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A STUDY OF RAILROAD BALLAST ECONOMICS

BALLAST AND FOUNDATION MATERIALS RESEARCH PROGRAM

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16. Abstract

This report presents the results of Phase V - Economic Evaluation of the Ballast and Foundation Materials Research Program. The present "State of the Art" in the ballast costing area is discussed. The individual ballast costs are quantified to the extent possible using the data base compiled from the literature review and from replies to a survey received from 70 U. S. and Canadian Railroads. A discussion of the differences in ballast performance is presented. An equation to compute the additional cost justified to place a ballast of superior stability is formulated.

It has been possible to quantify many of the costs associated with ballasting procedures; however, due to the wide diversity in operating conditions, procedures, gang organization, financial conditions and climatic factors, these costs vary greatly from railroad to railroad since many railroads do not take into account all costs in their costing exercises.

The costs derived in this study can be used as an input to a general model for ballast selection.

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PREFACE

This report has been generated as part of a sub-contract between the Association of American Railroads Research and Test Department and the University of Illinois.

This sub-contract is part of a larger contract which is a cooperative effort between the Federal Railroad Administration and the Association of American Railroads on improved track structures. The entire program is in response to recognition of the desire for a more durable track structure. To this end, the program is a multi-task effort involving (1) Mathematical modeling to develop equations that describe the behaviour of the track structure under loading, (2) ballast and foundation material research to describe the behaviour of ballast and foundation materials under repeated loads, (3) testing to develop information on the behaviour of the components of the track structure under repeated loads and to validate the mathematical models, and (4) the design of a track research facility in which accelerated service tests can be carried out.

This particular report presents the results of Economic Evaluation of the Ballast and Foundation Materials Research Program.

A special note of thanks is given to Mr. William S. Autrey, Chief Engineer, Atchison, Topeka and Santa Fe Railway; Mr. R. M. Brown, Chief Engineer, Union Pacific Railroad; Mr. F. L. Peckover, Railway Geotechnical Consultant; Mr. C. E. Webb, Asst. Vice President, Southern Railway System, as they have served in the capacity of members of the Technical Review Committee for this Ballast and Foundation Materials Research Program; and Dr. R. M. McCafferty as the Contracting Officer's Technical Representative of the FRA on the entire research program.

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Chapter 1

INTRODUCTION

GENERAL

An integral part of the "Ballast and Foundation Materials Research Program" is the development of a methodology to evaluate the economic performance of various ballast materials. This report summarizes the activities accomplished during the project phase entitled, "Economic Evaluation".

A methodology has been developed which will enable an evaluation of the differences in the costs of ballast purchase or transportation economically justified by the differences in the relative "surface life" among materials. This task has required the determination of the various cost items comprising the overall economic cost of ballast use and the application of contemporary knowledge to the problem of relating this cost to ballast type and railroad practice. Development of this methodology did provide a difficult task because of the current absence of difinitive data relating ballast type with in-trace stability and durability and with the length of associated maintenance cycles.

REPORT ORGANIZATION

Chapter 2 of this report discusses the present "State of the Art" in the ballast costing area. Chapter 3 discusses the major elements comprising the overall cost of ballast. The individual costs are quantified to the extent possible in Chapter 4. Chapter 5 presents a discussion of the differences in ballast performance. Chapter 6 presents an equation to compute the additional cost justified to place a ballast of superior stability, while Chapter 7 provides a summary of findings and conclusions.

Chapter 2

STATE OF THE ART

The understanding of track action under load has advanced considerably, yet accumulated engineering knowledge has not fully addressed all facets of maintenance policy and procedure. As a result, experience and engineering judgment remain the foundation of a decision maker's choice of the "what, when and how" of track maintenance. Significant diversities in materials, practices and procedures produce wide variations in the costs associated with track maintenance.

Perhaps no area of the railway track structure has been more neglected in research efforts than the ballast, subballast and subgrade. This is particularly important considering the magnitude of annual expenditures for ballast purchase (over $45 million in 1974) and the significant influence of ballast performance on the cost of the track laying and surfacing (which totalled $586 million in 1974).(1)* Much of the research which has been undertaken has merely involved analysis of piecemeal data derived from the opinion and experience of maintenance personnel. Unfortunately, this approach is not nearly adequate, considering the complexity of the ballast loading environment and the variances in the policies and conditions prevailing on different railroads. The use of personal opinions is also confounded by the limited experience of any one individual with respect to the vast spectrum of possible subgrade conditions, ballast and subballast materials and gradations, and traffic characteristics. Other attempts at the study of ballast performance have been limited by the incompleteness and inadequacies of railroad record keeping (including the lumping of figures into system averages.)

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* Numbers refer to references.

Efforts directed toward the establishment of more precise in-track performance tests have met with other difficulties. Among the more important of these are the absence of scientific rather than judgmental criteria of the need to perform track maintenance operations, the long time period required to conduct meaningful tests and the researcher's inability to control such vital factors as environment and subgrade stability. Even the development of engineering analyses of track system response under a single load has produced little information for the ballast selection decision, as short term responses are largely independent of ballast type and gradation and because limited contemporary knowledge of "transfer functions" does not permit translation of short-term response measurements to long term performance expectations. Lacking proper evaluatory abilities, efforts to produce a rational economic basis for ballast selection have been unsuccessful.

In the absence of a workable guide, railroads have long predicated their ballast decisions primarily upon purchase price, availability, and transportation cost. In fact, a 1938 American Railway Engineering Association (AREA) survey of railroad ballasting practices showed that these items collectively represented the fundamental basis for ballast selection on 73% of the railroads which replied, with only 27% of the respondents stating that service life and performance level considerations were foremost factors in their ballast choosing procedures.[2] (Similar surveys in 1953 and 1957 reported availability and service considerations to be of nearly equal weight.)[3,4] Perpetuation of this practice is fostered in part by the railroads desire to use on-line sources of material.

In recent years, however, there has been a renewed interest in ballasting policy and material selection, possibly as a result of railroads' efforts to address the demands of today's heavier wheel loads. In fact, for those systems whose rails, ties and other track structure components have been strengthened, a stress on improvements in ballast conditions is a desirable course.

One recent survey, for instance, indicated that most railroads' ballast selection criteria now give greatest weight to service life considerations.[5] However, in spite of forward strides in roadway maintenance costing,[6] a lack of definitive information relating ballast type with in-track performance has prevented adequate modeling of ballast's effects, with the result that ballast selection is still primarily a subjective process.

Chapter 3

BALLAST COST FACTORS

BASIC COST ELEMENTS

The principal goal of this economic evaluation phase is the formation of a model to evaluate the overall economic cost of ballast. The overall economic cost is a function of many elements. The basic cost elements can be classified as:

- . purchase price
- . transportation cost
- . unloading cost
- . cost of spotting operations
- . cost and frequency of lining and surfacing operations
- . cost and frequency of ballast renewal operations including disking and harrowing, cleaning, sledding, and undercutting
- . ballast effects on the cost and frequency of renewing rail, ties and other track materials

Each of these cost elements in itself is governed by many factors and may be interdependent on the other costs. For example, the frequency of lining and surfacing operations is very dependent on the nature of the spotting operations. If spotting is inadequate or not performed at all, lining and surfacing operations must be conducted more frequently than would otherwise be necessary. Similar mechanisms interconnect the remaining cost factors. The following sections describe each of these cost factors and will serve as a quantitative basis for the formation of a overall ballast cost model.

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PURCHASE PRICE

Of the elements of overall cost, purchase price is the most easily determined. The ready availability of this information plus the tremendous difficulty encountered in quantifying other cost elements predispose many railroads to overweigh the importance of purchase price in their ballast selection decisions. This tendency has been clearly demonstrated in several surveys of ballasting practices[2,3,4].

Although the variability in ballast purchase price among sources is a function of many factors, one element of particular significance concerns the supply and demand relationships prevailing in the proximity of each source. The unit price of a ballast material asked by a potential source is largely a function of market conditions, which are related, in turn, to the source's product. Most ballast materials apparently can be used interchangeably in many applications. Therefore, little difference in purchase price can be expected among various types due to difference in ballast material.

Another cause of price variation concerns the organizational structure of the ballast source. Among the more important elements in this category are the ownership of the source (railroad or independently owned), the employment of union or non-union labor, the management's sophistication and the scale of ballast production. These conditions vary widely from source to source.

Other factors relevant to purchase price considerations include the processes of material preparation required, the rigidity of production specifications involved, and the magnitude of individual orders prepared to a given set of specifications. Obviously, the greater the size of the order and the less demanding the ballast processing methods and specifications are, the lower will be the purchase price of the delivered material.

The nature of the ballast may also have significant cost ramifications. Waste products, being nearly endless in supply and requiring immediate disposition, usually exhibit market prices at the low end of the cost scale. Extractive materials, hampered by their somewhat more limited supply, by their more intensive labor nature, and by the environmental safeguards which accompany quarrying operations, may have a market price at the high end of the cost scale. Because of this relationship, material type may be related to purchase price, but within each group--slags or extractive materials--further classification by ballast type would have little intrinsic effect on the purchase price.

TRANSPORTATION COST

Due to the geographic expanse of many railroad systems and the limited number of large sources of good ballast material, the distance involved in ballast movement is often large. Thus, transportation cost represents a significant element in overall ballast cost. The specific magnitude of this element, however, is a function of numerous factors besides length of haul.

One important determinant of transport cost is road haul practice. Although crew size, crew districting, proportion of main line and branch line haul, and similar factors play a part, the most significant variable is the use of discrete vs. unit train technologies. The latter course involves the two-way shuttle of dedicated, special-purpose ballast cars between sources and points of ballast placement. It usually represents the minimum cost alternative if large volumes are to be moved, because the efficiency of a unit train markedly reduces the total number of cars which must be assigned to ballast service. However, for small projects or for roads having few special cars, the somewhat more costly conventional (non-unit train) movement of standard or specially-equipped hopper cars, assigned to ballast loading is often used. A third alternative, utilizing empty back-haul movement of regular revenue cars in conventional trains, may occasionally represent the minimum transportation cost option because it eliminates the need for costly empty backhaul of special ballast cars, but it often suffers from high unloading costs related to the use of standard revenue cars which are not well suited for ballast.

A second major element affecting the per mile cost of ballast transportation concerns the volume of material involved in an individual movement. Because the transportation cost between any two given end points includes a large portion independent of the number or size of cars participating in the movement, significant economies can be achieved by maximizing the volume of ballast moving as a block. Although occasionally related to loading limitations, the upper limit is usually a function of the maximum volume of ballast which can be unloaded in a reasonable length of time (usually one or two days). The limitations relating to interference with normal traffic, usually limit the time available to unload ballast to much less than the customary eight to ten hours' work day. The equipment design and ballast type will also affect the daily unloading rate, as explained later.

A third factor affecting transportation cost relates to the proportion of a ballast haul involving off-line movement. Because the Interstate Commerce Commission has jurisdiction over the rates charged for moving loaded ballast cars over a foreign line, and since these rates are considerably higher than those which railroads assess themselves when they are moving their own materials, railroads generally limit themselves to on-line sources except in cases of emergency. As pointed out previously, the use of purely on-line sources may preclude one's ability to truly optimize ballast selection because it tends to limit a railroad's experience to only a few materials and sources.

Another element of some importance is the density of the material to be shipped. Because standard or slightly modified coal hoppers constitute much of the ballast service fleet, and since ballast is considerably more dense than coal, weight rather than volume, limits the quantity of ballast loaded into each car. Because the track needs are measured in terms of volume (for instance, the number of cubic yards per mile needed to effect a particular raise), the number of cars required to fill the need is a function of material density. Adding extra cars increases the overall transportation cost of a small but real amount by incrementing the dead weight (hence, the train resistance), by enlarging the car ownership and maintenance charges assessed to ballast movement, by increasing the required amount of car handling, and so on.

UNLOADING COST

Upon delivery of loaded ballast cars to the work site, the ballast is unloaded and given a preliminary spreading. The cost of this operation is related to numerous climatic, equipment, material and operation considerations.

Because moisture can dramatically affect the flow rate of ballast, exposure to the environment during storage at the source and transport in open-top hoppers may have a significant influence on the per unit cost of unloading operations. As climatic influences may be so great as to obscure the importance of all other factors, it is essential that some standard conditions be used when comparing the overall costs of various ballast materials.

With climatic influences fixed, the single element with the greatest effect on unloading costs is probably the design of the ballast vehicle, for such design elements as car capacity, slope of hopper sheets, and layout of hopper doors greatly affect the flow rate of the ballast material. In this manner, equipment type also has an influence on the size of the unloading crew by the need to shovel down material in hard-to-unload cars. Quite obviously, the lower daily output and consequent higher unit costs resulting from poor car design are extremely important considerations.

A number of "discretionary elements" also have a significant impact on unloading cost. This category encompasses such factors as height of raise desired, use of work train or local or through train for delivery purposes, established policies concerning maintenance operations under traffic, size of crew, size of ballast train, and so on. Proper planning and timing are also critical, for interference between unloading operations and track surfacing activities may cause costly delays.

Another factor of some importance, ballast type, exerts its influence on unloading cost through its effects on the ease of ballast handling and on ballast unit weight. The unloading cost associated with each material is based both on the rapidity with which it can be unloaded and

and on the material's density, where the latter influences the number of cars which must be transported and unloaded to effect a given raise. Of these two elements, the unloading rate is probably the most significant. Ballast materials with a large percentage of fines (especially if exposed to rain and high humidity condition) generally exhibit poor unloading characteristics. In ballast materials where the fines have been removed, only the shape and surface texture of the ballast particles affect the unloading rate.

COST OF SPOTTING WORK

Between lining and surfacing operations, light spotting work is required to correct localized imperfections in track geometry and to maintain proper bolt tightness, spiking integrity and the like. Section gangs, the track inspector, and special cyclic spotting gangs may all be involved in these activities. The specific organization reflects the maintenance policies of the individual railroad. The costs of these operations are functions of their frequency and extent, both dictated by the decline in quality of track and track support. The presence of rail joints, weak subgrade, decayed ties, etc. become important considerations. There is no accepted formula for evaluating these costs, but the more stable the subgrade and ballast the less need there is for spotting.

Another type of spotting operation is the shimming of frost-heaved track. Sections with fouled, water-retaining ballast or with a subgrade having a significant fine fraction may require such treatments if freezing occurs.

