration of a good tie depends on the percentage of bad ties around it and (b) the limited availability of mechanized tie-renewal machinery, dictate that some tie renewal be performed on a routine basis by subdivision (basic-maintenance) forces.

There currently exists no analytical method of apportioning maintenance-of-way activities, such as tie renewal, between discretionary- and basic-maintenance operations. To develop an integrated approach to track maintenance planning, the model must identify the impact that a given level of basic-maintenance funding has on the required frequency of the discretionary-maintenance cycle.

CHARACTERISTICS OF MAINTENANCE GANGS

The most common discretionary-maintenance gangs are generally classified as rail, tie-renewal, or surfacing gangs and are characterized as follows:

1. They use track maintenance machinery—e.g., tie inserters and tie-spiking machines—extensively.
2. They are a large force of relatively inexperienced and unskilled labor, generally 40-80 men, performing repetitive tasks in an assembly-line type of operation.
3. The work must be planned well in advance. Because of the size of the gang and the fact that most of the track machinery is rail-bound, the gang cannot readily relocate. A summer's rehabilitation is generally planned the preceding winter.
4. They are designed to replace or repair a specific track component, such as ties, and modify or replace other components only to the extent necessary.
5. The gang has the capability to replace or repair a particular track component at the minimum unit cost.

Basic maintenance is performed by small gangs that may operate anywhere in a particular jurisdiction. These gangs have the following characteristics:

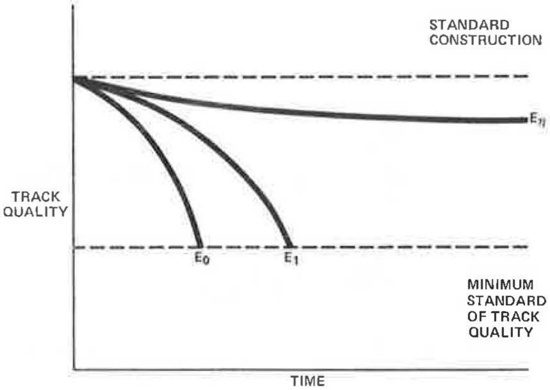
1. They make very limited use of track machinery and instead rely heavily on hand tools.
2. They are a small force, generally 3-10 men. Each individual, however, generally possesses a higher degree of skill and has had more varied track-work experience than personnel on rehabilitation gangs.
3. They have relatively high mobility. They may, in fact, perform maintenance in locations up to 80 km (50 miles) apart during the course of the day. Their mobility is a result of their limited use of track-bound machinery. Because of this, their work need not (although it may) be programmed in advance.
4. They are equipped to replace or repair a wide variety of track components.
5. The replacement or repair of a track component by basic-maintenance gangs is generally done at a higher unit cost than when it is done by discretionary-maintenance gangs.

Basic-maintenance gangs complement discretionary-maintenance gangs in that they (a) protect against catastrophic occurrences, such as a derailment, by giving prompt attention to discrete track failures, such as a broken rail; and (b) control the rate of deterioration of the track during the interval between service by the discretionary-maintenance gang.

QUANTIFICATION OF TRACK CONDITION

Prerequisite to the formulation of an analytical model for track maintenance planning is the development of a mathematical measure (or measures) of track quality. In general terms, track quality can be defined as the ability of the track structure to meet its functional requirements (2). According to this definition, the type of operations supported by the track will influence the selection of the parameters used to measure quality. Although many railroads have "in-house" estimators of track quality—such as Conrail's "condition index" (3)—existing estimators either lack universality or re-

Figure 1. Hypothetical track deterioration curves.



quire the collection of excessive amounts of field data to calculate the parameter for a given track segment.

A current FRA-sponsored research project is attempting to formulate measures of track quality, called "track quality indices" (TQIs), which can be derived either totally or primarily from data collected by automatic track geometry cars. Parameters that can be measured by these cars include gauge, cross level, warp (rate of change of cross level), and alignment (4). The FRA-owned cars are capable of recording measurements every 0.8 m (2 ft) at speeds up to 242 km/h (150 miles/h) and carry on-board computers so that a computer tape of the collected data, in addition to the strip chart supplied to maintenance-of-way personnel, is available at the conclusion of the survey. Each of these parameters of track geometry has a unique distribution over a section of track. The current FRA-sponsored project is investigating the suitability of various statistics of these distributions as TQIs.

Although it would be desirable to develop the TQIs solely from data that can be collected automatically, it will probably be necessary to supplement these parameters with other track data, such as bad-tie counts. This might be avoided by developing the capability to estimate track modulus—the ability of the track to resist deflection under load—by using automatic track geometry cars.

