# Evaluation of Life Cycle Costs of Alternate Tie (Sleeper)/ Fastener Systems and Their Use in Defining Maintenance Policy and Practice

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**Summary**

The selection of the optimum track system configuration is very much dependent on the performance requirements and economic characteristics of the rail operation that is being configured. One of the key decisions in selecting an appropriate track system is the selection of the proper cross-tie (sleeper)/fastener system. The range of available systems include a wide selection of cross-tie (sleeper) and fastener types and materials and their associated purchase price, installation cost, and maintenance activities. As a result, the selection of the economically "optimum" such system will vary greatly based on purchase prices, material and labor costs, and requirements of the rail operation itself.

In order to help in this decision making process, economic analyses models have been developed and implemented. These models are life cycle costing models that take into account not only initial costs but maintenance activities which occur over the life of the track system. By accurately accounting for these costs, and their associated timing, it is possible to evaluate alternate design configurations and cost structures in order to help select the system that is "best" for a given operation and geographic location. One such model, the Railway Tie Association' *SelecTie* Model, has been used by various railways in making decisions as to where to use different tie/fastener configurations and systems. The *SelecTie* Model has been widely used in North America, by railroads representing over 200,000 miles (300,000 kilometers) of track under a broad range of operating conditions to include heavy axle load freight and lighter axle load passenger operations. Its focus is to assist in the decision as to the most cost effective (on a life cycle basis) cross-tie material. The model, with its easy to use format and structure, has been the basis for decisions as to what ties to use (wood vs. concrete) and the definition of the usage "boundaries" (in terms of curvature and tonnage categories).

**Key Words**: Cross-tie, Sleeper, Life Cycle Costing, Maintenance, Model

## INTRODUCTION

As railroads continue to experience financial constraints and associated budgetary restrictions, the selection of track components that provide the lowest over-all cost throughout their life cycles becomes of increased importance. This selection of the optimum track system configuration is very much dependent on the performance requirements and economic characteristics of the railway operation that is being configured, as well as its operating and maintenance practices.

One of the key decisions in selecting an appropriate track system is the selection of the proper cross-tie (sleeper)/fastener system. The range of available systems include a wide selection of cross-tie (sleeper) materials [e.g. timber, concrete, steel, plastic] and a similar wide range of fastener types [cut spikes, elastic fasteners, threaded fasteners, etc.]. Concurrent with this wide range of materials and configurations is a corresponding range in purchase price, installation cost, and maintenance activities (and corresponding costs). As a result, the selection of the economically "optimum" such system will vary greatly based on purchase prices, material and labor costs, and requirements of the rail operation itself (to include such factors as traffic density, speed, axle load, type of traffic, etc.)

However, even before an economic decision can be made, it is first necessary to ensure that the performance of the different components under consideration is adequate to meet the needs of the intended service. This is the first step in the selection of a suitable track configuration, in general, and a suitable tie (sleeper)/fastener configuration in particular [Zarembski, 1988]. Thus, it is necessary to identify suitable components candidates that have sufficient "strength" to function and survive in the railway environment being considered. This is generally accomplished through the use of performance specifications, which define the range of performance deemed acceptable by the railway for each class of operating conditions. Such performance standards have been developed for both timber and concrete sleepers (American Railway Engineering Association, 1996) and their respective fastening systems (Zarembski, 1984, 1987) and have been used by both industry associations and individual railways in determining the adequacy of the tie system. These specifications, when used in combination with laboratory tests and field trials, provide the level of confidence needed by the railway in order to consider the component(s) to be safe and adequate for installation in track.

It is only when the tie/fastener component or system has been shown to provide adequate performance that its relative economics can be considered. At that point, the question becomes whether the cost of an alternate component is economically viable with the more traditionally used component. The history of the concrete cross-tie in North America is a good example of this two step process. While concrete tie designs had been introduced as early as 1893 [Hay, 1982] it has only been in the last two decades that their performance has been deemed to be adequate to withstand the severe loading environment of North American freight operations. With the introduction of an American Railway Engineering Association specification and the successful installation of several large scale test sites in severe loading environments, the issue of "adequate" performance of concrete ties was finally met in the 1980s.