FREQUENCY OF LINING AND SURFACING

Because lining and surfacing operations are central to the maintenance of proper track geometry, the need to perform the operations becomes a function of the deterioration of geometry related to traffic and climatic conditions and of the resistance to such decline offered by track and track support elements.

Figure 3.1 illustrates what might be considered a representative curve relating the frequency of lining and surfacing with the annual traffic volumes conveyed. This curve, developed in a recent track maintenance costing study,[6] was based upon the average of the replies to a 1959 AREA questionnaire[7]. The nature of the curve suggests that cumulative tonnage is not the lone determinant of the deterioration of track geometry, for the curve displays variations in the traffic volumes amassed between successive operations. The hidden element in this case is the deterioration accompanying continuous exposure to the environment, a factor whose importance is lessened as the time interval between lining and surfacing operations decreases. Besides this relationship, the relative roles which traffic and climatic conditions play may be altered by the severity of either element; the intensities of wheel loads, the number of freeze-thaw cycles, the magnitudes of wind-blown fouling material, the amount of precipitation and so on all have their effects. All of these factors acting together produce a wide scatter of actual data points about the representative curve.

Perhaps the most significant factor in the scatter of points about the curve is a difference in the abilities of various track, ballast and subgrade combinations to resist track geometry deterioration. Of these

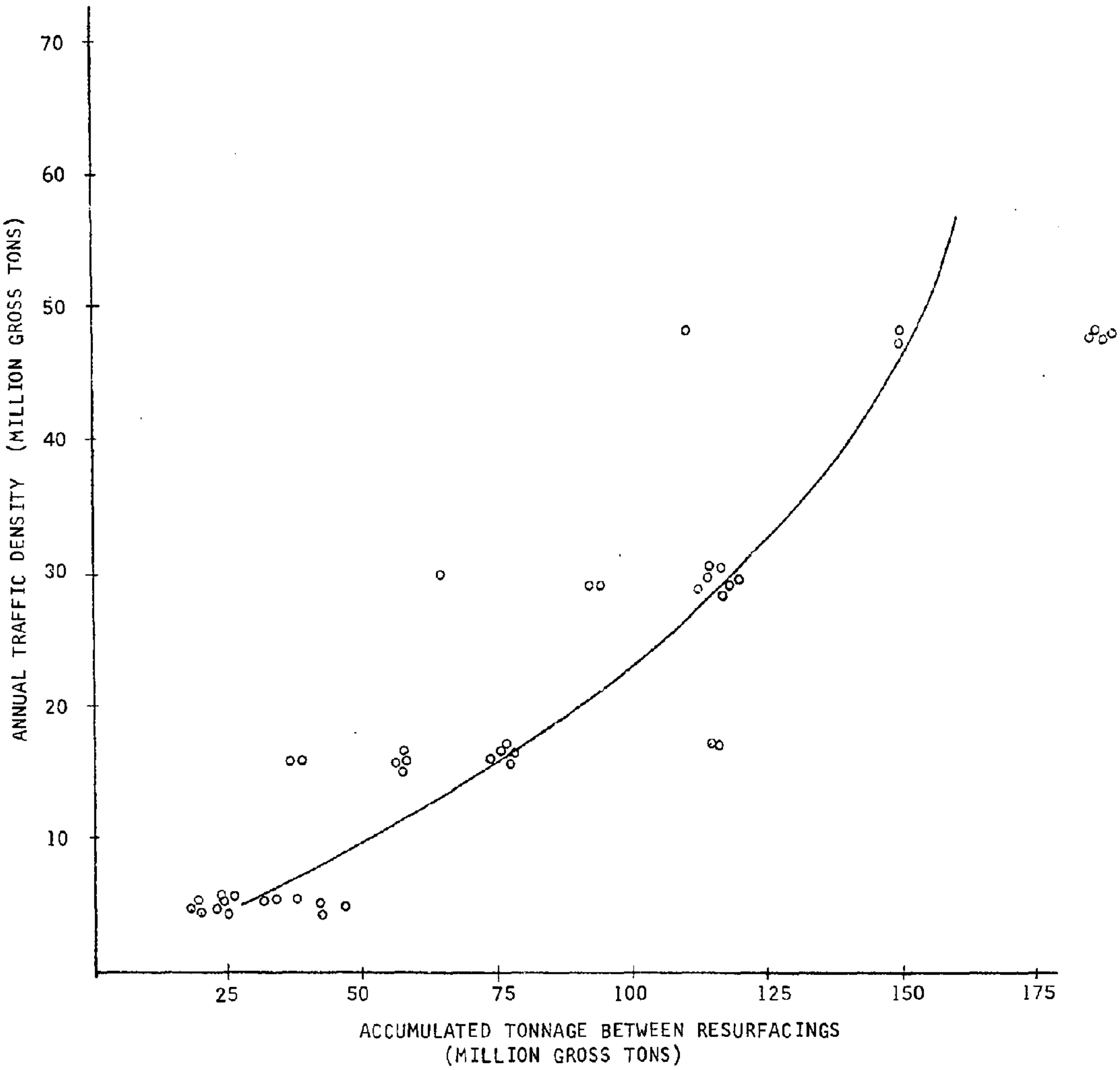

Figure 3.1a. Representative Lining and Surfacing Cycles.

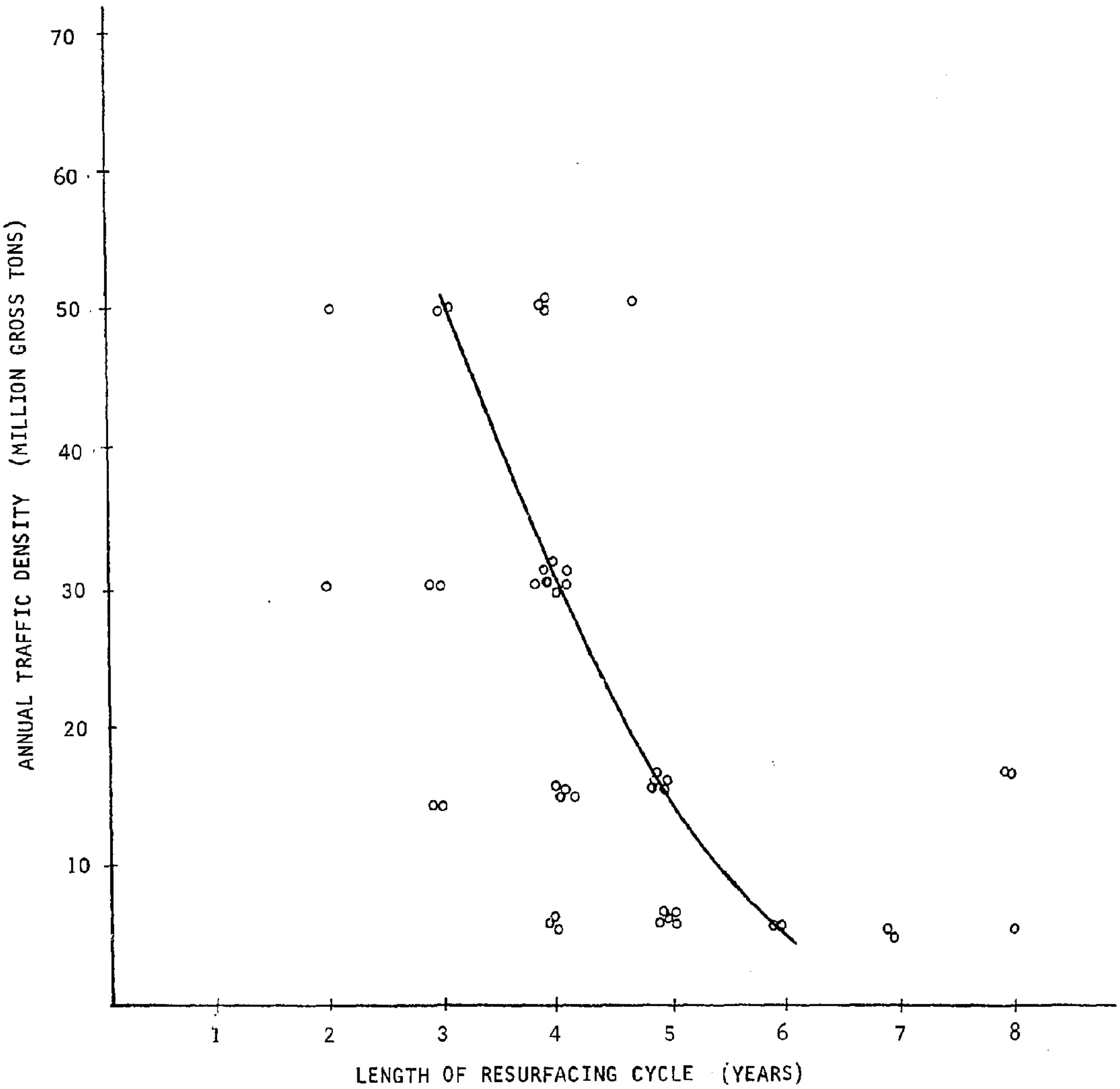

Figure 3.1b. Representative Lining and Surfacing Cycles.

factors, subgrade quality is possibly the most important single element, a fact reflected in the experience of many track personnel and substantiated by the parameter study embodied within the current project[13]. Such factors as rail weight, tie size, tie spacing, ballast type and depth and other track construction parameters likewise affect the lining and surfacing curve. Ballast type, for example, asserts some influence through its relationship with particle surface texture and hence the development of intergranular friction and resultant stability.

In most cases, however, the effects of the numerous traffic, track and climatic factors arc obscured by differences in the maintenance policies of the many railroads. The decision to line and surface reflects each system's standards of track excellence, the opinions of its experienced personnel, its financial circumstances and, of course, an appraisal of field conditions by men or by track geometry devices. Some companies prefer short lining and surfacing cycles which permit spotting and ballast renewal efforts to be reduced, while others desire to step up such activities to allow the cycle to coincide with the tie replacement frequency. Some even adopt specific cycles to ensure full time work for all maintenance machines and labor, a practice particularly noted for small companies whose entire system can be covered within a few years by several gangs.

COST PER TRACK FOOT OF A LINING AND SURFACING OPERATION

The cost per track foot of a lining and surfacing operation reflects the output and the overall cost of the procedure per unit time. While the latter element is simply the sum of crew wages and machinery capital and operating costs, the former element is somewhat more complex.

Perhaps the largest influence on output is the amount of productive time available per day. Besides a diversity in the length of the standard working day among railroads, production time differs markedly from job to job. This reflects a variation in the aggregate time for travel to and from the work site, for initial set-up, for clearing and resetting, etc.

Another element having considerable bearing on an operation's productivity is the deployment and function of men and machines. The use of high capacity tamper-liners and tandem tampers, full staffing of all manual tasks, employment of ballast regulators before and after the procession, etc., can increase production rates, but may also increase costs per track foot.

Track conditions, company maintenance policies and the track supervisor's judgement are also important considerations, exerting a significant influence through their combined effects upon the number of tamper insertions per tie, the proportion of all ties to be tamped and lined, the height of raise to be effected, and so on. Special complications, such as the linking of a lining and surfacing operation with rail and tie renewal programs, the prevalence of fouled ballast or special trackwork, etc., can have considerable weight. The type and gradation of ballast to be inserted may also be a factor as it may influence the amount of tamping effort needed to properly consolidate the ballast.

FREQUENCY OF MAJOR BALLAST RENEWALS

Because the primary purpose of a ballast renewal is the correction of undesirable ballast conditions, its frequency is a function of the many elements affecting the ballast section's degradation. General factors in this category are the intrusion of fouling materials from various sources, the ballast's resistance to weather and traffic imposed degradation, and the maintenance history of the track.

Fouling materials may enter the ballast section from above or below. Wind, blown dust, engine sanding, train braking, and car leakage come from above; abrasion introduces flour-like particles within the ballast; and soft subgrade particles and slurries infiltrate from below the section. While it is difficult to quantify or control the material which enters from above, individual track sections have specific characteristics which may alter intrusion from the subgrade. Tracks whose initial construction entailed the compaction of subgrade to adequate strength levels or whose routing entirely avoided locations having troublesome fine-grained, moisture-laden soils should be completely free from intrusion. Sections with a ballast depth which insures pressure distributions to within the bearing capacity of the subgrade and uniform subgrade pressures might also be spared this plight. Others, where inadequate maintenance or other causes have led to poor drainage and marked track irregularities, will probably experience accelerated intrusion due to the wet subgrade conditions and dramatic pounding actions which ensue. One would do well to remember, however, that both the nature and the volume of the material entering the ballast section determine the ramifications of this intrusion, with substances bearing highly plastic properties delivering the greatest damage.

Fouling materials may also be generated from within the ballast section itself. Deterioration of the ballast material, at least to some degree, will result from the climatic and loading environment in which the ballast is placed. The severity of the phenomenon for given conditions will vary among ballasts. Some types may be particularly resistant to climatically-imposed decay, especially that manifested under freeze-thaw conditions. The same material, or others, may be able to withstand the dynamic forces and intergranular rubbing accompanying loadings imposed by moving trains. These latter effects may be accelerated by the prevalence of heavy wheel loads or by an inadequate or poorly maintained track structure which delivers greater shock to the ballast bed. The influence of both the traffic and climatic factors will be magnified if particle breakage and fouling lead to cementing (which increases loading impact) and to water retention. Only those ballasts whose degradation produces plastic, cementitious fines seriously threaten the quality of the track support conditions.

There are several methods by which ballast can be used to deal with deterioration. The choice of methods affects the overall economics of ballast. If the problem is treated by the heavy raises (the cost of which is relatively low) these actions must be performed relatively frequently. If, on the other hand, one has implemented programs to correct the field ballast condition rather than cover it (such as ballast cleaning or track undercutting, see Chapter 4), decreased frequencies of ballast renewal will result. Adoption of this latter policy, then, may provide overall greater economy even though the individual operations may be somewhat more costly to perform.

COST PER TRACK FOOT OF A MAJOR RENEWAL

The primary factor influencing the cost per track foot of a major renewal is the specific type of operation performed. Each incurs a certain set of expenses related to the particulars of the process and to the need for and the costs of purchase, transportation and unloading of replacement ballast. Within each type of operation, however, such factors as labor and machine arrangement, wage scales, availability of on-track time and so on assert an influence on cost.

