Recent Experience with Risk Based Ultrasonic Rail Test Scheduling

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As the railroad industry continues its focus on increased safety, rail defects and resulting rail caused derailments, have become an important area of interest. Analysis of FRA statistics on reportable mainline derailments, attributed to rail defects, shows an overall industry increase in reported derailments per billion gross ton mile (BGTM) of 4% in the period 1997 to 1999 [1,2]. This trend is illustrated in Figure 1 together with the corresponding increase in the average cost of rail related derailments for that same time period of more than 40%.

Examining the FRA derailment data further, Figure 2 shows the distribution of derailments by rail defect type along with the average cost of derailment for that defect type. This figure clearly shows that the most predominant cause of rail related derailments is the transverse defect or TD class of defects, with the Detail Fracture (DF) representing the second most common cause of rail related derailments. For the entire range of rail defects, the average derailment cost varied from $200,000 to $1,400,000 depending on defect type, with an overall average of the order of $400,000. Note, this is FRA reportable cost only, the actual cost of the derailment, which could include loss of lading, train delays, or train rerouting, can be double that amount.

This increasing trend in rail related derailments suggests that there is a need for improved rail maintenance and/or inspection practices to prevent the occurrence of these defects or to find the defects before they cause these expensive derailments. These improvements can take several forms, to include more aggressive rail replacement or maintenance practices or improved rail testing equipment. However, the focus of this article is on a easier to implement approach, one that can be applied almost immediately with a relatively modest impact on a railroad's maintenance of way budget, specifically the improvement in the scheduling of conventional rail test equipment.

As rail accumulates tonnage, it tends to develop more internal fatigue defects, based on various factors such as metallurgy of the rail, traffic (to include such factors as axle loading and speed), track support conditions, etc. This behavior is illustrated in Figure 3. As defects occur more frequently, it becomes important to test more frequently in order to insure

that internal defects can be located and replaced before they have the opportunity to propagate to failure, and possibly result in a derailment. Earlier studies have indicated that approximately 1.3 derailments occur per thousand defects (detected plus service), thus highlighting the importance of matching test frequency to the rate of defect occurrence [3].

Simplistic rail test scheduling approaches, such as those based on annual tonnage levels, which do not account for aging rails and corresponding increased defects, do not give the railroad the flexibility to adjust test frequency to the actual rail conditions encountered. Likewise, simplified "rules of thumb" for scheduling ultrasonic testing, while often accounting for such factors as age of rail (usually in cumulative MGT) annual traffic density, class of track, type of traffic, defect counts, etc., do not do so in a manner that is directly tied into the "risk" of a derailment occurring. Rather, it is necessary to have a risk based scheduling methodology which makes use of site specific and directly measurable performance parameters that, in turn, can be related to a defined level of risk. Such a methodology was developed by US Department of Transportation Center Volpe National Transportation Systems Center [4], and further enhanced by ZETA-TECH Associates, Inc. [5].

RISK BASED THEORY

The risk-based test scheduling methodology is used to determine the required frequency of ultrasonic testing, on a segment by segment basis, so that a defined level of risk (failure), for each segment, is held constant, even as the rail ages. By doing so, the approach increases the percentage of defects found by detector cars, reduces the corresponding level of service failures (service to detected defect ratio) and correspondingly reduces risk of derailment. Risk, as defined by this methodology, is the allowable service defects per mile per year.

The analytical approach that forms the basis for this risk based scheduling methodology incorporates three primary phenomena that affect the occurrence of a service defect:

1) Defect Initiation: how frequent do defects initiate?
2) Defect Growth: how quickly does a defect grow from initiation to failure size?
3) Detection Reliability: how probable is it that a defect of certain size will be found?

Defect initiation refers to the rate of development of rail defects, which as illustrated in Figure 3, is directly related to the "age" of the rail, which is usually defined in terms of cumulative tonnage or cumulative MGT.