At that point, the economics of the alternate tie and fastener systems entered into the consideration of railway engineers. With adequate performance, the relative economics of these alternate systems must be compared with the existing conventional systems, wood ties with cut spikes. In addition, the relative economics of these systems would have to be compared with several other technically proven systems, such as wood ties with alternate (elastic) fastening systems.

Such an economic comparison however is not a simple matter. Because different tie/fastener systems exhibit different lives, require different maintenance activities, and affect other maintenance activities differently, simple comparison of the initial or "first" cost is not adequate. Rather, a comprehensive comparison of the costs and benefits of the alternate systems, over their entire service lives is required. This entails a "life cycle" cost analysis of the alternate systems.

## LIFE CYCLE MODELS

The performance of life cycle analyses is complex, in that a large number of factors must be properly accounted for. These factors are often strongly interdependent, thus changing one, effects many of the others. Thus the relative economics of a major track component such as the cross-tie are not constant for all conditions, but rather vary as relative costs and operating conditions vary.

In order to keep track of and properly account for these interdependent factors, economic analyses models have been developed and implemented. These models are life cycle costing models that take into account not only initial costs but maintenance activities (and costs) which occur over the life of the track system. By accurately accounting for these costs, and their associated timing, it is possible to evaluate alternate design configurations and cost structures in order to help select the system that is “best” for a given operation and geographic location.

Such a life cycle cost model combines the life and cost (both capital and maintenance) of the product, the cross-tie or sleeper, into a quantitative economic measure of overall product “performance”. Thus these models represent a tool for use by railroad personnel to help them make optimum economic decisions concerning material selection that is specific to both the actual operating conditions and the maintenance practices of a given line, route, or territory.