The standard renewal operation for many railroads is a simple heavy raise (six inches or more), a process which is thought to provide adequate relief if the fouling of the existing ballast is not too severe. Essentially, the procedure entails a sequence of smaller raises, performed either in rapid succession or with some traffic and time (as much as a year) intervening. Obviously, each light raise is similar to a lining and surfacing operation. This similarity suggests that the cost of a heavy raise is approximately a multiple of the cost of a lining and surfacing exercise.

An obvious exception arises in those instances where an under track-raising sled has been used to lift the track. The device, a locomotive-drawn or tractor-pulled framework whose upper surface raises the ties from below, incorporates fallen crib material into a smooth, newly-prepared roadbed upon which the track comes to rest. The sled is usually about 6-8 inches in depth. Greater depths can be had by re-sledding. No ballast is removed from the track structure in this procedure. Subsequent ballast unloading, tamping, and lining operations complete the job. It should be noted that this is not yet a commonly practiced procedure.

Some railroads take exception to heavy raises on a number of grounds. One is that the higher grade line produced will further constrict the clearances in tunnels, underpasses, etc. Others cite that the procedures provide inadequate treatment of badly fouled conditions or the possibility that the ballast bed disruption associated with the operation will reduce lateral restraint below adequate levels, particularly on track containing continuously welded rail because the new ballast particles will not be completely interlocked or bedded. When for any of these or other reasons it is the opinion of the railroad that a heavy raise is not appropriate, removal of the effected ballast must be undertaken by "surface treating" (cribbing, shoulder removal, etc.), plowing, or undercutting methodologies.

"Surface treatments" may be thought of as halfway measures which alleviate some distress by providing more adequate ballast section drainage. Cribbing operations, for instance, involves the removal of the fouled ballast material between the ties and replacing it with clean ballast. Drainage at the top of the section is improved and moisture flows away from around the ties.

To completely reverse deteriorated ballast conditions, however, the entire ballast bed should be removed and any subgrade problems corrected. The benefits to be derived may be expected to increase as the extent of removal increases, although the relationship is not well established and the effects of dirty ballast left in place are not fully understood.

One procedure for ballast removal employs an undercutting machine. In its most common form, this equipment utilizes a continuous chain of cutting teeth or scoops to excavate and remove the material from the undertrack space. Adjustments permit the depth of the cut thus effected to be altered within about 12 to 30 in. limits. This machine sometimes is combined with ballast cleaning capability. Another method of undercutting involves a plowing type operation in which the ballast bed is broken up with a locomotive-drawn or tractor-driven undertrack plow. Continuous chains may be used to remove the ballast material from under the ties. This machine usually does not have the ability to clean the removed ballast. With each pass of this machine 12" of ballast bed is removed.

The cost of any of the foregoing operations is a function of numerous factors, a principal one being the amount of material extraction involved, see Chapter 4. Indeed, the greater the extent of a given operation's removal procedures, the more significant is the reduction in its output per unit time. Of course, the condition of the ballast to be removed is a critical factor in any operation's output, with badly fouled and cemented ballast being quite detrimental. When to remove ballast is often a subjective decision guided by the difficulty in maintaining line and surface, pumping, mud-spattered track, ride quality and an approximate renewal cycle varying from 8 to 10 years on mainlines, 10 to 20 years on branch lines. It should be noted that the greater productivity of a specific type of operation does not necessarily translate into unit cost economies as the larger output may be accompanied by considerably higher capital and labor demands.

Another determinant of renewal cost is the depth of clean ballast to be placed. Besides its obvious influence on the expenditure for the purchase, transportation and unloading of replacement ballast, this factor controls the number of individual raising, tamping and lining runs required to properly consolidate the new ballast bed. Significantly, the importance of the initial cost of new material is lessened if any extracted material is cleaned and replaced, rather than discarded. This latter operation is economically practical where much of the ballast in the section is essentially sound and can be returned to the track.

Chapter 4

QUANTIFICATION OF BALLAST COST FACTORS

GENERAL

The last chapter demonstrated that the total cost of ballast is primarily a function of two general factors: the inherent characteristics of a ballast type (its stability, durability, weight, etc.), and the specifics of a railroad's maintenance practices. Significantly, both of these factors are within the control of railroad managers.

In order to establish an adequate data base a review of current literature was undertaken. The data base was further enhanced by a Survey which was sent to 70 railroads from which 28 replies were received.* Survey solicated specific replies on ballast materials used (type, weight, cost, etc.) and maintenance practices (methodologies, costs, cycle length, etc.). The data base enabled a limited quantification of the factors affecting overall ballast cost, which are presented in this and following chapters.

PURCHASE PRICE

Purchase price is largely independent of railroad maintenance practices, but might be thought directly related to ballast material type. Material type is a function of the ballast's origin (extractive or waste produce processes), the difficulty in its production and the substance's marketability for other tasks. However, the responses of the numerous railroads indicated that no discernible purchase price differences existed among ballast types (see Table 4.1) with statistical analysis showing

*See Appendix for a description of responding railroads.

TABLE 4.1. SUMMARY OF BALLAST PURCHASE PRICE DATA (1975)

Material Type	Number of Railroads Purchasing this Material	Range in Price ($ per Cubic Yard)	Average Price ($ per Cubic Yard)
Limestone	18	1.02 - 3.35	2.31
Granite	15	1.54 - 3.25	2.36
Blast Furnace and Open Hearth Slags	9	1.65 - 3.00	2.16
All Other Ballasts	16	0.70 - 3.78	2.40

Simple Mean Purchase Price = $2.33 per Cubic Yard

Mean Purchase Price -- Weighted by Quantity Purchased = $2.40 per Cubic Yard

Source: Survey

equality in the quoted costs of three materials -- granite, limestone, and slag -- at a 95% confidence level. It should be remembered, however, that this is viewed from the national perspective and that the practices of the actual sources available to an individual railroad within a limited geographical area, will establish the costs of the materials delivered.

Purchase price variations also might be expected to accompany differences in ballast gradation, as this latter parameter may influence the amount of material processing needed. Unfortunately, insufficient data are available to verify or discount this relationship.

TRANSPORTATION COST

Many railroads cite a ballast's availability as a significant consideration in ballast selection. This term reflects, in effect, the lengths of on-line and, more importantly, off-line hauls (if any) involved in the delivery of a specific material to its point of placement. Yet, in spite of this apparent preoccupation with transit costs, survey responses indicate that few railroads have quantified even the simple charges for on-line movements and fewer still assign such costs to their maintenance budgets. Given these circumstances, a railroad's avoidance of off-line sources is easily understood, for transport costs, as the railroad views them, would jump from zero to some finite amount if an off-line source were tapped. This situation can be rectified only when a railroad fully comprehends the magnitudes of home road and foreign road rates and charges both to the maintenance account.

Table 4.2 classifies the transportation costs reported by the survey respondents and compares these costs with information on the transport costs of construction aggregates[9], a ballast-like material. Because of the limited number of railroads reporting costs of revenue ballast movements it is impossible to draw any definitive conclusions on the comparative costs of the various methods of ballast transport.

The method of conveying the ballast cars from source to point of placement, as previously discussed, is also a major factor in the overall cost of ballast. Because of the greater car utilization associated with unit trains, ballast movement by unit trains could be expected to be somewhat lower than the cost of operation of ballast cars in conventional trains. Table 4.3 summarizes cost data and operational details provided by three western railroads with ballast unit train experience. Exhibit 4.1 presents similar data based on information extracted from a ballast study of a fourth railroad.[10] Note that these costs are generally lower than those quoted for ballast transport by conventional trains presented in Table 4.2. Although the economics of ballast unit trains are attractive, it must be emphasized that in order to realize these economics the railroad must have a sizable number of cars suited to ballast traffic and must be able to dependably unload the train (of fifty or sixty cars) within a reasonable period of time (one to two days). If the ballast cars cannot be unloaded rapidly, the level of car utilization will begin to approach that of ballast cars moved in conventional trains.

Unlike on-line charges, off-line ballast movement rates come under the jurisdiction of the Interstate Commerce Commission. Table 4.4 summarizes the information provided by survey respondents.
Because of the limited number of replies to this portion of the

TABLE 4.2. SUMMARY OF BALLAST TRANSPORT COST FOR ASSIGNED AND REVENUE CARS

Method of Transportation	From Survey: Cost of Ballast Transport ($ per Cubic Yard per Mile)	From Survey: Average Cost ($ per Cubic Yard per Mile)	From a Study of Construction Aggregate Transportation Costs (9): Equations[a] for Cost of Construction Aggregate Transport by Similar Method ($ per Cubic Yard)	From a Study of Construction Aggregate Transportation Costs (9): Average Cost ($ per Cubic Yard)
Blocks of cars assigned to ballast service are shuttled between ballast source and yard near point of usage by revenue train	Railroad A - 0.008 Railroad D - 0.005 Railroad E - 0.00837 Railroad M - 0.009 Railroad P - 0.010 Railroad R - 0.0118 Railroad W - 0.01052	0.009	Northeast Cost = 0.83 + 0.0056 x miles Southeast Cost = 0.89 + 0.0052 x miles Central Cost = 0.75 + 0.0052 x miles Western Cost = 0.88 + 0.0050 x miles	0.81 + 0.005 x miles
Blocks of cars normally in revenue service are loaded at ballast source and transported by revenue train to yard near point of usage; when empty, cars are released to general revenue service	Railroad R - 0.0081	0.0081	No information available	

[a]Equations are derived from IIC Rail Form A Cost Data for 1970 adjusted for regional conditions; costs are for movement of 2500 pound per cubic yard material in block of ten cars of approximately 70 ton capacity.

TABLE 4.3. SUMMARY OF TRANSPORTATION COST DATA FOR UNIT TRAIN MOVEMENTS

Railroad	Details of Unit Train	Cost of Ballast Transport ($ per Cubic Yard per Mile)
H	50 cars of 50 cubic yard capacity	0.0077
R	70 cars of 56 and 80 cubic yard capacity	0.0092
Z	60 to 65 cars of 68 cubic yard capacity	0.004

Simple Mean Transportation Cost for Unit Trains = $0.007 per Cubic Yard per Mile

Source: Survey

EXHIBIT 4.1. ANALYSIS OF TRANSPORTATION COST DATA FOR A UNIT TRAIN MOVEMENT

Assumptions:

50 car unit train

New cars of 85 tons capacity and 115 ton gross; for average ballast density of 2500 pounds per cubic yard, car will hold 68 cubic yards

Uninterrupted eight hour unloading time

New ballast car costs $25,000; daily ownership costs are $9.00 (based on 15 year life and 10% interest)

Two diesels are needed for ballast train; daily ownership costs are $288 (based on $400,000 each, 15 year life and 10% interest)

Cost of Movement:

Assume 30 mph average speed (= 0.033 hours per mile)

Cost for caboose miles, crew wages, diesel unit operation, train control

$\frac{\$4.50^{(a)}}{\text{train mile}} \times \frac{\text{1 train mile}}{\text{50 car miles}} \times \frac{\text{1 car}}{\text{68 cu.yd.}} =$ $0.001323 per cu.yd.per mile

Cost for car repairs

$\frac{\$0.0425^{(a)}}{\text{car mile}} \times \frac{\text{1 car}}{\text{68 cu.yd.}} =$ $0.000625 per cu.yd.per mile

Cost for maintenance of way and fuel

$\frac{\$0.0011^{(a)}}{\text{gross ton mile}} \times \frac{\text{115 gross tons}}{\text{car}} \times \frac{\text{1 car}}{\text{68 cu.yd.}} =$ $0.001860 per cu.yd.per mile

EXHIBIT 4.1. (Continued)

Cost of time

Diesel unit ownership

$$\frac{\$288}{\text{day}} \times \frac{1 \text{ day}}{24 \text{ hours}} \times \frac{0.033 \text{ hours}}{\text{mile}} \times \frac{1 \text{ car}}{68 \text{ cu.yd.}} \times \frac{1}{50 \text{ cars}} =$$ $0.000118 per cu.yd.per mile

Car ownership

$$\frac{\$9.00}{\text{day}} \times \frac{1 \text{ day}}{24 \text{ hours}} \times \frac{0.033 \text{ hours}}{\text{miles}} \times \frac{1 \text{ car}}{68 \text{ cu.yd.}} =$$ $0.000182 per cu.yd.per mile

Cost of Empty Backhaul:

Cost for caboose miles, crew wages, diesel unit operation, train control

(Same as before) $0.001323 per cu.yd.per mile

Cost for car repairs

(Same as before) $0.000625 per cu.yd.per mile

Cost of maintenance of way and fuel

$$\frac{\$0.0011^{(a)}}{\text{gross ton mile}} \times \frac{30 \text{ gross tons (empty)}}{\text{car}} \times \frac{1 \text{ car}}{68 \text{ cu.yd.}} =$$ $0.000485 per cu.yd.per mile

Cost of time

Diesel unit ownership

(Same as before) $0.000118 per cu.yd.per mile

Car ownership

(Same as before) $0.000182 per cu.yd.per mile

Total Cost = $0.0068 per cu.yd.per mile

[a] Data from Canadian National Railway Ballast Study (10)

TABLE 4.4. SUMMARY OF TRANSPORTATION RATE DATA FOR OFF-LINE MOVEMENTS

	From Survey		From a Study of Construction Aggregate Transportation Cost[9]
Region	Railroad	Rates for Movement of Foreign Line Ballast ($ per cu.yd.per mile[b])	Equations[a] for Rates for Movement of Construction Aggregates ($ per cu.yd.[b])
Northeast	B	0.0456	Rate = 0.75 + 0.0195 x miles
	D	0.079	
	Q	0.088	
Southeast	J	0.039	Rate = 1.07 + 0.0085 x miles
	V	0.0156	
Central	E	0.0494	Rate = 1.21 + 0.0110 x miles
	M	0.0156	
West	W	0.03	Rate equation is nonlinear
	Z	0.0243	
		Simple Mean Transportation Rate ($ per cu.yd.)per mile = 0.044	Simple Mean Transportation Rate Equation ($ per cu.yd.)= 1.01 + 0.0130 x miles

[a]Equations are derived from rate data provided by survey of construction aggregate rail shipping; rates are for single car movements.