Defect Growth refers to the rate of growth of the individual defect from initiation to full size, usually defined as when it will break under a passing wheel. The key in risk based rail testing is to find the defect between the time it grows to detectable size (minimum detection threshold) and the time when actual failure is eminent (maximum allowable defect

size). This interval is of the order of 10 to 50 MGT, depending on a number of track, traffic, and environmental factors. Figure 4 shows a defect growth model for a transverse defect, where the defect is first detectable at a size of approximately 10% rail head area (HA). "Failure", which is defined at a defect size of 80% HA, is reached in 40 MGT from first detectable size. This 40 MGT interval is thus defined as the defect growth life, and represents the maximum amount of traffic that should be permitted over the defect between tests.

Detection reliability represents the "probability" of finding any given defect based on its size. Figure 5 shows a detection reliability curve for convention (standard) ultrasonic equipment, along with a model that takes into account the effects of improved inspection equipment. It can be clearly seen that as a defect grows in size, it is much more likely to be found during an ultrasonic inspection.

Thus, combining the knowledge that not every defect will be found during a given test, with the understanding of how defects initiate and propagate, allows for a better understanding of how often ultrasonic tests must be conducted to increase the chance of finding these rail defects. By combining the rate of defect initiation and growth with the probability of finding a defect of a given size (the detection reliability), it is possible to adjust the testing rate (frequency) to improve the overall probability of finding a defect in a given section of track with known defect history and tonnage. The details of this approach were presented recently at the annual meeting of the American Railway Engineering and Maintenance of Way Association (AREMA) [5]. Also presented was the development and application of a user friendly computer model (*RailTest*) that was specifically developed to calculate the optimum rail test frequency based on actual, segment specific defect, traffic, and track data (Figure 6).

Figure 7 illustrates the sensitivity of the analysis approach to several key railroad input parameters, specifically; level of risk, annual MGT and number of service defects. As can be seen from Figure 7a, as the allowable level of derailment risk decreases, the number of tests required increases. With increasing annual traffic –MGT- (see Figure 7b) the required number of test also increases. Finally, as the number of service defects found in track increases, (see Figure 7c) the number of annual tests required increases as well.

APPLICATION ON BNSF

This methodology (and the associated *RailTest* model) has been successfully applied on the Burlington Northern Santa Fe (BNSF) for the past three years in the scheduling of ultrasonic rail testing of its mainline trackage [5]. The application of this methodology has lead to real measurable benefits for the BNSF, with a significant reduction in service failures and service to detected defect ratio, and a corresponding reduction in rail related mainline derailments.

The application on BNSF required the division of the railroad's mainline track into several hundred segments averaging 70 miles in length. It also required the development of appropriate risk factors, with different levels of risk assigned to passenger carrying lines, dark territory, single track territory and to BNSF defined key routes. Analyses were run for annual and semi-annual time frames to account for seasonal fluctuations and other time related factors.

The result of this multi-year application of *RailTest,* was a well defined reduction in both service defects and in rail related derailments. These results are illustrated in Figures 8 and 9. Figure 8 presents the reduction in both service defects per mile and service to total defect ratio for the years 1997 (prior to the start of this new scheduling procedure) through 1999. As can be seen in this figure, both the service defect rate (or risk), and the service to detected defect ratio have decreased significantly, on the order of 28%. This shows that more defects were being found by the detector cars as opposed to being found as service breaks. Noting that risk is defined as the number of service defects per mile per year, BNSF was able to reduce their service defect rate to reach their defined level of risk through the implementation of this program.

In addition to the significant reductions in defect rates, Figure 9 shows the reduction in rail caused derailments since the program was implemented, reduction of 33%. This reduction is made even more significant by the fact that the rest of the industry experienced an increase in rail caused derailments of 16%.

REFERENCES

[1] US Department of Transportation Federal Railroad Administration Report, “Railroad Safety Statistics”, July 1999.

[2] Federal Railroad Administration Web Site; http://safetydata.fra.dot.gov/officeofsafety/

[3] Zarembski, A. M., “Rail Defect Type vs. Derailment Risk”, *Railway Track & Structures*, July 1988.

[4] Orringer, O., “Control of Rail Integrity By Self-Adaptive Scheduling of Rail Tests”, US Department of Transportation Federal Railroad Administration Report, DOT/FRA/ORD-90/)05, June 1990.

[5] Palese , J. W. and Wright, T. W., Risk Based Ultrasonic Rail Test Scheduling on Burlington Northern Santa Fe, American Railway Engineering and Maintenance of Way Association Annual Technical Conference, September 2000.