Operating conditions will affect the selection of TQIs. One should expect different TQIs, for instance, to be applicable to tracks that support 80-km/h (50-mile/h) freight traffic and tracks that support 160-km/h (100-mile/h) Metroliner service.

The current FRA-Conrail project is focusing on operating conditions that are common to many North American freight railroads: mixed freight trains of 50-100 cars operating on conventional track (wood tie and stone ballast) at speeds of 64-80 km/h (40-50 miles/h). In Europe, the Office of Research and Experiments (ORE) is also attempting to develop an easily measurable quantifier of track condition based on automatic track geometry cars (5).

DEVELOPMENT OF TRACK DETERIORATION CURVES

The rate of deterioration of track structure is a function of (a) structural parameters, such as ballast type and depth, tie size and spacing, rail weight and cross section, track gradient, and alignment; (b) usage parameters, such as annual traffic load and its wheel-load distribution, and train speed; (c) environmental factors, such as annual rainfall and freeze-thaw cycles; and (d) the amount and type of basic maintenance performed.

Currently, there is no proven method of predicting the deterioration of track as a function of these variables (6, p. 2). The development of a workable set of TQIs will permit the experimental development of track deterioration curves. These curves would show the change in the quality of the track, as measured by the TQIs, as a function of time.

Figure 1 shows hypothetical track deterioration curves; each curve shows the degradation of track quality with time at constant levels of expenditure for basic maintenance E, where $E_i > E_{i-1}$. Various levels of expenditure (E_i) for basic maintenance provide for different rates of track deterioration. For all $E_i < E_\eta$, deterioration to the minimum standard eventually occurs. The minimum would represent, at worst, the FRA standards for each class of track. Since FRA standards are minimum standards, as dictated by safety considerations, many railroads prefer to define their minimum standard at a slightly higher track quality.

In Figure 1, E_0 represents the limiting case of zero expenditure for basic maintenance—i.e., once the track is rehabilitated, almost no maintenance is performed. Even in this case, there will be expenditure for certain required basic-maintenance tasks, such as safety inspections. Curve E_1 represents a slightly higher level of expenditure for basic maintenance. Thus, if E_0 = $50/year/track-km ($80/year/track mile), and this was expended for inspections and emergency repairs, E_1 might be $150/year/track-km ($242/year/track mile), the incremental expenditure being used for spot tie renewal, tightening joint bars, and other miscellaneous basic-maintenance tasks that serve to retard track deterioration.

At the level of expenditure E_0, the track is usable for some time but deteriorates rapidly. The other extreme, shown in Figure 1 as E_η, represents an intensive basic-maintenance effort. At this level of expenditure, no significant deterioration of the track occurs; this would be representative of track maintenance before the advent of mechanized discretionary-maintenance gangs. Conrail's current unit costs for renewal of one main-line tie by discretionary-maintenance and basic-maintenance gangs, respectively, are approximately $30 and $50. Obviously, the level of basic maintenance E_η does not capitalize on the inherent lower unit costs associated with mechanized gangs and is thus not desirable. This leads to the conclusion that the role of basic-maintenance forces should be to regulate the rate at which track deteriorates and not to maintain track at a steady-state condition. Thus, the level of expenditure for basic maintenance should be less than E_η.

Certain parameters that measure a particular aspect of track quality may actually show improvement of the track with use. Track modulus increases as trains are operated over newly rehabilitated track (7). This is attributable primarily to the compaction of the ballast as trains operate over track whose surface has recently been reworked. Even as this compaction is occurring and track modulus is increasing, individual components of the track structure (ties and rails) are continually deteriorating. Thus, although overall track quality increases for a short period of time immediately after the reworking of the track surface, the increase in track modulus caused by ballast compaction eventually comes to an end and deterioration begins.

It is generally agreed that the rate of deterioration of track is a function of its condition and, as the condition worsens, the rate of deterioration increases (8,

Figure 2. Suspended rail joint in good condition.