[b]Based on ballast weighing 2500 pounds per cubic yard.

survey and because of the similarity between ballast and construction aggregates and other bulk crushed stone products, the information on the transit rates of aggregates was used to augment this data.[9] Table 4.5 compares on and off-line costs for various lengths of haul based on both questionnaire responses and transit rates of aggregates. In spite of the diversity of rates quoted by the railroads, the average rate is 5 times greater than those quoted for on-line ballast movement in conventional trains.

While it is obvious that a change in density effects a directly proportional change in the number of cars needed, the manner in which this change is translated into increased or decreased transport costs is not apparent. Indeed, since a large portion of these costs are independent of the size of the block moved, any change in the number of cars would produce less than a proportional change in the transportation charges. For simplicity's sake and in the absence of definitive information on the subject, a linear relationship may be assumed to exist between car quantities and transportation costs, and therefore, by extrapolation, between ballast density and transit charges. This suggests the following relationship:

$$\frac{\text{density of given material}}{\text{mean density of all ballasts}} = \frac{\text{transport cost of given material}}{\text{mean transport cost of all ballasts}}$$

Table 4.6 reports the mean density of various ballasts as derived from the responses to the survey and specifies the costs of each material's transportation relative to the average transit charges for ballast as a whole. Unfortunately, the available data have not permitted the analysis of all material types and gradations in common railroad use,

TABLE 4.5 COMPARISON OF TRANSPORTATION COSTS AS CALCULATED BY THE VARIOUS METHODS

Distance (Miles)	Method	On-Line Transport in Revenue Train ($ per cubic yard)	Off-Line Transport in Revenue Train ($ per cubic yard)
50	Survey	0.45[a]	2.20[a]
	Aggregate Transport	1.07[b]	1.66[b]
100	Survey	0.90[a]	4.40[a]
	Aggregate Transport	1.34[b]	2.31[b]
150	Survey	1.35[a]	6.60[a]
	Aggregate Transport	1.61[b]	2.96[b]
200	Survey	1.80[a]	8.80[a]
	Aggregate Transport	1.88[b]	3.61[b]

[a]Based on a simple mean of survey responses.

[b]Based on Rail Form A Costs for 1970.

TABLE 4.6 RELATIVE TRANSPORTATION COSTS OF VARIOUS BALLAST MATERIALS

Ballast Type	Simple Mean Unit Weight[a] (Pounds per Cubic Yard)	Transport Cost Relative to Mean Transport Cost
All ballasts in survey	2512	1.00
Limestone	2487	0.99
Granite	2457	0.98
Blast Furnace and Open Hearth Slags	2311	0.92

[a]Determined from survey data.

but do indicate that limestone and granite should incur costs nearly equal to the average level while blast furnace and open hearth slags should record somewhat lower values because of their lower densities, as much as 8% as shown in Table 4.6.

UNLOADING COST

The specifics of a ballast unloading operation reflect the ballasting policies of individual railroads and the circumstances peculiar to each situation. Because total cost and total output tend to differ among operations, the cost per cubic yard will vary widely and become, at times, significant element of the total ballast cost.

Most of the railroads responding to the survey reported the use of work trains for all ballast unloading exercises. The costs assigned to this activity varied markedly among the roads, indicating that many failed to assess all of the appropriate elements. Yet, careful scrutiny of these data, followed by adjustments where necessary, produced fair agreement among the fully realized costs (see Table 4.7), and brought these data in line with charges determined from reasonable, and it is hoped, representative, costs and conditions (see Exhibit 4.2). While concurrence among these data is quite good, a somewhat more pronounced diversity may be expected in general, as costs will vary due to differences in wage rates, locomotive assignments, and other factors.

A few respondents to the survey, and the majority of lines replying to an AREA committee's study, reported their preference for ballast delivery by local or through revenue trains. However, as only one road quoted the cost incurred in such an operation, specific conclusions may not be drawn. It is interesting to note, though, that the available data support the belief that this method may produce some economics, particularly when several cars are to be unloaded.

TABLE 4.7 SUMMARY OF WORK TRAIN COST DATA

Railroad	Is Work Train Used?	Work Train Cost
A	For Projects Involving More than ten cars	
B	Yes	
C	Yes	$560 per 10-hour day
D	Yes	$400 per 8-hour day
E	Yes	$425 per 8-hour day
F	Yes	
G	Yes	$400 per 8-hour day
I	Yes	
J	No	
L	Yes	
N	Yes	
O	Yes	
P	Yes	
Q	Yes	
R	For Projects Involving More than three cars	
S	Yes	
T	Yes	
U	Yes	$450 per 8-hour day
V	Yes	$485 per 10-hour day
W	Work Train 40% of Time; Local Train 60% of Time	
Y	Either Work Train or Local Train	
Z	Yes	

Simple Mean Work Train Cost per 8-hour day = $418 (based on the 4 8-hour reports)

Simple Mean Work Train Cost per 8-hour day = $418 (based on all reports adjusted to 8-hour days)

Simple Mean Work Train Cost per 10-hour day = $522 (based on the 2 10-hour reports)

Simple Mean Work Train Cost per 10-hour day = $523 (based on all reports adjusted to 10-hour days)

Simple Mean Work Train Cost per Hour (Approximately) = $52

EXHIBIT 4.2 ANALYSIS OF WORK TRAIN COST DATA

Assumption:

4 man crew of 1 local engineer, 1 local conductor and 2 local brakemen

35 arbitraries

8-hour work period and 12-hour use of locomotive (includes time for refueling, servicing, etc.)

Daily ownership cost of diesel unit is $144 (based on $400,000 each, 15 year life and 10% interest)

Cost of diesel unit work is $8.50 per hour[a]

For Normal Work Train With One Diesel Unit:

Crew costs:

1 local engineer 1 x $7.36 per hour[b]		$ 7.36 per hour
1 local conductor 1 x $6.35 per hour[b]	=	$ 6.35 per hour
1 local brake men 2 x $5.76 per hour[b]	=	$11.52 per hour
		$25.23 per hour

Daily cost for 8-hour day and 35% arbitraries = $272.50 per day

Cost of diesel unit work:

1 unit x $8.50 per unit hour x 8 hours per day = $68.00 per day

Cost of diesel unit ownership:

1 unit x $144 per unit day x 0.5 day	$72.00 per day
Cost of caboose	$10,00 per day
Total Cost	$422.50 per day

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[a]Data from Canadian National Railway Ballast Study[(10)]

[b]Data from Association of American Railroads Statistical Summary for 1974[(1)]

EXHIBIT 4.2 (Continued)

<u>For Special Work Train With Two Diesel Units</u>: (Needed to unload Unit Ballast Train Having Many Cars)

Crew Costs	
Approximately same as before	$272.50 per day
Cost of diesel unit work	
2 units x $8.50 per unit hour x 8 hours per day	$136.00 per day
2 units x $144 per unit day x 0.5 day	$144.00 per day
Cost of caboose	
1 caboose x $10 per day	$ 10.00 per day
	$562.50 per day

Aside from demands for work train or revenue train use, unloading operations require the services of a supervisor and an unloading crew and occupy the time of cars in ballast service. Related costs have been derived from survey responses augmented by reasonable assumptions and are reported in Table 4.8 and Exhibit 4.3.

The cost per cubic yard of any given ballast handling procedure is primarily a function of daily output. This parameter, which is simply the product of the number and the capacity of the cars unloaded, varies greatly, as Table 4.9 indicates, largely because of differences in the length of the working period, the amount of train interference and the details of car design. Because of the wide fluctuations in output, any attempt to quantify and compare unloading costs must be based on average costs and outputs. Exhibit 4.4 illustrates the data derived in this manner and permits comparison of the unloading costs associated with three distinct ballast handling methods: road haul by revenue train -- unloading by work train; road haul by unit train -- unloading by work train; road haul by revenue train -- unloading by revenue train. Note the wide divergence in costs among the different procedures.

Although operational considerations are the primary determinants of unloading cost, one characteristic of a ballast material might also be expected to exert significant influences. In a previously circulated AREA survey (3) the few respondents stating that differences existed, cited the influence of fines on the unloading rate, but this factor is of little practical importance today as nearly all ballast materials, with the exception of pit run gravels, are processed to eliminate fine fractions.

TABLE 4.8 SUMMARY OF COST DATA FOR UNLOADING CREW

Railroad	Crew Size Foremen	Crew Size Laborers	Wages Including Arbitraries ($ per 8-Hour Day)
C	1	4	232
D	1	4	375
E	1	4	282
F	1	4	250
G	1	7	
I	1	6	
L	1	5	
N	1	5	
O	1	5	
P	1	3 or 4	
Q	1	8	
R	1	7[a]	480
T	1	4	
U	1	6	429
V	1	6	411
W	1	2 or 4	
Z	1	10[a]	

Simple Mean Unloading Crew Wages for 8-Hour Day:

From Survey

For 1 foreman and 4 laborers = $285

For 1 foreman and 6 laborers = $420

From Association of American Railroad Statistical Summary for 1974(1)

For 1 foreman and 4 laborers = $255[b]

For 1 foreman and 6 laborers = $355[b]

[a]Unloads unit train

[b]Includes 35% arbitraries

EXHIBIT 4.3 ANALYSIS OF COST DATA FOR SUPERVISION AND CAR TIME

Supervision

Assumption:

Each unloading operation requires approximately one-half day of a track supervisor's time

35% arbitraries

Cost:

Using wages from Association of American Railroads Statistics[1], supervisory costs total:

$7.00 per hour x 4 hours x 1.35 = $37.80 per unloading operation

Car Time

Based on Capital Cost:

Assuming a 10% annual interest rate and an economic life of 15 years, the daily capital cost of a hopper is:

$5.40 for a car costing $15,000 new

$7.20 for a car costing $20,000 new

$10.80 for a car costing $30,000 new

Based on Per Diem Rates:

Sample per diem rates given by a midwestern railroad are as follows:

Equipment Type	Per Diem Rate ($ per day)	Mileage Rate ($ per mile)
200,000 lb capacity hopper - 7 yrs old	$4.62	0.0271
166,000 lb capacity hopper - 7 yrs old	4.08	0.0271
166,000 lb capacity hopper - 10 yrs old	3.57	0.0271
166,000 lb capacity hopper - 15 yrs old	2.76	0.0227
154,000 lb capacity hopper - 10 yrs old	2.76	0.0256
154,000 lb capacity hopper - 15 yrs old	2.34	0.0227

TABLE 4.9 SUMMARY OF OUTPUT DATA FOR UNLOADING OPERATIONS

For Work Train Unloading Blocks of Cars Hauled by Revenue Train

Railroad	Simple Mean Daily Unloading Rate[a] (cars)	Simple Mean Car Capacity (cubic yards)	Simple Mean Daily Output[a] (cubic yards)
B	10	55	550
C	16[b]	65	1024
D	9	56	504
E	15	55	825
F	12	72	864
G	26	80	2080
I	10	32	320
P	22	50	1100
O	30	40	1200
S	25	40	1000
U	15	50	750
V	20	56	1120

Simple Mean Daily Unloading Rate[a] = 18 cars

Simple Mean Car Capacity = 54 cubic yards

Simple Mean Daily Output[a] = 970 cubic yards

For Work Train Unloading Large Blocks of Cars Hauled by Unit Train

Railroad	Simple Mean Daily Unloading Rate[a] (cars)	Simple Mean Car Capacity (cubic yards)	Simple Mean Daily Output[a] (cubic yards)
H	50	50	2500
R	40	68	2720
Z	47[c]	68	3195

Simple Mean Daily Unloading Rate[a] = 46 cars

Simple Mean Car Capacity - 64 cubic yards

Simple Mean Daily Output[a] = 2850 cubic yards

[a]Per 8 hour day

[b]20 cars unloaded in 10 hours

[c]62 cars unloaded in 10-1/2 hours

EXHIBIT 4.4 SUMMARY OF UNLOADING COST FOR DATA
THREE BALLAST HANDLING METHODS

Road Haul by Revenue Train - Unloading by Work Train

Assume work train use for 8 hour day (Table 4.7)	$425
Assume an unloading crew of 1 foreman and 4 laborers (Table 4.8)	$255
Assume one half day of track supervisor's time (Exhibit 4.3)	$ 38
Assume average output of 18 cars (Table 4.9)	
Assume cars are rather old, cost $15,000 when new, and have a capacity of 54 cubic yards each (approximately 140,000 lb) at $5.40 per car per day (Exhibit 4.3), the 18 cars cost $97	$ 97
Total Cost per Day	$815

Total output per day is 970 cubic yards.

Cost per cubic yard is $815/970 = $0.84

Road Haul by Unit Train - Unloading by Special Work Train (2 Diesel Units)

Assume work train use for 8 hour day (Exhibit 4.2)	$565
Assume an unloading crew of 1 foreman and 6 laborers (Table 4.8)	$355
Assume one half day of track supervisor's time (Exhibit 4.3)	$ 40
Assume average output of 46 cars (Table 4.9)	
Assume cars are new, cost $25,000, and have a capacity of 64 cubic yards each (approximately 160,000 lb) at $9.00 per car per day (Exhibit 4.3) the 46 cars cost $414	$414
Total Cost per Day	$1374

Total output per day is 2944 cubic yards

Cost per cubic yars is $1374/2944 - $0.47

Road Haul by Revenue Train - Unloading by Revenue Train

The respondent quoting the cost for this method provided a figure of $0.18 per cubic yard.

The second effect which ballast type may bear on unloading costs is related to its influence on ballast unit weight. The latter factor, of course, affects the number of cars unloaded in the placement of a given ballast volume. This, in turn, influences unloading costs, because certain labor activities accompany the preparation and unlatching of each car independent of the volume it contains. It follows that unloading cost economies may be achieved by adoption of ballast materials of lower densities, for these minimize the number of cars to be unloaded. However, present information is not sufficient to permit quantification of this influence. Neither does present state of the art permit evaluating the in-track performance of a low density ballast on that basis alone.