Figure 1. Mainline Rail Related Derailments.

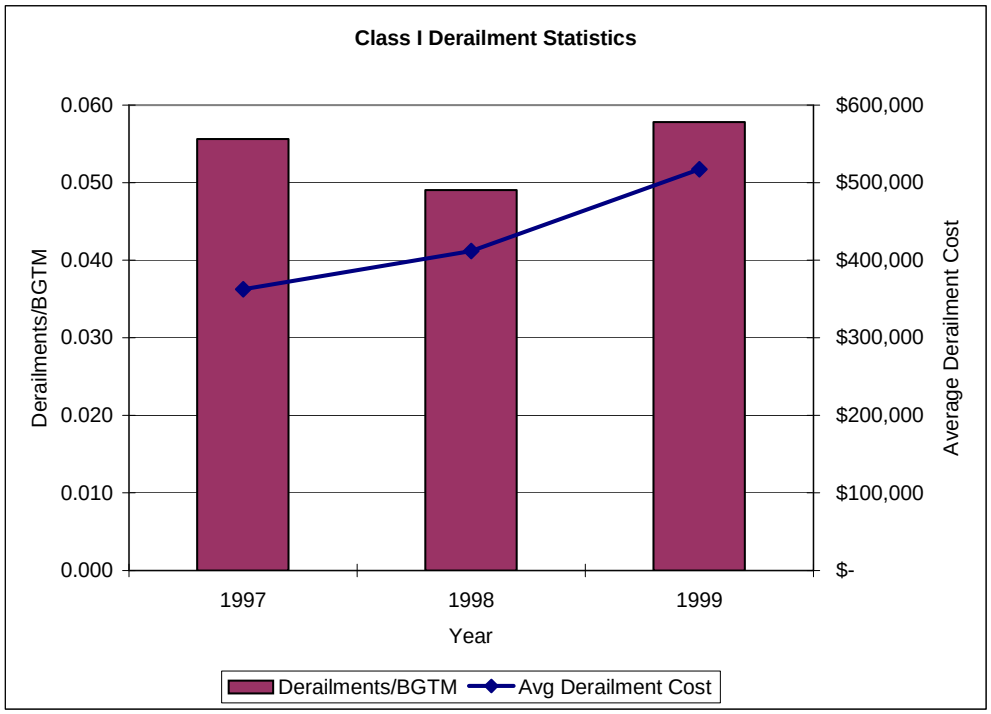


Figure 2. Rail Defect Related Derailments.

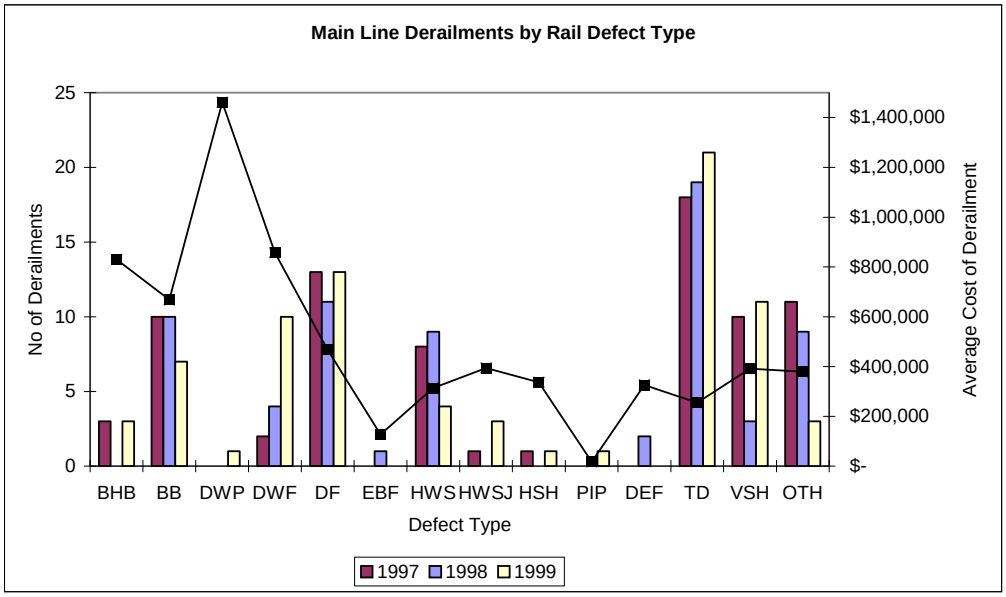


Figure 3: Defect Rate Increase with Rail Age (Cumulative Tonnage)

