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# Conditional Probability of Release (CPR) Estimates for Railroad Tank Cars in Accidents

RA 19-01

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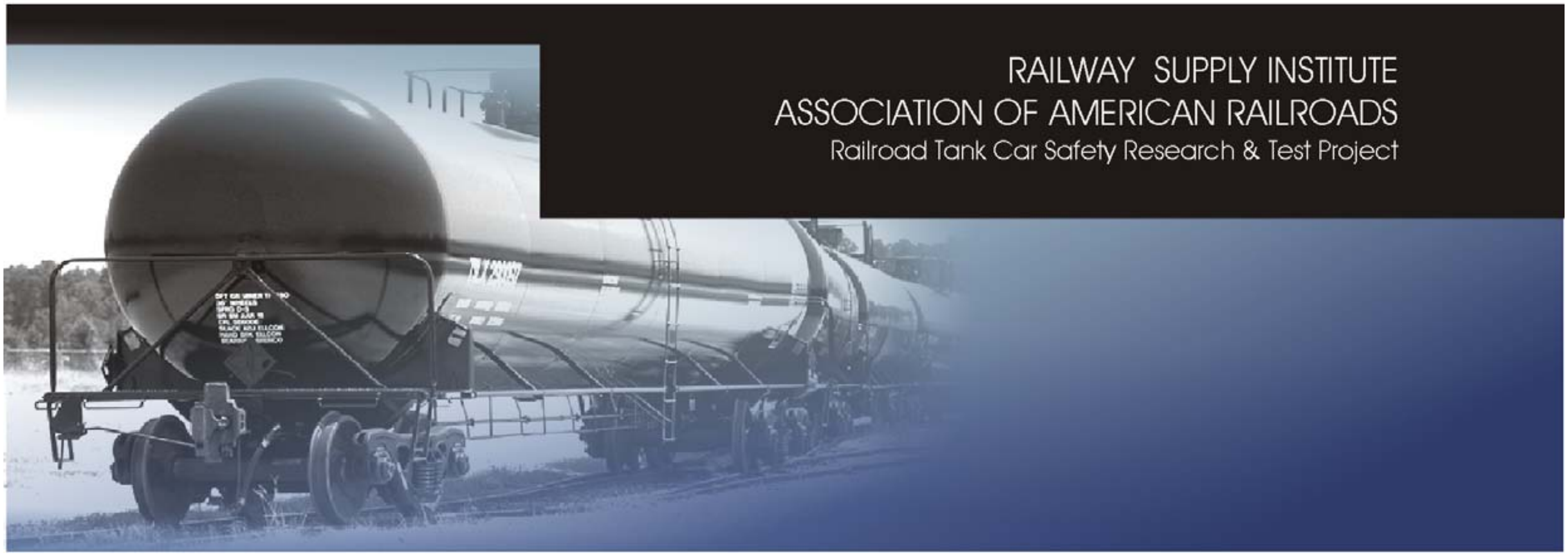

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**12. ABSTRACT**

This report presents estimates and formulas for conditional probabilities of release (CPR) for all common tank car configurations and components in service today, given that the tank car is involved in an FRA-reportable accident, as well as distributions of the quantity of lading lost in the event of a release. The study was funded by the industry partners of the Advanced Tank Car Collaborative Research Program, using data provided by the RSI-AAR Railroad Tank Car Safety Research and Test Project. The study updates and expands upon an earlier Tank Car Safety Project report: RA-05-02, "Safety Performance of Tank Cars in Accidents: Probabilities of Lading Loss", published in 2006.

The purposes of revising the RA-05-02 CPR estimates were to take advantage of data from more recent accidents, and to incorporate factors in the modeling of tank car performance that were not addressed by the earlier report. The new estimates are more reflective of current and future tank cars and accident environments.

CPR estimates for the more recent time period are generally lower than the RA-05-02 estimates for any given car. Some of the newly analyzed variables were revealed to be significant.

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# Conditional Probability of Release (CPR) Estimates for Railroad Tank Cars in Accidents

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# 1. Executive Summary

This report presents estimates and formulas for conditional probabilities of release (CPR) for most common tank car configurations and components in service today, given that the tank car is involved in an FRA-reportable accident, as well as distributions of the quantity of lading lost in the event of a release. The study was funded by the industry partners of the Advanced Tank Car Collaborative Research Program (The American Chemistry Council, The Association of American Railroads, The Chlorine Institute, The Fertilizer Institute, and The Railway Supply Institute), under the ATCCRP designation "TWP-17". The data used in the analysis were provided by the RSI-AAR Railroad Tank Car Safety Research and Test Project (the Tank Car Safety Project). The study updates and expands upon an earlier Tank Car Safety Project report: RA-05-02, "Safety Performance of Tank Cars in Accidents: Probabilities of Lading Loss", published in 2006.

The purposes of revising the RA-05-02 CPR estimates were to take advantage of data from more recent accidents, and to incorporate factors in the modeling of tank car performance that were not addressed by the analysis in RA-05-02. The new estimates are more reflective of current and future tank cars and accident environments. Some representative CPR estimates for average derailment conditions are shown in Table E1 (mainline/siding accidents).

Table E1
CPRs and $CPR_{>100}$s for Selected Tank Cars
Under Average Mainline Derailment Conditions[1]

| Car Specification | Head and Shell Thickness (in.) | Head and Shell Steel Type | Jacket | Head Shield | Top Fittings Protection | Bottom Fittings | Shell Inside Diameter (in.) | CPR | $CPR_{>100}$[2] |
|---|---|---|---|---|---|---|---|---|---|
| 111A100W1 | 0.4375 | A516 | No | No | No | Yes | 119 | 0.274 | 0.200[3] |
| 111A100W1/3 | 0.4375 | A516 | Yes | No | No | Yes | 119 | 0.134 | 0.089 |
| 111A100W1/2 | 0.4375 | A516 | No | No | No | No | 119 | 0.265 | 0.194 |
| 111A100W1/2/3 | 0.4375 | A516 | Yes | No | No | No | 119 | 0.130 | 0.086 |
| 111A100W2 | 0.5625 | A516 | No | No | Yes | No | 100.625 | 0.201 | 0.167 |
| 111A100W1 | 0.4375 | TC128B | Yes | Full | Yes | Yes | 119 | 0.064 | 0.046 |
| 111A/S100W1 | 0.500 | TC128B | No | Half | Yes | Yes | 119 | 0.132 | 0.103 |
| 117R100W | 0.4375 | A516 | Yes | Full | No[4] | Yes | 119 | 0.126 | 0.081 |
| 117R100W | 0.4375 | TC128B | Yes | Full | Yes | Yes | 119 | 0.064 | 0.046 |
| 117R100W | 0.500 | A516 | Yes | Full | No[4] | Yes | 119 | 0.106 | 0.067 |
| 117R100W | 0.500 | TC128B | Yes | Full | Yes | Yes | 119 | 0.052 | 0.037 |
| 117J100W | 0.5625 | TC128B | Yes | Full | Yes | Yes | 119 | 0.042 | 0.029 |
| 112J340W | 0.625 | TC128B | Yes | Full | Yes | No | 118.75 | 0.033 | 0.023 |
| 105J300W | 0.562 | TC128B | Yes | Full | Yes | No | 118.75 | 0.040 | 0.028 |
| 105A500W | 0.779 | TC128B | Yes | No | Yes | No | 102 | 0.040 | 0.030 |
| 105J500W | 0.797 | TC128B | Yes | Full | Yes | No | 102 | 0.031 | 0.022 |
| 112J500I | H1.03 / S0.89 | TC128B | Yes | Full | Yes | No | 115.34 | 0.017 | 0.011 |
| 105J600I | H1.136/S0.98 | TC128B | Yes | Full | Yes | No | 106 | 0.016 | 0.011 |

Criteria for the inclusion of a tank car in the study's dataset include:

- Accident occurred 1980 through 2011, the latest year for which complete data were available at the time of the analysis
- Car was built 1970 or later
- Loaded cars only
- Stub-sill cars with shelf couplers only

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[1] Assuming average conditions for a freight car in an FRA-reportable mainline accident: 29 mph train speed at the moment of derailment, 11 cars derailed, and the tank car of interest is the 6th derailed car. These averages are derived from FRA mainline and siding freight train accidents for the period 2003-2012. Note that $CPR_{>100}$ is defined in section 2(h) of the report.

[2] CPR adjusted to exclude releases of 100 gallons or less from an individual car. See Section 2(h).

[3] Preliminary analyses used CPR = 0.266 and $CPR_{>100}$ = 0.196 for non-jacketed DOT/TC-111 cars. Subsequently an adjustment was made to the tank steel assumption that resulted in a slight increase in the CPRs.

[4] Specifications for 117R100W require top fittings protection. However, while there are many different types and levels of top fittings protection today, the data used for this study did not allow those distinctions to be made quantitatively. Top fittings protection was either an impact-resistant protective housing, or none. Some current systems probably perform somewhere in between. Therefore, some examples using "No" for this field are presented, to suggest the range of performance that the real systems probably fall within.

- Tank car classes DOT/TC-111, 211, 105, 112, 114, 120 only
- Tank steel specifications TC128B, A515, A516 only
- Truck capacity 100 tons or more and 4 axles only
- Damaged by impact (as opposed to strictly by fire exposure).

This study focuses strictly on the effects of immediate impacts during a derailment. Subsequent effects of fire exposure, for example, are not addressed.

# Conditional Probability of Release (CPR) Estimates For Railroad Tank Cars in Accidents

## 1. Objectives

This report presents estimates and formulas for conditional probabilities of release (CPR) for most common tank car configurations and components in service today, given that (i.e., under the condition that) the tank car is involved in an FRA-reportable accident, as well as distributions of the quantity of lading lost in the event of a release. The study was funded by the industry partners of the Advanced Tank Car Collaborative Research Program (ATCCRP) (i.e., The American Chemistry Council, The Association of American Railroads, The Chlorine Institute, The Fertilizer Institute, and The Railway Supply Institute), under the ATCCRP designation "TWP-17" (Technical White Paper 17). The information on car features, accident details, tank car damage and lading loss that were used in the analysis was drawn from data that have been compiled since 1970 by the RSI-AAR Railroad Tank Car Safety Research and Test Project (the "Tank Car Safety Project"). This study updates and expands upon an earlier Tank Car Safety Project report: RA-05-02, "Safety Performance of Tank Cars in Accidents: Probabilities of Lading Loss" [Ref. 4], published in 2006.

The purposes of revising the RA-05-02 CPR estimates were to take advantage of data from more recent accidents, and to incorporate factors in the modeling of tank car performance that were not addressed by the analysis in RA-05-02.

The new estimates are more reflective of current and future tank cars and accident environments. The RA-05-02 dataset included accidents that occurred in the period 1965-1997. The TWP-17 analysis uses a more up-to-date dataset that extends through 2011[5] and excludes older data that are considered less relevant to current assessments of tank car safety performance.

Also, during the discussions of an Association of American Railroads (AAR) Tank Car Committee task force[6] and other activities, certain variables were identified as possibly affecting tank car accident performance that had not been explored in RA-05-02, such as tank inside diameter, jacket standoff distance, the presence of heater coils, new variables that measure the severity of the accident environment, and others. Additionally, some variables that were evaluated in RA-05-02 had not been incorporated directly into the regression analyses that produced the CPR estimates then, but instead were addressed by *ad hoc* side analyses. In TWP-17, they were included directly as independent variables in the regressions, yielding a more robust evaluation of the effects of those factors. The most prominent example of this is train speed at the time of derailment.

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[5] Although much of the crude oil fleet was built after this date, the probability estimates for these cars are valid, because all of the features on these cars had been present in the fleet for many years and are well-represented in the dataset. More discussion of this issue can be found in section 2(e).

[6] AAR Tank Car Committee Docket T87.5, "Consider Head and Shell Requirements for Non-Pressure Cars Transporting Packing Group I and II Materials".

Finally, the identification of significant variables and the determination of coefficients for those variables were accomplished in TWP-17 using more sophisticated statistical approaches than had been possible in RA-05-02. These techniques allow more robust coefficient estimation in cases where the dataset is complex.

Characterization or prediction of a single accident is not an objective of CPR analysis. CPR estimates predict the average behavior of a given car configuration over a group of accidents with similar conditions, and therefore can be used to compare predicted performance among car options. There are numerous factors in any individual accident that can cause a car's performance to diverge from the average performance over all circumstances. Appropriate uses of CPR estimates include incorporating quantitative performance data into risk assessments and supporting the benefits calculations in cost-benefit analyses aimed at selecting among a variety of packaging options.

This study presents the best understanding of statistical tank car accident performance, with respect to impact resistance, that could be developed when it was conducted. CPR estimates, as with any statistically derived estimates, are potentially subject to change over time, as accident environments evolve along with equipment and operating practices, as more and newer data come in, and as research continues. The intent is to present CPR estimates that will be useful tools now and moving forward, until updates or refinements are desired.

## 2. Approach

### a) Definition of "conditional probability of release"

A conditional probability is the probability of a specific event occurring, given that a specific condition is true. For the purpose of this report, the conditional probability of release (CPR) for a tank car is the probability that that single tank car releases any quantity[7] of lading, given that it is derailed in an FRA-reportable[8] accident.

### b) Analytic team

The TWP-17 analysis was conducted by a team consisting of experts on tank car safety data, statistics, and structural reliability at the University of Illinois at Urbana-Champaign, led by Dr. Christopher P.L. Barkan, Dr. M. Rapik Saat, and Laura Ghosh, along with Dr. Steve Kirkpatrick of Applied Research Associates and Todd Treichel of the Tank Car Safety Project.

### c) Data used in the study

The source of the data used in this study was the Tank Car Safety Project's database of tank cars damaged in accidents. The database contains records on tank cars that were damaged in

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[7] A modification wherein only releases above a certain quantity are considered will also be discussed.

[8] The Federal Railroad Administration requires that railroads report any accident that causes damage to track, equipment and/or structures exceeding a certain dollar threshold that is adjusted each year.

derailments and collisions, but only those cars for which the damage was incurred on tank-car-specific features, including the tank, fittings, jacket, head shields, and so on. For more information on this database, see Appendix A. Some additional data sources that were drawn upon for specific purposes outside of the main analytical calculations are described in Appendix E.

Cars in the Tank Car Safety Project data were included in the study dataset if they met the following criteria:

- Accident occurred 1980 through 2011, the latest year for which complete data were available at the time of the analysis
- Car was built 1970 or later
- Loaded cars only
- Cars with shelf couplers only
- Stub-sill cars only
- Tank car classes DOT/TC-111, -105, -112, -114, -120, AAR-211 only
- Tank steel specifications TC128B, A515, A516 only
- Truck capacity 100 tons or more, and 4 axles only
- All key fields had known values

Cars that were damaged only by fire and not by impact, or that released lading only because of fire exposure, were excluded. This study focuses strictly on the effects of immediate impacts during a derailment.

These criteria are essentially the same as those used in the RA-05-02 study, apart from the time frame.

As explained below, four analyses were conducted, one for each component of the car that can lose lading in an accident. The number of records used in each of the analyses, based on the criteria given above, were as shown in Table 1:

Table 1
The Number of Tank Car Records Used in Each Component Regression
And the Number of Accidents in which Those Cars Were Damaged

| Component | Tank Cars | Accidents |
|---|---|---|
| Shell | 7,165 | 4,993 |
| Head | 4,467 | 2,464 |
| Bottom Fittings | 5,484 | 3,905 |
| Top Fittings | 4,467 | 2,175 |

The differences in sizes among these datasets are due to unknowns in data fields that eliminated the record from one analysis but not the others. There are fewer accidents than cars because some accidents provided more than one car to the analyses.

d) Identification of variables for regression

The initial set of independent variables (i.e., potential factors that could affect CPR), as reflected in the four full models, was as follows:

1) Accident-related independent variables
    - Track type (main & siding, or yard & industrial)
    - Accident type (derailment vs. collision)
    - Train speed (mph)
    - Train speed squared ($mph^2$)
    - Estimated effective impact speed (mph)
    - Estimated effective impact speed squared ($mph^2$)
    - Impact opportunity factor (unit-less score)
    - Number of freight cars derailed
    - Date of accident
    - Various interactions among these variables

Notes on accident-related variables:

- Mainline and siding accidents were grouped because track and operational conditions are generally similar between the two track types. Similarly, yard accidents and industrial track accidents were grouped.

- Effective impact speed and impact opportunity factor are variables specifically developed for this study, and defined below. These and the number of freight cars derailed are intended as proxies for the amount of impact energy available for damaging a specific tank car in the accident. Although these proxies are not precise models for the behaviors they represent, they help the regression calculation to attribute different outcomes for otherwise apparently similar cars to varying amounts of available impact energy, rather than forcing these differences to be attributed to variables that are not actually driving them, i.e., they allow the regression to do a better job of evaluating the car characteristics of the most interest.

- Date of accident was included to capture any trends or changes in the accident environment over time that were not captured by other variables.

- The specific interactions included can be seen in the output from the statistical software package, provided in Appendix C.

2) Car-related independent variables

    - Shell thickness (inches)
    - Shell material type (steel specification TC128B, A516, or A515)
    - Shell inside diameter (inches)
    - Head thickness (inches)

- Head material type (steel specification TC128B, A516, or A515)
- Head shield presence/type (none, half-height, full-height)
- Jacket (yes/no)
- Insulation thickness (jacket standoff; inches)
- Tank capacity (gallons)
- External heater coils (yes/no)
- Top fittings type (pressure-car-style protective housing or not)
- Bottom fittings (equipped yes/no)
- Lading group (as a proxy for internal pressure)
- Year car built
- Car age at time of derailment
- Interactions among these variables

Notes on car-related variables:

- There were 51 records for cars that were known to have had trapezoidal head shields, which was not enough to segregate their performance from that of half-height head shields that are attached to the tank or integral to the jacket.

- Insulation thickness includes a thermal protection blanket if present.

- The only two top fittings configurations with sufficient data for the analysis were non-pressure car fittings with no derailment damage prevention system, and fittings enclosed in a pressure-car-style protective housing per 49 CFR 179.100-12. Although there are now numerous other definitions of top fittings protection, the results for the CPR performance of top fittings protection in this study are the best available for applying to all of these systems at this time.

- Lading groups were created by grouping ladings with similarity in

  a) internal pressure in the tank, because of previous impact simulations that indicated that this factor could be significant [Ref. 3], and in

  b) temperature in transportation, in case this might affect the performance of the steel.

  However, because the results were internally inconsistent and destabilized the CPR estimates, the lading groups were dropped from the final analysis.

- Bottom fittings protection is only addressed in terms of setting the CPR for bottom fittings to zero when they are absent from a car. The vast majority of cars with bottom fittings have AAR Level A protection, so there is little need to evaluate the effects of different levels, and little data to support an analysis of the uncommon B and C levels. New bottom outlet handle securement approaches have not been in the fleet long enough for there to be sufficient data to analyze those, either.

- The specific interactions included can be seen in the output from the statistical software package, provided in Appendix C.

- Uncommon or hypothetical tank thicknesses can be analyzed with the head and shell formulas derived in this study. The regression process fits a curve, and it is not necessary to have empirical data at every value that might undergo analysis. Good overall fit and predictive capabilities of the final model will preserve the accuracy of estimates for interim thicknesses. Thicknesses that extrapolate beyond the limits of the study's dataset require more care. Typically, values that are beyond but not far from the dataset range can be analyzed with good confidence, but the farther out the value lies from the dataset's range, the more caution must be taken.

3) <u>Variables Considered but Not Included</u>

The following variables were considered for inclusion, but omitted from the analysis for the reasons noted.

- Additional tank materials beyond TC128B, A515, A516 – Data exploration prior to analysis found that there were too few records for other materials, and many (other than stainless steel) are of little current interest.

- Normalization of the tank – The status of a significant fraction of tanks in the study was uncertain. Also, previous studies have found that normalization has a minimal effect on the likelihood of a failure (see Ref. 2).

- Ambient temperature – It was decided that commodity was a better proxy for internal pressure, and that ambient temperature was not a reliable proxy for tank material temperature because of the range of loading temperatures. Likewise, geographic location and season were rejected as not being reliable enough indicators of the temperatures that the tank steel would be exposed to.

- Train weight, train length – The available energy in the accident environment for the derailed tank cars generally comes from a more localized portion of the train, not the entire consist.

- Outage – The information was not available in the Tank Car Safety Project database, and there was no reliable source for this information for individual cars, especially given that outage changes during transportation.

- Loaded vs. Residue – Loaded is the more important case for safety analysis, due to the higher quantities of lading available to spill. Residue cars were excluded for homogeneity.

- Tank Class – A single class can encompass a variety of features; specifying actual features was regarded as more directly related to performance.

- Additional/specialty car specifications (e.g., DOT/TC-103, -113-, -115, AAR-204) – These cars are too different in design and failure modes from the major classes, and too few in number to support robust regression analysis.

- Full sills vs stub sills – There are too few recent full-sill records, which are also strongly correlated with certain other features. Full-sill cars were excluded for homogeneity.

- Continuous weld pads on shells – The information was not available in the Tank Car Safety Project database, and the effort to identify these was deemed greater than the value added to the study.

- Pressure car top fittings segregated by commodity – This was found to be significant in the RA-05-02 analysis, but exploratory data analysis performed early in this study did not suggest that this effect would need to be evaluated.

4) Definition of Effective Impact Speed

Although any given accident is assigned a speed at which the train derailed in its TCAD record and FRA report, the cars derailed in that accident do not all derail at the same speed, nor do they impact other objects at the same speed. Their lading loss outcomes are affected by this difference. Therefore it was hypothesized that inclusion of a variable to account for the difference could improve the modeling of variables of interest, including car features.

A new variable was created to measure this effect for any given accident, called Effective Impact Speed, or EIS.

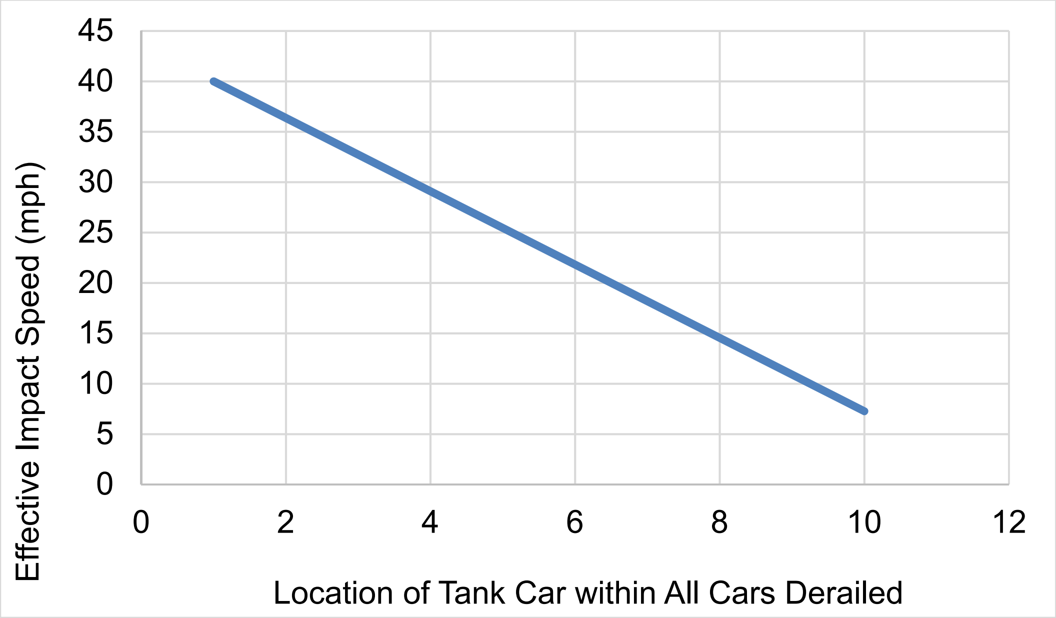
$$\mathrm{EIS} = \mathrm{TSP} \times (\mathrm{CDR}-\mathrm{TCL}+2)/(\mathrm{CDR}+1) \text{ where} \qquad (1)$$

TSP = reported train speed
TCL = tank car's location in derailed string (1 = 1st car derailed, etc.)
CDR = total number of freight cars derailed

For cars with unknown position in the derailment, or unknown derailment size, EIS was set to TSP/2.

This formula produces a linear reduction in effective impact speed from the front to the back of the derailment. Figure 1 shows an illustrative example:

Figure 1
Effective Impact Speed (EIS) Curve for a 10-Car Derailment at 40 mph



The formula does not precisely reflect the differences in real impact speeds, and is not intended to. Precision is not necessary because the purpose of this variable is not to analyze its effect on outcomes per se, but to give the regression process an additional data input to use in explaining some of the variation in outcomes that arises due to such an effect, and to minimize the effect of that variation on the characterization of other variables.

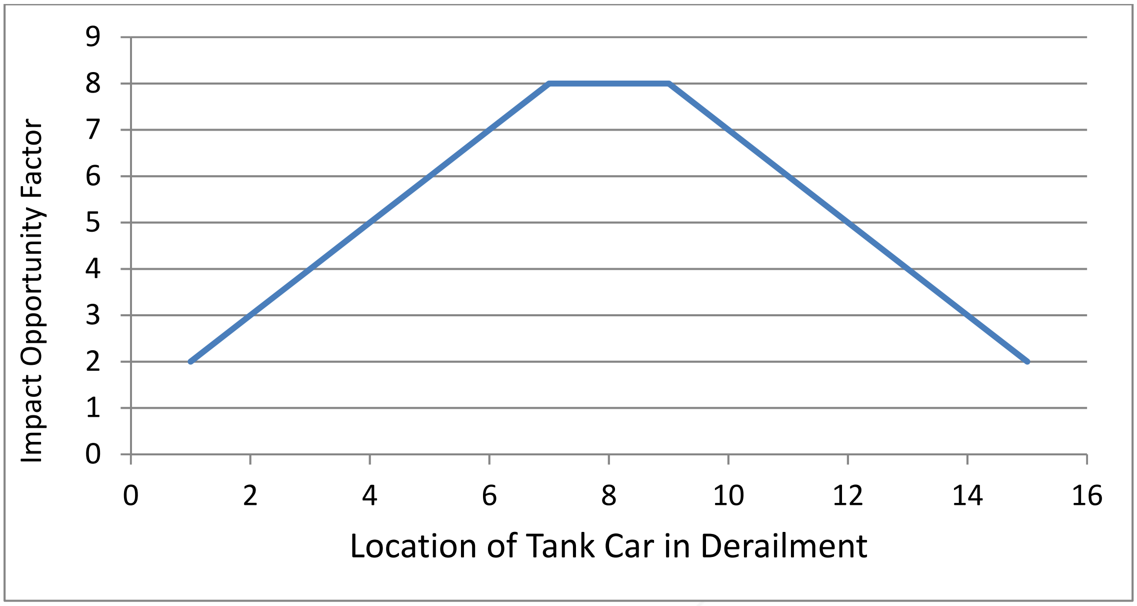
5) Definition of impact opportunity factor

Not all cars in a given accident have the same opportunities to strike or be struck by other freight cars. The cars at the front and back of the derailed string have fewer opportunities to impact other cars than do those towards the middle. The chance that a car will experience an impact capable of leak-causing damage is therefore different within the same accident. In order to account for this, a new variable was created, Impact Opportunity Factor, or IOF.