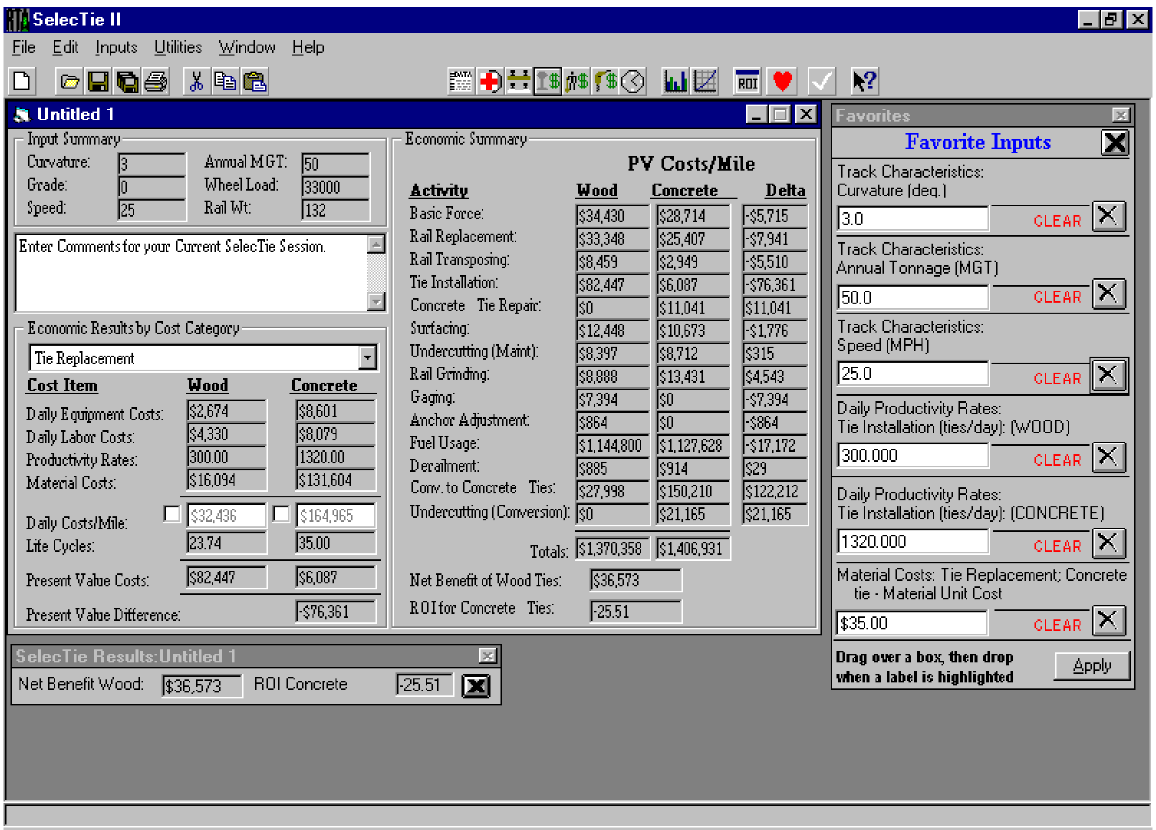
### SelecTie

One of the most successful of these life-cycle economic models is the SelecTie model developed for and distributed by the Railway Tie Association, the association of cross-tie producers in North America.

SelecTie was first introduced in 1989 as a spreadsheet model for comparing the relative (life cycle) costs of concrete and wood cross-ties with varying fastener types (Zarembski, 1989). SelecTie was obtained by virtually all of the major US and Canadian railroads for their own internal use in evaluating these comparative economics. As the first, user friendly, personal computer based cross-tie model, it quickly became the standard for life cycle modeling of alternate crosstie configurations. With over 2,500 line items of user changeable data, immediate access to analysis results, and research based life cycle equations, the user was quickly and easily provided with a look at the crosstie’s costs over its active service life. Economic comparison of alternate materials and maintenance practices could thus be performed, with immediate results. By providing the user with the present value costs for each component option, wood vs concrete, together with the corresponding return on investment, the user had the ability to determine which alternative was the best economical choice.

SelecTie II (See Figure 1) was recently introduced as an upgrade to SelecTie and represents a new generation of comprehensive engineering economics model designed for use on a personal computer running Microsoft Windows 3.1 or higher. This model combines the easy to use Windows operating environment and a sophisticated analytical approach that provides railroad users with a user friendly decision support tool. SelecTie II contains standard features common to Windows that will make most users familiar with the Windows environment comfortable in accessing and changing data in the SelecTie II program. These features include pull down menus, icon based toolbar, common file selection and print dialog windows, on-line help, etc. (Palese 1997).

Figure 1: SelecTie II Life Cycle Model for Comparison of Alternate Cross-Tie Systems




## ANALYSIS APPROACH

The analytical approach used in this model is the present worth analysis approach, in which all the costs associated with the two alternative systems are examined and compared in terms of a "present worth". In this approach, all future costs or savings associated with the two systems, such as future replacement or maintenance costs, are brought to the present, and the "worth" of these future costs calculated using an appropriate interest rate (thus taking into account the time value of money).

This approach is taken for each of the major cost categories for the alternative tie/fastener systems:

1. Initial Costs.
   These are costs that are incurred at year 0 and include:
   - Initial component costs
   - Initial installation costs
   - Cost of additional ballast (at installation)
   - Undercutting cost (at installation)
   - Salvage value due to components removed from the track
2. Life Cycle Costs.
   These are cost streams (i.e. cycle of costs) that are incurred in the future, rather than at the present. These include maintenance costs, operating costs, derailment risk, etc. As noted previously, these future costs must be converted into their "present" cost. The specific cost areas addressed by the model include:
   - Rail replacement costs
   - Rail transposition costs
   - Tie replacement costs
   - Basic track force costs
   - Concrete tie repair costs
   - Surfacing costs
   - Undercutting (maintenance) costs
   - Rail grinding costs
   - Gaging costs
   - Anchor adjustment costs
   - Fuel costs
   - Derailment costs

Note, not all costs are applicable to each of the component systems (i.e. concrete ties with elastic fasteners do not require gaging or anchor adjustment). These different costs are then combined, in terms of “current” dollars, to determine if there is a net benefit for either tie/fastener system.