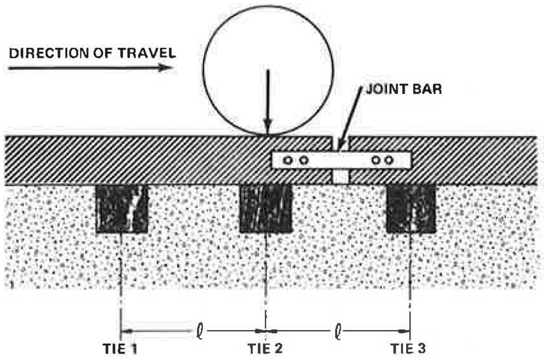
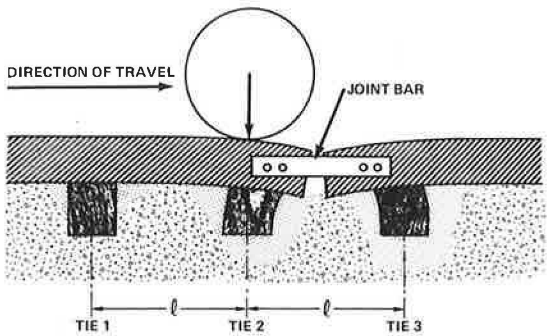


Figure 3. Suspended rail joint in poor condition.



p. IV-40). A qualitative illustration of why this occurs can be obtained by considering the suspended rail joint shown in Figure 2, which supports a point load, the wheel, where shown. A currently used design practice calls for the assignment of 50 percent of the dynamic axle loading to tie 2 and 25 percent of this loading to each of ties 1 and 3 (9). This assumes that the joint bar is stiff, the wheel rolls over a smooth joint, and the rail acts as a continuously supported beam in supporting the wheel load (10).

Although this may be a good assumption for track in perfect condition, use of the track causes the joint bar to loosen. As the joint bar loosens, the rail end begins to act more like a cantilever than a continously supported beam. This causes a greater loading on tie 2 and, thus, accelerated deterioration of this tie and of the ballast beneath it. As the tie and ballast degrade, the structure loses its ability to support the load without significant movement. A differential movement between rails of 0.39 cm (0.125 in) or more is not uncommon and causes rapid deterioration of the rail because of the deformation that results from cold working of the steel. This is manifested in rail-end batter and surface bending of the rail, as shown in Figure 3. Ties 1 and 3 also deteriorate at an accelerated rate because of the impact loading imposed on them when the wheel crosses the joint.

FACTORS THAT AFFECT DETERIORATION

For a given level of expenditure E_i, different deterioration curves will evolve for each variation of the significant structural and usage parameters. For example, Figure 4 qualitatively demonstrates the effect of doubling the yearly gross traffic load while all other parameters remain unchanged. Figure 5 shows the

Figure 4. Track deterioration as a function of traffic load.

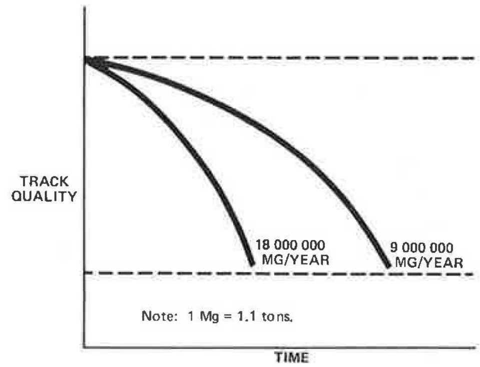


Figure 5. Track deterioration as a function of curvature.

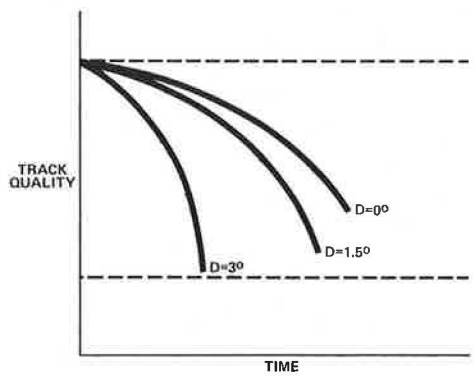
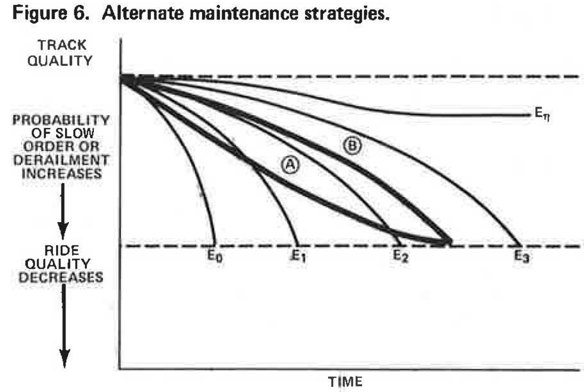


Figure 6. Alternate maintenance strategies.



effect of track curvature on rate of deterioration.