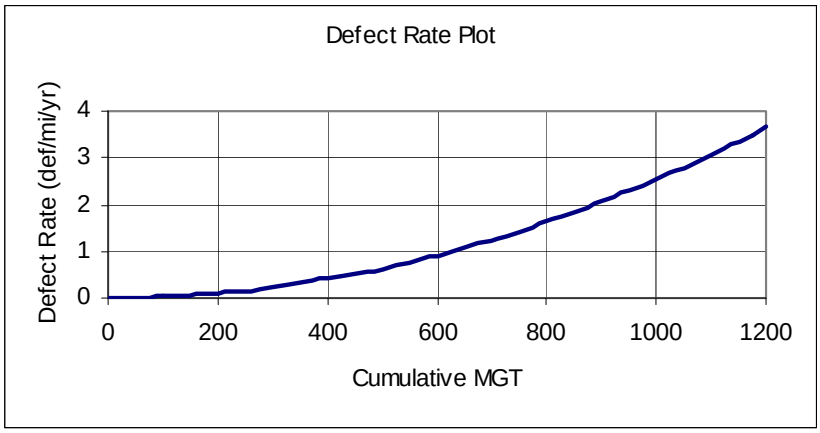


Figure 4. Defect Growth Model.

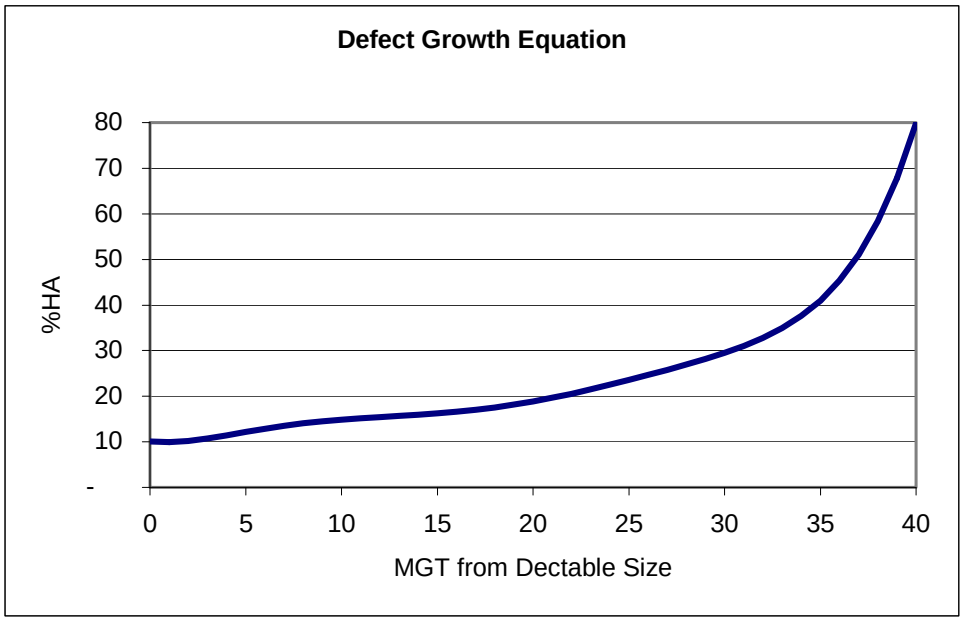


Figure 5. Detection Reliability Models.