COST OF SPOTTING WORK

Spotting operations are performed principally to correct the relatively minor flaws in track geometry resulting from local instabilities in the track system. These faults derive primarily from weak subgrade, improperly compacted ballast and poorly maintained joints and ties. However, ballast type is implicated to some degree, for different materials may exhibit different abilities to stand up under the shock imposed by traffic -- particularly the impact delivered at rail joints. Unfortunately, spotting practices are so widely variant (respondents reported a range from a daily to a biennial frequency) that neither the operations' costs nor the relative performance of various ballasts can be determined at this time. Spotting work may be one of many tasks assigned to a housekeeping or section gang. The time spent can range from a few hours per week (64 man hours per week, 3328 man hours per year) to the operation of a full time 8-10 man spotting gang. Since much of the effort is spent in tamping joint ties, the use of CWR will reduce this operation and costs in the approximate ratio of 8 to 270. The more stable ballasts and subgrades require the least amount of tamping. No satisfactory system has been devised to keep a record of spotting costs, much less to apportion those costs to a particular ballast material. One recent study[6] found maintenance of way house keeping costs per track mile (in 1974 dollars) equal to:

Single Track: 765 + 28G

Double Track: 645 + 24G

where G is the annual gross tonnage in millions.

Spotting operations also encompass the occasional shimming activities required for frost-heavy track. Shimming costs are a function of the extent of frost heaving along the track and the thickness of shims being applied. Cost factors are materials used (shims) and man hours. Such costs are indeterminate. Although fine-grained moisture-retaining subgrade soils are the most frequent causes of the distress, frost-heaved conditions may also stem from fouled, poorly-drained ballast beds. Obviously any ballast whose degradation jeopardizes drainage and facilitates cementing may contribute to the dilemma. However, it should be noted that there proved to be little difference in degradation characteristics among the materials tested in the current project, and only one type -- limestone -- produced fines of a plastic nature.[8]

COST PER TRACK FOOT OF A LINING AND SURFACING OPERATION

The cost per unit of output of a lining and surfacing operation is very strongly linked to the manner in which that operation is performed. Survey replies indicated a great variety in surfacing practices among the responding railroads and a diversity in conditions at the work site (see Table 4.10). The task of constructing a unit cost is further complicated by the varying nature of the constituent costs. Overall cost is the sum of labor cost and machinery's capital and operating costs. Since each of these is assessed on a different time basis, conversion to a common base is necessary.

Labor cost is simply the crews hourly wage (direct pay and arbitraries). The magnitude of this cost is determined by the make-up of the surfacing gang and hourly wages for the various groups in that gang. Table 4.10 illustrates the great diversity in gang organization found in the responding railroads.

The capital cost of equipment is usually assigned on a daily basis. Since each machine type has its own capital costs associated with it, the number and type of machines used in the operation is the major factor in capital costs. Again responding railroads indicated a great diversity in the equipment organization (see Table 4.10). Of course each machine's daily capital cost is a function of the annual depreciation charge. This annual charge is based on the equipment purchase price, expected life of the machine and the financing arrangements. The daily capital charge is simply the annual cost divided by the number of working days per year, this relating the length of the work season to the resultant cost.

TABLE 4.10 SUMMARY OF DATA FOR LINING AND SURFACING OPERATIONS

Equipment Used	Railroad	Foremen	Operators	Laborers	Cost ($) per Productive Hour	Ties Raised	Ties Tamped	Number of Tamping Head Insertions Per Tie	Output (ft.) Per Productive Hour
Tamper, Liner and Ballast Regulator	F	2	3	1	N.A.	All	All	3	763
	Q	2	3	3	N.A.	All	All	N.A.	583
	W	1	3	2	179	All	All	2	800
	W	1	3	2	179	All	All	1	600
Tamper, Liner and 2 Ballast Regulators	D	1	4	1	200	All	All	1	640
	D	1	4	1	65	All	All	1	570
	R	1	4	2	218	All	All	2	900
	R	1	4	2	97	All	All	2	900
Mean of Above					190				720
Tamper, Liner, Tandem Tamper and Ballast Regulator	F	1	4	2	N.A.	All	All	2	1048
	W	1	4	2	N.A.	All	All	2	500
Tamper-Liner	E	1	1	4	N.A.	All	All	3	775
Tamper-Liner, Tandem Tamper and 2 Ballast Regulators	C	1	2	2	142	All	All	1.5	900
	E	1	2	5	N.A.	All	All	3	677
	F	1	2	3	N.A.	All	All	2	632
	J	1	2	1	101	All	All	2	586
	M	1	2	3	150	All	All	1	600
	V	2	2	4	148	All	All	1	726
	V	1	2	1	N.A.	All	All	1	475
Mean of Above					135				657
Tamper-Liner Tandem Tamper and Ballast Regulator	H	1	3	2	N.A.	Even	Odd	2	910
	S	1	3	2	210	Even	Odd	2	993
	S	1	3	2	191	Even	Odd	2	910
Mean of Above					200				938
Tamper-Liner Tandem Tamper and 2 Ballast Regulators	O	2	4	2	N.A.	All	All	2	1200

Machine operating cost, which consists primarily of the charge for fuel, supplies, and machine maintenance is largely a function of the number of productive hours worked. Of course, operating costs also vary with the number, type and age of the equipment in use.

In order to provide a common base for these costs the format chosen was cost per productive hour. This cost is determined by:

Cost per Productive Hour = L + C + O

where:

$$L = \text{hourly labor costs} = \frac{\text{hourly wages x number of hours per working day}}{\text{number of productive hours per working day}}$$

$$C = \text{capital costs} = \frac{\text{daily capital charge}}{\text{number of productive hours per working day}}$$

O = operating cost per productive hour

Productive hour costs as given by survey respondents are shown in Table 4.10. Note the wide fluctuations reflecting the differences in labor and machine usage, available track time etc. Fortunately, three of the responding railroads provided detailed information for two specific machine organizations working approximately four productive hours per day. These costs, adjusted where necessary to place them in the desired form, appear in Exhibit 4.5.

The cost per unit of production is basic to any economic model. Thus, the output of lining and surfacing operations is necessary input to that model. One of the major items affecting production rates is the thoroughness of the procedure. This factor reflects the percentage of ties which are raised and the number of tamping insertions made for each of these ties. As Table 4.10 indicates, most railroads raise and tamp every tie, but

EXHIBIT 4.5 SUMMARY OF DETAILED COST DATA FOR LINING AND SURFACING OPERATIONS

All figures presented assume approximately four productive hours per eight hour day.

Railroad C:

Machinery employed - 1 Tamper-liner, 1 Ballast Regulator

Labor employed - 1 Foreman, 2 Operators, 2 Laborers

Cost per productive hour:	
For labor	$ 68
For supervision	10
For fuel, supplies & machine capital and maintenance cost	64
Total cost per productive hour	$142

Railroad J:

Machinery employed - 1 Tamper-liner, 1 Ballast Regulator

Labor employed - 1 Foreman, 2 Operators, 1 Laborer

Cost per productive hour:	
For labor	$ 56
For supervision	10
For fuel and supplies	3
For machine capital cost	15
For machine maintenance cost	17
Total cost per productive hour	$101

Railroad W:

Machinery employed - 1 Tamper, 1 Liner, 1 Ballast Regulator

Labor employed - 1 Foreman, 3 Operators, 2 Laborers

Cost per productive hour:	
For labor	$101
For supervision	7
For fuel and supplies	6
For machine capital and maintenance cost	64
Total cost per productive hour	$178

adjust insertions to reflect local conditions. Although logic would suggest that thoroughness is inversely related to output, there appears to be no consistant tendencies between the two elements.

Another major influence on output is the organization of labor and equipment. Of these factors, machine assignment appears to be the more important. As indicated in Table 4.10, there are significant differences in output associated with machine deployment.

From the data summarized in Table 4.10 a representative cost per track foot of a lining and surfacing operation may be determined. These representative values are presented in the upper portion of Table 4.11. However, because of the wide diversity of responses from which these numbers were obtained, they should be considered only reasonable approximations of the true costs. The figures obtained from the detailed cost estimates presented in Exhibit 4.5 are presented in the bottom of Table 4.11. Because of the more exact nature of these figures, somewhat greater confidence may be accorded them, although they are faulted by their small sample size.

Any ballast characteristic which affects the effort necessary to adequately compact that material will also affect lining and surfacing output. Although it would be highly desirable to directly relate ballast type with the number and duration of tamping head insertions needed, the information available depends upon the experience of track maintenance personnel as reported in the survey and two earlier questionnaires[2,3]. While views varied, few respondents noticed significant differences in lining and surfacing ease by material types. Opinions concerning the influence of ballast gradation, however, were more diverse. Several

TABLE 4.11. SUMMARY OF COST DATA FOR LINING AND SURFACING OPERATIONS

Machine Organization	Mean Cost ($) per Productive Hour	Mean Output (ft) per Productive Hour	Mean Cost ($) per Track Foot	Mean Cost ($) per Track Mile
<u>From Data of Table 4.10</u>				
Tamper, Liner and one or more ballast regulators	190	720	0.26	1372.80
Tamper-Liner and one ballast regulator	135	657	0.21	1108.80
Tamper-Liner, tandem tamper, and one ballast regulator	200	938	0.21	1108.80
<u>From Data of Exhibit 4.5</u>				
Tamper, Liner and one ballast regulator	178	700	0.25	1320.00
Tamper-Liner and one ballast regulator	122	743	0.16	844.80

individuals reported lower production on coarser materials. They suggested that the outputs on AREA #24 (2.5 in - 0.75 in nominal, 63.5 mm - 19.0 mm) might be as much as 15 to 25% lower than on AREA #5 (1.0 in - 0.375 in nominal, 25.4 mm - 9.5 mm). A few respondents also stated that ballasts having many fines were somewhat more difficult to handle. However, most individuals reported no correlation between gradation and output, leading one to conclude that the factor is probably of negligible importance except in a few specific cases.

COST PER TRACK FOOT OF A MAJOR BALLAST RENEWAL OPERATION

The cost per unit of output of a major ballast renewal operation is of course a function of the type of renewal operation undertaken. Survey replies included costs for heavy raises, plowing, cribbing, shoulder cleaning, sledding, undercutting and undercutting with cleaning. As with the costs associated with lining and surfacing operations the cost figures included in this report are complicated by the various reporting methods used by the responding railroads. The costs included in the major renewal cost, as were those reported for lining and surfacing operations, consist of labor cost and machinery's capital and operating costs. The reader is refered to the previous section for a discussion of the nature and makeup of these costs. In addition, major ballast renewal operations have large material costs associated with them.

Like the lining and surfacing operations, the total cost of a major ballast renewals must include the cost of ballast material used in that operation. In most major renewal operations, however, be it a heavy raise or an undercutting operation, the volumes of ballast material are substantially larger than those associated with lining and surfacing operations. In addition major renewals using plowing, sledding, undercutting or undercutting-cleaning techniques require excellent tie conditions. Ties which drop off the rail during the ballast renewal operation are generally discarded and replaced with new ties. The question arises as to the assignment of the cost of these ties. Some feel that these ties should have been renewed anyway and therefore should not be charged against ballast renewal. In many cases, however, these ties still have some mainline life left, which is lost as a result of the ballast renewal operation. Because of these considerations most railroads charge the cost of replacing ties lost or damaged during the renewal operation itself to the ballast renewal operation. The reported costs are summarized in Tables 4.12 and 4.13.

TABLE 4.12. MAJOR RENEWAL COSTS - HEAVY RAISE

Railroad	Height of Raise	Cost per Track Foot	Cost per Track Mile
B	9"	$0.40	$2,110
F	8"	0.20[a]	1,060[a]
H	5"-6"	0.20[a]	1,060[a]
I	3"	1.00	5,280
O	8"	0.95	5,020
R	4"-4½"	0.57	3,101
V	2½"	0.82	4,330
V	4"-5"	1.61	8,500
BB	5"	0.33[a]	1,760[a]
BB	6"	1.10	5,810
BB	6"	1.25	6,600
BB	6"	0.33[a]	1,760[a]
BB	7"	0.25[a]	1,300[a]
Average[b]	5.4"	0.96	5,082

[a] Labor only

[b] Excluding labor only responses

TABLE 4.13. MAJOR RENEWAL COSTS - BY OPERATION

Railroad	Cribbing Cost per Track Foot	Cost per Track Mile
Z	$0.36	$1,900
Railroad	Shoulder Cleaning Cost per Track Foot	Cost per Track Mile
H	$0.10	$ 530
Railroad	Plowing Cost per Track Foot	Cost per Track Mile
F	$2.57[b]	$13,570[b]
BB	0.39[a]	2,060[a]
BB	0.39[a]	2,060[a]
Average[e]	$2.57	$13,570
Railroad	Sledding Cost per Track Foot	Cost per Track Mile
E	$2.39	$12,620
E	2.34	12,355
H	3.30	17,425
BB	0.20	1,00
Average	$2.67	$14,098
Railroad	Undercutting Cost per Track Foot	Cost per Track Mile
C	$5.00	$26,400
F	1.89[b]	9,980[b]
R	2.24[c]	11,830[c]
BB	10.00	52,800
Average	$4.78	$25,252
Railroad	Undercutting-Cleaning Cost per Track Foot	Cost per Track Mile
H	$3.30	$17,425
V	2.73	14,415
W	1.31[d]	6,920[d]
W	1.01[d]	5,335[d]
Average	$2.09	$11,022

[a] Labor only

[b] 1967 Dollars

[c] 4" cut

[d] 6" cut

[e] Excluding labor only responses

Undenoted entries had variable or unspecified cutting depths.

Chapter 5

FREQUENCY OF LINING AND SURFACING OPERATIONS

The need for track lining and surfacing is primarily related to the deterioration of track geometry. The point at which the procedure is performed, however, is a subjective matter. Each company establishes its own basis for undertaking maintenance operations. Conventionally each track officer applies these rules based on his personal track appraisals and judgment. For the future,the use of track geometry car outputs can facilitate a more uniform and precise indication of track conditions and need for maintenance. Of the eighteen survey respondents discussing lining and surfacing frequency, thirteen reported that their decisions are based primarily upon inspection and evaluation of field conditions. Of the remaining 5 railroads, two chose to line and surface only with tie and rail renewal operations, two adhered to a predetermined cycle regardless of field conditions and the remaining railroad based its frequency upon a desire to keep all gangs working continuously. Only 3 of the responding railroads reported using the output of a track geometry car, either alone or in combination with the above methods to determine the need for lining and surfacing operations. In addition, cycle lengths are affected by the maintenance goals of the various railroads and the budget conditions at any point in time. Thus, even for identical traffic, subgrade and climatic conditions an individual ballast material may exhibit vastly differing cycle lengths on different railroads.