In general, the change in track quality can be expressed as

$$\Delta TQI = f(e, S, T, P, V, M) \quad (1)$$

where

- e = level of basic maintenance;
- S = structural characteristics of the track, such as continuously welded or jointed rail, ballast depth, and subgrade type;
- T = annual traffic load;
- P = wheel-load distribution of the annual traffic load;
- V = train speed; and

M = miscellaneous parameters, such as weather and train consist.

Current research in the FRA-Conrail program is attempting to determine the sensitivity of ΔTQI to each of these factors and to determine which set of factors will account for the bulk (80-90 percent) of track degradation. The functional dependence of the change in track quality on each of these significant factors must then be determined for inclusion in the deterioration model. Graphically, this means that a unique family of deterioration curves must be developed for each variation of the factors that are found to significantly affect the change in TQI.

DEVELOPMENT OF BASIC-MAINTENANCE STRATEGY

Once the track deterioration function is formulated, the TQI can be graphed as a function of time for any given set of structural and usage parameters. Curves that indicate the desired condition of the track, as measured by TQI, at any given time can then be superimposed on this coordinate system. Such curves describe a "basic-maintenance strategy".

Two typical strategies are shown in Figure 6. The selection of a particular strategy may be based on a variety of criteria. A curve such as A in Figure 6 can be selected for certain freight-only lines when it is desirable to keep basic maintenance to a minimum. The presence of passenger service or hazardous materials on a certain route may indicate the selection of curve B, for, as Figure 6 indicates, the probability of "slow orders" and track-caused derailments increases, and ride quality decreases, as track quality decreases. Thus, strategy B allows the track to spend more time in a condition in which ride quality is good and probability of derailment is low.

Note that both strategies must prevent the track from deteriorating beyond the minimum standard and, for purposes of comparison, the minimum standards for both cases are assumed to be identical. In practice, however, the minimum standard for a line with passenger service or hazardous materials might well be fixed at a better quality of track. When the track reaches its minimum, discretionary maintenance should be performed to return the track to the "new" condition. Note that a rehabilitation gang—a tie-and-surfacing operation, for example—does not quite return the track to the as-constructed standard because conventional rehabilitation gangs are not designed to effect a complete renewal of track structure.

The total cost of a given maintenance strategy over a complete cycle of deterioration and renewal consists of the cost of the discretionary-maintenance operation plus the cost of the basic-maintenance strategy. The latter is given by the expression

$$C_A = \int_A e(dt) \tag{2}$$

where C_A is the total cost of basic maintenance for strategy A and e is the expenditure for basic maintenance for an increment of time dt. The integral is computed along curve A.

The total cost of maintenance if strategy B is selected is the cost of rehabilitation plus the cost of basic maintenance for strategy B. The latter is

$$C_B = \int_B e(dt) \tag{3}$$

where the integral is computed along curve B. In the case shown in Figure 6, since both rehabilitation operations are identical and occur at the same time, the total cost of maintenance strategy A will be greater than that for strategy B by the expression

$$\Delta C = \left[\int_B e(dt)\right] - \left[\int_A e(dt)\right] \tag{4}$$

Because an analysis of this type relates the condition of track at a given time, and its rate of change, to the funding level for basic maintenance, it can be used in conjunction with the unit costs for discretionary maintenance to determine the total cost of a desired maintenance cycle. It can therefore be used to evaluate alternate maintenance strategies—for example, the effects of varying the interval on which discretionary maintenance is performed.

This model also identifies the avoidable costs related to maintenance of way, such as the cost of providing commuter service. In addition, it clearly identifies occurrences of deferred maintenance as occasions in which the maintenance strategy allows the track quality to fall below the minimum standard.

EXAMPLE OF USE OF THE MODEL

The following example of the use of this model has been developed by using purely hypothetical data and is included for illustrative purposes only. Some of the terms used in the equations are given in SI. For the most part, however, the equations have been formulated in U.S. customary units, without SI equivalents.

Assume a track quality index Q whose value immediately subsequent to the passage of tie-and-surfacing gangs to tangent, jointed rail track is 100 and whose minimum accepted value for this type of track is 76. Also assume that, for the fixed structural parameters of this type of track, the following three usage parameters are found to account for 90 percent of the rate of track degradation: (a) annual tonnage (T), (b) percentage of tonnage that moves in cars larger than 100 gross tons (P), and (c) average speed (V).