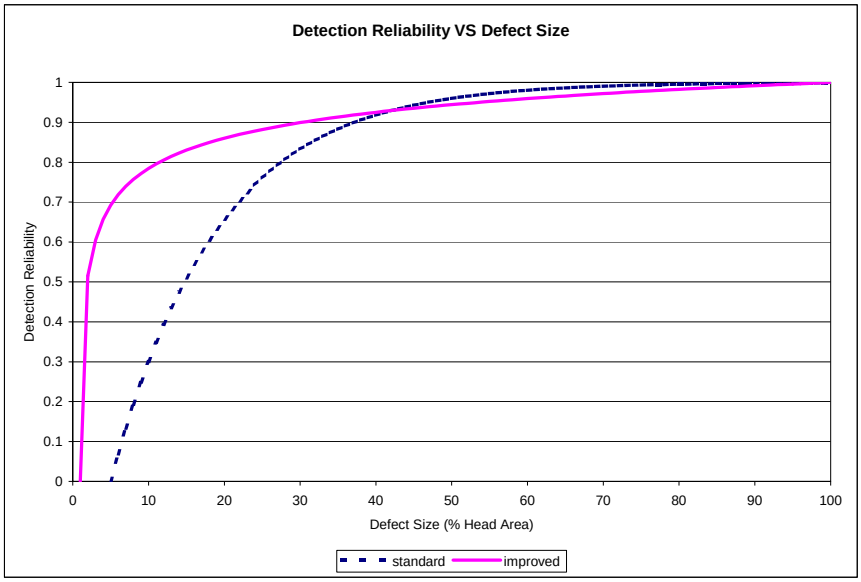


Figure 6. ***RailTest.***

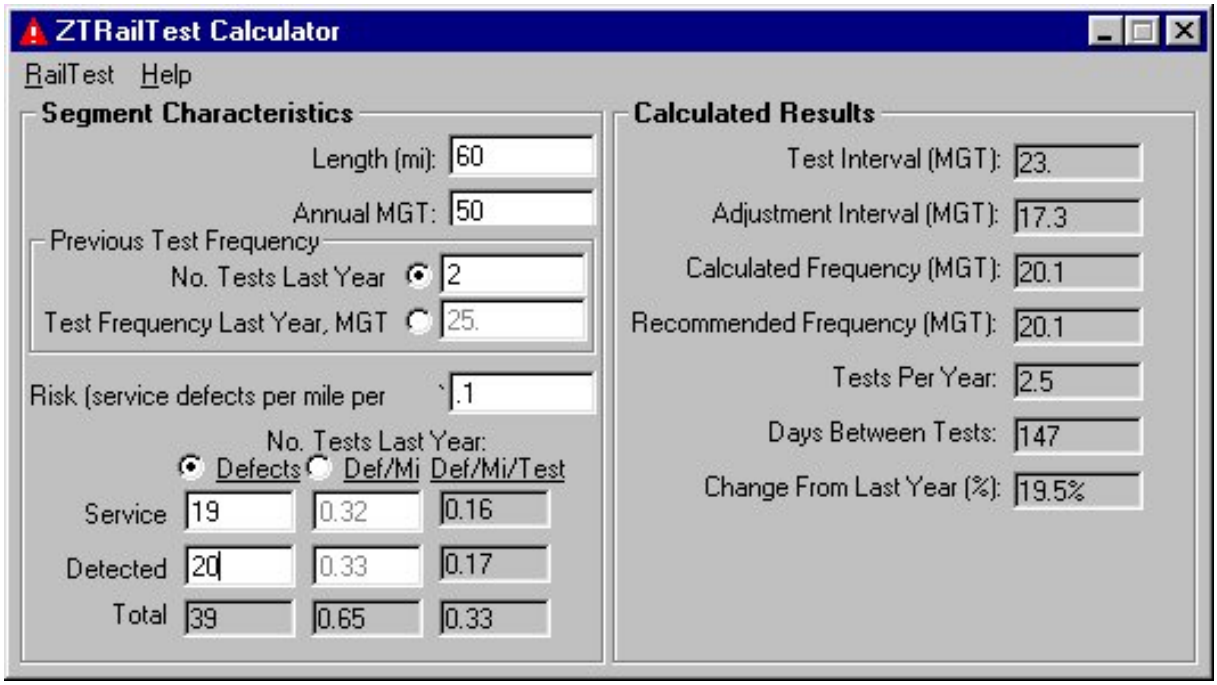
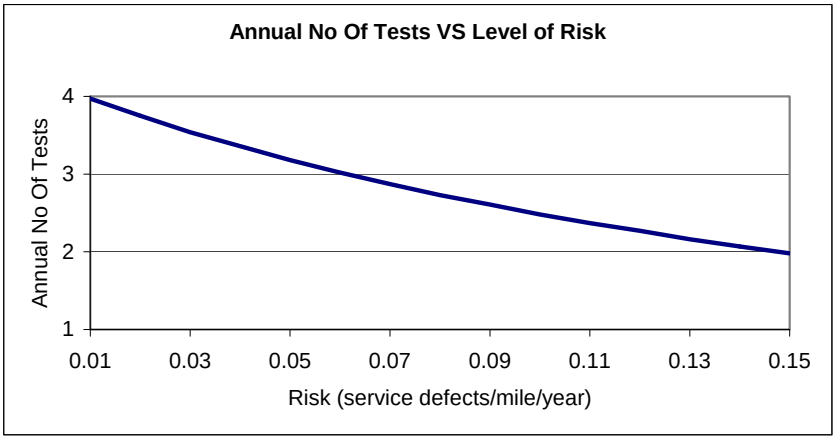
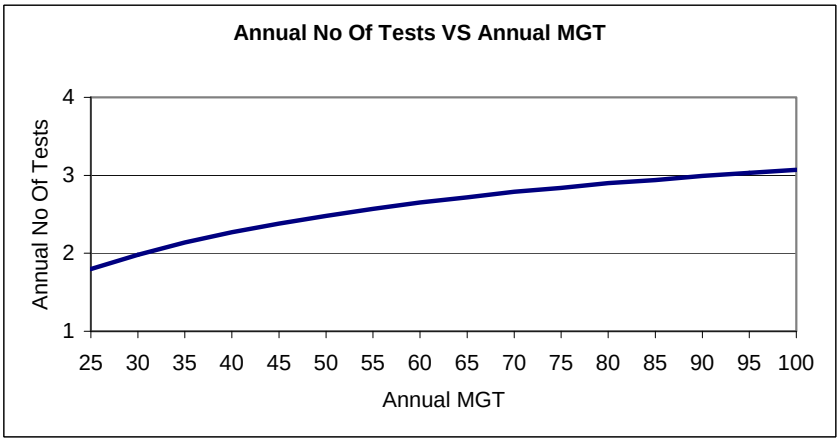