IOF = 1 for single-car derailments
= 2 for a car at either end of a multiple-car derailment
= 3 for a car one spot inwards from the end of a derailed string of at least 3
….and so on up to maximum of 8

This formula produces a curve that peaks in the middle of the derailed string. Figure 2 shows an illustrative example:

Figure 2
Impact Opportunity Factor Curve for a 15-Car Derailment



As with EIS, the curve does not precisely reflect the behavior of impact opportunities, but it does not need to in order to improve the regression.

6) Advanced variable selection approach

The power of regression is undermined when the independent variables are closely correlated. This is because the process is unable to determine which of two correlated variables is more responsible for a given car's outcome. These datasets do have correlated variables. For example, in the time period under consideration, head shields were far more likely to be found on cars with higher tank thickness than with lower thickness.

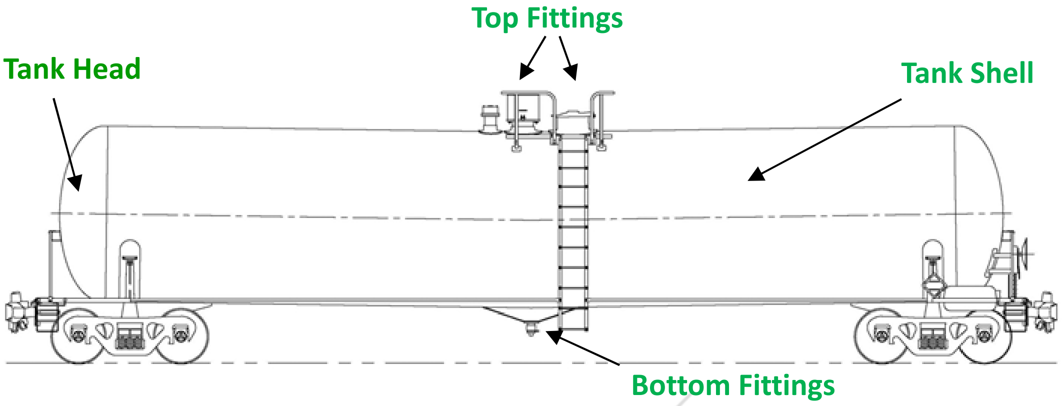
To minimize this problem, an advanced variable selection procedure, the group minimax concave penalty approach (gMCP), was conducted to identify groups of related variables that were more likely to be significant, before beginning each regression. This process helps to separate the effects of correlated variables. The technique resulted in more robust and accurate CPR estimates than would have been possible without such a step. More on gMCP can be found in Appendix B.

e) Regression approach

As in RA-05-02, a regression analysis was applied to four logistic regression formulas, or models. Each of the formulas selected as most representative of the data generates estimated CPRs that are specific to one of four components of the tank car: shell (S), head

(H), top fittings (T) and bottom fittings (B). Accident-caused lading losses come from one (or more) of these four components. A graphic representation of this scheme is shown in Figure 3.

Figure 3
Four Components of a Tank Car That Can Lose Lading



These component CPRs are then combined using a standard probabilistic formula[9] into a CPR for the car as whole:

$$CPR_{CAR} = 1 - (1 - CPR_{H})\,(1 - CPR_{S})(1 - CPR_{T})(1 - CPR_{B}) \qquad (2)$$

The regression approach begins with an equation relating the outcomes, in this case the probability of lading loss, with the independent variables, i.e., explanatory factors that are assumed to have a reasonable chance to affect those outcomes. The initial equation is the full model, which includes all of the independent variables. Logistic regression is a standard technique that is used when the dependent variable being estimated is a proportion, and therefore ranges from zero to one, such as a probability estimate.

The observations in the dataset have values for each explanatory term in the model (tank thickness, presence of a jacket, and the others), and binary outcomes of zero or one, e.g., released lading from that component, or did not. The logistic regression procedure estimates the fraction of further observations, i.e., future derailed cars of a similar nature, that will have a value of one, that is, that will release lading. The curve (i.e., subset of significant independent variables and associated coefficients) that best explains the observed data and best predicts future observations is selected as the final regression equation. The independent variables in that final equation, and the coefficients assigned to each such term by the regression computation, provide the formula for estimating CPR.

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[9] Use of this formula assumes that the component CPRs are independent, given a set of accident circumstances. This is not strictly true. However, the authors believe that the dependence is not large enough to significantly bias the results, and is additionally mitigated by the design of the full models, for example, including shell parameters in the top fittings model.

The component CPR formulas take the form:

$$\mathrm{CPR}_i = e^{L(X_i)} / [1 + e^{L(X_i)}] \times \text{FRA multiplier, where} \quad (3)$$

- $i$ = index to the car component, i.e., head, shell, top fittings or bottom fittings
- $\mathrm{CPR}_i$ = the estimated probability of loss from source i
- $L(X_i)$ = the calculated logistic regression equation for component i
- FRA multiplier as defined below

The CPR for the car as a whole then is:

$$\mathrm{CPR}_{car} = 1 - \prod_i (1 - \mathrm{CPRi}) \quad (4)$$

The features and properties of each car in the dataset are incorporated separately into the regression. That is, the input to the regression is not a car specification like "111A100W1", but a set of values that precisely describe each car's actual physical characteristics. This approach enables the wide range of characteristics in the fleet to enhance the statistical power and robustness of the analysis. Configurations that were not common in the dataset, but whose *features* are common, e.g., DOT-111 with top fittings protective housing, or DOT-117, can be analyzed accurately because of the component-by-component approach.

f) CPR for one-component losses

Cars that release lading might do so from one of the four components (shell, head, top fittings, bottom fittings), or more than one. Equation (3) above shows the formula for the CPR for one component, including the cases in which the car releases lading from more than one source. If it is desirable to consider releases strictly from one component alone, the component CPRs can be converted into mutually-exclusive ones using Equations (5a) and (5b):

$$\mathrm{CPR}_{j*} = \mathrm{CPR}_j \times \prod_{i \neq j} (1 - \mathrm{CPR}_j), \text{ and} \quad (5a)$$
$$\mathrm{CPR}_{mult} = \mathrm{CPR}_{car} - \sum_i \mathrm{CPR}_{j*}, \text{ where} \quad (5b)$$

- $\mathrm{CPR}_{j*}$ = the exclusive CPR for component j, i.e., releases from j and no other component,
- j = index to the car component for which an exclusive CPR is desired, i.e., head, shell, top fittings or bottom fittings only,
- CPRmult = CPR for releases from more than one source (any combination of two or more).

g) FRA multiplier

The FRA multiplier adjusts the condition on the probability from "given that the car is damaged" (i.e., recorded in the Safety Project accident data) to "given that the car is derailed in an FRA-reportable accident"[10]. This is important when CPR estimates are used as part of a larger quantitative risk assessment, and combined with FRA accident rates and other data based on that metric. The FRA-compatible probability is the form of CPR that is most often used by the industry.

Calculated as shown in Appendix E, the FRA multiplier is 1.00. However, this has not been the case in previous studies, and might not be in the future, or additional work might reveal a need for different multipliers for specific contexts, so the term is left in Equation (3) to be thorough and accurate.

h) CPRs adjusted for minimum quantity lost

In some cases, an analysis using CPRs provides better focus on the questions at hand if small releases are excluded from consideration. For example, industry analyses of flammable liquid package options in the past few years have excluded releases of 100 gallons or less from individual tank cars, because the users of the analyses were trying to address the risk of large pool fires resulting from substantial releases of flammable lading. Releases of 100 gallons or less could not produce this scale of incident, and the various package options did not all have the same distribution of loss quantities, so it made sense to adjust the CPRs to account for this.

This adjustment to CPR is calculated by multiplying the unadjusted CPR by the fraction of releases for the specific car configuration in question that are over 100 gallons (or any other quantity[11]), based on empirical quantity-lost distributions.

The approach to handling this is to calculate the CPR according to this formula:

$$CPR_{>X,CAR} = 1 - \Pi_{i=H,S,T,B}\,(1 - CPR_i \times Q(i,X)), \text{ where} \tag{6}$$

- $CPR_{>X,CAR}$ = the quantity-adjusted CPR for the car as a whole,
- X = the gallon threshold; releases of X gallons or less will be excluded from $CPR_{>X,CAR}$
- i = index to the car component, , i.e., head, shell, top fittings or bottom fittings,

---

[10] It sometimes occurs that cars are damaged in a way that qualifies them for inclusion in the Safety Project accident database, but does not bring the total cost of the accident up to the FRA reportability threshold. The opposite frequently occurs, i.e., a car is derailed as part of an FRA-reportable accident, but not damaged in a way that threatens containment of the lading.

[11] Note that the quantity-lost distribution data necessary to do this for other quantities are not presented here, and are beyond the scope of this report.

- $CPR_i$ = the unadjusted component CPR for component i, and
- Q(i,X) = the probability that a release from component i on the car being estimated is greater than X gallons.

So $CPR_{>X}$ is the probability that a single tank car releases more than X gallons, given that it is derailed in an FRA-reportable accident.

i) Quantity lost

The quantity of lading lost, given a release, was also analyzed, separately from CPR. The study characterized the distribution of lading lost from each of the four car components. Initially, regressions were attempted with categories of quantity lost as the dependent variable. However, there are far fewer release observations than damaged car observations, and not enough to support a robust regression. Therefore empirical histograms are provided instead.

j) Expected Quantity Released (EQR)

The term expected quantity of release (EQR) represents the average quantity lost per car derailed. (Note: It is not the average per car releasing. All non-releasing cars contribute zeros to the sum of all losses in the numerator of the calculation, while each releasing car contributes its own specific loss quantity to the numerator.) This metric is sometimes used instead of CPR for car comparisons. EQR is calculated by combining the four component CPRs for a particular car configuration with the quantity-lost distributions for each of those components. In principle the general form of such a calculation would be

$$EQR_i = \sum_{c=H,S,TF,BF} (CPRc,i * Qc,i) \tag{7}$$

where

- $EQR_i$ = Expected Quantity Released for car i
- CPRc,i = CPR for car i and component c = H, S, TF or BF
- Qc,i = Average quantity lost from releases from component c on car i

However, some releases occur from multiple components on the same derailed car. When an accident data record is created, there is generally no way to determine how much of the total loss from the car came from each separate release location, so such data are not available. In equation (7) above, losses from multiple components are double-counted. Therefore, an adjustment must be made. A fifth “component”, or loss source, is created: Multiple, for losses from two or more sources. This source will be associated with its own average loss quantity. (Note that no effort is made to segregate the different pairings and combinations of sources that all contribute to the Multiple category. These differences are often small and are relevant to a small percentage of releases, and therefore this further adjustment is not necessary.)

If $CPR^*_c$ designates the probability of a loss from component c alone, then

$$CPR'_c = CPR_c \times \prod_{n \neq c} (1 - CPR_n) \tag{8}$$

where c and n are indices to the principal four sources: H, S, TF, and BF.

And

$$CPR'_m = CPR_{car} - \sum_c CPR^*_c \tag{9}$$

where $CPR_m$ is the probability of a multiple-source release, and $CPR_{car}$ is the CPR for the whole car.

These single-source CPRs for the four principal sources and Multiple are mutually exclusive, and can therefore be summed to arrive at the overall car CPR. They also allow the proper calculation of EQR for car *i*:

$$EQR_i = \sum_{c=H,S,TF,BF,M} (CPR'c, i * Qc, i) \tag{10}$$

Safety features that reduce CPR for a component that experiences relatively small releases (e.g., top fittings) will reduce EQR to a smaller degree than they will reduce CPR, and to a smaller degree than alternative features that create the same reduction in CPR, but for a component that typically experiences larger releases (e.g., shell).

In practice, a simplifying assumption needs to be made if an analyst is relying on this report. The data on release quantities for some car/component combinations are not very numerous. Therefore the loss quantity data in the Results section of this report are given for pressure cars and non-pressure cars, rather than a more fine-grained selection of cars and features. The EQR example is calculated this way.

Note that this assumes that pressure car ladings are pressurized, and non-pressure car ladings are not under high pressure. It is assumed that the foremost reason for differences between the two groups of cars in terms of quantities lost given a release has to do with internal pressure and differences in lading behavior. If the cars of interest depart from these assumptions, for example, flammable liquids transported in DOT-120 cars, then the analyst should use the most reasonable assumptions about the distributions of quantity lost.

With this simplified approach, the quantity lost for a given component does not vary with the presence or absence of safety features or tank thickness differences. Only the component CPR portion of the calculation varies. Protection for those components that generally release more lading will still affect the EQR more than protection for components that release less. The EQR still is affected by relevant changes to each component, and can discriminate appropriately among car options in this regard.

## 3. Results

### a) CPR formulas

The variables that had a significant effect on the four component CPRs in the regressions are shown below. Note that “significant” here means statistically significant, i.e., there is sufficient evidence in the data to conclude that the factor has a measurable effect on CPR. Variables that were not statistically significant have dropped out of the calculated regression equations. It should be noted that "statistically significant" is not the same as "materially significant". The regression coefficient for a given factor may be small enough that the effect of the factor on CPR is quite small, even though we are confident that there is a non-zero effect.

These expressions 1 through 4 below are represented by the term $L(X_i)$ in the CPR equation (4) in Section 2(e) above.

#### 1) Shell CPR formula

| | Coefficient | | Variable | |
|---|---|---|---|---|
| $L_{SHELL}$ = | 5.6289 | | (Intercept) | (11) |
| + | -5.2092 | × | Shell thickness (inches) | |
| + | -1.0986 | × | Jacket (yes=1) | |
| + | -0.0588 | × | Shell inside diameter (inches) | |
| + | -0.0514 | × | Train speed (mph) | |
| + | 0.00147 | × | Train speed squared ($mph^2$) | |
| + | -0.0254 | × | Effective impact speed (mph) | |
| + | -0.00032 | × | Effective impact speed squared ($mph^2$) | |
| + | -0.0953 | × | Cars derailed | |
| + | 0.0739 | × | Impact oppo×tunity factor (scalar) | |
| + | 0.00729 | × | Train speed x cars derailed | |
| + | -0.00009 | × | Train speed squared x cars derailed | |
| + | 0.00736 | × | Effective impact speed x Impact opportunity | |

#### 2) Head CPR formula

| | Coefficient | | Variable | |
|---|---|---|---|---|
| $L_{HEAD}$ = | -1.5145 | | (Intercept) | (12) |
| + | -3.0699 | × | Head shield – Full (yes=1) | |
| + | -2.8387 | × | Head shield – Half/jacket (yes=1) | |
| + | -0.6773 | × | Head shield – Half/no jacket (yes=1) | |
| + | -1.6871 | × | Jacket – no head shield (yes=1) | |

| | | | | |
|---|---|---|---|---|
| + | -0.3447 | × | Head thickness (inches) | |
| + | 0.5572 | × | Heater coils (yes=1) | |
| + | 0.000433 | × | Train speed (mph) | |
| + | -0.2281 | × | Impact opportunity factor (scalar) | |
| + | -0.7613 | × | Derailment vs. collision (Der.=1) | |
| + | 0.00709 | × | Train speed x impact opportunity | |

3) Top fittings CPR formula

| | Coefficient | | Variable | |
|---|---|---|---|---|
| $L_{TOPFTG}$ = | 0.5555 | | (Intercept) | (13) |
| + | 0.6168 | × | Shell material A515 (yes=1) | |
| + | 0.0675 | × | Shell material A516 (yes=1) | |
| + | -2.7467 | × | Shell thickness (inches) | |
| + | -0.5928 | × | Jacket (yes=1) | |
| + | -0.0198 | × | Shell inside diameter (inches) | |
| + | -1.0092 | × | Top fittings protective housing (yes=1) | |
| + | 0.8004 | × | Derailment vs collision (Der.=1) | |
| + | 0.000483 | × | Effective impact speed squared ($mph^2$) | |
| + | 0.0195 | × | Train speed (mph) | |
| + | -0.00084 | × | Train speed squared ($mph^2$) | |
| + | 0.0584 | × | Impact opportunity (scalar) | |
| + | -0.0009 | × | Train speed x cars derailed | |
| + | 0.00002 | × | Cars derailed x train speed squared | |
| + | 0.00004 | × | Train speed squared x impact opportunity | |

4) Bottom fitting CPR formula

| | Coefficient | | Variable | |
|---|---|---|---|---|
| $L_{BOTFTG}$ = | -2.3275 | × | (Intercept) | (14) |
| + | -0.873 | × | Jacket (yes=1) | |
| + | -5.2546 | × | Shell thickness (inches) | |
| + | 0.00328 | × | Train speed (mph) | |
| + | 0.000846 | × | Train speed squared ($mph^2$) | |
| + | -0.0275 | × | Effective impact speed (mph) | |
| + | 0.0578 | × | Cars derailed (integer) | |
| + | -0.2307 | × | Impact opportunity factor (scalar) | |
| + | -0.00003 | × | Train speed squared x cars derailed | |
| + | 0.0111 | × | Effective impact speed x impact opportunity | |

Note if the car is not equipped with bottom fittings, then $CPR_{BOTFTG}$ is automatically set to zero.

A few of the factors in these formulas are less intuitive than others at first consideration. For example, the presence of heater coils appears in the Head CPR formula, even though heater coils are not applied to tank heads. Perhaps heater coils affect the way that shells and heads interact to absorb energy during an impact; however, this would require more study to confirm or explain. But in a regression done in conjunction with gMCP, groups of related variables identified as important by that pre-regression process are included together unless there is a strong reason not to do so. These must be interpreted as a group for the following reason. Heater coils appear on jacketed cars, and jacket, head shield type and head thickness form a complex group of correlated factors that are all related to head puncture resistance. In such cases, the gMCP reduces the impact of correlations among the variables, but cannot eliminate it. (Note too that although the effect of coils is statistically significant, it is minimal; for a typical DOT-111, the $CPR_{>100}$ goes from 0.196 to 0.189 when coils are added.)

Another way that gMCP treats a group of variables together is when it uses an interaction term to temper the effect of a main-effect factor. This can result in a counter-intuitive coefficient sign on some factors. For example, the coefficient on the Impact Opportunity Factor in the Head model is negative, apparently implying that CPR for a given tank car will go down as the number of derailed cars around the tank car (i.e., that it could potentially be impacted by) increases, which is counter-intuitive. However, this factor in this model is tied together with train speed by an interaction term, and the collective effect works in the direction that one would intuitively expect. There are several possible explanations for this analytic result. First, the calculations determined that the overall fit of the resulting formula to the data is best when these are the coefficients. Secondly, there could be complex effects at work that are beyond the capability of these formulations to reflect. For example, some derailments unfold in a linear fashion, while others form the common “accordion” pattern. The opportunities for heads to be damaged are different in these scenarios, and they may occur under different conditions, including train speed. More work would need to be done to settle whether phenomena like that are at work. In the shell model, train speed, cars derailed, and effective train speed receive negative coefficients. Again, interaction terms involving these three factors (and with other variables) are included in the model, and the collective effect works in the expected direction. CPRs move in the expected direction when any of these factors is increased or decreased. Taken collectively, the effects are logical. If this were not the case in this study, the example CPR estimates shown in Table 2 below and elsewhere would produce illogical comparisons, but they do not.

A few other inclusions may need explanation. The formulas consistently find little effect from tank steel specification. This is consistent with previous research using empirical accident data (Ref. 4). However, in the top fittings model, A515 steel is found to significantly differ from A516 or TC128B, and there is a modest difference between A516 and TC128B (Note that TC128B was indicated by setting the A515 and A516 variables to zero). This may be due to the effects on top fittings from the behavior of the tank and fittings nozzle, but more work would be needed to explore the cause. In any event, the result is not counter-intuitive and there is no evident reason to remove the factor, so it has been retained. (The overall CPR effect of the variable is again modest but not totally negligible; see for example the difference between DOT-111s with TC-128 tanks vs, A516 in Table 4 below, which is attributable to this factor in this model.)

Shell thickness has a significant effect on bottom-fittings CPR, and this also deserves explanation, as it might be thought that all cars with bottom fittings would have the same tank thickness, thereby preventing an effect from that variable being found. Although a substantial majority (about 90%) of the cars in the database that were equipped with bottom fittings had the same shell thickness, 7/16", not all of them did. The remaining 10% (over 500 cars) had thicker shells, which is enough to allow the regression to determine an effect. For example, there are 159 cars with bottom fittings and a shell thickness of 5/8" and only three of these cars had bottom fittings losses (1.9%), compared to 3.0% for 7/16" cars. The data robustly support this finding.

### b) CPRs for common tank cars and other cars of interest

Table 2 shows mainline CPR estimates for a variety of common tank cars and other cars of interest, based on the assumed configurations given. The following accident details are also assumed, based on the average mainline freight train accident reported to FRA from 2003 to 2012: train speed of 26 mph, 11 cars derailed, the tank car is the 6th car derailed. (Variations in these assumptions would change the CPR estimates in accord with the component CPR formulas.) Also assumed for comparative purposes is that the first car derailed was the first freight car in the train. The latter assumption affects only the EIS calculation, and any value could have been chosen as long as it was held constant from one estimate to the next.

Table 2[12]
CPRs and CPR$_{>100}$s for Selected Tank Cars
Under Average Mainline Derailment Conditions

| Car Specification | Head and Shell Thickness (in.) | Head and Shell Steel Type | Jacket | Head Shield | Top Fittings Protection | Bottom Fittings | Shell Inside Diameter (in.) | CPR | CPR$_{>100}$ |
|---|---|---|---|---|---|---|---|---|---|
| 111A100W1 | 0.4375 | A516 | No | No | No | Yes | 119 | 0.274 | 0.200[13] |
| 111A100W1/3 | 0.4375 | A516 | Yes | No | No | Yes | 119 | 0.134 | 0.089 |
| 111A100W1/2 | 0.4375 | A516 | No | No | No | No | 119 | 0.265 | 0.194 |
| 111A100W1/2/3 | 0.4375 | A516 | Yes | No | No | No | 119 | 0.130 | 0.086 |
| 111A100W2 | 0.5625 | A516 | No | No | Yes | No | 100.625 | 0.201 | 0.167 |
| 111A100W1 | 0.4375 | TC128B | Yes | Full | Yes | Yes | 119 | 0.064 | 0.046 |
| 111A/S100W1 | 0.500 | TC128B | No | Half | Yes | Yes | 119 | 0.132 | 0.103 |
| 117R100W | 0.4375 | A516 | Yes | Full | No[14] | Yes | 119 | 0.126 | 0.081 |
| 117R100W | 0.4375 | TC128B | Yes | Full | Yes | Yes | 119 | 0.064 | 0.046 |
| 117R100W | 0.500 | A516 | Yes | Full | No14 | Yes | 119 | 0.106 | 0.067 |
| 117R100W | 0.500 | TC128B | Yes | Full | Yes | Yes | 119 | 0.052 | 0.037 |
| 117J100W | 0.5625 | TC128B | Yes | Full | Yes | Yes | 119 | 0.042 | 0.029 |
| 112J340W | 0.625 | TC128B | Yes | Full | Yes | No | 118.75 | 0.033 | 0.023 |
| 105J300W | 0.562 | TC128B | Yes | Full | Yes | No | 118.75 | 0.040 | 0.028 |
| 105A500W | 0.779 | TC128B | Yes | No | Yes | No | 102 | 0.040 | 0.030 |
| 105J500W | 0.797 | TC128B | Yes | Full | Yes | No | 102 | 0.031 | 0.022 |
| 112J500I | H1.03 / S0.89 | TC128B | Yes | Full | Yes | No | 115.34 | 0.017 | 0.011 |
| 105J600I | H1.136/S0.98 | TC128B | Yes | Full | Yes | No | 106 | 0.016 | 0.011 |

c) Tank thickness effects

The results confirm that increased tank thickness reduces CPR, all else being equal. Examples can be found in Table 3. Some of these cars are hypothetical, and are only included for illustrative purposes. The comparison would change with changes in other car and accident factors, but increasing tank thickness always reduces CPR.

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[12] Table 2 is identical to Table E1 in the Executive Summary.

[13] Preliminary analyses used CPR = 0.266 and CPR$_{>100}$ = 0.196 for non-jacketed DOT/TC-111 cars. Subsequently an adjustment was made to the tank steel assumption that resulted in a slight increase in the CPRs.

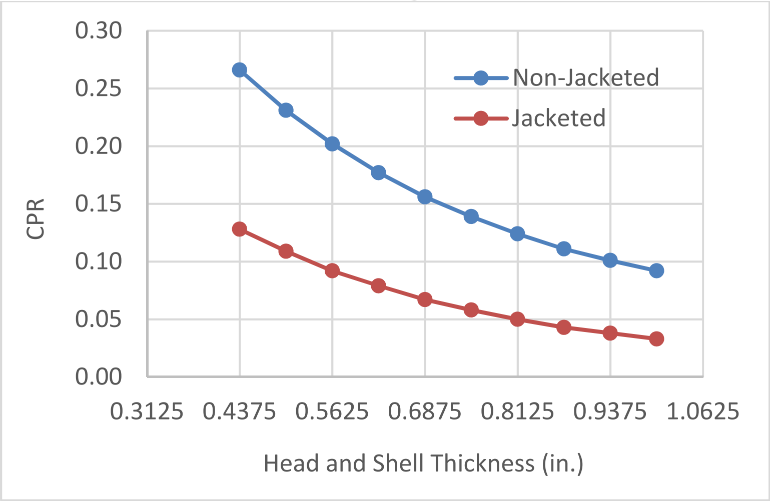
[14] Specifications for 117R100W require top fittings protection. However, while there are many different types and levels of top fittings protection today, the data used for this study did not allow those distinctions to be made quantitatively. Top fittings protection was either an impact-resistant protective housing, or none. Some current systems probably perform somewhere in between. Therefore, some examples using "No" for this field are presented, to suggest the range of performance that the real systems probably fall within.