Assume that track quality Q as a function of time t is given by

$$Q = Q_0 - A(t^2) \tag{5}$$

where

$$A = f(T, P, V, e) \tag{6}$$

and where

Q_0 = 100,
t = time (years),
T = annual tonnage (million gross tons),
P = percentage of tonnage in cars larger than 100 gross tons,
V = average speed of trains, and
e = level of expenditure for basic maintenance.

Further assume that it has been shown experimentally that A is determined by the functional relation

$$A = (T/10)(P/50)(V^2/900)(E_0/e) \tag{7}$$

where E_0 is the minimum level of basic-maintenance funding necessary to meet requirements for inspection and emergency repairs.

Now the basic-maintenance budget for a selected unit

Figure 7. Hypothetical track deterioration curves at three funding levels.

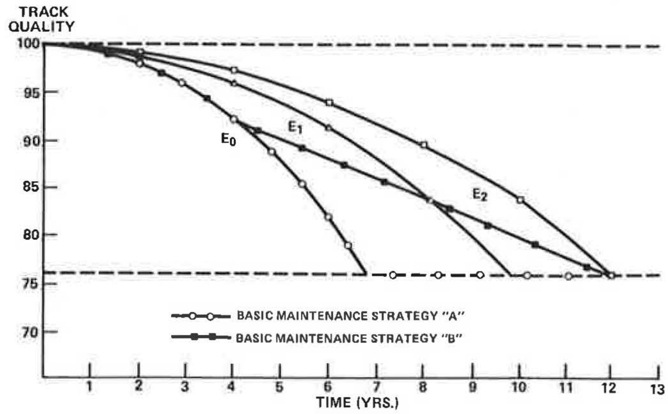
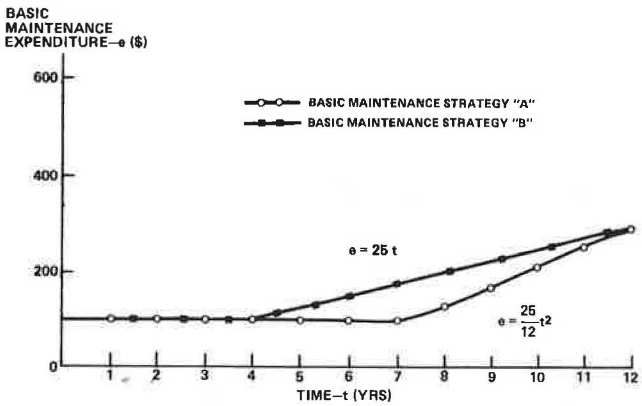


Figure 8. Expenditure for alternative basic-maintenance strategies as a function of time.



of track can be developed. Assume that the track to be budgeted for has the following usage parameters: T = 100 million gross tons/year, P = 25 percent, V = 30 miles/h, and E_0 = \$100/track-km/year. Substitution of these values into Equations 4 and 6 yields

$$Q = 100 - (50/e)\,t^2 \qquad (8)$$

Figure 7 shows deterioration curves for this track at three levels of basic-maintenance funding: E_0 = \$100/track-km/year, E_1 = \$200/track-km/year, and E_2 = \$300/track-km/year. Suppose that the discretionary maintenance required to return the track quality to Q = 100 is to be performed on a 12-year cycle. The expenditures for any basic-maintenance strategy can now be easily calculated.

Consider strategies A and B in Figure 7. Strategy A provides the minimum total basic maintenance for the 12 years. The cost per kilometer of this strategy is as follows:

$$\int_{t=0}^{12} e(dt) = (7)\,(100) + \int_{7}^{12} e(dt) = 700 + \int_{7}^{12} (50/24)t^2(dt)$$

$$= 700 + 962 = \$1662/\text{track-km} \qquad (9)$$

Further assume that this route carries commuter trains that must be "slow ordered" when Q is less than 80. Since commuter trains would be slow ordered for six years under basic-maintenance strategy A, another strategy might be preferred.

Strategy B, which is defined mathematically as

$$Q = 100 - (2t) \quad \text{for } t > 4 \qquad (10)$$

and

$$e = E_0 \quad \text{for } t < 4 \qquad (11)$$

allows trains to operate at normal speed for a greater period and would be more acceptable. Note that, each year after the fourth, strategy B requires an increment in the level of basic-maintenance funding. Its total cost is

$$\int_{t=0}^{12} e(dt) = 4(100) + \int_{4}^{12} e(dt)$$

$$= 400 + \int_{4}^{12} (25t)dt$$

$$= 400 + 1600 = \$2000/\text{track-km} \qquad (12)$$

Figure 8 shows basic-maintenance expenditure for strategies A and B as a function of time. The total expenditure for each alternative is the area under its curve in this figure.