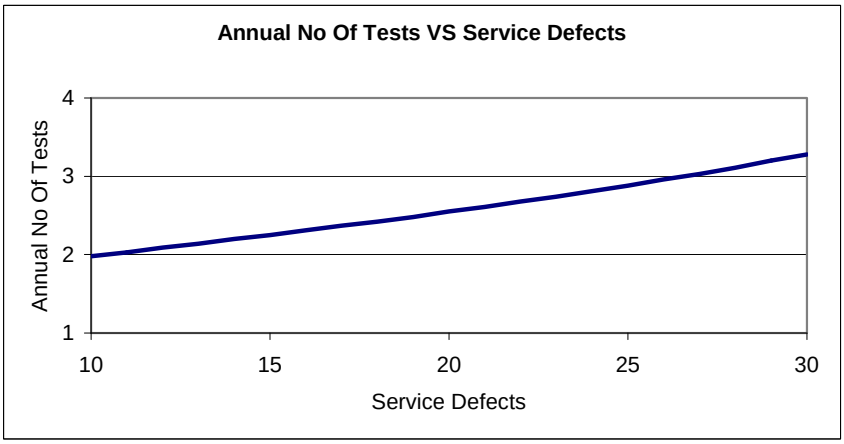
Figure 7. Sensitivity of Test Requirements to Primary Variables.



(a) Risk.



(b) Annual MGT.



(c) Service Defects.

Figure 8. Changes in Defect Rates.