In examining the life cycle component and maintenance costs, it became apparent that component lives and maintenance cycles are dependent on specific track, traffic, and operating characteristics which are specific to a given location and/or railroad. Therefore, in order to allow for such a model to be used in determining the relative economics of the different systems, it was necessary to make the model itself sensitive to these characteristics that influence lives and corresponding costs. These characteristics include:

- Track Characteristics
  - Curvature
  - Grade
  - Rail weight
  - Tie spacing

  - Ballast depth
  - Superelevation
  - Premium rail
  - Lubrication
- Traffic Characteristics
  - Operating speed
  - Axle load
  - Traffic density (annual tonnage)
- Economic Characteristics
  - Interest rate
- Maintenance Activities
  (see listing under life cycle costs)
- Costs
  - Component (material) costs
  - Labor costs
  - Operating costs

By providing for the ability to vary each of these areas, the desired level of flexibility and sensitivity is achievable in this cost benefit model.

**SENSITIVITIES**

A life cycle model, such as *SelecTie,* is capable of analyzing a very large range of conditions, with the final results, the relative benefits of wood vs. concrete cross-ties dependent on the specific assumptions and input values. Since there are literally hundreds of variables, the model has a built in capability of performing sensitivity analysis that allows for the ready evaluation of the sensitivity to key variables which effect the relative costs. Such a sensitivity analysis is illustrated in Figures 2 and 3, which show the effect of changing curvature MGT respectively (note the “base” values for this sensitivity include annual tonnage of 50 MGT, a timber tie cost of $27.74 and a concrete tie cost of $41.00).

Figure 2 Effect of Curvature of the Relative Economics

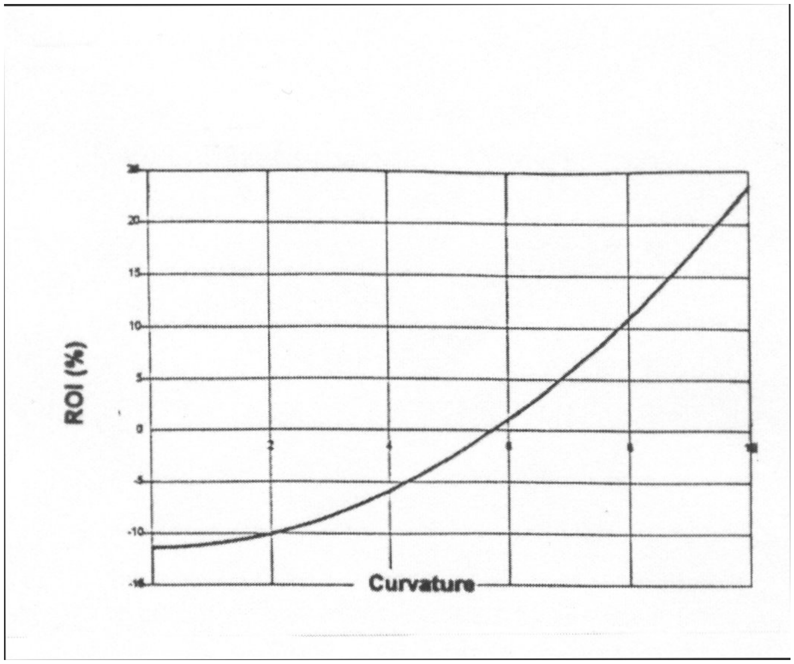
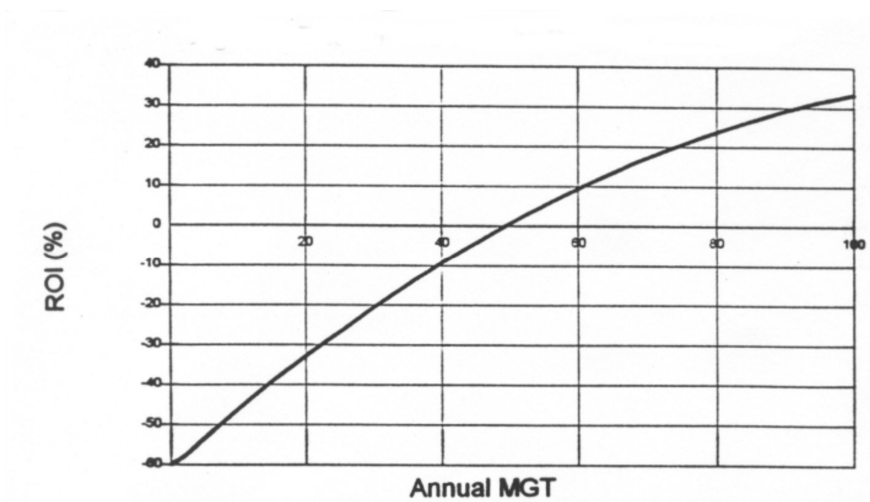