Table 3
CPRs and $\text{CPR}_{>100}$s for Selected Groups of Comparable Tank Cars
With Different Tank Thicknesses
Under Average Mainline Derailment Conditions

| Car Spec. | Head and Shell Thickness (in.) | Head and Shell Steel Type | Jacket | Head Shield | Top Fittings Protection | Bottom Fittings | Shell Inside Diameter (in.) | CPR | $\text{CPR}_{>100}$ |
|---|---|---|---|---|---|---|---|---|---|
| 111A100W1 | 0.4375 | A516 | No | No | No | Yes | 119 | 0.274 | 0.200 |
| 111A100W1 | 0.5000 | A516 | No | No | No | Yes | 119 | 0.239 | 0.173 |
| 111A100W1 | 0.5625 | A516 | No | No | No | Yes | 119 | 0.208 | 0.151 |
| 111A100W1 | 0.6250 | A516 | No | No | No | Yes | 119 | 0.182 | 0.133 |
| 105J300W | 0.5625 | TC128B | Yes | Full | Yes | No | 118.75 | 0.040 | 0.028 |
| 112J340W | 0.625 | TC128B | Yes | Full | Yes | No | 118.75 | 0.033 | 0.023 |

Figure 4 illustrates the general relationship between tank thickness and CPR. The DOT-111 cars are assumed to have bottom fittings and 119” inside diameter, and no top fittings protection or head shields.

Figure 4
Relationship Between Tank Thickness and CPR
Illustrated for Jacketed and Non-Jacketed 111A100W1 Tank Cars
Under Average Mainline Derailment Conditions



### d) Tank steel type effects

The results indicate that there is little difference in empirical CPR performance between TC128B steel and A516, but both provide lower CPRs than A515, all else being equal. Examples can be found in Table 4. The laboratory performance of TC128B and A516 is not equal, but this study finds that the difference in yield strength and other properties does not translate into a significant difference in accident performance. This is possibly because impacts that deliver forces that fall within the interval between the two strengths might not dominate the accident environments. Similar studies over the years have found the same result. It should be noted that the differences between A516 and TC128B in this table are less than the uncertainty surrounding either estimate, i.e., they are not statistically significant, although they are directionally consistent with lab data.

Table 4
CPRs and $\text{CPR}_{>100}$s for Selected Pairs of Comparable Tank Cars
With Different Tank Steel Types
Under Average Mainline Derailment Conditions

| Car Spec. | Head and Shell Thickness (in.) | Head and Shell Steel Type | Jacket | Head Shield | Top Fittings Protection | Bottom Fittings | Shell Inside Diameter (in.) | CPR | $\text{CPR}_{>100}$ |
|---|---|---|---|---|---|---|---|---|---|
| 111A100W1 | 0.4375 | A515 | No | No | No | Yes | 119 | 0.354 | 0.246 |
| 111A100W1 | 0.4375 | A516 | No | No | No | Yes | 119 | 0.274 | 0.200 |
| 111A100W1 | 0.4375 | TC128B | No | No | No | Yes | 119 | 0.266 | 0.196 |
| 112J340W | 0.625 | A515 | Yes | Full | Yes | No | 118.75 | 0.051 | 0.033 |
| 112J340W | 0.625 | A516 | Yes | Full | Yes | No | 118.75 | 0.034 | 0.024 |
| 112J340W | 0.625 | TC128B | Yes | Full | Yes | No | 118.75 | 0.033 | 0.023 |

e) Top fittings protection effects

The results confirm that there are benefits to protecting the top fittings in a damage-resistant housing. Table 5 shows one comparison. The comparison would change with changes in other car and accident factors, and as noted in the notes on the data in Section 2(d)(2), there are other top fittings protection systems in the fleet now[15] whose

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[15] Another aspect of top fittings can be considered, and further work should be done to determine whether an adjustment should be made to account for this. Top fittings protection as defined in this study is a pressure car protective housing design, and its performance is based on the accident history with that system. Historically, cars with a protective housing were pressure cars, and therefore did not have a separate manway; the housing was mounted on a pressure plate that also sealed the manway. On a DOT/TC-117 car, on the other hand, the manway generally will be separate from the fittings nozzle. Therefore, with respect to top fittings protection overall, the 117 car falls somewhere in between the 111 car and a pressure car. Based on Tank Car Safety Project data for the study period, 29% of top fittings releases from flammable liquid and combustible liquid 111s came from the manway. It may make sense to adjust the benefit of top fittings protection for these cars by that amount. However, there are other factors, including possible protection due the manway's placement directly adjacent to the robust protective housing that might provide some safety benefit in certain types of accident scenarios. Resolution of this question will require analysis beyond this study. CPR studies require revisiting and updating over time as new or more refined data become available and the TWP-17 study is no exception. When new work indicates that CPR estimates need adjustment, supplemental reports will be issued to provide analysts with more current data and statistics.

performance cannot be distinguished in this study. Adding top fittings protection always reduces CPR.

Table 5
CPRs and $CPR_{>100}$s for Comparable Tank Cars
With Different Top Fittings Protection Levels
Under Average Mainline Derailment Conditions

| Car Spec. | Head and Shell Thickness (in.) | Head and Shell Steel Type | Jacket | Head Shield | Top Fittings Protection | Bottom Fittings | Shell Inside Diameter (in.) | CPR | $CPR_{>100}$ |
|---|---|---|---|---|---|---|---|---|---|
| 111A100W1 | 0.4375 | A516 | No | No | No | Yes | 119 | 0.274 | 0.200 |
| 111A100W1 | 0.4375 | A516 | No | No | Yes | Yes | 119 | 0.187 | 0.151 |
| 117R100W | 0.4375 | A516 | Yes | Full | No[16] | Yes | 119 | 0.126 | 0.081 |
| 117R100W | 0.4375 | A516 | Yes | Full | Yes | Yes | 119 | 0.066 | 0.047 |

Note that the effectiveness of top fittings protection is based on the design being similar to the traditional pressure-car-style protective housing described in the federal regulations at 49 CFR 179.100-12(c). This is because the CPR estimation is empirically based, and this protection design is the only one represented by meaningful numbers of cars in TCAD. In recent years, many additional types of top fittings protection have been introduced. However, none of these designs have been widespread in the fleet for long enough for their effects to be quantifiable. Therefore, at this time, the best estimate of the performance of any of these systems is the same estimate that has been derived for the traditional pressure-car housing. Future CPR analyses will be better able to distinguish between the various top fittings protection approaches.

The predecessor to this report, RSI-AAR Report RA-05-02 (Ref. 4), found a difference between pressure car housings on different specification cars, for example, chlorine cars vs. anhydrous ammonia cars. However, in the TWP-17 study, no evidence was found for this in the exploratory phase of the project, and the pressure car fittings type variable was not selected for inclusion in the full top fittings model.

f) Jacket effects

The results confirm that there are significant tank damage resistance benefits to a jacket, even though its main purpose is to contain insulation and/or thermal blankets. Table 6 shows some example comparisons. The comparisons would change with changes in other car and accident factors, but the presence of a jacket always confers benefits in this regard. Note that the potential effect of the standoff distance, i.e., the distance between

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[16] Specifications for 117R100W require top fittings protection. However, while there are many different types and levels of top fittings protection today, the data used for this study did not allow those distinctions to be made quantitatively. Top fittings protection was either an impact-resistant protective housing, or none. Some current systems probably perform somewhere in between. Therefore, some examples using “No” for this field are presented, to suggest the range of performance that the real systems probably fall within.

the tank and the jacket, was also studied, but this variable was found to not be statistically significant.

Table 6
CPRs and $CPR_{>100}$s for Selected Pairs of Comparable Tank Cars
With and Without Standard 11-Gauge Jackets
Under Average Mainline Derailment Conditions

| Car Spec. | Head and Shell Thickness (in.) | Jacket | Head Shield | Top Fittings Protection | Bottom Fittings | Shell Inside Diameter (in.) | CPR | $CPR_{>100}$ |
|---|---|---|---|---|---|---|---|---|
| 111A100W1 | 0.4375 | No | No | No | Yes | 119 | 0.274 | 0.200 |
| 111A100W1 | 0.4375 | Yes | No | No | Yes | 119 | 0.134 | 0.089 |
| 111A100W1 | 0.5 | No | No | No | Yes | 119 | 0.239 | 0.173 |
| 111A100W1 | 0.5 | Yes | No | Yes | No | 119 | 0.114 | 0.075 |
| 112S340W | 0.625 | No | Half | Yes | No | 118.75 | 0.091 | 0.071 |
| 112J340W | 0.625 | Yes | Half | Yes | No | 118.75 | 0.034 | 0.023 |

g) Head protection effects

The results confirm that there are benefits to head protection systems, and more benefits to full-height protection than for half-height. Table 7 shows some example comparisons. The comparisons in Table 7 would change with changes in other car and accident factors, but the presence of head protection always confers benefits in this regard. The relative benefits are affected by where impacts on the tank head occur (mostly below the centerline) and the protective effects of a jacket head or partial jacket head, which is less resistant to damage than a head shield, but still offers significant resistance.

Table 7
CPRs and $CPR_{>100}$s for Selected Groups of Comparable Tank Cars
With Different Levels of Head Protection
Under Average Mainline Derailment Conditions

| Car Spec. | Head and Shell Thickness (in.) | Head and Shell Steel Type | Jacket | Head Shield | Top Fittings Protection | Bottom Fittings | Shell Inside Diameter (in.) | CPR | $CPR_{>100}$ |
|---|---|---|---|---|---|---|---|---|---|
| 111A100W1 | 0.4375 | A516 | No | No | No | Yes | 119 | 0.274 | 0.200 |
| 111A100W1 | 0.4375 | A516 | No | Half | No | Yes | 119 | 0.252 | 0.178 |
| 111A100W1 | 0.4375 | A516 | Yes | No | No | Yes | 119 | 0.134 | 0.089 |
| 111A100W1 | 0.4375 | A516 | Yes | Half | No | Yes | 119 | 0.127 | 0.082 |
| 111A100W1 | 0.4375 | A516 | Yes | Full | No | Yes | 119 | 0.126 | 0.081 |
| 112J340W | 0.625 | TC128B | Yes | Half | Yes | No | 118.75 | 0.034 | 0.023 |
| 112J340W | 0.625 | TC128B | Yes | Full | Yes | No | 118.75 | 0.033 | 0.023 |

h) Speed effects (mainline/siding)

Given a specific tank car configuration, CPRs are lower at lower derailment speeds. Note that "derailment speed" means the speed that the train was traveling at the moment of derailment, not the impact speed at which an impactor struck the car or the car struck the ground. The latter speeds are almost always lower than the derailment speed, but they are unknown, so derailment speed must serve as one indicator of how high the impact speeds might have been, relatively. Table 8 shows some example comparisons. The example speeds of 25 and 40 mph are the speed limits for FRA Class 2 and 3 track, respectively. 50 mph is the AAR OT-55 speed limit for key trains [Ref. 1] and the regulatory limit for trains meeting the definition of "high-hazard flammable train". The comparisons in Table 8 would change with changes in other car and accident factors, and in particular, would change if computed with the average derailment size for a given speed, rather than the overall average.

Table 8
CPRs and $\text{CPR}_{>100}$s for Selected Cars
Derailed at Different Speeds
Under Otherwise Average Mainline Derailment Conditions

| Car Spec. | Head and Shell Thickness (in.) | Head and Shell Steel Type | Jacket | Head Shield | Top Fittings Protection | Bottom Fittings | Shell Inside Diameter (in.) | Mph | CPR | $\text{CPR}_{>100}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 111A100W1 | 0.4375 | A516 | Yes | No | No | Yes | 119 | 25 | 0.132 | 0.087 |
| 111A100W1 | 0.4375 | A516 | Yes | No | No | Yes | 119 | 40 | 0.176 | 0.129 |
| 111A100W1 | 0.4375 | A516 | Yes | No | No | Yes | 119 | 50 | 0.241 | 0.193 |
| 117J100W | 0.5625 | TC128B | Yes | Full | Yes | Yes | 119 | 25 | 0.041 | 0.029 |
| 117J100W | 0.5625 | TC128B | Yes | Full | Yes | Yes | 119 | 40 | 0.064 | 0.050 |
| 117J100W | 0.5625 | TC128B | Yes | Full | Yes | Yes | 119 | 50 | 0.102 | 0.085 |
| 105A500W | 0.779 | TC128B | Yes | No | Yes | No | 102 | 25 | 0.040 | 0.030 |
| 105A500W | 0.779 | TC128B | Yes | No | Yes | No | 102 | 40 | 0.044 | 0.036 |
| 105A500W | 0.779 | TC128B | Yes | No | Yes | No | 102 | 50 | 0.066 | 0.057 |

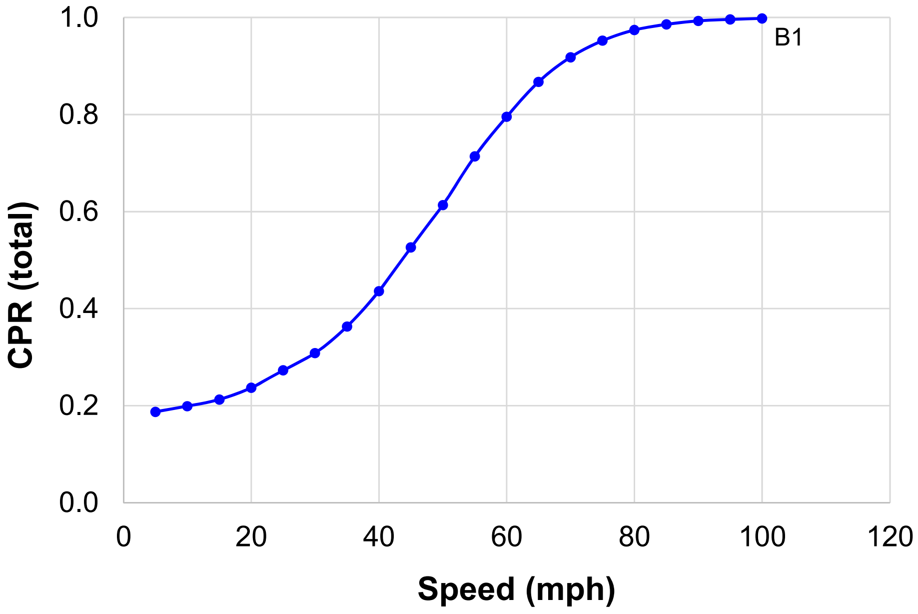
Figure 5 graphically depicts the speed effect on overall car mainline CPR, for non-jacketed 111A100W1s with no additional protective features. Figure 6 shows the same, for jacketed cars. In these figures, at each speed, the average derailment size for that speed is incorporated into the CPR calculation.

Note that the speed effect curve does not go through the origin. On the face of it, CPR at speeds very near zero mph should also be very near zero. When constructing the models for regression, one must choose whether or not to force the intersection to occur at one particular point, such as the origin. This can be done, but often at a cost to the goodness-of-fit elsewhere in the data domain. The curve must in a sense be bent away from a shape that would fit more data points better, in order to go to the origin. A decision was made that the accuracy of analyses at speeds very near zero was less important than the accuracy of analyses at typical mainline speeds. Therefore the speed effect was not forced through [0,0].

Figure 5

Non-Jacketed 111A100W1 Mainline CPR vs. Train Speed
As Predicted by TWP-17 Formulas, and Empirical Counts

Subfigure 5a
TWP-17 CPR Predictions



Subfigure 5b
Empirical Lading-Loss Rates

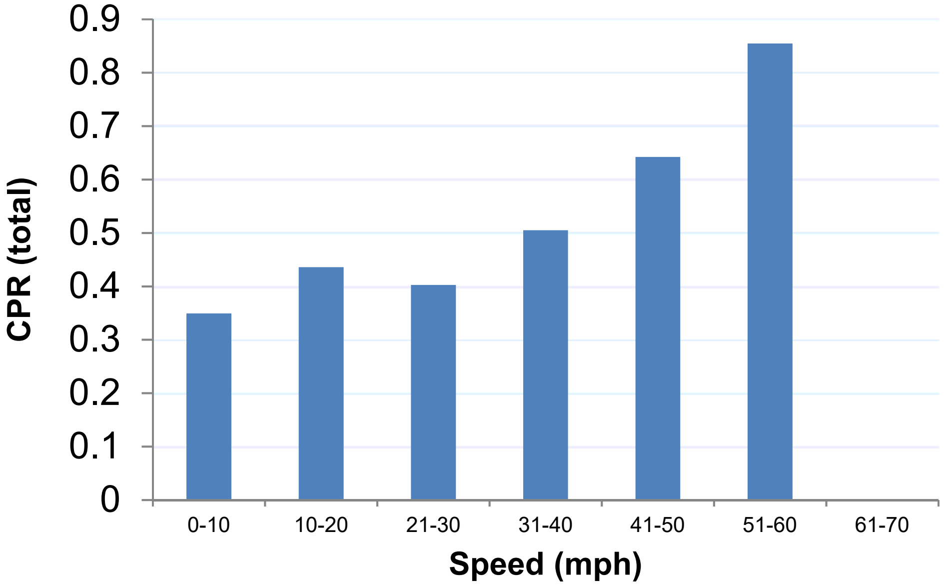
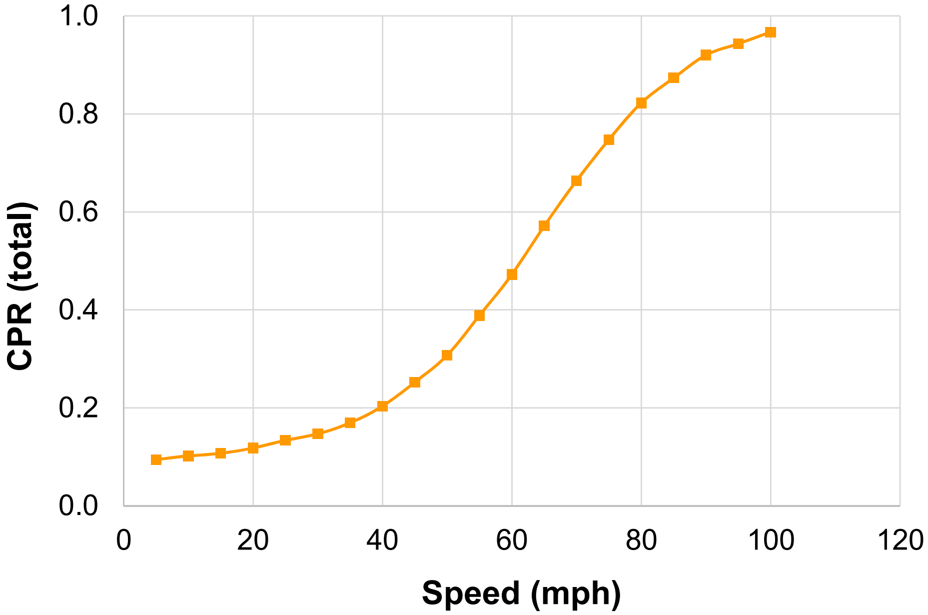


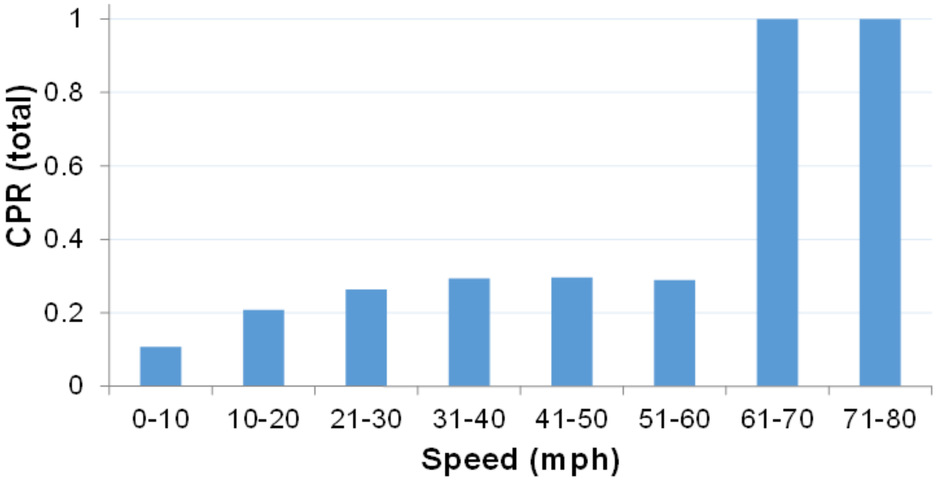
Figure 6

Jacketed 111A100W1 Mainline CPR vs. Train Speed
As Predicted by TWP-17 Formulas, and Empirical Counts

Subfigure 6a
TWP-17 CPR Predictions



Subfigure 6b
Empirical Lading-Loss Rates



i) Yard/Industrial CPRs

CPRs on yard or industrial track are always lower than CPRs for the same cars on mainline or siding track. However, the variable for track type was not statistically significant in any of the component CPR models, so the dominant factors are the lower speeds and smaller derailments. Table 9 shows some example comparisons. The average derailment conditions for mainline track in the FRA accident data are 26 mph, 11 cars derailed, tank car of interest 6th in the derailed string. The average conditions for yards are 6 mph, 5 cars derailed and tank car of interest 3rd in the derailed string.

Table 9
CPRs and $\text{CPR}_{>100}$s for Selected Cars
Derailed on Different Track Types
Under Average Derailment Conditions for Each Type

| Car Spec. | Head and Shell Thickness (in.) | Jacket | Head Shield | Top Fittings Protection | Bottom Fittings | Shell Inside Diameter (in.) | M= Main Y= Yard | CPR | $\text{CPR}_{>100}$ |
|---|---|---|---|---|---|---|---|---|---|
| 111A100W1 | 0.4375 | No | No | No | Yes | 119 | M | 0.274 | 0.200 |
| 111A100W1 | 0.4375 | No | No | No | Yes | 119 | Y | 0.075 | 0.051 |
| 117J100W | 0.5625 | Yes | Full | Yes | Yes | 119 | M | 0.042 | 0.029 |
| 117J100W | 0.5625 | Yes | Full | Yes | Yes | 119 | Y | 0.010 | 0.007 |
| 105A500W | 0.779 | Yes | No | Yes | No | 102 | M | 0.040 | 0.030 |
| 105A500W | 0.779 | Yes | No | Yes | No | 102 | Y | 0.007 | 0.005 |

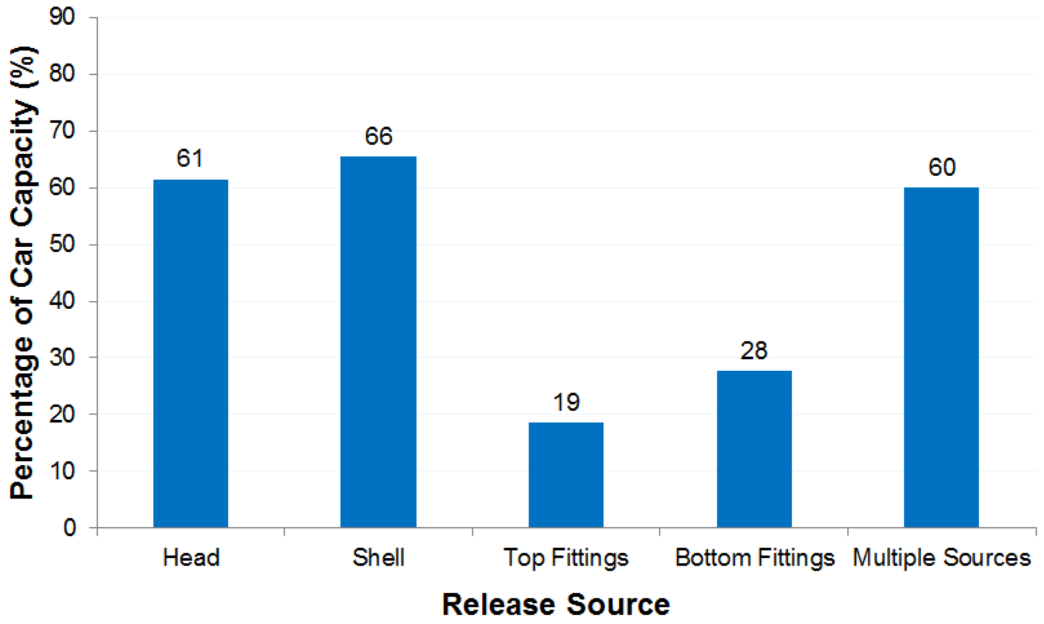
j) Quantity lost results

Because tank cars have a wide range of capacities, a loss of a given gallon volume can represent a different severity of outcome for different cars. For example, a 15,000 gallon loss is 50% of the lading from a 30,000 gallon car, but a total loss from a 15,000 gallon car. Therefore quantity lost data are represented in this study in terms of percentage of car capacity lost. Figure 7 shows the average percentage of car capacity lost in releases from each of the four car components, in four sub-tables based on car type and track type. The average percent-lost figures for each car/component in Figure 7 are shown with only two significant digits in order to avoid presenting a level of precision that may not be supportable, given the relatively small number of release accidents available for the calculation and the number of factors that can affect the quantity lost. Also, the thousandths place on the percentage of a loaded tank represents tens of gallons, and generally a round-off at that level will not bias an analysis.

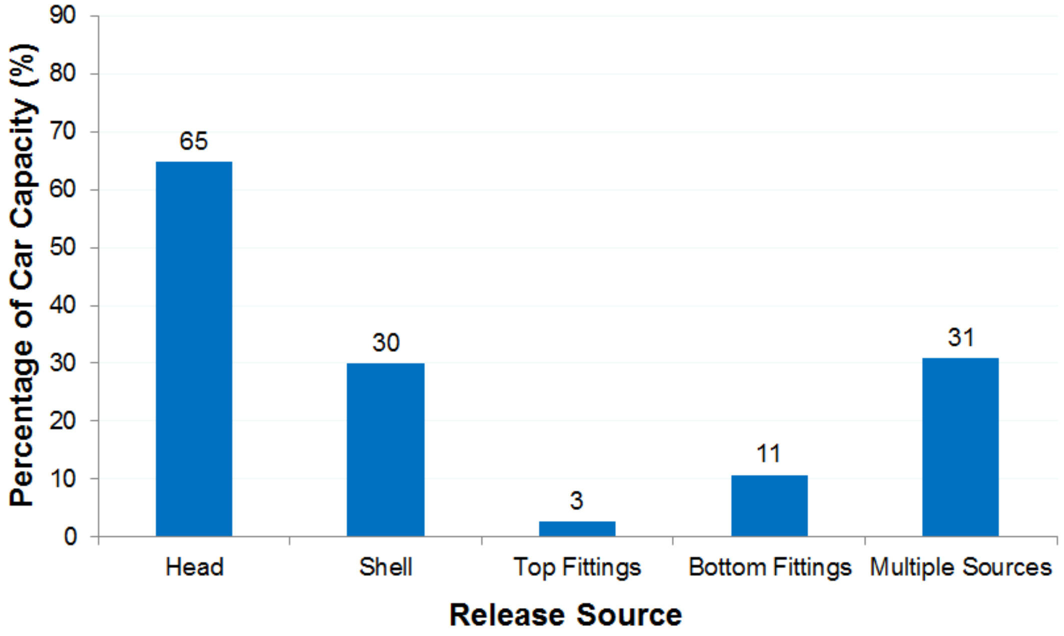
Figure 8 shows the distribution of loss quantities for each component, broken down into five bins of percentages. The bins are not uniform because of how loss quantity contributes to risk. For example, very small releases often present a disproportionally smaller hazard than 20% or 25% losses, so it is not helpful to lump these together. Table 10 shows the data behind Figure 8. Note that there are few releases from pressure cars, and the distributions shown may not be reliable representations of the relative likelihoods of different release sizes.