Most research on the frequency of lining and surfacing operations concentrated on linking cycle lengths to various ballast parameters, primarily particle characteristics. Various AREA committees[2,3,4] and other sources have addressed this problem, but have been unable to reach any meaningful conclusions. Much of the effort has entailed the solicitation and analysis of the opinions of many track maintenance officers, an approach which is complicated by the limited range of materials and conditions with which any individual may be familiar.

One of the primary goals of the survey was the establishment of a data base of lining and surfacing frequency. Each respondent has been asked to provide information on sections of high traffic density (10 to 30 million gross tons annually), well-maintained track with relatively clean, uncemented ballast on a stable, well-drained subgrade. The data derived from the survey is shown in Figure 5.1, which includes a reference curve of average cycle lengths reported in a 1959 AREA questionnaire[6, 7] In spite of the restriction on subgrade, etc., placed on survey responses, the data is randomly distributed about the reference curve. However, if the diversity of track conditions at the reported locations is taken into account (see Table 5.1) the scatter does not necessarily preclude a ballast material, cycle length relationship.

In order to provide a basis for comparison between ballast materials, it is necessary to normalize the cycle lengths reported in order to take into account the varying conditions at each location. The method chosen for the normalizing process is based on procedures developed in "Procedures for Analyzing the Economic Cost of Railroad Roadway for Pricing Purposes"[6]. This process involves the use of adjustment factors applied to conditions which deviate from the arbitrarily chosen norm.

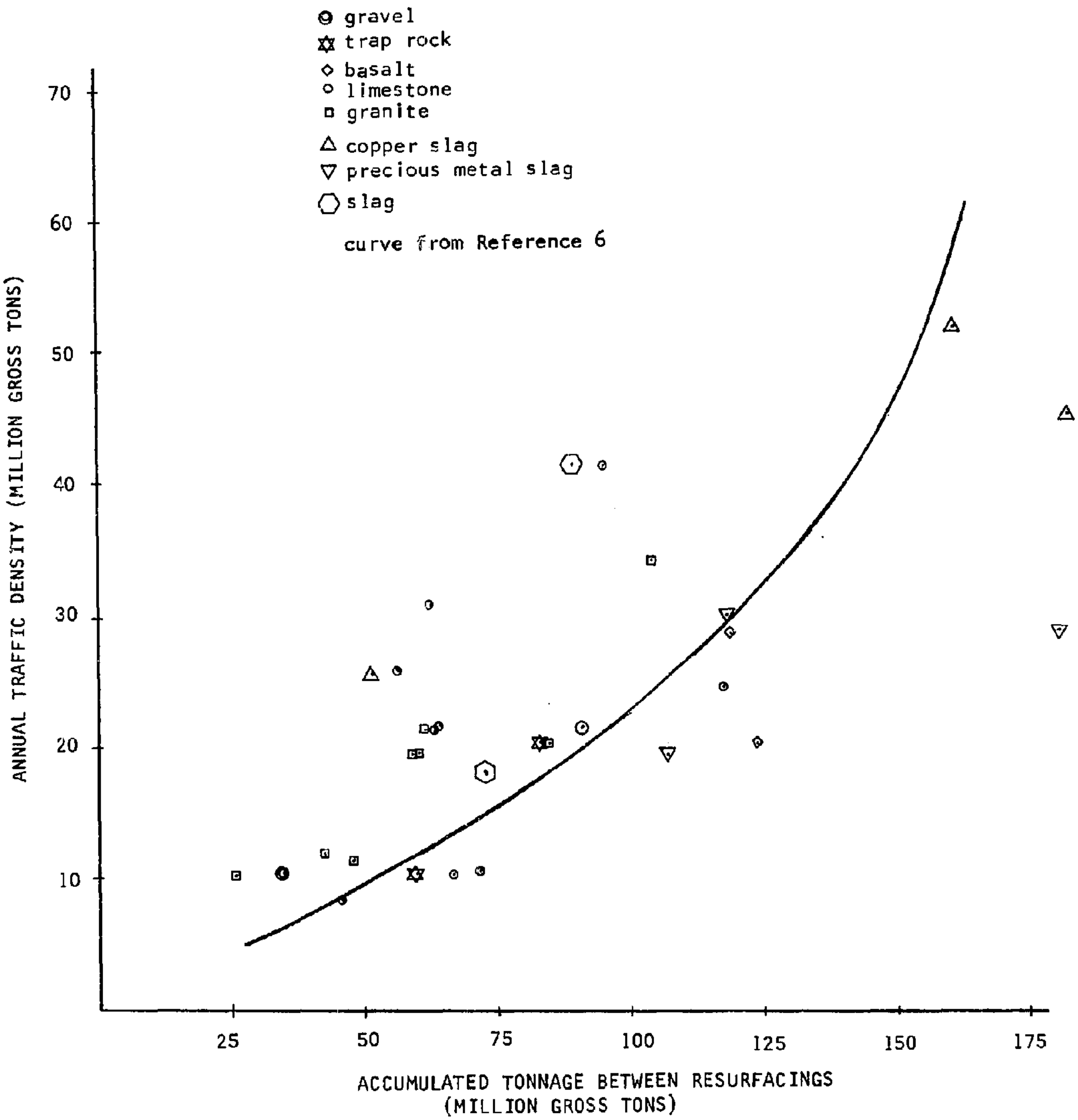

Figure 5.1. Surfacing Cycles as Reported by Survey Respondents.

TABLE 5.1. TRACK CHARACTERISTICS OF THE REPORTED LINING AND SURFACE OPERATIONS

Railroad Ballast Type	Cycle Length (years)	FRA Track Class	% Wheel Loads over 26,000 lbs	Ballast Depth (in.)	Rail Type	Rail Weight	Normalized Cycle Length (years)
C-LMS	2	4	75	20	CWR	140	1.87
D-TRR	4	3	35	12	CWR	115	3.38
D-TRR	6	3	35	12	Jointed	112	6.09
E-LMS	4	3	--	6	Jointed	112	4.29
E-BST	6	4	--	10	Jointed	115	6.34
F-SLG	4	4	--	12	Jointed	115	4.23
F-LMS	3	4	--	24	Jointed	140	2.9
F-LMS	3	4	--	8	Jointed	115	3.5
G-LMS	6.5	4	65	12	CWR	112	6.38
J-LMS	2	3	40	24	Jointed	132	1.68
K-PMS	7	5	17	12	CWR	136	8.07
K-PMS	4	5	18	12	Jointed	136	4.619
K-PMS	6	5	10	12	Jointed	115	7.26
N-LMS	5	4	40	16	Jointed	132	5.37
N-LMS	6	4	30	16	Jointed	115	6.68
N-LMS	5	2	40	12	Jointed	115	4.07
O-GRN	2.5	4	70	12	CWR	132	2.24
P-DNA	4	2	10	6	CWR	132	3.04
Q-GRV	3	3	5	6	Jointed	115	3.25
R-GRN	4	4	1	12	CWR	132	3.7
R-GRN	3	4	1	12	CWR	132	2.77

TABLE 5.1. (Continued)

Railroad Ballast Type	Cycle Length (years)	FRA Track Class	% Wheel Loads over 26,000 lbs	Ballast Depth (in.)	Rail Type	Rail Weight	Normalized Cycle Length (years)
R-GRN	3	4	1	12	CWR	119	2.89
S-LMS	2.33	4	25	15	CWR	132	2.25
S-SLG	2	4	25	15	CWR	132	1.93
T-DNA	3	--	100	10	CWR	132	3.26
V-GRN	3	5	3.4	18	Jointed	132	3.41
V-GRN	4	4	5.8	16	CWR	132	3.38
V-GRN	3	5	7.6	25	CWR	132	3.27
W-CSL	5	5	15	9	CWR	136	4.83
W-CSL	3	5	25	10	CWR	136	2.92
W-CSL	4	5	1	8	CWR	136	3.84
Z-GRN	3	5	10	--	Jointed	133	3.82
Z-CSL	2	5	20	--	Jointed	133	2.58
Z-BST	4	5	6	--	Jointed	133	5.05

Ballast Types:

LMS - Limestone
BST - Basalt
PMS - Precious Metal Slag
DNA - Data Not Available
CSL - Copper Slag
TRR - Trap Rock
SLG - Slag
GRN - Granite
GRV - Gravel

The normal conditions were chosen as:

Rail weight - 132 lb/yd

Rail type - jointed (39 or 78 foot)

Level - tanget track

Operating speed - 50 mph

All wheel loads - less than 15,000 lbs*

Ballast depth - 6-8 in. below bottom of tie#

Stable, well drained subgrade

No passenger or unit trains

Using the factors developed in the costing study, each surfacing operation reported by survey respondents was normalized to these conditions subject to the limitations on data provided by the respondents. Sample normalizing calculations are presented in Exhibit 5.1. A plot of the normalized cycle lengths vs. traffic density is presented in Figure 5.2. However, it is still difficult to recognize any major differences in performance between the various materials.

One of the difficulties in attempting to discern any differences between the various materials is the relatively sparse data on several of the materials. There are, for example, only one report of a surfacing operation using steel mill slag as ballast, only one with basalt, only two with trap rock, only three with precious metal slag and only three with copper slag. The only two materials with more than a few data points are limestone, with 10 locations, and granite with 8 locations. Further investigation of the material type cycle length relationship is based on these two materials.

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*Average - including empties.

#Typical good ballast depth on many railroads; not the recommended depth.

EXHIBIT 5.1. SAMPLE CALCULATION OF NORMALIZED CYCLE LENGTH

Take for example the 2nd surfacing cycle reported by Railroad N. This location had the following characteristics:

Reported cycle length	= 6 years
FRA track class	= 4
% wheel loads over 26,000 lbs	= 30
Ballast depth	= 16"
Rail type	= jointed
Rail weight	= 115 lb

Actual surfacing cycle = normalized cycle · S · W · D · R_t · R_W

S = speed factor
W = car weight factor
D = ballast depth, subgrade condition factor
R_t = rail type factor
R_W = rail weight factor

The factors developed in "Procedures for Analyzing the Economic Costs of Railroad Roadway for Pricing Purposes" are:

Speed factor

FRA class 4 (assumed speed - 60 mph)

Factor = 0.90

Car weight factor

Wheel loads $\leq$ 15,000 lb	Factor = 1.0
Wheel loads $\geq$ 26,000 $\leq$ 30,000	Factor = 0.85
At 30% of traffic greater than 26,000 lb	Weight Factor = (0.7x1.0) + (0.3x0.85) = 0.955

Ballast depth, subgrade condition factor for a ballast depth greater than 8"

On good subgrade	Factor = 1.1056
Rail type - jointed	Factor = 1.0
Rail weight for rails weighing more than 100 lbs/yd, less than or equal to 115 lbs/yd	Factor = 0.95

$$\text{Normalized cycle} = \frac{6}{(0.90) \times (0.955) \times (1.1056) \times (1.0) \times (0.95)}$$

Normalized cycle = 6.68 years

EXHIBIT 5.1. (Continued)

As another example of the normalization procedure consider the surfacing operation reported by Railroad P. This location had the following characteristics:

Reported cycle length	= 4 years
FRA track class	= 2
% wheel loads over 26,000 lbs	= 10
Ballast depth	= 6"
Rail type	= CWR
Rail weight	= 132

Speed factor

FRA class 2 (assume speed = 25 mph)

Factor = 1.25

Car weight factor

Wheel loads ≤ 15,000 lb — Factor = 1.0

Wheel loads ≥ 26,000 ≤ 30,000 — Factor = 0.85

At 10% of traffic greater than 26,000 lb — Weighted Factor = (0.9x1.0)+(0.1x0.85) = 0 .985

Ballast depth, subgrade condition factor for a ballast depth of 6" or less

On good subgrade — Factor = 0.891

Rail type - CWR — Factor = 1.2

Rail weight for rails weighing more than 119 lb/yd, less than or equal to 132 lb/yd — Factor = 1.0

$$\text{Normalized cycle} = \frac{4}{1.25 \cdot 0.985 \cdot 0.891 \cdot 1.2 \cdot 1.0} = 3.04 \text{ years}$$

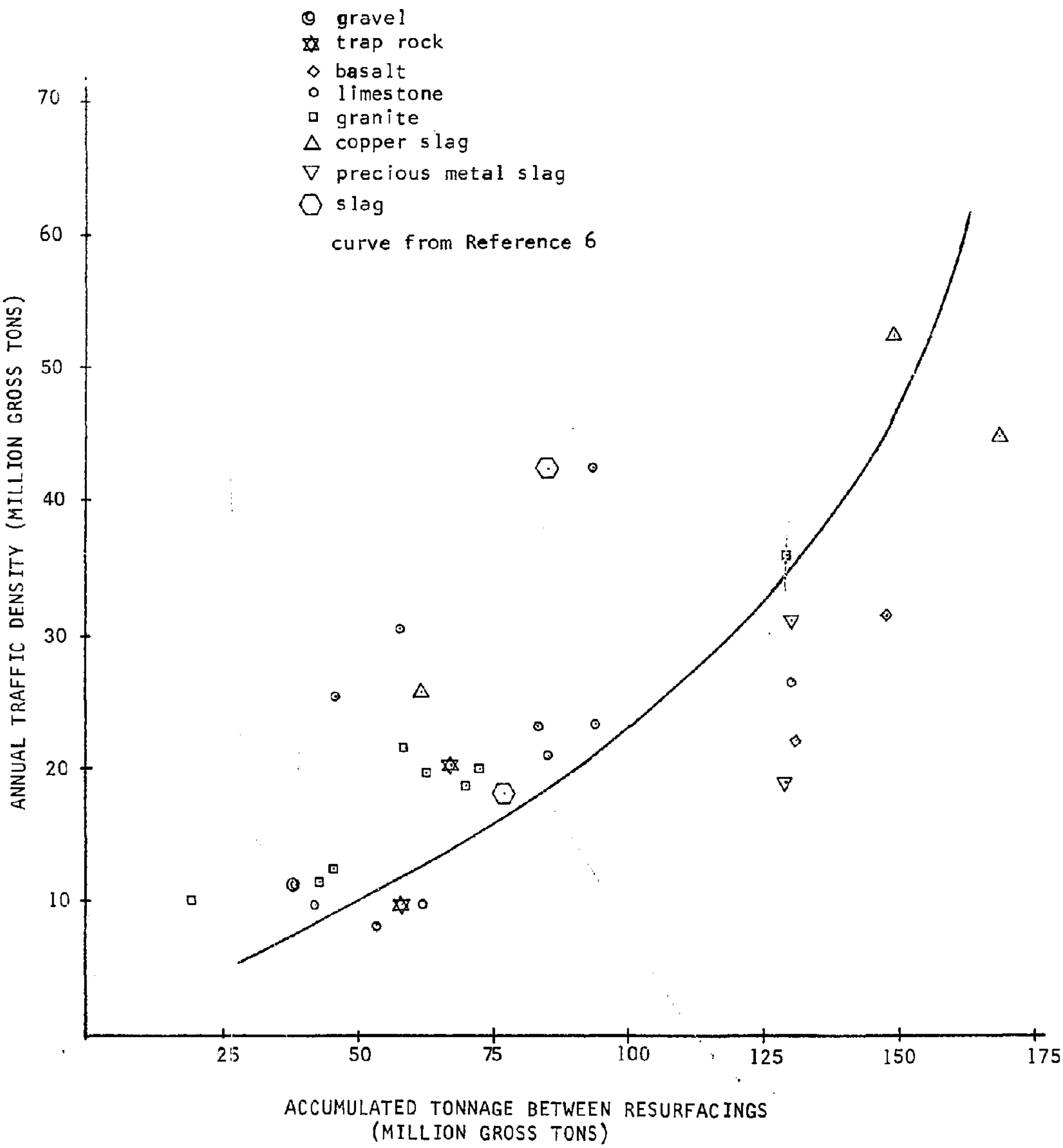

Figure 5.2. Normalized Surfacing Cycles

Based on the cycle lengths reported for these two materials, it was possible to construct a mathematical model of surfacing cycle length. Several model forms were considered and tried; however, the one which appeared to have the most promise was a form similar to the AREA rail life equation:(11)

$$T = K\ W\ D^{.565}$$

where:

T = life of rail in main line track (MGT)

K = composite constant reflecting level of track maintenance

W = weight of rail (lbs/yd)

D = annual tonnage density (MGT)

The surfacing cycle equation would appear as:

$$T = C\ K\ D^{N}$$

where:

T = accumulated tonnage between surfacing operations (MGT)

K = composite constant reflecting surfacing practices

C = constant reflecting ballast type and subgrade conditions

D = annual tonnage density (MGT)

N = exponent reflecting the relative importance of time and weather in establishing the length of the surfacing cycle.

The one discretionary item in each railroad's surfacing practices which was found to have some significance in the relative length of the surfacing cycle was the height of raise used in that cycle. The greater the height of raise the more good clean ballast material is incorporated into the track structure. (The upper limit on the height of a single raise is dictated by the depth to which the tamping machinery can adequately compact the new ballast material). If more new ballast is incorporated into the track structure, logic would indicate that the time period between lining and surfacing operations could be extended. It was found that the life (in MGT) of a lining and surfacing operation responded most closely to the square root of the raise measured in inches.

In spite of having normalized the surfacing cycle lengths for rail weight, there remained some differences in cycle lengths which appeared to be linked to rail weight. Further study revealed that the rail weight correction factors used in the costing study(6) were based on the vertical stiffness of the rail (moment of inertia of the section). Sonneville also found the lateral strength of the track structure to be largely dependent on the lateral moment of inertia of the rail sections.(12) Accordingly the lateral moments of inertia of the various rail sections were approximated (exact values for the lateral moment of inertia of the rail could not be found) and incorporated in the surface life model. The lateral moment of inertia raised to the 1.5 power appeared to work well in the model.

The value of the exponent N on the annual tonnage density reflects the relative importance of time effects on the "surface life" of the track. Values used must be less than one. The smaller the value of N the lesser the importance of time related deterioration. It was found that for the data vailable a value of N of about .5 appeared to give the best fit.

The cycle length model proposed thus has the following form:

$$T = D^{.5} R^{.5} I_2^{1.5}$$

where:

T = accumulated tonnage between surfacing operations (MGT)

D = annual tonnage density (MGT)

R = height of raise (in.)

I_2 = lateral moment on inertia of rail

Figures 5.3 and 5.4 are the values of $D^{.5} R^{.5} I_2^{1.5}$ vs. the normalized value of the reported surface life (in million gross tons) for limestone and granite ballast material, respectively.

The plots of $D^{.5} R^{.5} I_2^{1.5}$ vs. normalized values of the reported surface life shows less scatter than the plot of annual traffic density vs. normalized surfacing cycles (Figure 5.2). The reduction in scatter is especially apparent in Figure 5.4 for granite ballast. The values of $D^{.5} R^{.5} I_2^{1.5}$ for limestone do not, however, appear to relate to normalized surfacing cycles as well as for granite. Much of the remaining scatter can probably be attributed to the variable nature of the limestone materials. Indeed if the points farthest to the right of Figure 5.3 are ignored, the remaining points appear to lie very closely along a straight line. The four points to the right also appear to lie along a straight line of their own. Granite does not have the same degree of variability as limestone, which would account for the relatively ordered nature of Figure 5.4.

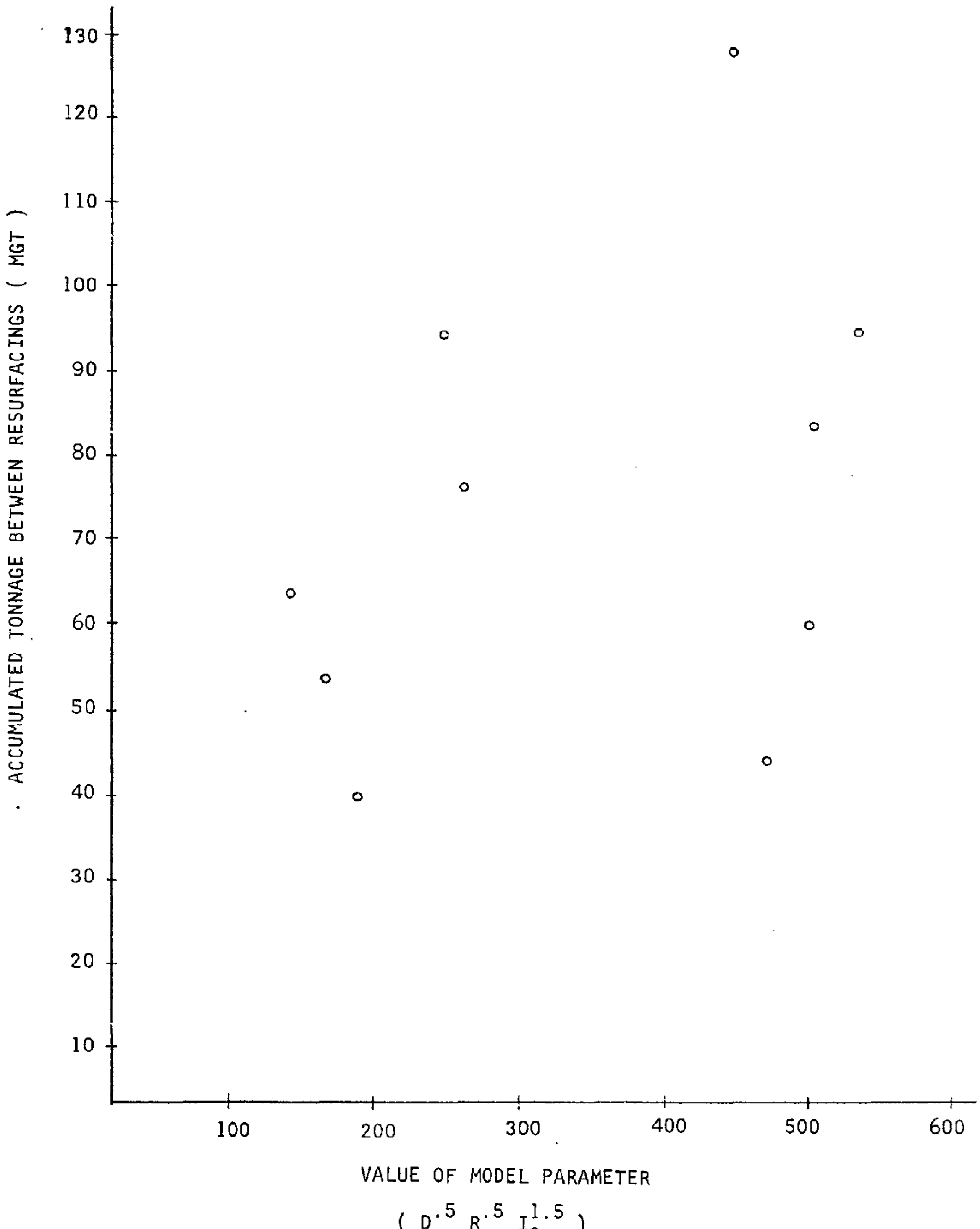

Figure 5.3. Surfacing Cycle Model Parameters-Limestone

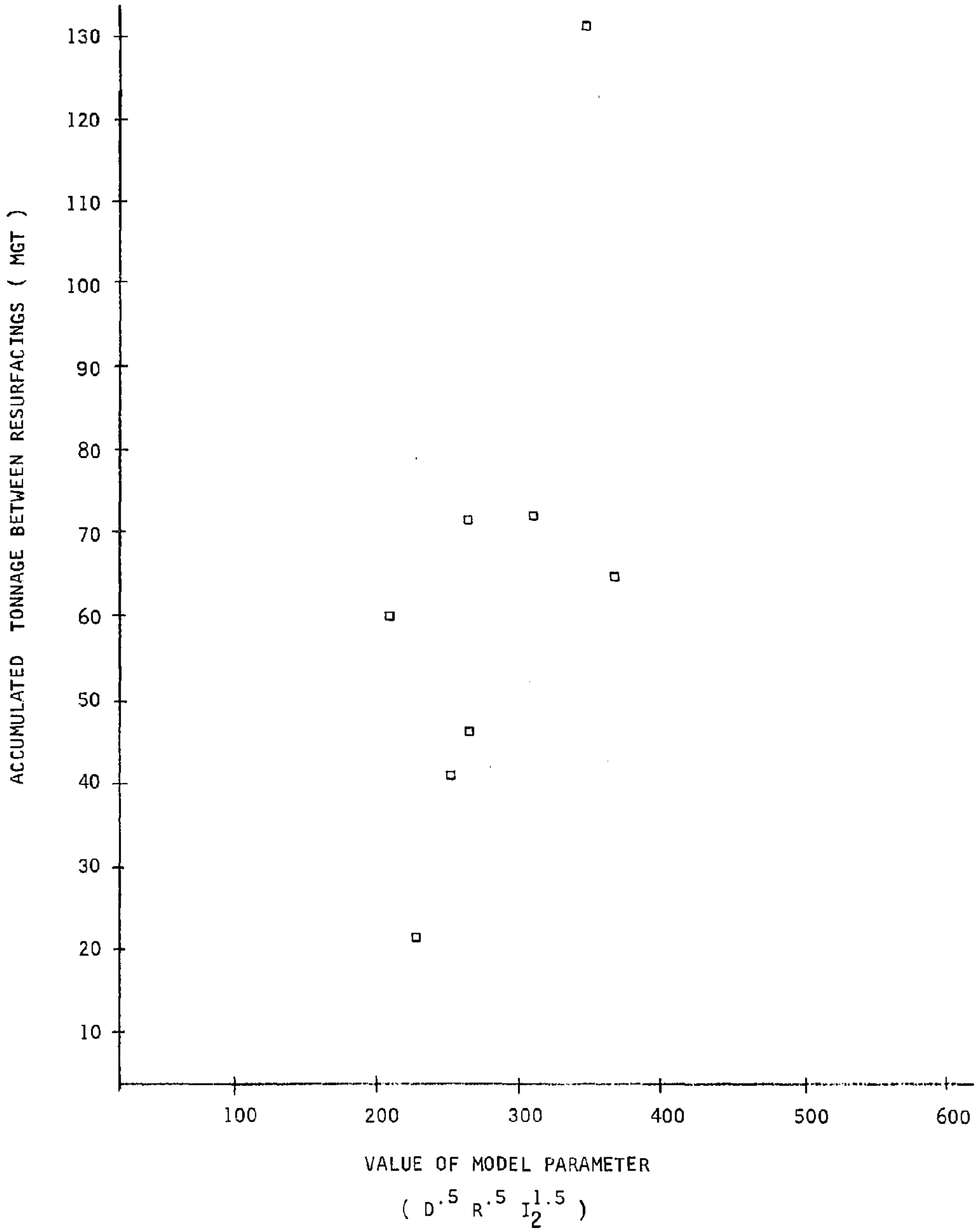

Figure 5.4. Surfacing Cycle Model Parameters-Granite

It should be pointed out that this proposed relationship for surfacing cycle length is very tentative and based on a very small sample. The powers to which each of the parameters are raised should be further refined and constants determined, based on much larger samples than are available here, before this model can be used to estimate surfacing cycle length. The use of this relationship does illustrate some differences in the performance of these two ballast materials.

FREQUENCY OF MAJOR BALLAST RENEWAL

The reported major ballast renewal cycles are summarized in Table 5.2. Also included in the table are the characteristics of the various sections. As with the lining and surfacing responses insufficient information is available to draw any conclusions concerning the effect of ballast type, or subgrade and subballast conditions or ballast cycle length.

TABLE 5.2. FREQUENCY OF MAJOR RENEWAL

Railroad	Annual Traffic Density (MGT)	Ballast Material and AREA Gradation	Years Since Last Renewal	Number of Linings and Surfacings Since Last Renewal	Rail Wt.	Rail* Type	FRA Class	Ballast Depth Below Ties	Subballast
B	10	Standard Stone**	15-20	Every Year	100,112,115	J	3&4	9"	None
C	32	Steel Slag/4	30	15	140,155	W	4	12"	Granulated Slag
E	16	Scoria/4	21	1 (out of face)	112	J	4	12"	None
E	17	Scoria/4	26	Spot Each Year	112	J	3	10"	None
I	10	Lime Stone **	20	4	115	J	3	3"	None
P	8	Rock & Slag/4	8	None	132	J	2	5-6"	None
R	22	Cr. Rock-Rhyolite/4	12	4	112&119	J&W	4	12"	None
R	10	Chatt-Limestone**	15	6	119	W	4	10"	None
V	13.5	Granite/4	20	1	132	J	5	18"	None
W	50	Copper Slag**	8	2	136	W	5	12"	None
W	50	Steel Slag & Cr. Rock**	7	2	136	J	4	10"	None
Z	16	Granite**	22	6	133	J&W	5	9"	6" Granite

* J = Jointed

W = Continuous Welded Rail

** = AREA Gradation not available

Chapter 6

BALLAST COST MODEL

The overall economic cost of ballast is recognized as the optimal criterion for material selection. The parameter best serves this task when it is formulated to quantify the additional costs which may be paid for a ballast of superior long-term performance. The time frame utilized for the analysis is an important consideration.