Figure 2 presents the Return on Investment (ROI) for concrete tie track as a function of the track curvature (all other variables being held constant). As can be seen in this figure, there is a negative benefit (ROI) for concrete tie track for curvatures up until 5½°. Beyond that value, the ROI for concrete becomes positive. This indicates that for this base case, wood tie track is more economic until approximately 6° after which concrete tie track becomes economically viable.

Figure 3. Effect of Annual Traffic Density (MGT) on the Relative Economics




In a similar manner Figure 3 presents the effect of varying the annual MGT for the base case with a curvature of 5 1/2°. As can be seen in this figure, the ROI for concrete tie track becomes positive as the annual tonnage increases above the MGT per year. Thus for the base case shown (and all of the associated assumed values for the 5 1/2 ° curve), if the annual MGT increases above 50, the ROI becomes positive for the conversion to concrete tie track.

As can be seen from these two examples, as individual variables are changed, to include track, traffic, maintenance, or cost characteristics, the specific "break even" points for the two sets of analysis will change.

## USE OF *SELECTIE* BY RAILWAYS

The *SelecTie* Model is the most widely used such economic model in North America, having been used by railroads representing over 200,000 miles of track (300,000 kilometers) under a broad range of operating conditions to include heavy axle load freight and lighter axle load passenger operations. This model has been used extensively by freight railroads, passenger railways, and transit systems in both the United States and Canada to assist in the decision as to where and when to use alternate cross-tie materials and has been the basis of major policy decisions on the use of these materials.

For example, CP Rail, one of the two major Canadian railways, used *SelecTie* in its evaluation process when it made the decision in 1989 to standardize on a premium wood tie for all of its heavy usage lines and conventional wood ties for its lighter usage lines. In the analysis, it found that the economics of concrete ties were simply not favorable in light of its own costs and operations.

Other railroads, such as CSX and Union Pacific the United States, which made the decision to use concrete ties on select heavy usage (high curvature, high density) lines, made use of *SelecTie* to define the “boundaries” for this usage. This was done by performing sensitivity analyses such as were shown in Figure 2. Experience led to a further refining of these boundaries, and more intense scrutiny of the interdependence of the variables (curvature, traffic density, speed, etc.) Norfolk Southern and Burlington Northern recently upgraded their models to include the newest life-cycle equations and forecasting tools as part of their ongoing economic decision making process.

Other rail systems, such as commuter railways (Los Angeles MetroLink) likewise uses *SelecTie* to decide between wood and concrete ties for major rehabilitation and upgrade projects.

## SUMMARY

The issues associated with the overall costs and benefits of alternate track components, such as timber and concrete ties (sleepers), are complex and interwoven. As such, it is not possible to universally state when concrete is economically viable or when wood is the economically attractive alternative. These decisions must be made on a case by case basis. Because of the number and range of factors (variables) that affect such a decision, use of a sophisticated analysis model is often the best way to proceed. This was certainly the case in North America with the *SelecTie* model.

Such detailed analyses show that there are locations and conditions under which either wood or concrete tie track is economically viable. That is, there are locations in track, where wood is the economically attractive alternative and there are locations in track where concrete is an economically attractive alternative. However, specific analysis must be carried out to define the respective boundaries. This was the process used by different railway systems in the US and Canada to help decide if they should use concrete ties, where they should use them, and how best to install and maintain them. This latter area, which also allows for examination of alternate maintenance practices, to include gang size, make-up, and productivity, makes is possible to examine the effects of different maintenance practice on overall (life cycle) costs. This allows for the ultimate broadening of this type of economic analysis model to investigate the sensitivity of track costs to a wide range of variables both within and outside the control of railroad engineering departments. As such, it offers the potential for being an extremely powerful economic analysis tool, one which cost conscious railways must make use of in order to help them get the maximum benefit for each “dollar” of expenditure.

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