Figure 7
Average Quantity of Lading Lost for Each Car Component
Expressed as a Percentage of Car Capacity

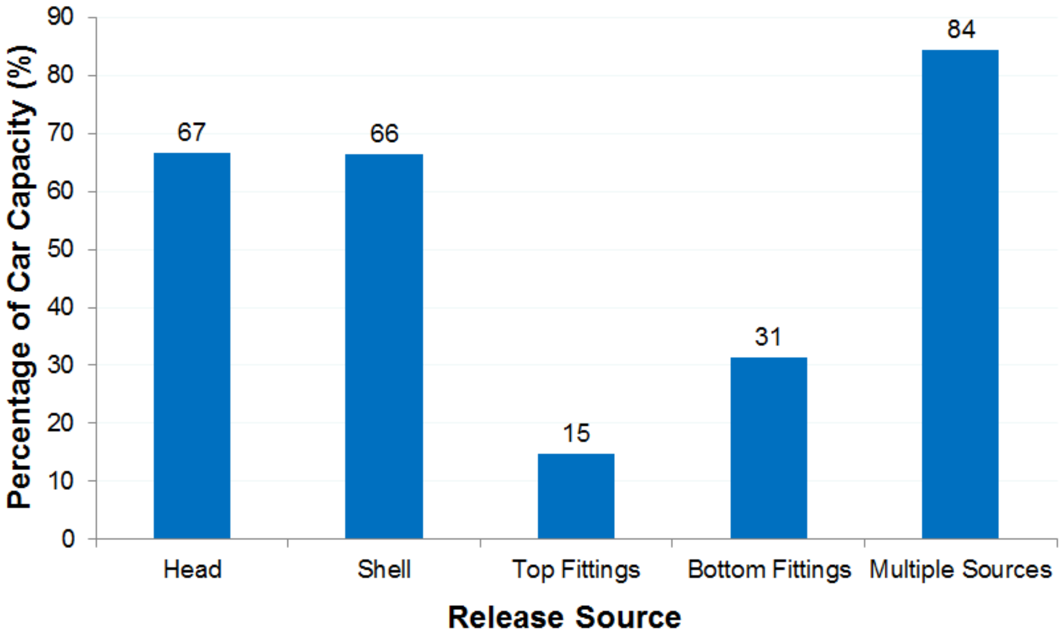
Subfigure 7a
Non-Pressure Cars, Mainlines and Sidings



Subfigure 7b
Non-Pressure Cars, Yards and Industrial Track



Subfigure 7c
Pressure Cars, Mainlines and Sidings



Subfigure 7d
Pressure Cars, Yards and Industrial Tracks

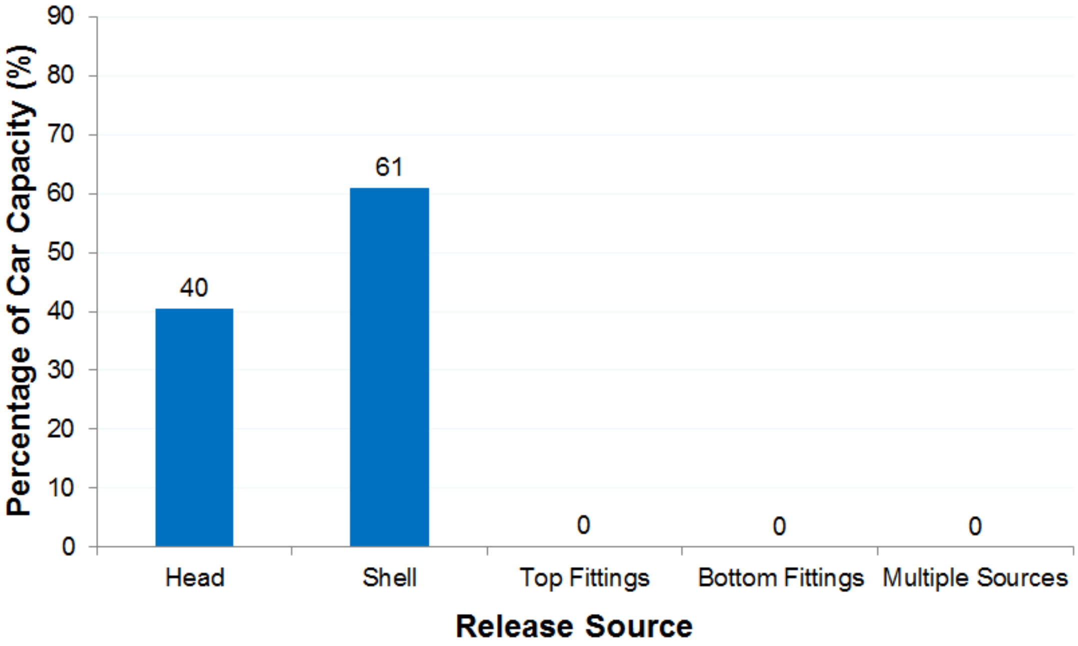
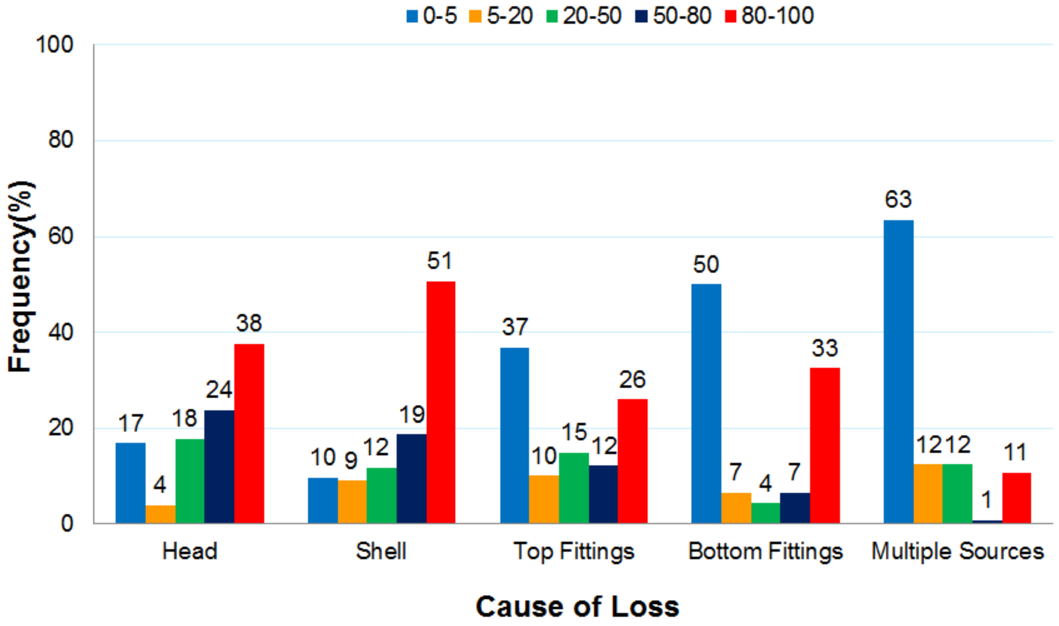
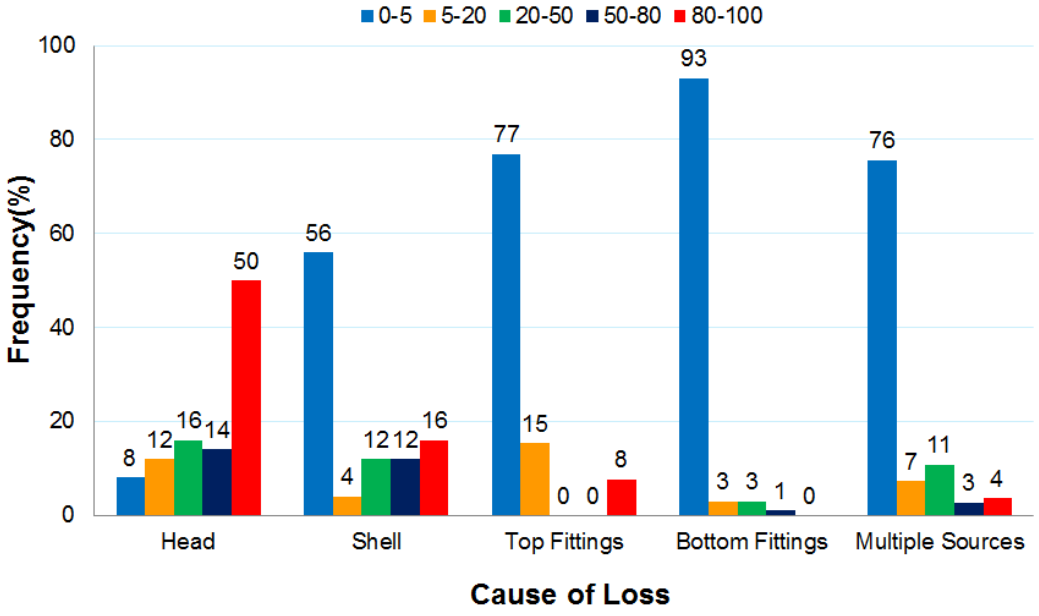


Figure 8
Distribution of Quantity of Lading Lost, Expressed as a Percentage of Loaded Quantity, for Each Car Component
(Bar Color Indicates Category of the Quantity Lost, as a Percentage)

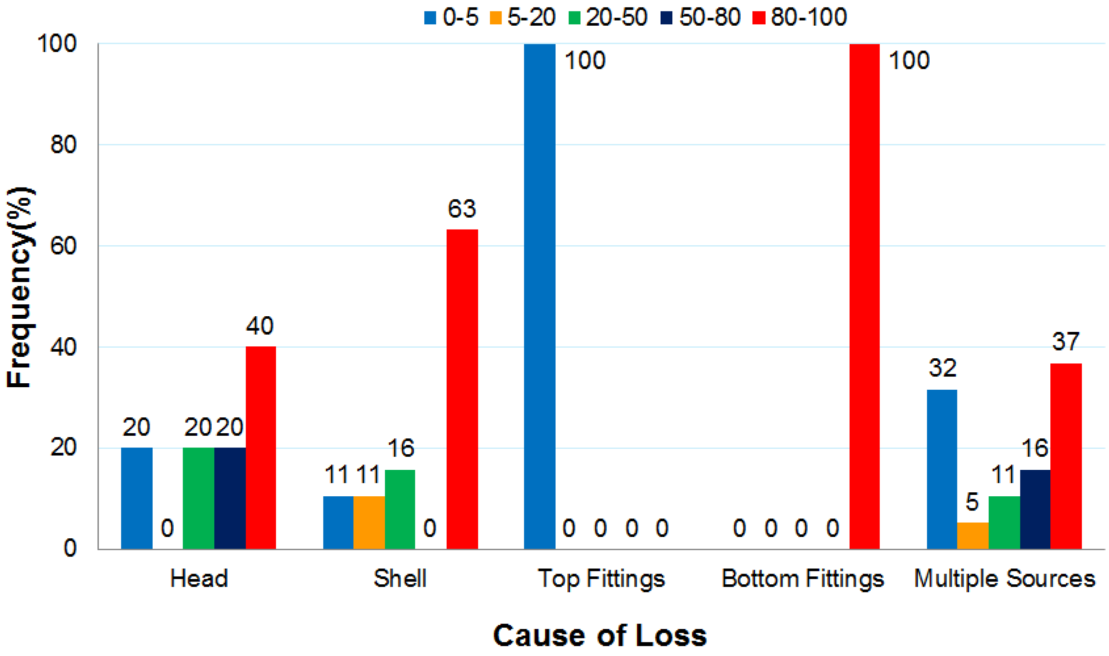
Subfigure 8a
Non-Pressure Cars, Mainline and Sidings



Subfigure 8b
Non-Pressure Cars, Yards and Industrial Tracks



Subfigure 8c
Pressure Cars, Mainline and Sidings



Subfigure 8d
Pressure Cars, Yards and Industrial Tracks

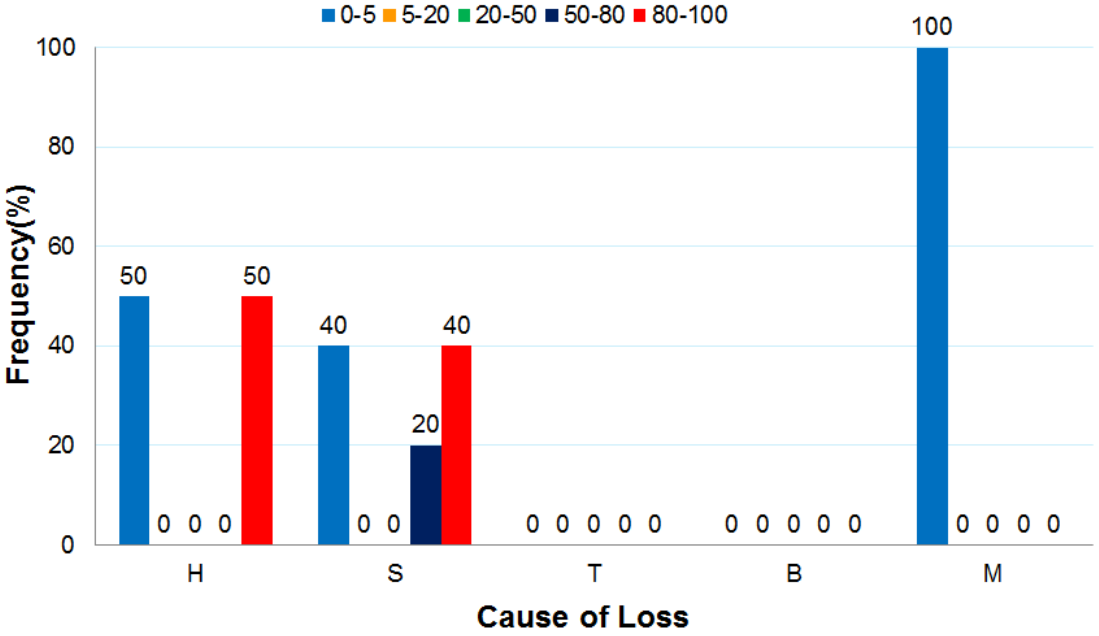


Table 10 provides the count data displayed as percentages in Figure 8.

## Table 10
## Number of Tank Cars that Lost Lading, by Percent of Tank Capacity

### Subtable 10a
### Non-Pressure Cars on Mainlines and Sidings

| Percent of Capacity Lost | | | | | | |
|---|---|---|---|---|---|---|
| Loss Source | 0-5 | 5-20 | 20-50 | 50-80 | 80-100 | Total Cars |
| H | 17 | 4 | 18 | 24 | 38 | 101 |
| S | 28 | 26 | 34 | 54 | 146 | 288 |
| T | 106 | 29 | 43 | 35 | 75 | 288 |
| B | 23 | 3 | 2 | 3 | 15 | 46 |
| M | 153 | 30 | 30 | 2 | 26 | 241 |
| Total Cars | 327 | 92 | 127 | 118 | 300 | 964 |

### Subtable 10b
### Non-Pressure Cars, Yards and Industrial Tracks

| Percent of Capacity Lost | | | | | | |
|---|---|---|---|---|---|---|
| Loss Source | 0-5 | 5-20 | 20-50 | 50-80 | 80-100 | Total Cars |
| H | 4 | 6 | 8 | 7 | 25 | 50 |
| S | 14 | 1 | 3 | 3 | 4 | 25 |
| T | 10 | 2 | 0 | 0 | 1 | 13 |
| B | 94 | 3 | 3 | 1 | 0 | 101 |
| M | 84 | 8 | 12 | 3 | 4 | 111 |
| Total Cars | 206 | 20 | 26 | 14 | 34 | 300 |

### Subtable 10c
### Pressure Cars, Mainlines and Sidings

| Percent of Capacity Lost | | | | | | |
|---|---|---|---|---|---|---|
| Loss Source | 0-5 | 5-20 | 20-50 | 50-80 | 80-100 | Total Cars |
| H | 1 | 0 | 1 | 1 | 2 | 5 |
| S | 2 | 2 | 3 | 0 | 12 | 19 |
| T | 6 | 0 | 0 | 0 | 0 | 6 |
| B | 0 | 0 | 0 | 0 | 1 | 1 |
| M | 6 | 1 | 2 | 3 | 7 | 19 |
| Total Cars | 15 | 3 | 6 | 4 | 22 | 50 |

### Subtable 10d
### Pressure Cars, Yards and Industrial Tracks

| Percent of Capacity Lost | | | | | | |
|---|---|---|---|---|---|---|
| Loss Source | 0-5 | 5-20 | 20-50 | 50-80 | 80-100 | Total Cars |
| H | 1 | 0 | 0 | 0 | 1 | 2 |
| S | 2 | 0 | 0 | 1 | 2 | 5 |
| T | 0 | 0 | 0 | 0 | 0 | 0 |
| B | 0 | 0 | 0 | 0 | 0 | 0 |
| M | 9 | 0 | 0 | 0 | 0 | 9 |
| Total Cars | 12 | 0 | 0 | 1 | 3 | 16 |

k) Expected Quantity Released (EQR) example

To illustrate why EQR calculations might be of interest, here is an example in which a non-jacketed 111A100W1 tank car with a bottom outlet is compared to 1) the same car with the bottom outlet removed, 2) the same car with top fittings protection added, and 3) the same car with a jacket added. Table 11 displays CPR and EQR estimates for these three cars. Note that the percentage of improvement can vary significantly for the same risk reduction measure, depending on the performance metric used.

Table 11
EQRs, CPRs and $CPR_{>100}$s for 30,000-Gallon DOT-111 Tank Cars
With Different Risk Reduction Options (RROs)
(7/16" Tanks, 119" Shell Inside Diameter)
Under Average Mainline Derailment Conditions

| Car | Jacket | Head Shield | Top Fittings Protection | Bottom Fittings | CPR | % Reduction | $CPR_{>100}$ | % Reduction | EQR (gals.) | % Reduction |
|---|---|---|---|---|---|---|---|---|---|---|
| Base | No | No | No | Yes | 0.274 | n/a | 0.200 | n/a | 3,120 | n/a |
| RRO1 | No | No | No | No | 0.257 | 3.4 % | 0.189 | 3.6% | 3,026 | 3.0 % |
| RRO2 | No | No | Yes | Yes | 0.183 | 31.2 % | 0.149 | 24.0 % | 2,613 | 16.3% |
| RRO3 | Yes | No | No | Yes | 0.128 | 51.9 % | 0.085 | 56.6 % | 1,199 | 61.6 % |

RRO1 = Remove bottom fittings
RRO2 = Add top fittings protection
RRO3 = Add jacket to head and shell

EQRs in Table 11 are based on the shell-full capacity of the tanks, i.e., 30,000 gallons in this case. For purposes of comparisons among car options with the same tank capacity, this is the simplest approach. For other analyses, it might be important to focus on the actual gallons loaded, or the estimated gallons of lading at a typical point in transit, or the tons (which do not vary during the trip). Note that the reported loss quantities from accidents, which the fractions in Figure 7 are based upon, come from cars that have been in transit for some period of time. Vapor lost from the tank is generally not part of the reported loss quantity unless vapor is all that is lost (for example if a fitting is damaged but is above the liquid level so that only vapor is lost). The analyst will need to consider the best approach for a given study.

## 4. References

1. Association of American Railroads. "Recommended Railroad Operating Practices for Transportation of Hazardous Materials, Circular No. OT-55-Q (CPC-1337)". 6 September 2018.

2. Hughes, J.P., C.F. Heuer and T.L. Anderson. "Fracture Behavior of Tank Car Steels in Accidents from 1981 through 1994. RSI-AAR Railroad Tank Car Safety Research and Test Project Report RA-03-6-62. December 1998.

3. Kirkpatrick, S. W. "Detailed Puncture Analyses of Tank Cars: Analysis of Different Impactor Threats and Impact Conditions." DOT/FRA/ORD-13-17. March 2013.

4. Treichel, T.T., J.P. Hughes, C.P.L. Barkan, R.D. Sims, E.A. Phillips, and M.R. Saat. "Safety Performance of Tank Cars in Accidents: Probabilities of Lading Loss". RSI-AAR Railroad Tank Car Safety Research and Test Project Report RA-05-02. January 2006.

## Appendix A
## Tank Car Safety Project Collection of Data on Tank Cars Damaged in Accidents

The source of the data used in this study was the Tank Car Safety Project's database of tank cars damaged in accidents, known as the Tank Car Accident Database, or TCAD. The database contains records on tank cars damaged in derailments and collisions, for which the damage was incurred on tank-car-specific features, including the tank, fittings, jacket, head shields, and so on. If there was no damage to these features, the car is not included in TCAD, even if there was damage to running gear, safety appliances, brake equipment, etc.

TCAD includes data on any tank cars damaged in the United States or Canada, regardless of specification, design features, lading (including non-regulated materials), load/residue status, and whether or not lading was released in the accident.

The Tank Car Safety Project began collection and analysis of accident data in 1970. At the time of publication of this report, TCAD contained records on almost 47,000 damaged tank cars and just over 30,000 associated accidents. Not all of these are used in any one analysis. The set of cars used in TWP-17 is described in the Approach section of the main report.

For each car TCAD contains data in three categories: 37 fields describing the accident that damaged the car, 40 fields describing the car's features and lading, and 34 fields describing the damage to and performance of the car.

These data are collected from 28 disparate sources, including public data reported to FRA and PHMSA, proprietary data provided by car owners, car builders and railroads, NTSB, TSB and FRA investigations, Tank Car Safety Project accident investigations, and others. Engineers experienced in assessing tank car damage collate whichever of these sources are available for a particular car, resolve conflicts and gaps, and record an accurate summation of the event.

# Appendix B
# gMCP

The power of regression is undermined when the independent variables are closely correlated. This is because the process is unable to determine which of two correlated variables is more responsible for the outcome. These datasets do have correlated variables. For example, in the time period under consideration, head shields were far more likely to be found on cars with higher tank thickness than with lower thickness.

To minimize this problem, an advanced variable selection procedure, the group minimax concave penalty approach (gMCP), was conducted to identify groups of related variables that were more likely to be significant, before beginning each regression. This process helps to separate the effects of correlated variables. It also allows both related groups of variables and individual variables to be selected for their importance. The technique resulted in more robust and accurate CPR estimates than would have been possible without such a step.

In brief, gMCP optimizes an objective function with respect to a single group of related variables at a time, cycling through the groups until convergence is reached. The process includes all variables in groups at first, then considers them individually for exclusion. Whether an individual variable enters the regression model is affected by both its own explanatory value and that of its group.

Note that coefficients with confidence limits encompassing zero, and therefore considered not significant in unmodified regression, are often left in the final model with this approach if they were identified as significant in the group selection process. This is because the process shrinks coefficients towards zero, trading some bias for prediction accuracy, and the usual statistical tests must be adjusted. Such variables still explain some of the variation.

Technical details of the approach used are:

- A coordinate descent algorithm was used,
- Continuous variables were standardized to have variance = 1,
- Continuous variables were transformed to center on zero,
- 10-fold cross-validation applied to help counter the possibility that a global minimum is not found, and
- Where interaction terms were included, both main effects were included as well.

The gMCP process was chosen after an attempt with LASSO (least absolute shrinkage and selection operator) had mixed results.

The principal diagnostics used in the gMCP process for selecting the best groupings to include were

- Bayesian Information Criterion (BIC)
- Akaike Information Criterion (AIC)
- Generalized cross-validation (GCV)
- 10-fold cross-validation error (CVE) (six different orders)

## Appendix C
## Final Model Output, Model Fit and Diagnostics

Following are the computational outputs for the final selected regression models for the four car components. In all cases the computational procedure was SAS PROC LOGISTIC.

For the regressions, the following diagnostic guidelines were followed:

- The coefficients and associated odds ratios needed to be interpretable.
- The Hosmer-Lemeshow test for goodness-of-fit had to be passed.
- The concordance index and ROC curves had to indicate sufficient predictive accuracy.
- Outliers and high-influence points had to be sparse.
- Strong correlations among variables had to have been addressed by the gMCP process.
- Wald chi-square statistics were examined, even where the gMCP suggested retaining variables that failed a chi-square test

Outliers were retained in the dataset. The binary nature of the outcomes limited the influence of outliers, and the outlier records were not of the sort that could be rejected as errors. There are many variables that affect accident environments, and among thousands of records which account for some but not all of these factors, unusual but valid combinations of these factors will arise, even if rarely. Finally, outliers made up a small percentage of records anyway, and tended to be evenly distributed throughout the domain. Examination of the plots in this chapter supports these conclusions.