As discussed in Chapter 3, all of the elements of overall cost are incurred in a cyclic manner. This suggests that ballasts should be evaluated on the basis of the total costs encountered within a certain maintenance cycle. However, because several distinct cycles exist, it is not immediately clear which would form the most ideal base.

Unquestionably, an approach entailing the analysis of ballast costs between major renewals has some significant advantages. It accounts for both ballast stability (as reflected in spotting and lining and surfacing requirements) and durability (as reflected in the interval between major renewals). Unfortunately, the approach is faulted by several considerations which make it difficult to implement effectively. Its principal shortcoming is its reliance on the estimated costs of the many spotting exercises and lining and surfacing operations to be undertaken at some future date within the renewal cycle.

Analysis based on the lining and surfacing frequency is the best alternative. The method properly selects the ballast to be placed in a lining and surfacing operation without requiring the knowledge of many maintenance operations far in the future. The approach fails to address ballast durability, but this is not a serious limitation. After all, ballast type is but one factor affecting the need for renewal, with other elements -- intrusion of subgrade or air borne materials, etc.-- often being much more important.

Derivation of the equation for economic evaluation of ballast materials is rather straightforward. At the outset, all costs incurred within a ballast cycle are brought to the cycle's beginning. A ballast cycle is defined as the interval between major ballast renewal operations. Purchase, transport and insertion costs are already expressed in such terms, while spotting costs and lining and surfacing costs require the application of a single payment present worth factor for each spotting exercise. Initial value becomes:

$$\text{Initial value} = PP+TC+UC+IC+SC_1(\text{SPPWF}, i\%\ t_1)+SC_2(\text{SPPWF}, i\%, t_2)+\ldots$$
$$SC_n(\text{SPPWF}, i\%, t_n)+LSC_j(\text{SPPWF}, i\%, t_j)+LSC_m(\text{SPPWF}, i, t_m),+\ldots$$

The cost for each year of a ballast cycle is then:

$$\text{Annual cost} = \text{Initial value }(\text{CRF}, i\%, t_c)$$
$$=(PP+TC+UV+IC+SC_1(\text{SPPWF}, i\%, t_1)+SC_2(\text{SPPWF}, i\%, t_2)+\ldots$$
$$SC_n(\text{SPPWF}, i\%, t_n)+LSC_j(\text{SPPWF}, i\%, t_j)+LSC_m(\text{SPPWF}, i, t_m)+\ldots)$$
$$(\text{CRF}, i\%, t_c)$$

where:

PP = ballast purchase price

TC = transportation cost

UC = unloading cost

IC = insertion cost (cost to raise, tamp and remove and/or clean old ballast material)

SC_1 = spotting cost during year 1 of cycle

SC_2 = spotting cost during year 2 of cycle

LSC_j = lining and surfacing cost during year j of the ballast cycle (including the purchase, transport, and unloading cost of ballast used in the surfacing operation)

LSC_m = lining and surfacing cost during year m of the ballast cycle.

CRF = capital recovery factor

SPPWF = single payment present worth factor

i = rate of return on investment specified

t_c = length of ballast cycle in years

For different ballasts to be economically competitive, their annual costs must be nearly equal. The two major ballast performance factors which would affect the annual cost are; the length of the ballast cycle itself and the length and cost of the imbedded surfacing cycles. If the ballast cycle is longer, the initial purchase price, unloading costs etc. are distributed over a greater number of years, lowering the annual cost. A ballast which resists degradation and subsequent fouling would be associated with longer ballast cycles. Any ballast material which allows a longer interval between lining and surfacing operations would require a lower level of expenditure during the ballast cycle, thus lowering annual costs. A ballast material which resists lateral and vertical deformation would allow such a lengthening of the surfacing cycle. Thus any ballast material which had a longer ballast cycle and/or a longer lining and surfacing cycle could be purchased at a higher initial cost and/or transported farther, up to the limits of equal annual cost with the inferior ballast material.

To illustrate the use of the cost model consider two ballast materials, A and B with the following characteristics.

	Ballast Material	
Characteristics	A	B
Initial purchase price ($/cu yd)	2.16	2.31
Transportation cost ($/mile)	.009	.009
Transportation distance (miles)	100	250
Unloading cost (Exhibit 4.4, Special work train)($/cu yd)	.47	.47
Lining and surfacing cycle	3 years	4 years
Ballast cycle	9 years	12 years
Cost for Major Renewal (Assume 6" raise)		
Volume of ballast used for 6" raise (cu yd/mile)	1726.	1726.
Total material cost (purchase and transport cost)($/mile)	5283.27	7873.11
Unloading cost ($/mile)	811.48	811.48
Sledding cost (from Table 4.13) ($/mile)	14097.00	14097.00
TOTAL	20191.75	22781.59

	A	B
Costs for Lining and Surfacing 2" raise		
Volume of ballast used for 2" raise		
(cu. yd./mile)	420	420
Total material cost ($/mile)	1285.20	1915.20
Unloading cost ($/mile)	197.40	197.40
Lining and surfacing operation		
(Table 4.11)($/mile)	1109.00	1109.00
TOTAL ($/mile)	2591.60	3221.60

Assume spotting costs to be $1000 per mile per year for both materials (in actual practice spotting costs will probably increase during the ballast cycle)

Assuming a 10% rate of return the model yields the following:

$$\text{Initial value (ballast A)} = 2091.75 + \sum_{n=1}^{9} 1000\ (\text{SPPWF, 10\%, } t_n)$$

$$+\ 2591.60\ (\text{SPPWF, 10\%, 3 years}) + 2591.60\ (\text{SPPWF, 10\%, 6 years})$$

$$= \$29360.88$$

$$\text{Initial value (ballast B)} = 22781.51 + \sum_{n=1}^{12} 1000\ (\text{SPPWF, 10\%, } t_n)$$

$$+\ 3221.60\ (\text{SPPWF, 10\%, 4 years}) + 3221.60\ (\text{SPPWF, 10\%, 8 years})$$

$$= \$26631.57$$

Annual cost

Ballast A = 29360.88 (CRF, 10%, 9 years) = $5098.20/mile/year

Ballast B = 26631.57 (CRF, 10%, 12 years) = $3908.45/mile/year

As is illustrated by the result of the cost comparison ballast B, in spite of its slightly higher purchase price and higher transportation cost, has a substantially lower annual cost. This model can be used to determine the lowest cost ballast material for use in a given location based on the performance of the various ballast materials in the environment found at that location. However, it is not possible, at this time, to determine the performance of a specific ballast material in a given environment based on laboratory testing procedures. If in-service testing of materials is used the time periods required and the variation of loading conditions and maintenance practices during that time may prohibit a reasonable comparison of the materials tested.

An unsolved problem remains of developing transfer functions whereby the length of ballast renewal cycles and intermediate maintenance cycles can be related to the relative stability characteristics of subgrade and ballast materials established by laboratory tests and related specifications.

Chapter 7

SUMMARY AND CONCLUSIONS

GENERAL

Based on the results of the survey produced as a part of this study, it has been possible to quantify many of the costs associated with ballasting procedures. Due to the wide diversity in operating conditions, procedures, gang organization, financial conditions and climatic factors, these costs vary greatly from company to company. It is also apparent that many companies do not take into account all costs in their costing exercises.

PURCHASE PRICE

It was found that purchase price did not vary from material to material. The average price for each of the various materials did not differ by more than 11%. Apparently, the purchase is dictated by alternate uses of the material rather than their value as railroad ballast material. Thus, subject to local conditions of availability, it should cost very little for a railroad to upgrade its ballast material.

TRANSPORTATION COST

On line transportation costs of ballast material reported by the survey indicate that the cost of on-line transportation is significantly lower than the cost of off-line transportation. The reported on-line charges are only about 20% of the reported off-line charges. Based on this large difference, a railroad would have to expect great savings from change to a better ballast material if off-line charges would be incurred. Even then, the material could probably not be shipped any great distance off line. The use of assigned ballast cars in large blocks or in exclusive unit train operation will, somewhat, reduce the transportation costs. Transport costs of the various materials differ in proportion to their unit weight with the lighter material exhibiting the lower cost.

UNLOADING COST

No difference in unloading costs of various ballast materials was found due to the surface characteristics of the material. Although the tendency for less dense materials to exhibit lower unloading costs was reported, the information supplied was insufficient to quantify this influence. The use of properly designed ballast cars that permit close control of quantity and center-shoulder placement can reduce unloading costs. The lowest cost method of unloading ballast uses revenue trains for both the road haul and unloading operations. The quoted cost of this operation is \$0.18 per cubic yard. However, this is based on a single railroad reporting this type of handling. The use of special unit trains for road haul and special work trains for unloading had the second lowest unloading cost for cubic yard (\$0.47). This method, however, is associated with high output ballasting operations. Finally, the use of revenue trains for road haul and work trains for unloading had the highest unloading cost at \$0.84 per cubic yard. The average daily output for this handling method is usually much lower than if special work trains are used.

SPOTTING COSTS

Insufficient data was provided to quantify spotting costs. Spotting practices vary widely even on a single railroad. Railroads rarely record spotting costs much less assign them to specific sections of track with particular ballast and subgrade properties. Previous research has established the yearly maintenance housekeeping costs (all functions performed by a section gang, most of which fall into the category of spotting) per track mile as (1974 dollars):

Single track: 765 + 28G

Double Track: 645 + 24G

where G is the annual gross tonnage in millions and reflects a measure of the number of trains operated (based on freight only track).

LINING AND SURFACING COSTS

The unit costs of lining and surfacing operations were found to depend primarily on gang organization as it affected total costs and output. The unit production cost did not vary a great deal on the average as the gang organizations which were associated with high rates of output also exhibited high total costs. As production rates declined so did total costs. The highest output gang (tamper-liner, tandem tamper and one ballast regulator) had an hourly output of 938 ft and an hourly cost of $200, giving a cost per track foot of $0.21 the lowest output gang (tamper-liner and a ballast regulator) had an hourly output of 657 ft and an hourly cost of $135, giving a cost per track foot of $0.21. The highest cost per track foot was $0.26, the lowest $0.16.

FREQUENCY OF LINING AND SURFACING

Based on the limited amount of data provided from the survey it was possible to examine the cycle lengths associated with only two ballast materials. Using a tentative model, similar to the currently used rail life model, there was found to be some differences in the surfacing cycles associated with these two ballast materials. However, due to the limited nature of the available data, these results are non conclusive.

COST OF MAJOR BALLAST RENEWAL OPERATIONS

The cost of major ballast renewal operations is largely a function of the type of renewal operation utilized. The so-called surface treatments, cribbing and shoulder cleaning, were reported as having the lowest costs ($0.36 and $0.10 per track foot, respectively). Heavy raises were reported as having costs of about $1.00 per track foot, but ranging from $.40 to $1.61. The more sophisticated renewal methods (plowing, sledding, undercutting and undercutting-cleaning) generally were reported as having higher costs, although several railroads reported costs comparable to heavy raises.

FREQUENCY OF MAJOR BALLAST RENEWALS

The information provided on the length of the major ballast renewal cycles is insufficient to relate these cycles to ballast type, track class or other conditions. The length of the major renewal cycles varied from 7 to 30 years, with most in the 20 year range. The accumulated tonnage between major renewals was usually in the 200 to 300 million gross tons range.

CONCLUSIONS

1. Many items relative to ballast costs have been identified. Of these, the one having a principal impact on comparative costs is the frequency of ballast renewal and maintenance, i.e., the length of maintenance and renewal cycles.

2. The relations between the length of maintenance and renewal cycles cannot yet be fully identified by means of laboratory tests and specifications. More specifically, the relation between short term effects and long term response of ballast materials in track is not completely defined. Subgrade characteristics, a highly variable item, also have a close relation to ballast stability and renewal cycles. Hence a greater sophistication of the foregoing model is not currently feasible or warranted until data is available for validation.

3. Other factors than the laboratory-established characteristics of ballasts must still be used as set forth in the model herebefore developed.

4. The model herein developed will enable the making of an economic choice between alternative materials when experience (or later improved understanding) has indicated a difference in the stability and renewal maintenance cycles of the materials being compared.

5. Once steps have been taken to adjust lining and surfacing costs by the various railroads for the differences in the way they are reported, there is surprising similarity among the costs reported (see Table 4.11. This similarity suggests that either through study or experience, uniformity in costs have been obtained by the industry.

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APPENDIX

RAILROADS RESPONDING TO SURVEY

Railroad	Size	Territory
A	Large	Western U.S.
B	Small	Northeastern U.S.
C	Small	Northeastern U.S.
D	Medium	Northeastern U.S.
E	Large	Western U.S.
F	Large	Northeastern U.S.
G	Small	Midwestern U.S.
H	Large	North Central U.S.
I	Small	Midwestern U.S.
J	Small	Southeastern U.S.
K	Small	Southwestern U.S.
L	Small	Northeastern U.S.
M	Medium	West Central U.S.
N	Small	Northeastern U.S.
O	Small	Southeastern U.S.
P	Small	North Central U.S.
Q	Small	Northeastern U.S.
R	Large	South Central U.S.
S	Large	Northeastern U.S.
T	Small	Eastern Canada
U	Medium	Northeastern U.S.
V	Large	Southeastern U.S.
W	Large	Western U.S.
X	Large	Southern U.S.
Y	Small	South Central U.S.
Z	Large	Western U.S.
AA	Small	Northern U.S.
BB	Large	Canadian

Note: Small - less than 1000 miles
Medium - Between 1000 & 2500 miles
Large - Larger than 2500 miles

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