The avoidable costs of track maintenance associated with the commuter service (strategy B) can be graphically identified on an annual basis. If this service had been provided at the bequest of a government agency, e.g., an operating authority, these costs could be billed to that agency.

This model could also be used for the costing of freight service. If, for example, a particular shipper's traffic were to double the percentage of annual tonnage moved in cars that weigh more than 91 gross Mg (100 gross tons), the additional costs incurred could be readily identified by adjusting the value of the coefficient A in Equation 6.

SUMMARY

An analytical, integrated methodology for railroad track maintenance planning would be of use to the railroad industry. The following tasks are currently being researched jointly by Conrail and FRA:

1. Formulation of parameters of track quality entirely from data generated by automatic track geometry cars;
2. Identification of variables such as average speed and annual traffic load, which account for 80-90 percent of track deterioration as measured by TQIs;
3. Identification of the basic-maintenance tasks that optimize a given level of basic-maintenance expenditure;
4. Formulation of a track deterioration function that expresses the change in track quality as a function of track use and level of basic maintenance; and
5. Integration of the track deterioration model with an existing discretionary-maintenance planning methodology to form a combined model that can then be used as the basis for analytically planning both the basic and discretionary maintenance of track.

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PROFILE: Gradient Simulation for Rail Hump Classification Yards

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Designers of rail hump yards traditionally execute a long, tedious manual process to optimally design hump grades and retarder placements. This design process entails checking the velocities and headways of a worst-case sequence of cars to ensure that proper values of these variables can be maintained on the gradient. The computer simulation model PROFILE automatically computes these quantities and thus frees the designer from tedious work and allows him or her to generate and study more design alternatives. The model uses the usual static (velocity-independent) rolling-resistance formulation of car rollability but includes the option of using velocity-dependent rolling resistance. User input requirements and program-generated output are described, and an example of the application of the model to a typical design problem is given.

In rail hump yards, classification is performed by rolling a cut of cars down a grade and switching the cars into various classification tracks. To perform switching properly, sufficient headway between cars must be created and maintained. The principal problems in the design of the hump profile and in the development of an effective speed-control scheme are to ensure that (a) the headway maintained in the switching area [e.g., 15.2 m (50 ft)] is sufficient to throw switches and prevent catch-up in retarders, (b) speed restrictions [e.g., 24.1 km/h (15 miles/h)] at switches and curves are observed, and (c) proper coupling occurs on the class tracks within specified speed limits [e.g., 3.2-9.7 km/h (2-6 miles/h)]. Controlling headway and speeds would not be difficult if all cars had identical characteristics and rolling resistances (or rollability) because the initial time separation established at the crest would result in a uniform and predictable headway between cars.

However, car rollability is not uniform; it varies with weather and type of car and changes during the rolling of a car. Nonetheless, the profile designer must ensure that a large percentage of the cars (e.g., 99.9 percent) are delivered to the bowl tracks in a manner that satisfies the above design constraints. Moreover, because car speed is directly translatable into hump throughput, it is desirable that the fastest car speeds meeting these constraints be used.

Achievement of these aims is usually approached by considering the hardest-rolling (slowest) and easiest-rolling (fastest) cars. Hump grades are usually designed to deliver the hardest-rolling car to the clear point at a specified speed [e.g., 6.4 km/h (4 miles/h)] or to a specified distance into the classification track [e.g., 152.4 m (500 ft)]. The sizing and placement of retarder sections are usually determined by examining a worst-case triplet of a design hardest-rolling car followed by a design easiest-rolling car followed by a design hardest-rolling car traveling to the last switch on the farthest outside track. The retarders are placed where the separation between the two lead cars becomes less than a specified value; the retarder slows down the second car to reestablish proper headway. The length (power) of the retarder is based on the amount of energy that must be removed from the second car in this worst-case situation (of course, railroad policies may require sufficient retarder power to stop any car). At the same time, caution must be exercised to ensure that the second (easiest-rolling) car is not slowed so much that the third (hardest-rolling) car catches it.

The purpose of the PROFILE model is to provide the yard designer with an iterative and interactive computer design tool to perform such an analysis and to ensure that the design constraints are satisfied. The need for some automation of the hump design procedure has long been recognized. The labor and hours involved in plotting velocity head diagrams and converting them to car velocity, integrating velocity of cars to obtain time-distance plots, and finally comparing time-