# Head

| **Model Information** | |
|---|---|
| **Data Set** | WORK.HEADCPR |
| **Response Variable** | Head_Loss |
| **Number of Response Levels** | 2 |
| **Model** | binary logit |
| **Optimization Technique** | Fisher's scoring |
| **Likelihood Penalty** | Firth's bias correction |

| | |
|---|---|
| **Number of Observations Read** | 4467 |
| **Number of Observations Used** | 4467 |

| Response Profile | | |
|---|---|---|
| **Ordered Value** | **Head_Loss** | **Total Frequency** |
| **1** | 0 | 4286 |
| **2** | 1 | 181 |

***Probability modeled is Head_Loss='1'.***

| Class Level Information | | |
|---|---|---|
| **Class** | **Value** | **Design Variables** |
| **HSF** | **0** | 0 |
| | **1** | 1 |
| **HSHJ** | **0** | 0 |
| | **1** | 1 |
| **HSHNJ** | **0** | 0 |
| | **1** | 1 |
| **FJKT** | **0** | 0 |
| | **1** | 1 |
| **HTR** | **0** | 0 |
| | **1** | 1 |
| **ACCTYP** | **0** | 0 |
| | **1** | 1 |

| Intercept-Only Model Convergence Status |
|---|
| Convergence criterion (GCONV=1E-8) satisfied. |

| Model Convergence Status |
|---|
| Convergence criterion (GCONV=1E-8) satisfied. |

| Model Fit Statistics | | |
|---|---|---|
| **Criterion** | **Intercept Only** | **Intercept and Covariates** |
| **AIC** | 1467.509 | 1308.031 |
| **SC** | 1473.914 | 1378.480 |
| **-2 Log L** | 1465.509 | 1286.031 |

| Testing Global Null Hypothesis: BETA=0 | | | |
|---|---|---|---|
| **Test** | **Chi-Square** | **DF** | **Pr > ChiSq** |
| **Likelihood Ratio** | 179.4788 | 10 | <.0001 |
| **Score** | 174.8086 | 10 | <.0001 |
| **Wald** | 141.6655 | 10 | <.0001 |

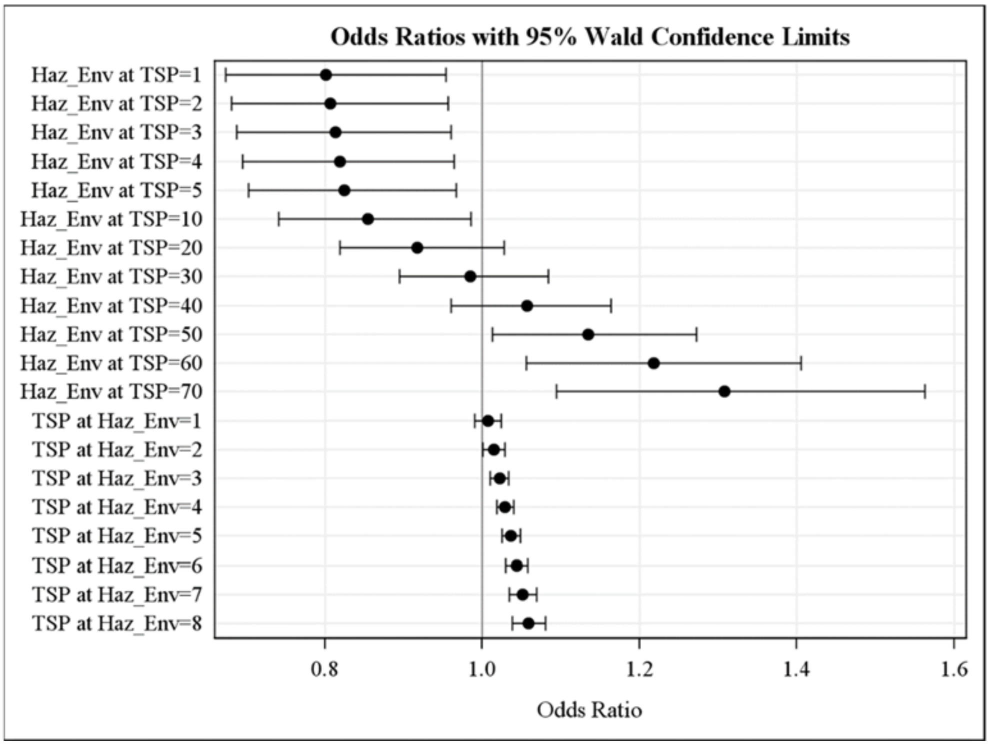
| Type 3 Analysis of Effects | | | |
|---|---|---|---|
| **Effect** | **DF** | **Wald Chi-Square** | **Pr > ChiSq** |
| **HSF** | 1 | 21.0898 | <.0001 |
| **HSHJ** | 1 | 11.2014 | 0.0008 |
| **HSHNJ** | 1 | 0.9603 | 0.3271 |
| **FJKT** | 1 | 20.4187 | <.0001 |
| **HMT** | 1 | 0.0743 | 0.7851 |
| **HTR** | 1 | 2.0189 | 0.1554 |
| **TSP** | 1 | 0.0018 | 0.9664 |
| **Haz_Env** | 1 | 6.3502 | 0.0117 |
| **ACCTYP** | 1 | 8.2247 | 0.0041 |
| **TSP*Haz_Env** | 1 | 10.3836 | 0.0013 |

| Analysis of Maximum Likelihood Estimates | | | | | | |
|---|---|---|---|---|---|---|
| **Parameter** | | **DF** | **Estimate** | **Standard Error** | **Wald Chi-Square** | **Pr > ChiSq** |
| **Intercept** | | 1 | -1.5145 | 0.6403 | 5.5954 | 0.0180 |
| **HSF** | **1** | 1 | -3.0699 | 0.6685 | 21.0898 | <.0001 |
| **HSHJ** | **1** | 1 | -2.8387 | 0.8482 | 11.2014 | 0.0008 |
| **HSHNJ** | **1** | 1 | -0.6773 | 0.6911 | 0.9603 | 0.3271 |
| **FJKT** | **1** | 1 | -1.6871 | 0.3734 | 20.4187 | <.0001 |
| **HMT** | | 1 | -0.3447 | 1.2641 | 0.0743 | 0.7851 |
| **HTR** | **1** | 1 | 0.5572 | 0.3921 | 2.0189 | 0.1554 |
| **TSP** | | 1 | 0.000433 | 0.0103 | 0.0018 | 0.9664 |
| **Haz_Env** | | 1 | -0.2281 | 0.0905 | 6.3502 | 0.0117 |
| **ACCTYP** | **1** | 1 | -0.7613 | 0.2655 | 8.2247 | 0.0041 |
| **TSP*Haz_Env** | | 1 | 0.00709 | 0.00220 | 10.3836 | 0.0013 |

| Association of Predicted Probabilities and Observed Responses | | | |
|---|---|---|---|
| **Percent Concordant** | 77.5 | **Somers' D** | 0.551 |
| **Percent Discordant** | 22.4 | **Gamma** | 0.552 |
| **Percent Tied** | 0.1 | **Tau-a** | 0.043 |
| **Pairs** | 775766 | **c** | 0.776 |

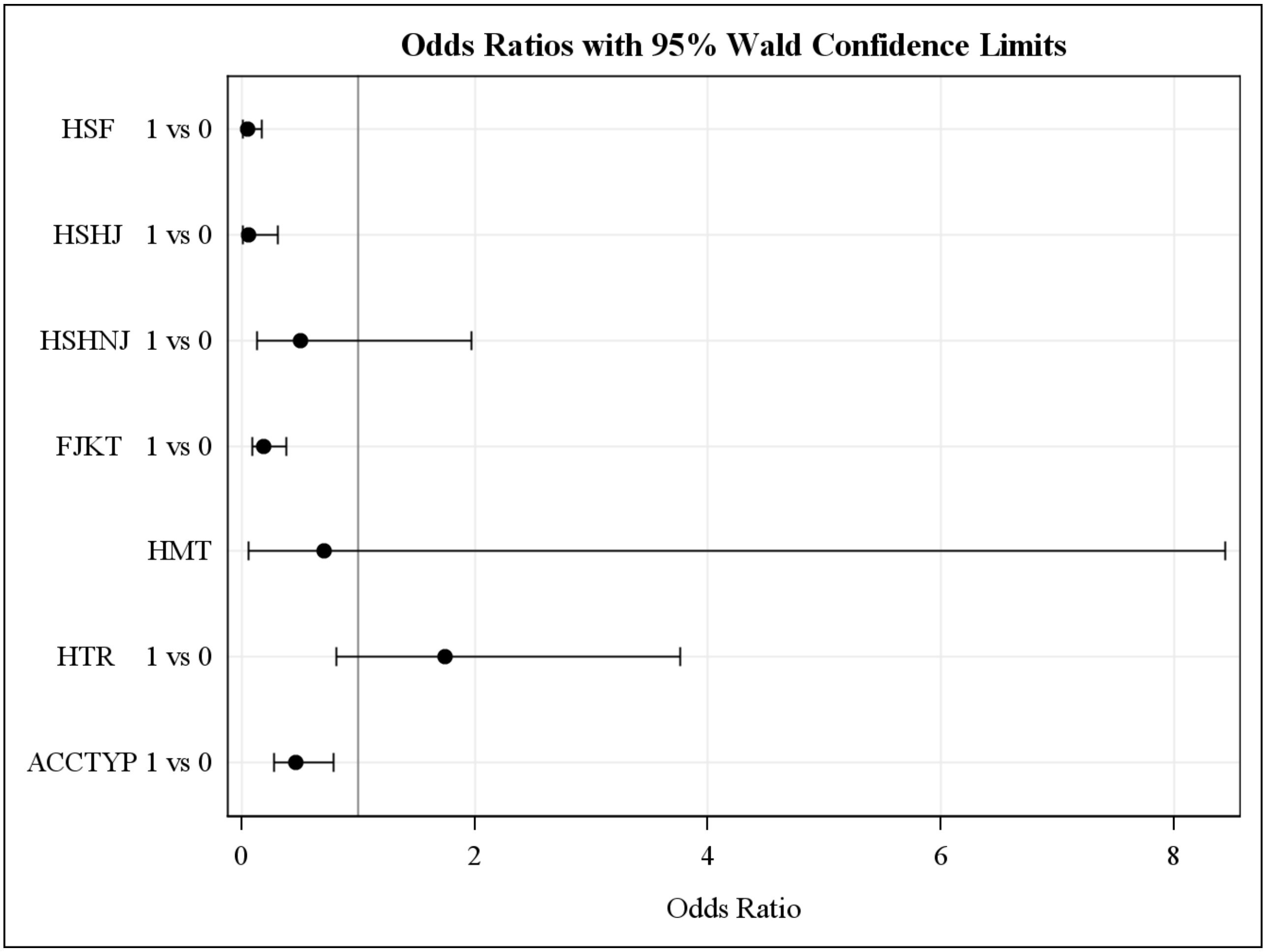
| Odds Ratio Estimates and Wald Confidence Intervals | | | |
|---|---|---|---|
| **Label** | **Estimate** | **95% Confidence Limits** | |
| Haz_Env at TSP=1 | 0.802 | 0.674 | 0.954 |
| Haz_Env at TSP=2 | 0.807 | 0.681 | 0.957 |
| Haz_Env at TSP=3 | 0.813 | 0.688 | 0.961 |
| Haz_Env at TSP=4 | 0.819 | 0.696 | 0.964 |
| Haz_Env at TSP=5 | 0.825 | 0.703 | 0.967 |

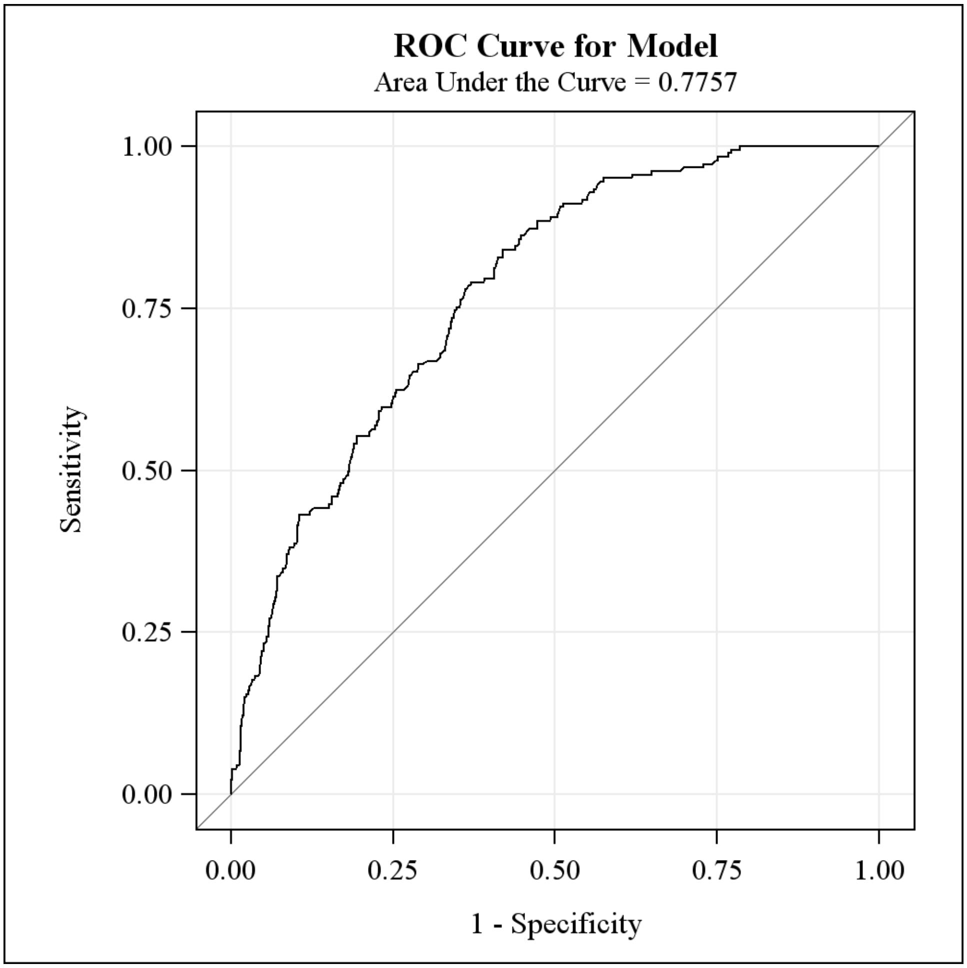
| Odds Ratio Estimates and Wald Confidence Intervals | | | |
|---|---|---|---|
| **Label** | **Estimate** | **95% Confidence Limits** | |
| Haz_Env at TSP=10 | 0.855 | 0.741 | 0.986 |
| Haz_Env at TSP=20 | 0.917 | 0.819 | 1.028 |
| Haz_Env at TSP=30 | 0.985 | 0.895 | 1.084 |
| Haz_Env at TSP=40 | 1.057 | 0.960 | 1.164 |
| Haz_Env at TSP=50 | 1.135 | 1.013 | 1.272 |
| Haz_Env at TSP=60 | 1.218 | 1.056 | 1.406 |
| Haz_Env at TSP=70 | 1.308 | 1.095 | 1.562 |
| TSP at Haz_Env=1 | 1.008 | 0.991 | 1.024 |
| TSP at Haz_Env=2 | 1.015 | 1.001 | 1.028 |
| TSP at Haz_Env=3 | 1.022 | 1.011 | 1.033 |
| TSP at Haz_Env=4 | 1.029 | 1.019 | 1.040 |
| TSP at Haz_Env=5 | 1.037 | 1.025 | 1.048 |
| TSP at Haz_Env=6 | 1.044 | 1.030 | 1.058 |
| TSP at Haz_Env=7 | 1.051 | 1.034 | 1.069 |
| TSP at Haz_Env=8 | 1.059 | 1.038 | 1.080 |



| Parameter Estimates and Wald Confidence Intervals | | | | |
|---|---|---|---|---|
| **Parameter** | | **Estimate** | **95% Confidence Limits** | |
| **Intercept** | | -1.5145 | -2.7693 | -0.2596 |
| **HSF** | **1** | -3.0699 | -4.3801 | -1.7597 |
| **HSHJ** | **1** | -2.8387 | -4.5011 | -1.1763 |
| **HSHNJ** | **1** | -0.6773 | -2.0318 | 0.6773 |
| **FJKT** | **1** | -1.6871 | -2.4188 | -0.9553 |
| **HMT** | | -0.3447 | -2.8223 | 2.1329 |
| **HTR** | **1** | 0.5572 | -0.2114 | 1.3258 |
| **TSP** | | 0.000433 | -0.0197 | 0.0206 |
| **Haz_Env** | | -0.2281 | -0.4055 | -0.0507 |
| **ACCTYP** | **1** | -0.7613 | -1.2817 | -0.2410 |
| **TSP*Haz_Env** | | 0.00709 | 0.00278 | 0.0114 |

| Odds Ratio Estimates and Wald Confidence Intervals | | | | |
|---|---|---|---|---|
| **Effect** | **Unit** | **Estimate** | **95% Confidence Limits** | |
| **HSF 1 vs 0** | 1.000 | 0.046 | 0.013 | 0.172 |
| **HSHJ 1 vs 0** | 1.000 | 0.059 | 0.011 | 0.308 |
| **HSHNJ 1 vs 0** | 1.000 | 0.508 | 0.131 | 1.969 |
| **FJKT 1 vs 0** | 1.000 | 0.185 | 0.089 | 0.385 |
| **HMT** | 1.000 | 0.708 | 0.059 | 8.440 |
| **HTR 1 vs 0** | 1.000 | 1.746 | 0.809 | 3.765 |
| **ACCTYP 1 vs 0** | 1.000 | 0.467 | 0.278 | 0.786 |



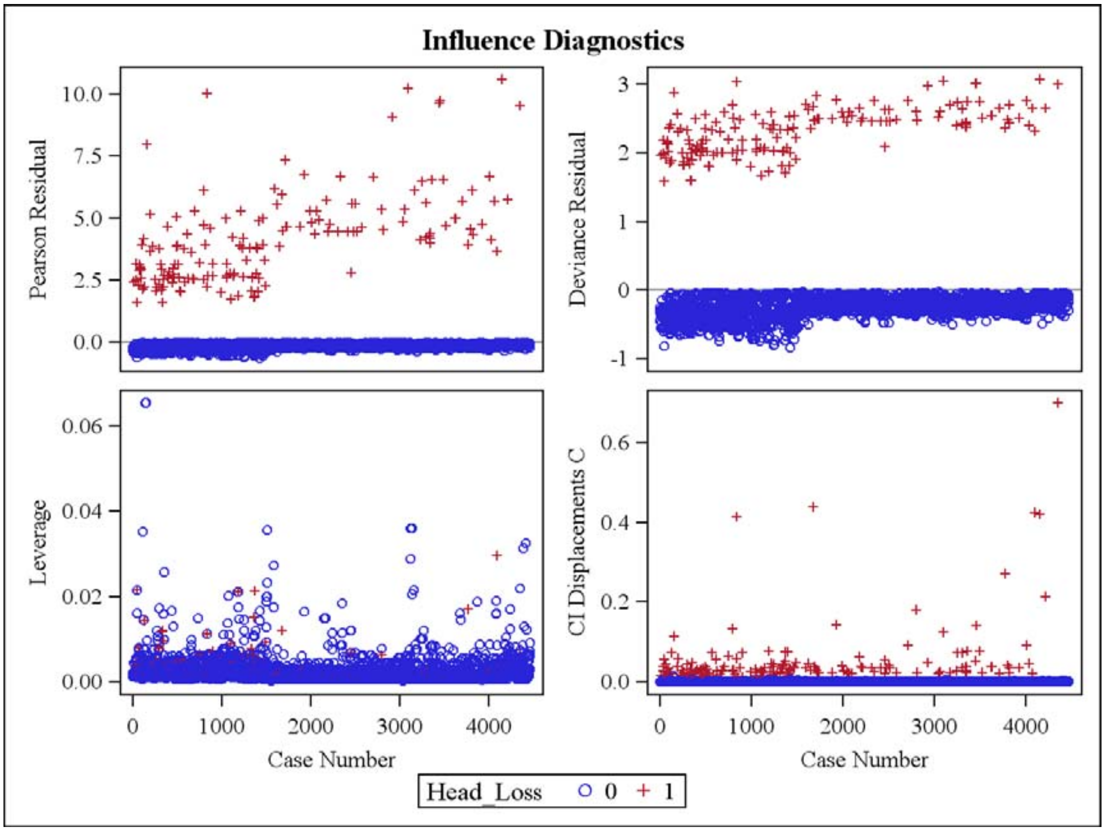


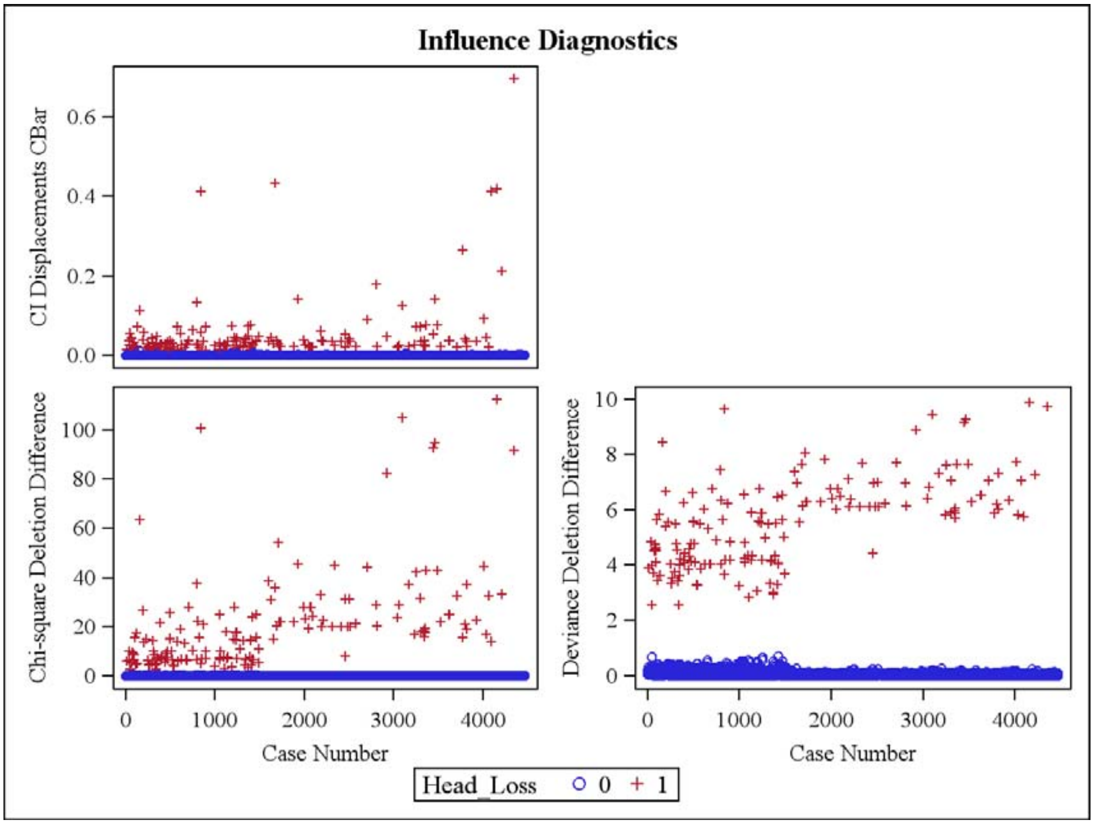
| Estimated Correlation Matrix | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **Intercept** | **HSF1** | **HSHJ1** | **HSHNJ1** | **FJKT1** | **HMT** | **HTR1** | **TSP** |
| **Intercept** | 1.0000 | 0.2361 | 0.2025 | 0.2119 | 0.2660 | -0.9180 | -0.3742 | -0.1869 |
| **HSF1** | 0.2361 | 1.0000 | 0.0934 | 0.0996 | 0.1628 | -0.2982 | -0.1381 | 0.0386 |
| **HSHJ1** | 0.2025 | 0.0934 | 1.0000 | 0.0819 | 0.1223 | -0.2496 | -0.1029 | 0.0268 |
| **HSHNJ1** | 0.2119 | 0.0996 | 0.0819 | 1.0000 | 0.1511 | -0.2572 | -0.1276 | 0.0122 |
| **FJKT1** | 0.2660 | 0.1628 | 0.1223 | 0.1511 | 1.0000 | -0.3468 | -0.9020 | 0.0239 |
| **HMT** | -0.9180 | -0.2982 | -0.2496 | -0.2572 | -0.3468 | 1.0000 | 0.4014 | -0.0604 |
| **HTR1** | -0.3742 | -0.1381 | -0.1029 | -0.1276 | -0.9020 | 0.4014 | 1.0000 | -0.0179 |
| **TSP** | -0.1869 | 0.0386 | 0.0268 | 0.0122 | 0.0239 | -0.0604 | -0.0179 | 1.0000 |
| **Haz_Env** | -0.1858 | 0.0456 | 0.0266 | 0.0144 | 0.0511 | -0.0785 | -0.0237 | 0.6047 |
| **ACCTYP1** | -0.0162 | -0.0111 | -0.0042 | 0.0021 | -0.0256 | 0.0434 | 0.0244 | -0.4457 |
| **TSPHaz_Env** | 0.1810 | -0.0437 | -0.0281 | -0.0169 | -0.0342 | 0.0800 | 0.0239 | -0.8600 |

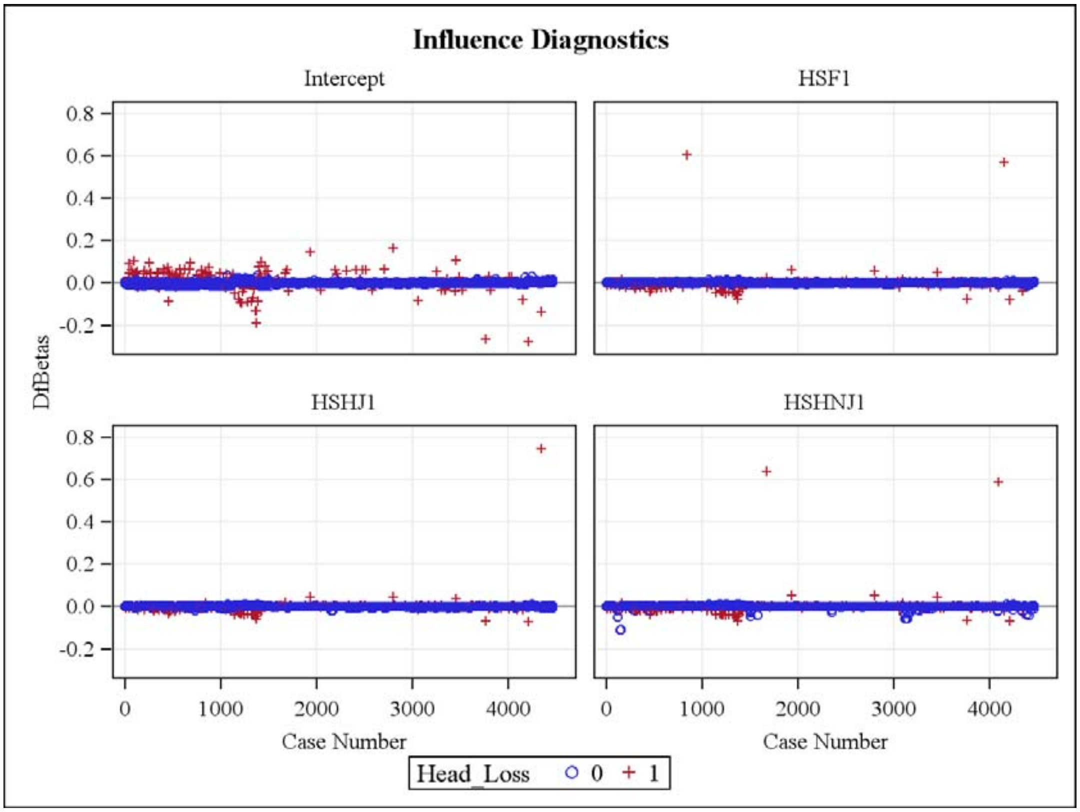
| Estimated Correlation Matrix | | | |
|---|---|---|---|
| **Parameter** | **Haz_Env** | **ACCTYP1** | **TSPHaz_Env** |
| **Intercept** | -0.1858 | -0.0162 | 0.1810 |
| **HSF1** | 0.0456 | -0.0111 | -0.0437 |
| **HSHJ1** | 0.0266 | -0.0042 | -0.0281 |
| **HSHNJ1** | 0.0144 | 0.0021 | -0.0169 |
| **FJKT1** | 0.0511 | -0.0256 | -0.0342 |
| **HMT** | -0.0785 | 0.0434 | 0.0800 |
| **HTR1** | -0.0237 | 0.0244 | 0.0239 |
| **TSP** | 0.6047 | -0.4457 | -0.8600 |
| **Haz_Env** | 1.0000 | -0.5980 | -0.8494 |
| **ACCTYP1** | -0.5980 | 1.0000 | 0.4361 |
| **TSPHaz_Env** | -0.8494 | 0.4361 | 1.0000 |