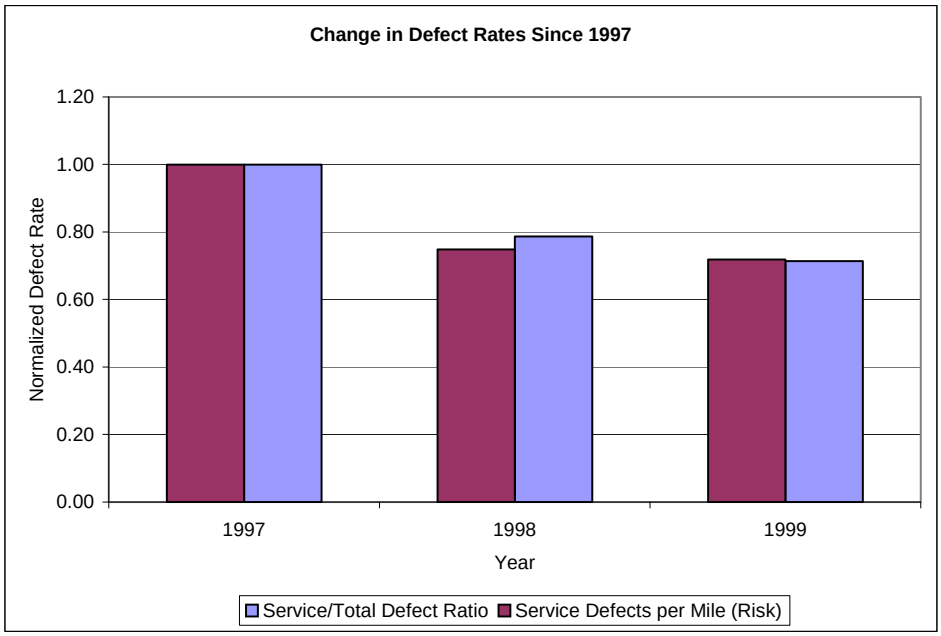
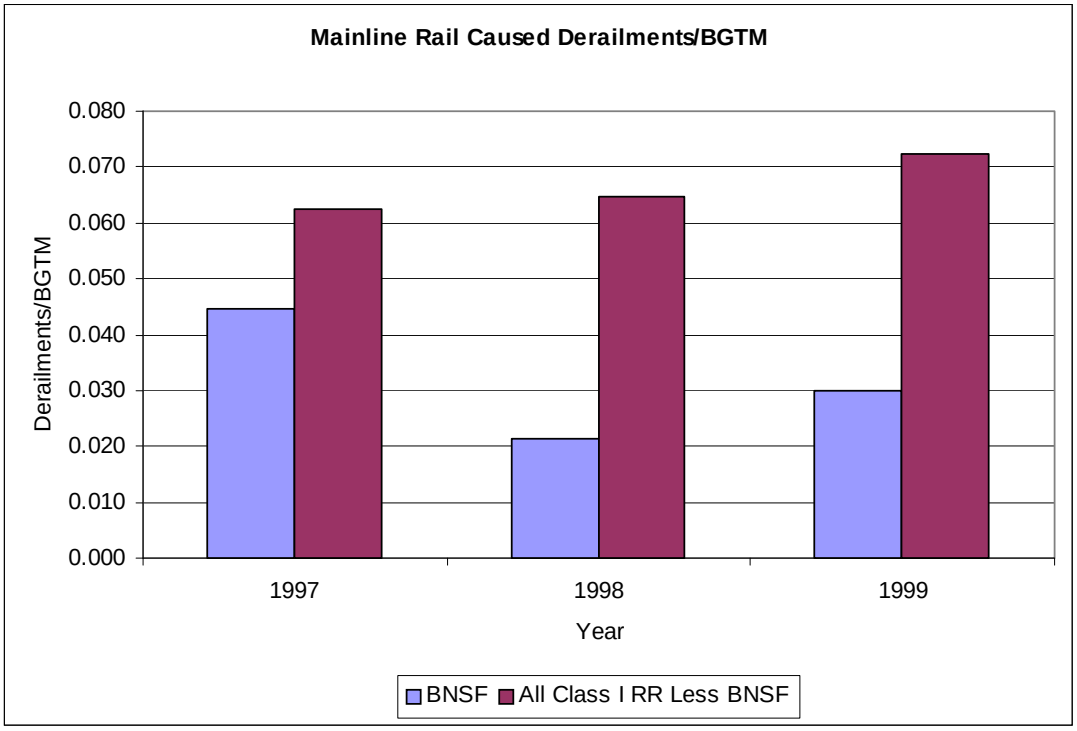



Figure 9. Mainline Rail Caused derailments.