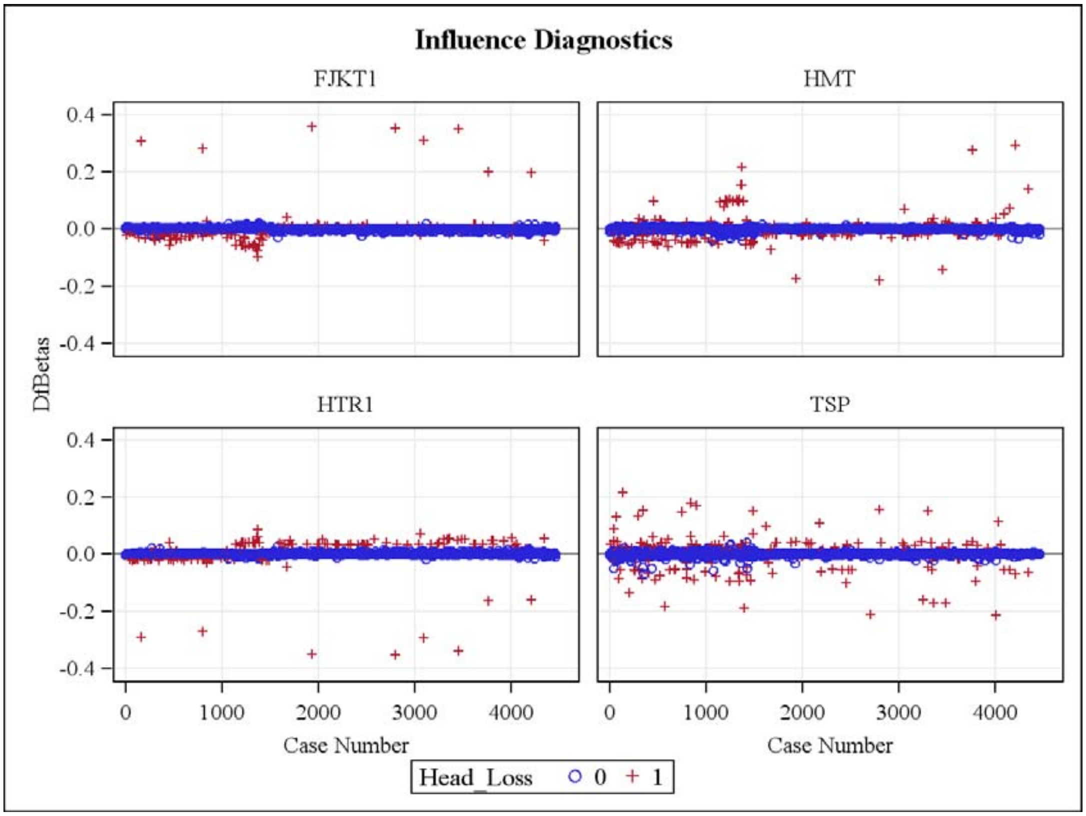
| Partition for the Hosmer and Lemeshow Test | | | | | |
|---|---|---|---|---|---|
| | | **Head_Loss = 1** | | **Head_Loss = 0** | |
| **Group** | **Total** | **Observed** | **Expected** | **Observed** | **Expected** |
| **1** | 445 | 0 | 1.07 | 445 | 443.93 |
| **2** | 447 | 0 | 2.76 | 447 | 444.24 |
| **3** | 448 | 7 | 4.74 | 441 | 443.26 |
| **4** | 452 | 2 | 7.50 | 450 | 444.50 |
| **5** | 449 | 12 | 10.86 | 437 | 438.14 |
| **6** | 438 | 17 | 14.19 | 421 | 423.81 |
| **7** | 448 | 25 | 19.14 | 423 | 428.86 |
| **8** | 447 | 24 | 23.67 | 423 | 423.33 |
| **9** | 447 | 27 | 35.12 | 420 | 411.88 |
| **10** | 446 | 67 | 66.73 | 379 | 379.27 |

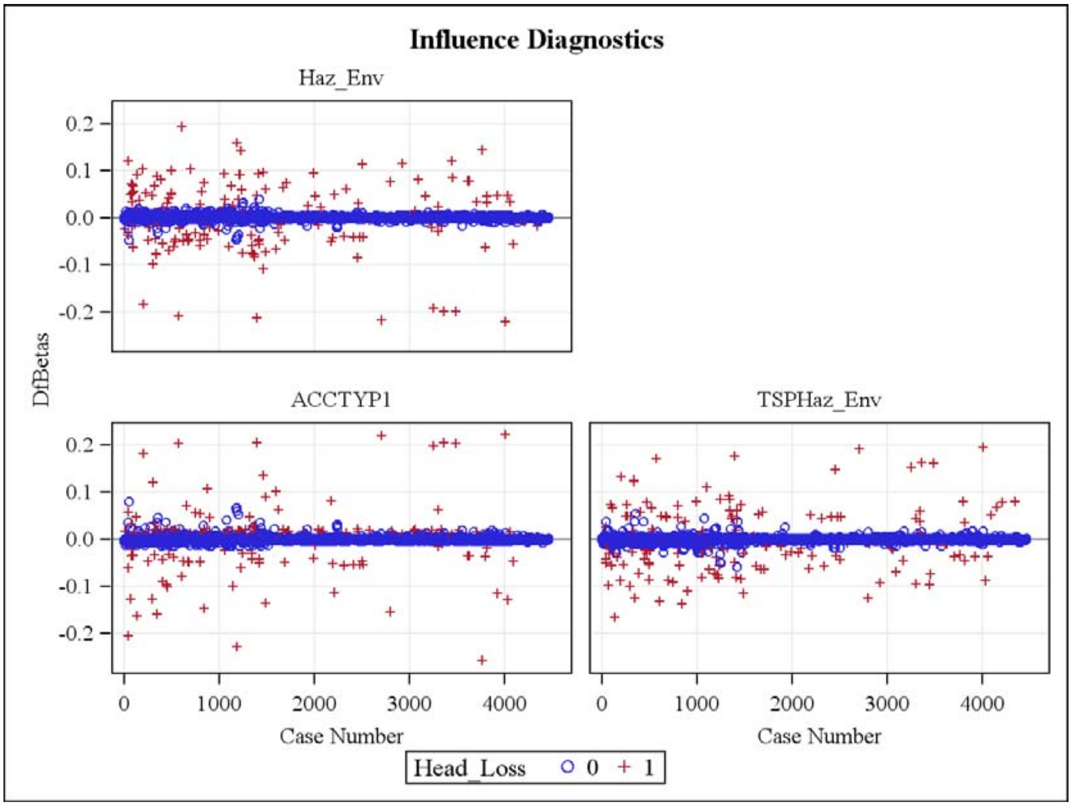
| Hosmer and Lemeshow Goodness-of-Fit Test | | |
|---|---|---|
| **Chi-Square** | **DF** | **Pr > ChiSq** |
| 13.6615 | 8 | 0.0910 |


Influence Diagnostics
Pearson Residual
Deviance Residual
Leverage
CI Displacements C
Case Number
Head_Loss ○ 0 + 1
0.0
2.5
5.0
7.5
10.0
-1
0
1
2
3
0.00
0.02
0.04
0.06
0.0
0.2
0.4
0.6
0
1000
2000
3000
4000


Influence Diagnostics
CI Displacements CBar
Chi-square Deletion Difference
Deviance Deletion Difference
Case Number
Head_Loss ○ 0 + 1
0.0
0.2
0.4
0.6
0
20
40
60
80
100
0
2
4
6
8
10
0
1000
2000
3000
4000


Influence Diagnostics
Intercept
HSF1
HSHJ1
HSHNJ1
DfBetas
0.8
0.6
0.4
0.2
0.0
-0.2
0
1000
2000
3000
4000
Case Number
Head_Loss
○ 0
+ 1


Influence Diagnostics
FJKT1
HMT
HTR1
TSP
DfBetas
0.4
0.2
0.0
-0.2
-0.4
0
1000
2000
3000
4000
Case Number
Head_Loss
○ 0
+ 1



# Shell

| Model Information | |
|---|---|
| **Data Set** | WORK.SHELL_CPR |
| **Response Variable** | Shell_Loss |
| **Number of Response Levels** | 2 |
| **Model** | binary logit |
| **Optimization Technique** | Fisher's scoring |
| **Likelihood Penalty** | Firth's bias correction |

| | |
|---|---|
| **Number of Observations Read** | 7165 |
| **Number of Observations Used** | 7165 |

| **Response Profile** | | |
|---|---|---|
| **Ordered Value** | **Shell_Loss** | **Total Frequency** |
| **1** | 0 | 6815 |
| **2** | 1 | 350 |

***Probability modeled is Shell_Loss='1'.***

| **Class Level Information** | | | | | | |
|---|---|---|---|---|---|---|
| **Class** | **Value** | **Design Variables** | | | | |
| **Shell_Lad_Grp** | **A** | 0 | 0 | 0 | 0 | 0 |
| | **D** | 1 | 0 | 0 | 0 | 0 |
| | **G** | 0 | 1 | 0 | 0 | 0 |
| | **H** | 0 | 0 | 1 | 0 | 0 |
| | **L** | 0 | 0 | 0 | 1 | 0 |
| | **O** | 0 | 0 | 0 | 0 | 1 |

| **Intercept-Only Model Convergence Status** |
|---|
| Convergence criterion (GCONV=1E-8) satisfied. |

| **Model Convergence Status** |
|---|
| Convergence criterion (GCONV=1E-8) satisfied. |

| Model Fit Statistics | | |
|---|---|---|
| **Criterion** | **Intercept Only** | **Intercept and Covariates** |
| **AIC** | 2648.441 | 1999.073 |
| **SC** | 2655.318 | 2122.858 |
| **-2 Log L** | 2646.441 | 1963.073 |

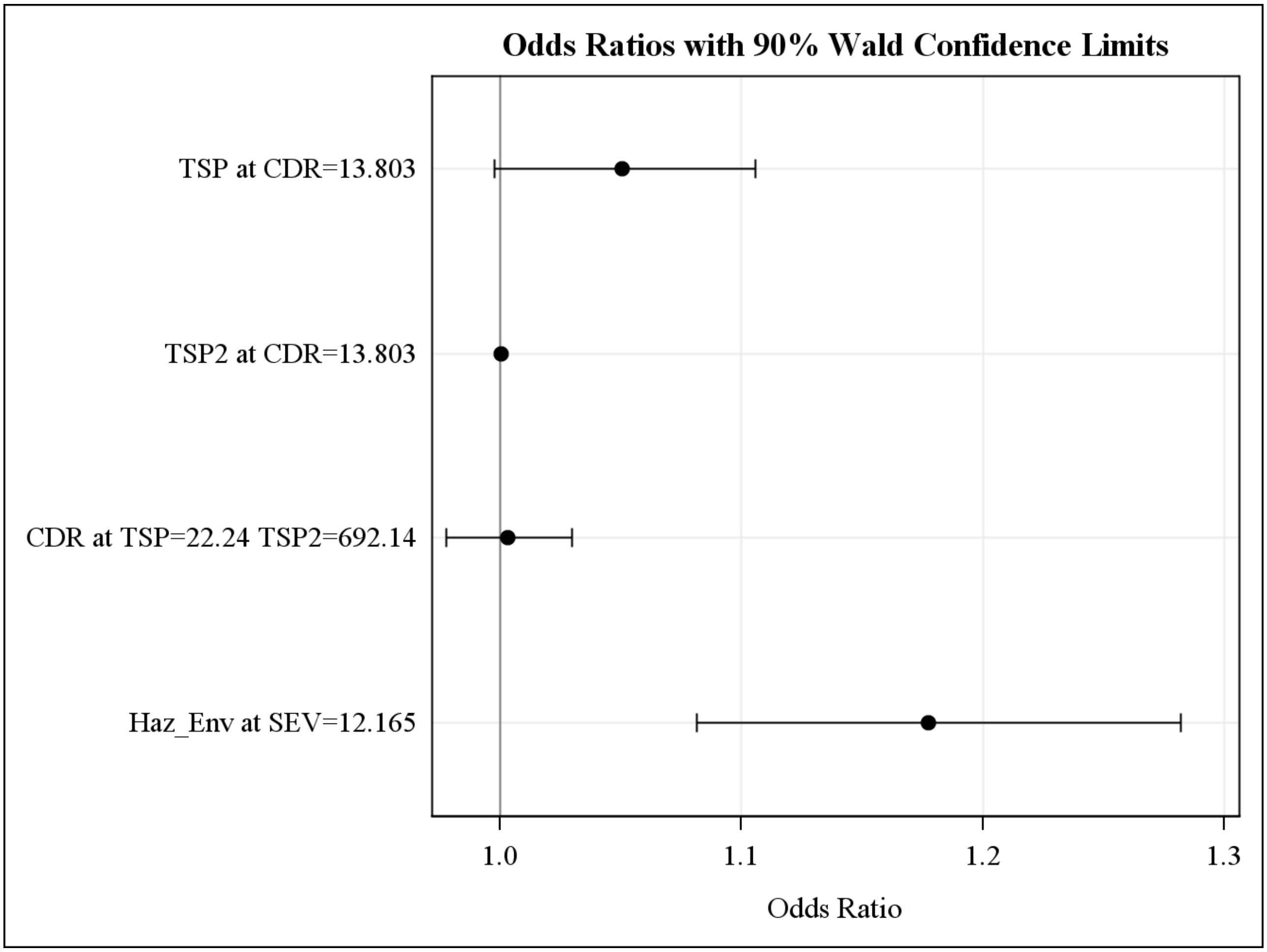
| Testing Global Null Hypothesis: BETA=0 | | | |
|---|---|---|---|
| **Test** | **Chi-Square** | **DF** | **Pr > ChiSq** |
| **Likelihood Ratio** | 683.3684 | 17 | <.0001 |
| **Score** | 926.4661 | 17 | <.0001 |
| **Wald** | 561.1429 | 17 | <.0001 |

| Type 3 Analysis of Effects | | | |
|---|---|---|---|
| **Effect** | **DF** | **Wald Chi-Square** | **Pr > ChiSq** |
| **STS** | 1 | 21.0475 | <.0001 |
| **JKT** | 1 | 53.9564 | <.0001 |
| **SID** | 1 | 25.1491 | <.0001 |
| **TSP** | 1 | 2.5472 | 0.1105 |
| **TSP2** | 1 | 8.2004 | 0.0042 |
| **SEV** | 1 | 0.4567 | 0.4992 |
| **SEV2** | 1 | 0.2924 | 0.5887 |
| **CDR** | 1 | 6.1236 | 0.0133 |
| **Haz_Env** | 1 | 0.8297 | 0.3624 |
| **TSP*CDR** | 1 | 19.3758 | <.0001 |
| **TSP2*CDR** | 1 | 20.9714 | <.0001 |
| **SEV*Haz_Env** | 1 | 5.2947 | 0.0214 |
| **Shell_Lad_Grp** | 5 | 37.1427 | <.0001 |

| Analysis of Maximum Likelihood Estimates | | | | | | |
|---|---|---|---|---|---|---|
| **Parameter** | | **DF** | **Estimate** | **Standard Error** | **Wald Chi-Square** | **Pr > ChiSq** |
| **Intercept** | | 1 | 5.6289 | 1.3984 | 16.2030 | <.0001 |
| **STS** | | 1 | -5.2092 | 1.1355 | 21.0475 | <.0001 |
| **JKT** | | 1 | -1.0986 | 0.1496 | 53.9564 | <.0001 |
| **SID** | | 1 | -0.0588 | 0.0117 | 25.1491 | <.0001 |
| **TSP** | | 1 | -0.0514 | 0.0322 | 2.5472 | 0.1105 |
| **TSP2** | | 1 | 0.00147 | 0.000514 | 8.2004 | 0.0042 |
| **SEV** | | 1 | -0.0254 | 0.0376 | 0.4567 | 0.4992 |
| **SEV2** | | 1 | -0.00032 | 0.000594 | 0.2924 | 0.5887 |
| **CDR** | | 1 | -0.0953 | 0.0385 | 6.1236 | 0.0133 |
| **Haz_Env** | | 1 | 0.0739 | 0.0811 | 0.8297 | 0.3624 |
| **TSP*CDR** | | 1 | 0.00729 | 0.00166 | 19.3758 | <.0001 |
| **TSP2*CDR** | | 1 | -0.00009 | 0.000020 | 20.9714 | <.0001 |
| **SEV*Haz_Env** | | 1 | 0.00736 | 0.00320 | 5.2947 | 0.0214 |
| **Shell_Lad_Grp** | **D** | 1 | -0.7976 | 0.3437 | 5.3845 | 0.0203 |
| **Shell_Lad_Grp** | **G** | 1 | -0.9089 | 0.2699 | 11.3439 | 0.0008 |
| **Shell_Lad_Grp** | **H** | 1 | -0.4355 | 0.2406 | 3.2760 | 0.0703 |
| **Shell_Lad_Grp** | **L** | 1 | 1.4745 | 0.3781 | 15.2044 | <.0001 |
| **Shell_Lad_Grp** | **O** | 1 | -1.5734 | 0.6590 | 5.6993 | 0.0170 |

| Association of Predicted Probabilities and Observed Responses | | | |
|---|---|---|---|
| **Percent Concordant** | 86.0 | **Somers' D** | 0.721 |
| **Percent Discordant** | 13.9 | **Gamma** | 0.721 |
| **Percent Tied** | 0.0 | **Tau-a** | 0.067 |
| **Pairs** | 2385250 | **c** | 0.860 |

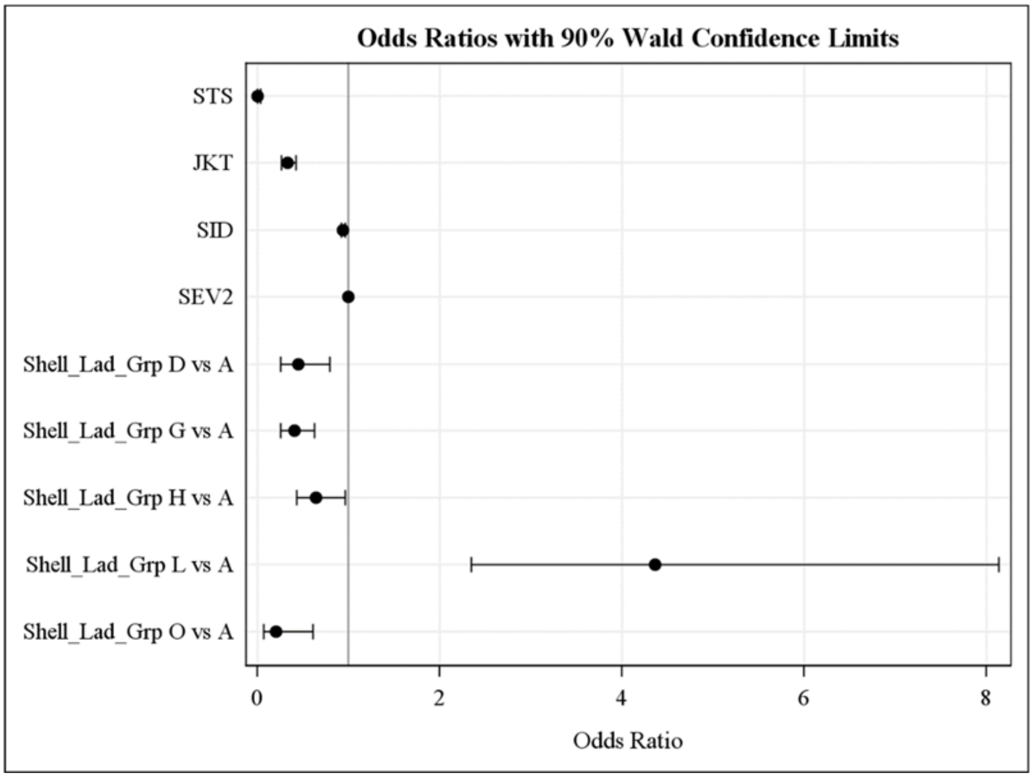
| Odds Ratio Estimates and Wald Confidence Intervals | | | |
|---|---|---|---|
| **Label** | **Estimate** | **90% Confidence Limits** | |
| TSP at CDR=13.803 | 1.050 | 0.998 | 1.106 |
| TSP2 at CDR=13.803 | 1.000 | 0.999 | 1.001 |
| CDR at TSP=22.24 TSP2=692.14 | 1.003 | 0.977 | 1.030 |
| Haz_Env at SEV=12.165 | 1.177 | 1.081 | 1.282 |

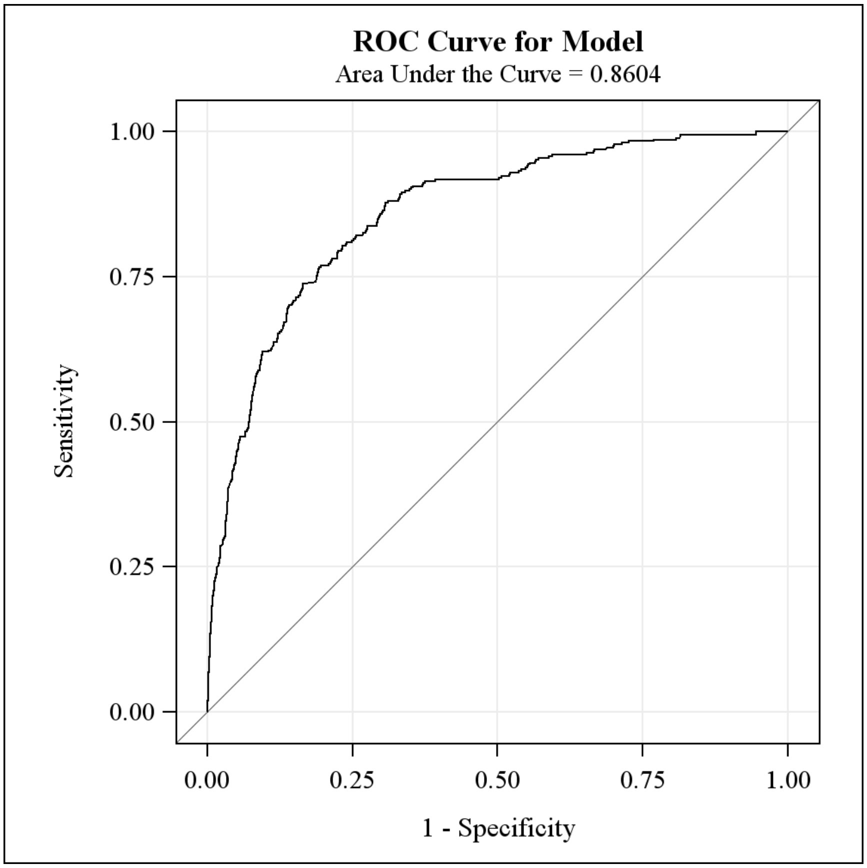


| Parameter Estimates and Wald Confidence Intervals | | | | |
|---|---|---|---|---|
| **Parameter** | | **Estimate** | **90% Confidence Limits** | |
| **Intercept** | | 5.6289 | 3.3288 | 7.9290 |
| **STS** | | -5.2092 | -7.0769 | -3.3416 |
| **JKT** | | -1.0986 | -1.3446 | -0.8526 |

| Parameter Estimates and Wald Confidence Intervals | | | | |
|---|---|---|---|---|
| **Parameter** | | **Estimate** | **90% Confidence Limits** | |
| **SID** | | -0.0588 | -0.0781 | -0.0395 |
| **TSP** | | -0.0514 | -0.1045 | 0.00157 |
| **TSP2** | | 0.00147 | 0.000627 | 0.00232 |
| **SEV** | | -0.0254 | -0.0873 | 0.0365 |
| **SEV2** | | -0.00032 | -0.00130 | 0.000656 |
| **CDR** | | -0.0953 | -0.1587 | -0.0320 |
| **Haz_Env** | | 0.0739 | -0.0595 | 0.2073 |
| **TSP*CDR** | | 0.00729 | 0.00457 | 0.0100 |
| **TSP2*CDR** | | -0.00009 | -0.00012 | -0.00006 |
| **SEV*Haz_Env** | | 0.00736 | 0.00210 | 0.0126 |
| **Shell_Lad_Grp** | **D** | -0.7976 | -1.3629 | -0.2322 |
| **Shell_Lad_Grp** | **G** | -0.9089 | -1.3528 | -0.4650 |
| **Shell_Lad_Grp** | **H** | -0.4355 | -0.8312 | -0.0397 |
| **Shell_Lad_Grp** | **L** | 1.4745 | 0.8525 | 2.0965 |
| **Shell_Lad_Grp** | **O** | -1.5734 | -2.6574 | -0.4893 |

| Odds Ratio Estimates and Wald Confidence Intervals | | | | |
|---|---|---|---|---|
| **Effect** | **Unit** | **Estimate** | **90% Confidence Limits** | |
| **STS** | 1.000 | 0.005 | <0.001 | 0.035 |
| **JKT** | 1.000 | 0.333 | 0.261 | 0.426 |
| **SID** | 1.000 | 0.943 | 0.925 | 0.961 |
| **SEV2** | 1.000 | 1.000 | 0.999 | 1.001 |
| **Shell_Lad_Grp D vs A** | 1.000 | 0.450 | 0.256 | 0.793 |
| **Shell_Lad_Grp G vs A** | 1.000 | 0.403 | 0.259 | 0.628 |
| **Shell_Lad_Grp H vs A** | 1.000 | 0.647 | 0.436 | 0.961 |
| **Shell_Lad_Grp L vs A** | 1.000 | 4.369 | 2.345 | 8.137 |
| **Shell_Lad_Grp O vs A** | 1.000 | 0.207 | 0.070 | 0.613 |


Odds Ratios with 90% Wald Confidence Limits
STS
JKT
SID
SEV2
Shell_Lad_Grp D vs A
Shell_Lad_Grp G vs A
Shell_Lad_Grp H vs A
Shell_Lad_Grp L vs A
Shell_Lad_Grp O vs A
0
2
4
6
8
Odds Ratio


ROC Curve for Model
Area Under the Curve = 0.8604
Sensitivity
1.00
0.75
0.50
0.25
0.00
0.00
0.25
0.50
0.75
1.00
1 - Specificity

**Estimated Correlation Matrix**

| Parameter | Intercept | STS | JKT | SID | TSP | TSP2 | SEV | SEV2 | CDR | Haz_Env |
|---|---|---|---|---|---|---|---|---|---|---|
| **Intercept** | 1.0000 | -0.2336 | -0.3312 | -0.8920 | -0.0189 | -0.0021 | -0.1754 | 0.1426 | -0.1402 | -0.0919 |
| **STS** | -0.2336 | 1.0000 | -0.2434 | -0.1353 | -0.0069 | 0.0020 | 0.0199 | -0.0121 | -0.0155 | 0.0183 |
| **JKT** | -0.3312 | -0.2434 | 1.0000 | 0.3924 | 0.0329 | -0.0241 | -0.0086 | 0.0274 | -0.0218 | 0.0256 |
| **SID** | -0.8920 | -0.1353 | 0.3924 | 1.0000 | -0.0593 | 0.0899 | 0.0735 | -0.1012 | 0.0823 | -0.0527 |
| **TSP** | -0.0189 | -0.0069 | 0.0329 | -0.0593 | 1.0000 | -0.9264 | -0.5110 | 0.3930 | 0.1271 | -0.3800 |
| **TSP2** | -0.0021 | 0.0020 | -0.0241 | 0.0899 | -0.9264 | 1.0000 | 0.2946 | -0.2421 | 0.0560 | 0.2192 |
| **SEV** | -0.1754 | 0.0199 | -0.0086 | 0.0735 | -0.5110 | 0.2946 | 1.0000 | -0.8387 | -0.1324 | 0.4716 |
| **SEV2** | 0.1426 | -0.0121 | 0.0274 | -0.1012 | 0.3930 | -0.2421 | -0.8387 | 1.0000 | 0.0153 | -0.0677 |
| **CDR** | -0.1402 | -0.0155 | -0.0218 | 0.0823 | 0.1271 | 0.0560 | -0.1324 | 0.0153 | 1.0000 | -0.3333 |
| **Haz_Env** | -0.0919 | 0.0183 | 0.0256 | -0.0527 | -0.3800 | 0.2192 | 0.4716 | -0.0677 | -0.3333 | 1.0000 |
| **TSPCDR** | 0.1304 | 0.0185 | 0.0024 | -0.0426 | -0.3973 | 0.2718 | 0.1215 | 0.0007 | -0.9110 | 0.3333 |
| **TSP2CDR** | -0.0961 | -0.0180 | 0.0012 | -0.0064 | 0.5720 | -0.5452 | -0.0831 | -0.0255 | 0.6980 | -0.2737 |
| **SEVHaz_Env** | 0.1416 | -0.0293 | -0.0336 | -0.0069 | 0.3323 | -0.2047 | -0.5512 | 0.0921 | 0.2817 | -0.8580 |
| **Shell_Lad_GrpD** | -0.3216 | -0.4743 | 0.4515 | 0.5160 | -0.0127 | 0.0291 | 0.0249 | -0.0385 | -0.0220 | -0.0431 |
| **Shell_Lad_GrpG** | -0.3307 | 0.0713 | -0.0868 | 0.3307 | 0.0232 | -0.0279 | 0.0348 | -0.0545 | -0.0348 | -0.0245 |
| **Shell_Lad_GrpH** | 0.0685 | 0.1451 | -0.2567 | -0.1235 | -0.0338 | 0.0439 | 0.0059 | -0.0296 | 0.0206 | -0.0179 |
| **Shell_Lad_GrpL** | 0.3594 | -0.3226 | -0.1659 | -0.2488 | 0.0210 | -0.0159 | -0.0262 | 0.0011 | 0.0465 | -0.0801 |
| **Shell_Lad_GrpO** | -0.1304 | 0.0310 | -0.0468 | 0.1274 | -0.0006 | -0.0036 | -0.0064 | -0.0031 | -0.0013 | -0.0051 |

**Estimated Correlation Matrix**

| Parameter | TSPCDR | TSP2CDR | SEVHaz_Env | Shell_Lad_GrpD | Shell_Lad_GrpG |
|---|---|---|---|---|---|
| **Intercept** | 0.1304 | -0.0961 | 0.1416 | -0.3216 | -0.3307 |
| **STS** | 0.0185 | -0.0180 | -0.0293 | -0.4743 | 0.0713 |
| **JKT** | 0.0024 | 0.0012 | -0.0336 | 0.4515 | -0.0868 |
| **SID** | -0.0426 | -0.0064 | -0.0069 | 0.5160 | 0.3307 |
| **TSP** | -0.3973 | 0.5720 | 0.3323 | -0.0127 | 0.0232 |
| **TSP2** | 0.2718 | -0.5452 | -0.2047 | 0.0291 | -0.0279 |
| **SEV** | 0.1215 | -0.0831 | -0.5512 | 0.0249 | 0.0348 |
| **SEV2** | 0.0007 | -0.0255 | 0.0921 | -0.0385 | -0.0545 |

| Estimated Correlation Matrix | | | | | |
|---|---|---|---|---|---|
| **Parameter** | **TSPCDR** | **TSP2CDR** | **SEVHaz_Env** | **Shell_Lad_GrpD** | **Shell_Lad_GrpG** |
| **CDR** | -0.9110 | 0.6980 | 0.2817 | -0.0220 | -0.0348 |
| **Haz_Env** | 0.3333 | -0.2737 | -0.8580 | -0.0431 | -0.0245 |
| **TSPCDR** | 1.0000 | -0.9238 | -0.2838 | 0.0122 | -0.0247 |
| **TSP2CDR** | -0.9238 | 1.0000 | 0.2326 | -0.0210 | 0.0576 |
| **SEVHaz_Env** | -0.2838 | 0.2326 | 1.0000 | 0.0101 | 0.0125 |
| **Shell_Lad_GrpD** | 0.0122 | -0.0210 | 0.0101 | 1.0000 | 0.1536 |
| **Shell_Lad_GrpG** | -0.0247 | 0.0576 | 0.0125 | 0.1536 | 1.0000 |
| **Shell_Lad_GrpH** | -0.0138 | -0.0018 | 0.0267 | -0.0926 | 0.0972 |
| **Shell_Lad_GrpL** | -0.0629 | 0.0686 | 0.0719 | 0.0306 | -0.0349 |
| **Shell_Lad_GrpO** | 0.0071 | -0.0050 | 0.0142 | 0.0451 | 0.0949 |

| Estimated Correlation Matrix | | | |
|---|---|---|---|
| **Parameter** | **Shell_Lad_GrpH** | **Shell_Lad_GrpL** | **Shell_Lad_GrpO** |
| **Intercept** | 0.0685 | 0.3594 | -0.1304 |
| **STS** | 0.1451 | -0.3226 | 0.0310 |
| **JKT** | -0.2567 | -0.1659 | -0.0468 |
| **SID** | -0.1235 | -0.2488 | 0.1274 |
| **TSP** | -0.0338 | 0.0210 | -0.0006 |
| **TSP2** | 0.0439 | -0.0159 | -0.0036 |
| **SEV** | 0.0059 | -0.0262 | -0.0064 |
| **SEV2** | -0.0296 | 0.0011 | -0.0031 |
| **CDR** | 0.0206 | 0.0465 | -0.0013 |
| **Haz_Env** | -0.0179 | -0.0801 | -0.0051 |
| **TSPCDR** | -0.0138 | -0.0629 | 0.0071 |
| **TSP2CDR** | -0.0018 | 0.0686 | -0.0050 |
| **SEVHaz_Env** | 0.0267 | 0.0719 | 0.0142 |
| **Shell_Lad_GrpD** | -0.0926 | 0.0306 | 0.0451 |
| **Shell_Lad_GrpG** | 0.0972 | -0.0349 | 0.0949 |

| Estimated Correlation Matrix | | | |
|---|---|---|---|
| **Parameter** | **Shell_Lad_GrpH** | **Shell_Lad_GrpL** | **Shell_Lad_GrpO** |
| **Shell_Lad_GrpH** | 1.0000 | 0.0707 | 0.0367 |
| **Shell_Lad_GrpL** | 0.0707 | 1.0000 | -0.0187 |
| **Shell_Lad_GrpO** | 0.0367 | -0.0187 | 1.0000 |

| Partition for the Hosmer and Lemeshow Test | | | | | |
|---|---|---|---|---|---|
| | | **Shell_Loss = 1** | | **Shell_Loss = 0** | |
| **Group** | **Total** | **Observed** | **Expected** | **Observed** | **Expected** |
| **1** | 711 | 2 | 2.09 | 709 | 708.91 |
| **2** | 717 | 3 | 4.37 | 714 | 712.63 |
| **3** | 719 | 6 | 6.74 | 713 | 712.26 |
| **4** | 681 | 5 | 8.78 | 676 | 672.22 |
| **5** | 704 | 13 | 11.51 | 691 | 692.49 |
| **6** | 718 | 1 | 14.43 | 717 | 703.57 |
| **7** | 717 | 27 | 18.75 | 690 | 698.25 |
| **8** | 668 | 34 | 27.96 | 634 | 640.04 |
| **9** | 717 | 53 | 53.76 | 664 | 663.24 |
| **10** | 813 | 206 | 207.71 | 607 | 605.29 |

| Hosmer and Lemeshow Goodness-of-Fit Test | | |
|---|---|---|
| **Chi-Square** | **DF** | **Pr > ChiSq** |
| 20.2341 | 8 | 0.0095 |

| Classification Table | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Correct | | Incorrect | | Percentages | | | | |
| Prob Level | Event | Non-Event | Event | Non-Event | Correct | Sensi-tivity | Speci-ficity | False POS | False NEG |
| **0.000** | 350 | 0 | 6815 | 0 | 4.9 | 100.0 | 0.0 | 95.1 | . |
| **0.020** | 320 | 4082 | 2733 | 30 | 61.4 | 91.4 | 59.9 | 89.5 | 0.7 |
| **0.040** | 275 | 5211 | 1604 | 75 | 76.6 | 78.6 | 76.5 | 85.4 | 1.4 |
| **0.060** | 244 | 5724 | 1091 | 106 | 83.3 | 69.7 | 84.0 | 81.7 | 1.8 |
| **0.080** | 227 | 5949 | 866 | 123 | 86.2 | 64.9 | 87.3 | 79.2 | 2.0 |
| **0.100** | 212 | 6160 | 655 | 138 | 88.9 | 60.6 | 90.4 | 75.5 | 2.2 |
| **0.120** | 194 | 6243 | 572 | 156 | 89.8 | 55.4 | 91.6 | 74.7 | 2.4 |
| **0.140** | 173 | 6313 | 502 | 177 | 90.5 | 49.4 | 92.6 | 74.4 | 2.7 |
| **0.160** | 166 | 6392 | 423 | 184 | 91.5 | 47.4 | 93.8 | 71.8 | 2.8 |
| **0.180** | 153 | 6442 | 373 | 197 | 92.0 | 43.7 | 94.5 | 70.9 | 3.0 |
| **0.200** | 146 | 6478 | 337 | 204 | 92.4 | 41.7 | 95.1 | 69.8 | 3.1 |
| **0.220** | 135 | 6525 | 290 | 215 | 93.0 | 38.6 | 95.7 | 68.2 | 3.2 |
| **0.240** | 104 | 6611 | 204 | 246 | 93.7 | 29.7 | 97.0 | 66.2 | 3.6 |
| **0.260** | 94 | 6652 | 163 | 256 | 94.2 | 26.9 | 97.6 | 63.4 | 3.7 |
| **0.280** | 86 | 6677 | 138 | 264 | 94.4 | 24.6 | 98.0 | 61.6 | 3.8 |
| **0.300** | 82 | 6701 | 114 | 268 | 94.7 | 23.4 | 98.3 | 58.2 | 3.8 |
| **0.320** | 79 | 6716 | 99 | 271 | 94.8 | 22.6 | 98.5 | 55.6 | 3.9 |
| **0.340** | 79 | 6726 | 89 | 271 | 95.0 | 22.6 | 98.7 | 53.0 | 3.9 |
| **0.360** | 74 | 6731 | 84 | 276 | 95.0 | 21.1 | 98.8 | 53.2 | 3.9 |
| **0.380** | 72 | 6735 | 80 | 278 | 95.0 | 20.6 | 98.8 | 52.6 | 4.0 |
| **0.400** | 69 | 6744 | 71 | 281 | 95.1 | 19.7 | 99.0 | 50.7 | 4.0 |
| **0.420** | 62 | 6753 | 62 | 288 | 95.1 | 17.7 | 99.1 | 50.0 | 4.1 |
| **0.440** | 53 | 6765 | 50 | 297 | 95.2 | 15.1 | 99.3 | 48.5 | 4.2 |
| **0.460** | 48 | 6773 | 42 | 302 | 95.2 | 13.7 | 99.4 | 46.7 | 4.3 |
| **0.480** | 43 | 6777 | 38 | 307 | 95.2 | 12.3 | 99.4 | 46.9 | 4.3 |
| **0.500** | 36 | 6785 | 30 | 314 | 95.2 | 10.3 | 99.6 | 45.5 | 4.4 |

**Classification Table**

| Prob Level | Correct | | Incorrect | | Percentages | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Event | Non-Event | Event | Non-Event | Correct | Sensitivity | Specificity | False POS | False NEG |
| **0.520** | 31 | 6787 | 28 | 319 | 95.2 | 8.9 | 99.6 | 47.5 | 4.5 |
| **0.540** | 26 | 6791 | 24 | 324 | 95.1 | 7.4 | 99.6 | 48.0 | 4.6 |
| **0.560** | 20 | 6797 | 18 | 330 | 95.1 | 5.7 | 99.7 | 47.4 | 4.6 |
| **0.580** | 12 | 6800 | 15 | 338 | 95.1 | 3.4 | 99.8 | 55.6 | 4.7 |
| **0.600** | 9 | 6803 | 12 | 341 | 95.1 | 2.6 | 99.8 | 57.1 | 4.8 |
| **0.620** | 4 | 6808 | 7 | 346 | 95.1 | 1.1 | 99.9 | 63.6 | 4.8 |
| **0.640** | 3 | 6808 | 7 | 347 | 95.1 | 0.9 | 99.9 | 70.0 | 4.8 |
| **0.660** | 2 | 6810 | 5 | 348 | 95.1 | 0.6 | 99.9 | 71.4 | 4.9 |
| **0.680** | 1 | 6812 | 3 | 349 | 95.1 | 0.3 | 100.0 | 75.0 | 4.9 |
| **0.700** | 1 | 6812 | 3 | 349 | 95.1 | 0.3 | 100.0 | 75.0 | 4.9 |
| **0.720** | 1 | 6812 | 3 | 349 | 95.1 | 0.3 | 100.0 | 75.0 | 4.9 |
| **0.740** | 0 | 6813 | 2 | 350 | 95.1 | 0.0 | 100.0 | 100.0 | 4.9 |
| **0.760** | 0 | 6814 | 1 | 350 | 95.1 | 0.0 | 100.0 | 100.0 | 4.9 |
| **0.780** | 0 | 6814 | 1 | 350 | 95.1 | 0.0 | 100.0 | 100.0 | 4.9 |
| **0.800** | 0 | 6814 | 1 | 350 | 95.1 | 0.0 | 100.0 | 100.0 | 4.9 |
| **0.820** | 0 | 6814 | 1 | 350 | 95.1 | 0.0 | 100.0 | 100.0 | 4.9 |
| **0.840** | 0 | 6814 | 1 | 350 | 95.1 | 0.0 | 100.0 | 100.0 | 4.9 |
| **0.860** | 0 | 6815 | 0 | 350 | 95.1 | 0.0 | 100.0 | . | 4.9 |

## Top Fittings

| Model Information | |
|---|---|
| **Data Set** | WORK.TFCPR |
| **Response Variable** | TF_Loss |
| **Number of Response Levels** | 2 |
| **Model** | binary logit |
| **Optimization Technique** | Fisher's scoring |
| **Likelihood Penalty** | Firth's bias correction |

| | |
|---|---|
| **Number of Observations Read** | 4467 |
| **Number of Observations Used** | 4467 |

| **Response Profile** | | |
|---|---|---|
| **Ordered Value** | **TF_Loss** | **Total Frequency** |
| **1** | 0 | 3946 |
| **2** | 1 | 521 |

***Probability modeled is TF_Loss='1'.***

| **Class Level Information** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Class** | **Value** | **Design Variables** | | | | | | | | | | |
| **SMS** | **128** | 0 | 0 | | | | | | | | | |
| | **515** | 1 | 0 | | | | | | | | | |
| | **516** | 0 | 1 | | | | | | | | | |
| **JKT** | **0** | 0 | | | | | | | | | | |
| | **1** | 1 | | | | | | | | | | |
| **TFT** | **0** | 0 | | | | | | | | | | |
| | **1** | 1 | | | | | | | | | | |
| **ACCTYP** | **0** | 0 | | | | | | | | | | |
| | **1** | 1 | | | | | | | | | | |
| **TF_Lading_Grp** | **A** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **B** | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **D** | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **E** | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **F** | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **G** | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **H** | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | **K** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| | **M** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |

| Class Level Information | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Class** | **Value** | **Design Variables** | | | | | | | | | | |
| | **O** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | **Q** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | **T** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

| Intercept-Only Model Convergence Status |
|---|
| Convergence criterion (GCONV=1E-8) satisfied. |

| Model Convergence Status |
|---|
| Convergence criterion (GCONV=1E-8) satisfied. |

| Model Fit Statistics | | |
|---|---|---|
| **Criterion** | **Intercept Only** | **Intercept and Covariates** |
| **AIC** | 3040.970 | 2535.692 |
| **SC** | 3047.375 | 2702.208 |
| **-2 Log L** | 3038.970 | 2483.692 |

| Testing Global Null Hypothesis: BETA=0 | | | |
|---|---|---|---|
| **Test** | **Chi-Square** | **DF** | **Pr > ChiSq** |
| **Likelihood Ratio** | 555.2789 | 25 | <.0001 |
| **Score** | 503.7059 | 25 | <.0001 |
| **Wald** | 353.1420 | 25 | <.0001 |

| Type 3 Analysis of Effects | | | |
|---|---|---|---|
| **Effect** | **DF** | **Wald Chi-Square** | **Pr > ChiSq** |
| **SMS** | 2 | 22.1531 | <.0001 |
| **STS** | 1 | 1.9989 | 0.1574 |
| **JKT** | 1 | 17.9973 | <.0001 |
| **SID** | 1 | 1.7225 | 0.1894 |
| **TFT** | 1 | 4.1741 | 0.0410 |
| **ACCTYP** | 1 | 13.7555 | 0.0002 |
| **SEV2** | 1 | 8.1144 | 0.0044 |
| **TSP** | 1 | 1.1729 | 0.2788 |
| **TSP*CDR** | 1 | 3.0099 | 0.0828 |
| **TSP2** | 1 | 3.9557 | 0.0467 |
| **CDR*TSP2** | 1 | 3.6516 | 0.0560 |
| **Haz_Env** | 1 | 1.5996 | 0.2060 |
| **TSP2*Haz_Env** | 1 | 1.5749 | 0.2095 |
| **TF_Lading_Grp** | 11 | 114.8696 | <.0001 |

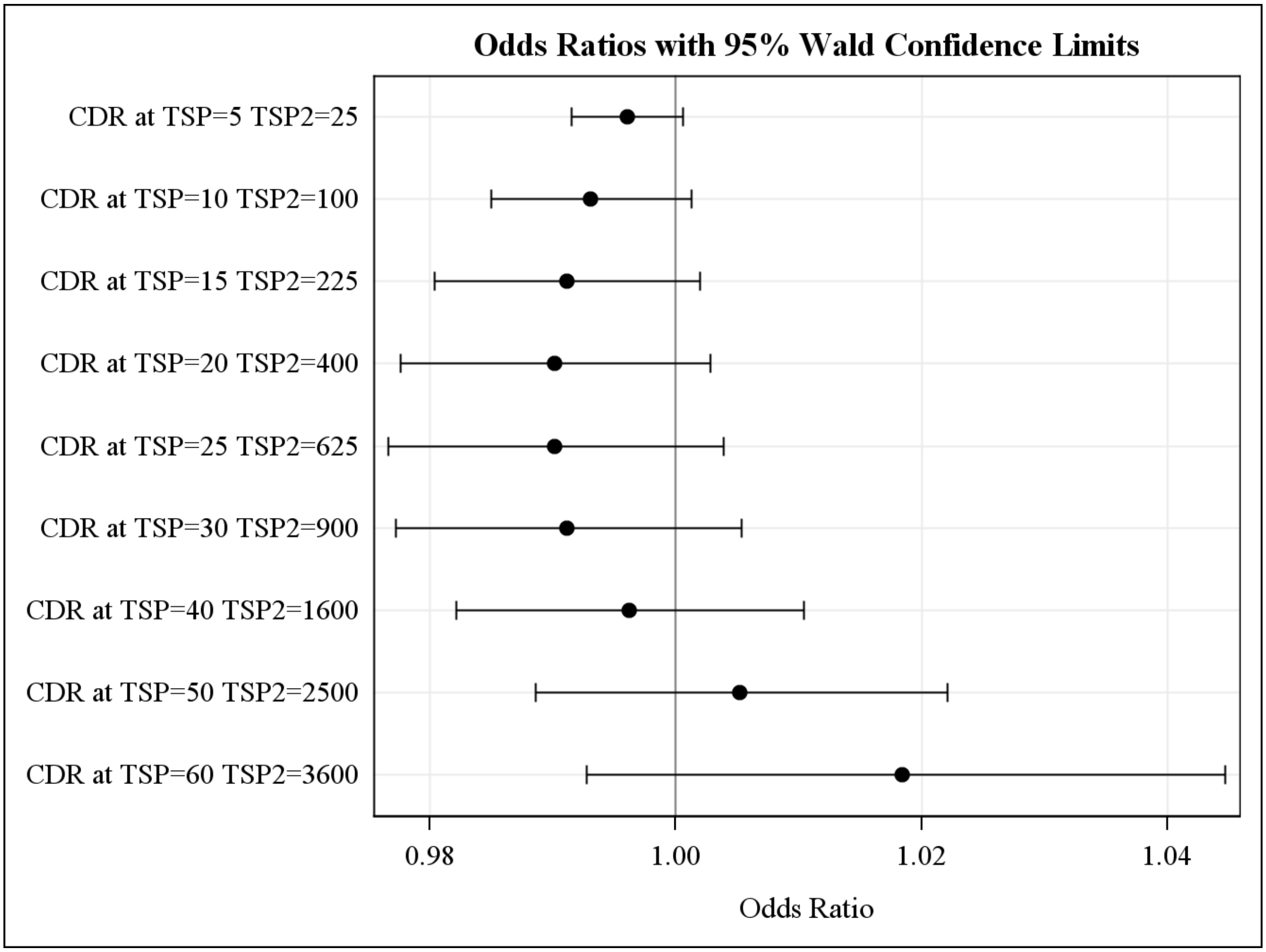
| Analysis of Maximum Likelihood Estimates | | | | | | |
|---|---|---|---|---|---|---|
| **Parameter** | | **DF** | **Estimate** | **Standard Error** | **Wald Chi-Square** | **Pr > ChiSq** |
| **Intercept** | | 1 | 0.5555 | 1.9739 | 0.0792 | 0.7784 |
| **SMS** | **515** | 1 | 0.6168 | 0.2007 | 9.4462 | 0.0021 |
| **SMS** | **516** | 1 | 0.0675 | 0.1958 | 0.1191 | 0.7300 |
| **STS** | | 1 | -2.7467 | 1.9427 | 1.9989 | 0.1574 |
| **JKT** | **1** | 1 | -0.5928 | 0.1397 | 17.9973 | <.0001 |
| **SID** | | 1 | -0.0198 | 0.0151 | 1.7225 | 0.1894 |
| **TFT** | **1** | 1 | -1.0092 | 0.4939 | 4.1741 | 0.0410 |
| **ACCTYP** | **1** | 1 | 0.8004 | 0.2158 | 13.7555 | 0.0002 |
| **SEV2** | | 1 | 0.000483 | 0.000170 | 8.1144 | 0.0044 |
| **TSP** | | 1 | 0.0195 | 0.0180 | 1.1729 | 0.2788 |
| **TSP*CDR** | | 1 | -0.00090 | 0.000516 | 3.0099 | 0.0828 |
| **TSP2** | | 1 | -0.00084 | 0.000423 | 3.9557 | 0.0467 |

| Analysis of Maximum Likelihood Estimates | | | | | | |
|---|---|---|---|---|---|---|
| **Parameter** | | **DF** | **Estimate** | **Standard Error** | **Wald Chi-Square** | **Pr > ChiSq** |
| **CDR*TSP2** | | 1 | 0.000020 | 0.000010 | 3.6516 | 0.0560 |
| **Haz_Env** | | 1 | 0.0584 | 0.0462 | 1.5996 | 0.2060 |
| **TSP2*Haz_Env** | | 1 | 0.000040 | 0.000032 | 1.5749 | 0.2095 |
| **TF_Lading_Grp** | **B** | 1 | 0.1975 | 0.2177 | 0.8231 | 0.3643 |
| **TF_Lading_Grp** | **D** | 1 | 0.8302 | 0.3485 | 5.6741 | 0.0172 |
| **TF_Lading_Grp** | **E** | 1 | 0.6831 | 0.2061 | 10.9844 | 0.0009 |
| **TF_Lading_Grp** | **F** | 1 | 0.3576 | 0.2261 | 2.5020 | 0.1137 |
| **TF_Lading_Grp** | **G** | 1 | -2.0358 | 0.4077 | 24.9345 | <.0001 |
| **TF_Lading_Grp** | **H** | 1 | -1.8599 | 0.4182 | 19.7778 | <.0001 |
| **TF_Lading_Grp** | **K** | 1 | -0.9286 | 0.4530 | 4.2012 | 0.0404 |
| **TF_Lading_Grp** | **M** | 1 | 1.1469 | 0.5453 | 4.4242 | 0.0354 |
| **TF_Lading_Grp** | **O** | 1 | -1.3968 | 0.5753 | 5.8938 | 0.0152 |
| **TF_Lading_Grp** | **Q** | 1 | -1.1367 | 0.6854 | 2.7502 | 0.0972 |
| **TF_Lading_Grp** | **T** | 1 | -2.3648 | 1.4465 | 2.6728 | 0.1021 |

| Association of Predicted Probabilities and Observed Responses | | | |
|---|---|---|---|
| **Percent Concordant** | 79.9 | **Somers' D** | 0.598 |
| **Percent Discordant** | 20.1 | **Gamma** | 0.598 |
| **Percent Tied** | 0.0 | **Tau-a** | 0.123 |
| **Pairs** | 2055866 | **c** | 0.799 |

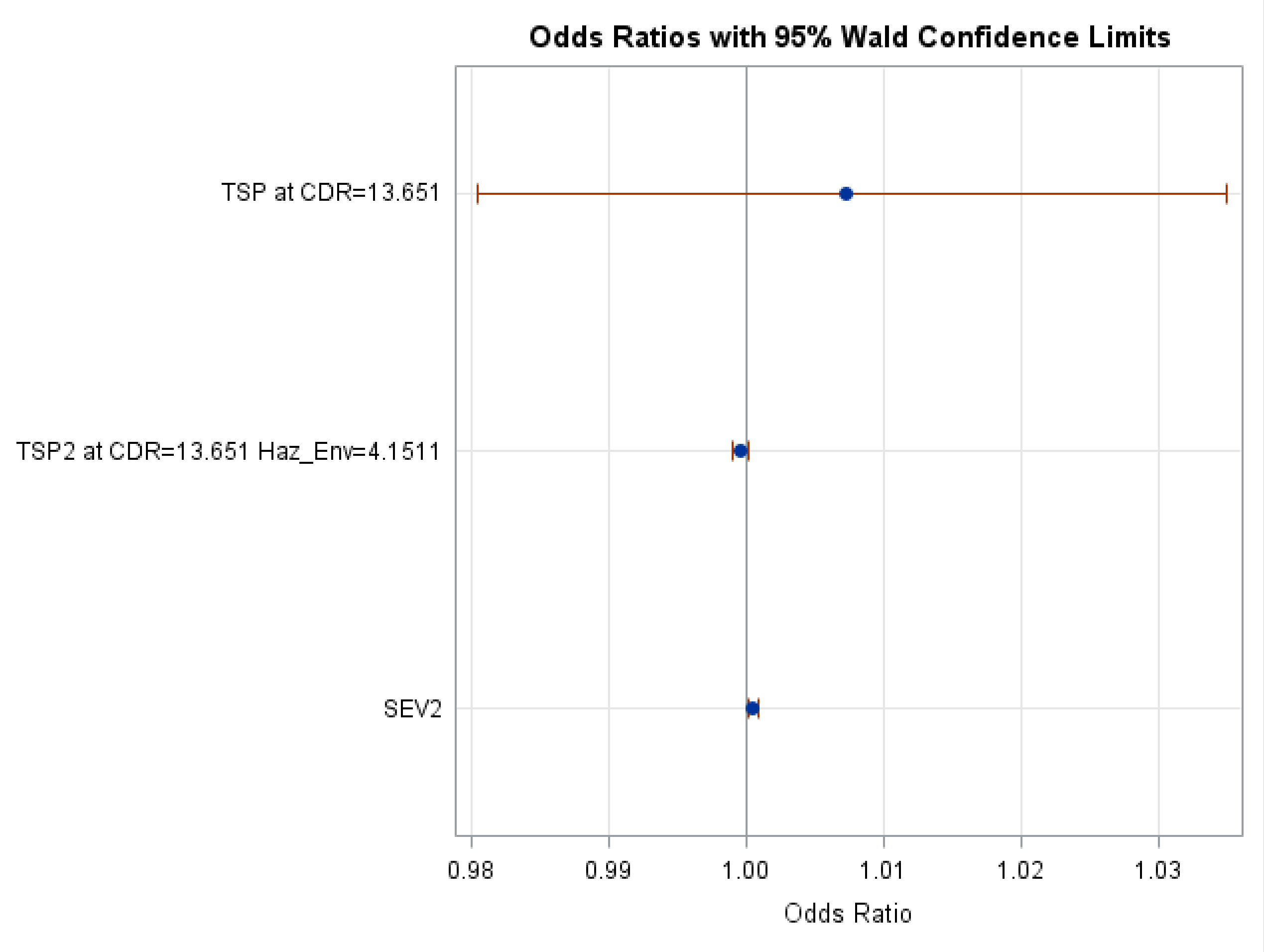
| Odds Ratio Estimates and Wald Confidence Intervals | | | |
|---|---|---|---|
| **Label** | **Estimate** | **95% Confidence Limits** | |
| CDR at TSP=5 TSP2=25 | 0.996 | 0.991 | 1.001 |
| CDR at TSP=10 TSP2=100 | 0.993 | 0.985 | 1.001 |
| CDR at TSP=15 TSP2=225 | 0.991 | 0.980 | 1.002 |

| Odds Ratio Estimates and Wald Confidence Intervals | | | |
|---|---|---|---|
| **Label** | **Estimate** | **95% Confidence Limits** | |
| CDR at TSP=20 TSP2=400 | 0.990 | 0.978 | 1.003 |
| CDR at TSP=25 TSP2=625 | 0.990 | 0.977 | 1.004 |
| CDR at TSP=30 TSP2=900 | 0.991 | 0.977 | 1.005 |
| CDR at TSP=40 TSP2=1600 | 0.996 | 0.982 | 1.010 |
| CDR at TSP=50 TSP2=2500 | 1.005 | 0.989 | 1.022 |
| CDR at TSP=60 TSP2=3600 | 1.018 | 0.993 | 1.045 |



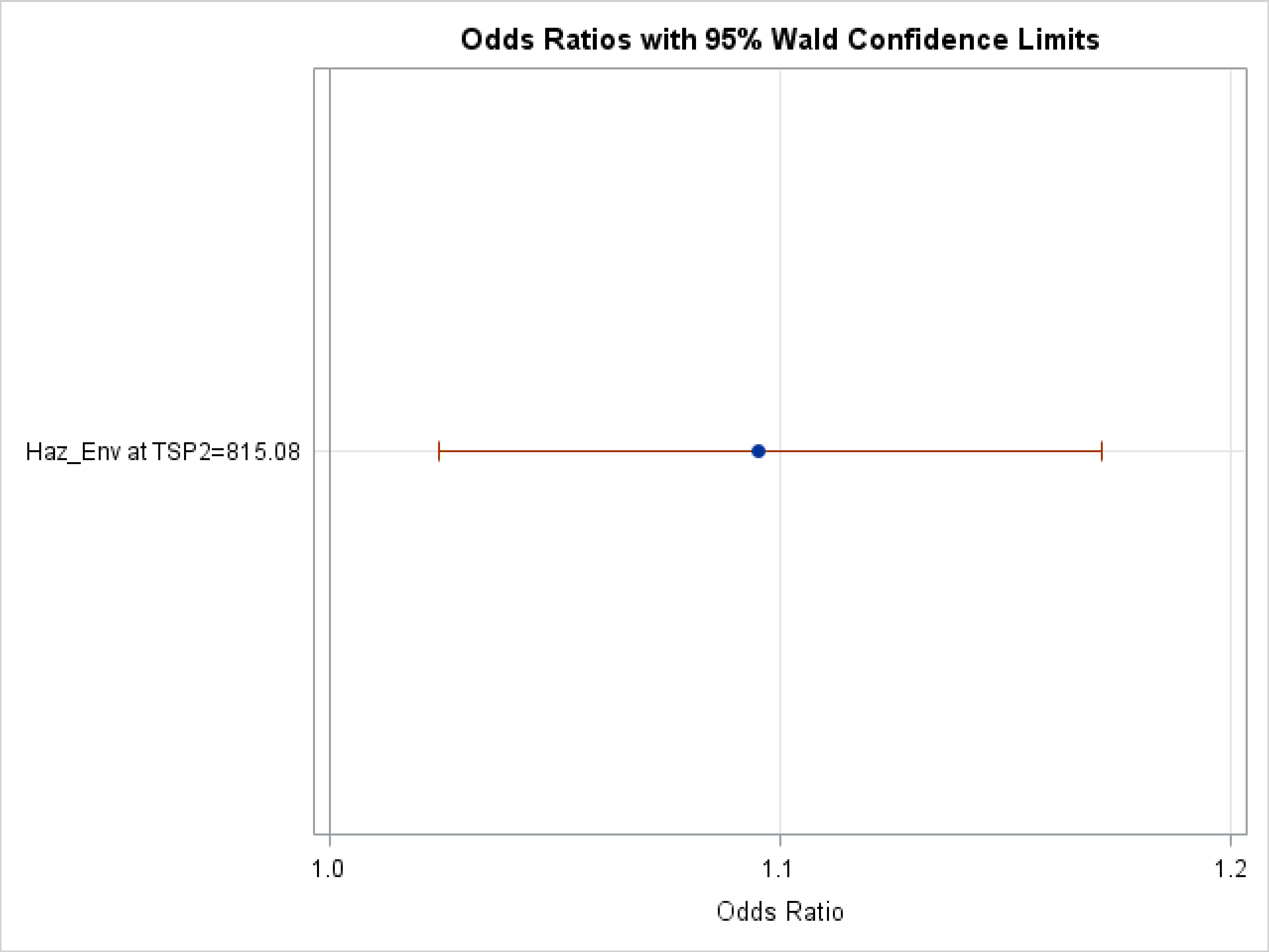
**Odds Ratio Estimates and Wald Confidence Intervals**

| Label | Estimate | 95% Confidence Limits | |
|---|---|---|---|
| TSP at CDR=13.651 | 1.007 | 0.980 | 1.035 |
| TSP2 at CDR=13.651 Haz_Env=4.1511 | 1.000 | 0.999 | 1.000 |
| SEV2 | 1.000 | 1.000 | 1.001 |



**Odds Ratio Estimates and Wald Confidence Intervals**

| Label | Estimate | 95% Confidence Limits | |
|---|---|---|---|
| Haz_Env at TSP2=815.08 | 1.095 | 1.024 | 1.171 |



| Parameter Estimates and Wald Confidence Intervals | | | | |
|---|---|---|---|---|
| **Parameter** | | **Estimate** | **95% Confidence Limits** | |
| **Intercept** | | 0.5555 | -3.3132 | 4.4243 |
| **SMS** | **515** | 0.6168 | 0.2234 | 1.0101 |
| **SMS** | **516** | 0.0675 | -0.3161 | 0.4512 |
| **STS** | | -2.7467 | -6.5543 | 1.0610 |
| **JKT** | **1** | -0.5928 | -0.8667 | -0.3189 |
| **SID** | | -0.0198 | -0.0494 | 0.00978 |
| **TFT** | **1** | -1.0092 | -1.9773 | -0.0410 |
| **ACCTYP** | **1** | 0.8004 | 0.3774 | 1.2234 |
| **SEV2** | | 0.000483 | 0.000151 | 0.000815 |
| **TSP** | | 0.0195 | -0.0158 | 0.0547 |
| **TSP*CDR** | | -0.00090 | -0.00191 | 0.000116 |
| **TSP2** | | -0.00084 | -0.00167 | -0.00001 |

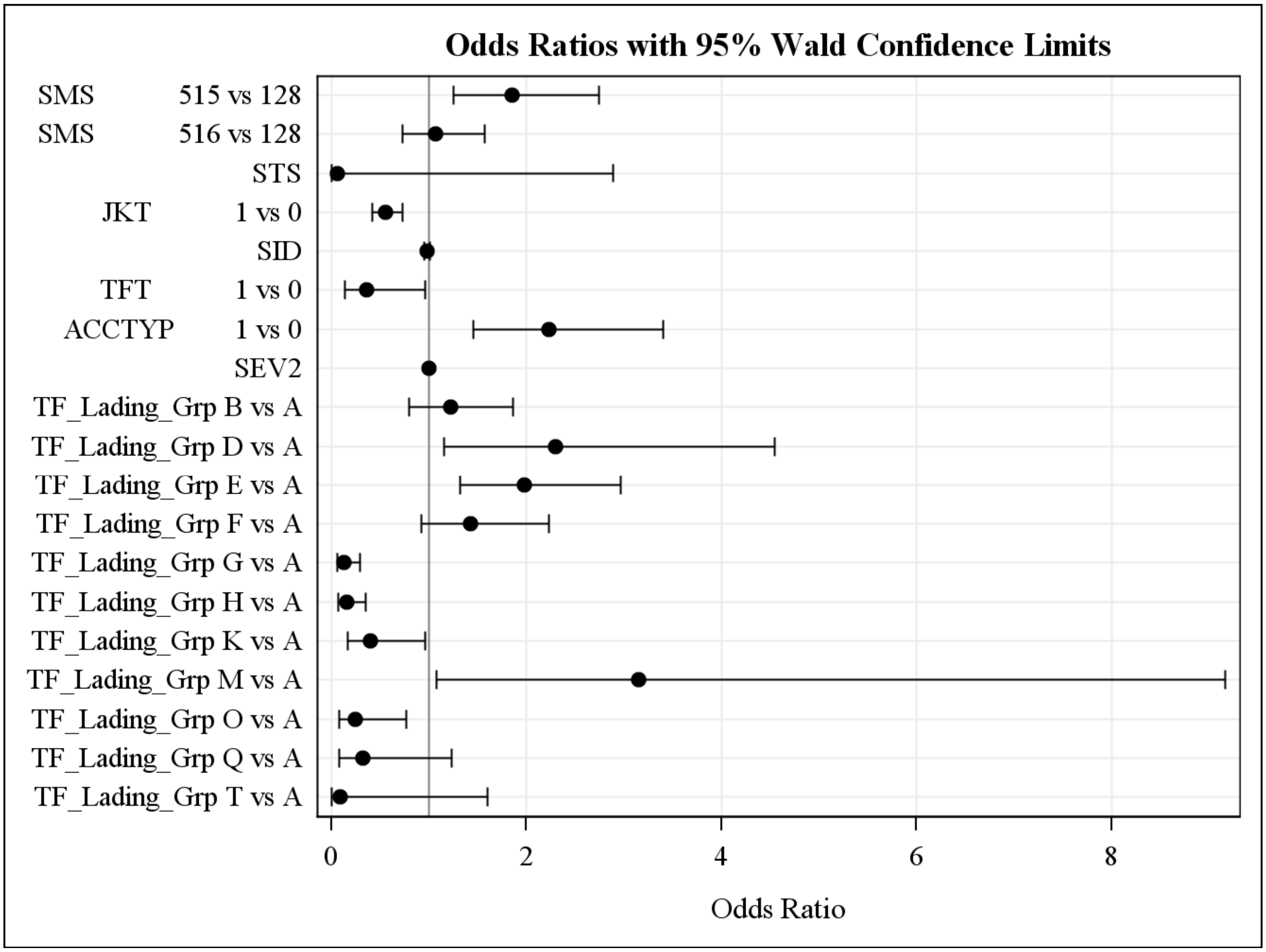
**Parameter Estimates and Wald Confidence Intervals**

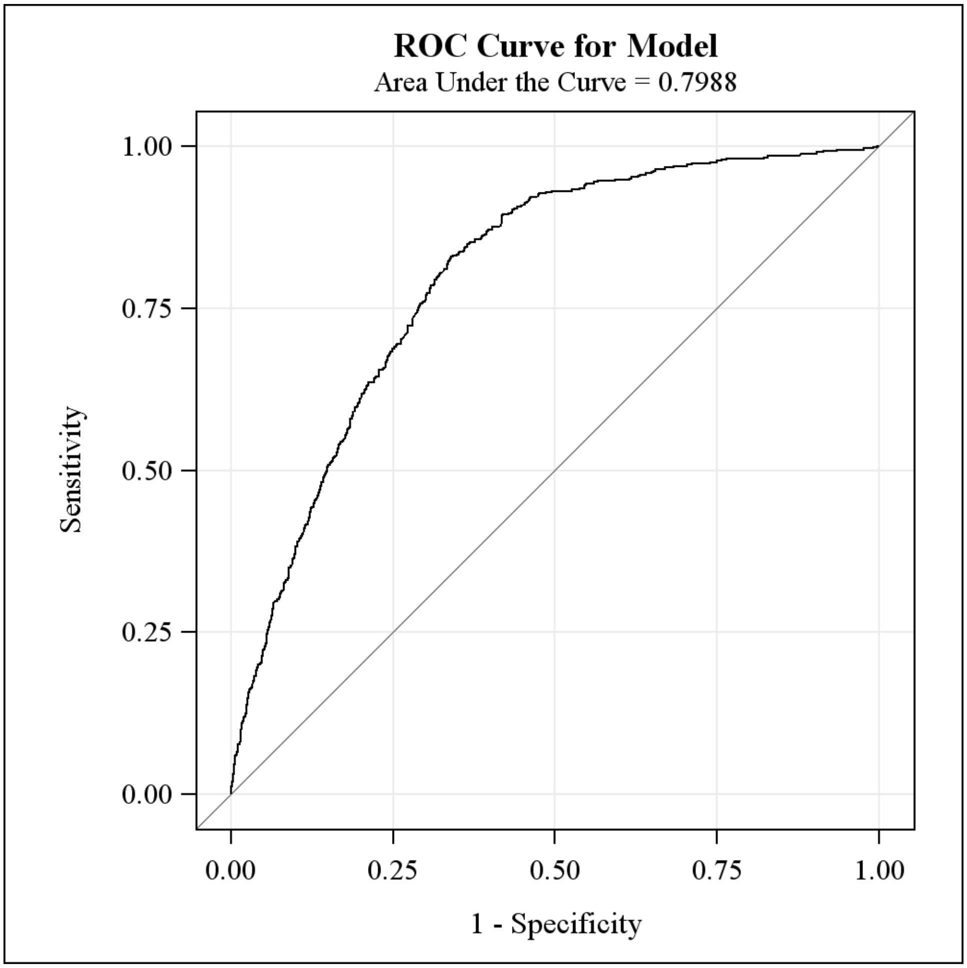
| Parameter | | Estimate | 95% Confidence Limits | |
|---|---|---|---|---|
| CDR*TSP2 | | 0.000020 | -5.13E-7 | 0.000040 |
| Haz_Env | | 0.0584 | -0.0321 | 0.1489 |
| TSP2*Haz_Env | | 0.000040 | -0.00002 | 0.000103 |
| TF_Lading_Grp | B | 0.1975 | -0.2291 | 0.6241 |
| TF_Lading_Grp | D | 0.8302 | 0.1471 | 1.5133 |
| TF_Lading_Grp | E | 0.6831 | 0.2791 | 1.0870 |
| TF_Lading_Grp | F | 0.3576 | -0.0855 | 0.8008 |
| TF_Lading_Grp | G | -2.0358 | -2.8349 | -1.2368 |
| TF_Lading_Grp | H | -1.8599 | -2.6796 | -1.0402 |
| TF_Lading_Grp | K | -0.9286 | -1.8165 | -0.0406 |
| TF_Lading_Grp | M | 1.1469 | 0.0782 | 2.2156 |
| TF_Lading_Grp | O | -1.3968 | -2.5244 | -0.2691 |
| TF_Lading_Grp | Q | -1.1367 | -2.4800 | 0.2067 |
| TF_Lading_Grp | T | -2.3648 | -5.1998 | 0.4702 |

**Odds Ratio Estimates and Wald Confidence Intervals**

| Effect | Unit | Estimate | 95% Confidence Limits | |
|---|---|---|---|---|
| SMS 515 vs 128 | 1.000 | 1.853 | 1.250 | 2.746 |
| SMS 516 vs 128 | 1.000 | 1.070 | 0.729 | 1.570 |
| STS | 1.000 | 0.064 | 0.001 | 2.889 |
| JKT 1 vs 0 | 1.000 | 0.553 | 0.420 | 0.727 |
| SID | 1.000 | 0.980 | 0.952 | 1.010 |
| TFT 1 vs 0 | 1.000 | 0.365 | 0.138 | 0.960 |
| ACCTYP 1 vs 0 | 1.000 | 2.226 | 1.459 | 3.399 |
| SEV2 | 1.000 | 1.000 | 1.000 | 1.001 |
| TF_Lading_Grp B vs A | 1.000 | 1.218 | 0.795 | 1.867 |
| TF_Lading_Grp D vs A | 1.000 | 2.294 | 1.158 | 4.542 |
| TF_Lading_Grp E vs A | 1.000 | 1.980 | 1.322 | 2.965 |
| TF_Lading_Grp F vs A | 1.000 | 1.430 | 0.918 | 2.227 |
| TF_Lading_Grp G vs A | 1.000 | 0.131 | 0.059 | 0.290 |
| TF_Lading_Grp H vs A | 1.000 | 0.156 | 0.069 | 0.353 |

| Odds Ratio Estimates and Wald Confidence Intervals | | | | |
|---|---|---|---|---|
| **Effect** | **Unit** | **Estimate** | **95% Confidence Limits** | |
| **TF_Lading_Grp K vs A** | 1.000 | 0.395 | 0.163 | 0.960 |
| **TF_Lading_Grp M vs A** | 1.000 | 3.148 | 1.081 | 9.167 |
| **TF_Lading_Grp O vs A** | 1.000 | 0.247 | 0.080 | 0.764 |
| **TF_Lading_Grp Q vs A** | 1.000 | 0.321 | 0.084 | 1.230 |
| **TF_Lading_Grp T vs A** | 1.000 | 0.094 | 0.006 | 1.600 |





| Estimated Correlation Matrix | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Parameter** | **Intercept** | **SMS515** | **SMS516** | **STS** | **JKT1** | **SID** | **TFT1** | **ACCTYP1** | **SEV2** | **TSP** |
| **Intercept** | 1.0000 | -0.5739 | -0.4458 | -0.4950 | -0.2591 | -0.8903 | 0.4340 | -0.0469 | 0.0068 | -0.0295 |
| **SMS515** | -0.5739 | 1.0000 | 0.8032 | 0.0317 | -0.1052 | 0.5937 | 0.1653 | 0.0184 | 0.0032 | 0.0213 |
| **SMS516** | -0.4458 | 0.8032 | 1.0000 | -0.0027 | -0.2012 | 0.4690 | 0.2078 | 0.0195 | 0.0081 | 0.0040 |
| **STS** | -0.4950 | 0.0317 | -0.0027 | 1.0000 | 0.0825 | 0.0715 | -0.7664 | -0.0097 | 0.0394 | 0.0085 |
| **JKT1** | -0.2591 | -0.1052 | -0.2012 | 0.0825 | 1.0000 | 0.2451 | -0.3062 | -0.0329 | 0.0225 | 0.0462 |
| **SID** | -0.8903 | 0.5937 | 0.4690 | 0.0715 | 0.2451 | 1.0000 | -0.1605 | 0.0044 | -0.0283 | -0.0041 |
| **TFT1** | 0.4340 | 0.1653 | 0.2078 | -0.7664 | -0.3062 | -0.1605 | 1.0000 | 0.0180 | -0.0540 | -0.0438 |
| **ACCTYP1** | -0.0469 | 0.0184 | 0.0195 | -0.0097 | -0.0329 | 0.0044 | 0.0180 | 1.0000 | -0.0508 | -0.0830 |
| **SEV2** | 0.0068 | 0.0032 | 0.0081 | 0.0394 | 0.0225 | -0.0283 | -0.0540 | -0.0508 | 1.0000 | 0.0225 |
| **TSP** | -0.0295 | 0.0213 | 0.0040 | 0.0085 | 0.0462 | -0.0041 | -0.0438 | -0.0830 | 0.0225 | 1.0000 |
| **TSPCDR** | -0.0038 | 0.0316 | 0.0373 | -0.0157 | -0.0600 | 0.0345 | 0.0861 | 0.0840 | -0.0585 | -0.7215 |
| **TSP2** | 0.0104 | -0.0404 | -0.0280 | -0.0292 | -0.0241 | 0.0219 | 0.0493 | -0.0322 | -0.2147 | -0.8850 |

**Estimated Correlation Matrix**

| Parameter | Intercept | SMS515 | SMS516 | STS | JKT1 | SID | TFT1 | ACCTYP1 | SEV2 | TSP |
|---|---|---|---|---|---|---|---|---|---|---|
| **CDRTSP2** | -0.0049 | -0.0153 | -0.0118 | 0.0255 | 0.0414 | -0.0312 | -0.0866 | -0.0939 | 0.0445 | 0.7638 |
| **Haz_Env** | -0.0429 | -0.0277 | -0.0324 | 0.0100 | 0.0456 | 0.0108 | -0.0389 | -0.4782 | 0.0689 | -0.1610 |
| **TSP2Haz_Env** | 0.0183 | 0.0604 | 0.0376 | 0.0230 | -0.0010 | -0.0109 | -0.0057 | 0.2932 | 0.1670 | 0.2044 |
| **TF_Lading_GrpB** | 0.3478 | -0.2178 | -0.1656 | -0.0209 | -0.1124 | -0.4602 | 0.2854 | -0.0036 | -0.0351 | -0.0736 |
| **TF_Lading_GrpD** | 0.0691 | 0.1122 | 0.0176 | -0.6945 | 0.1974 | 0.2313 | 0.5822 | 0.0258 | -0.0423 | -0.0457 |
| **TF_Lading_GrpE** | 0.3273 | -0.1134 | -0.1138 | -0.0118 | -0.0267 | -0.4589 | 0.3065 | -0.0136 | -0.0402 | -0.0757 |
| **TF_Lading_GrpF** | 0.0993 | -0.0510 | -0.0127 | -0.0266 | -0.2977 | -0.1598 | 0.2860 | 0.0139 | -0.0580 | -0.0710 |
| **TF_Lading_GrpG** | -0.1257 | 0.0877 | 0.0954 | 0.0104 | -0.1161 | 0.1144 | 0.1133 | 0.0023 | -0.0522 | -0.0330 |
| **TF_Lading_GrpH** | 0.2062 | -0.1160 | -0.0690 | -0.0154 | -0.1830 | -0.2635 | 0.1767 | 0.0047 | -0.0523 | -0.0294 |
| **TF_Lading_GrpK** | 0.2008 | -0.1231 | -0.0773 | -0.0199 | -0.1931 | -0.2529 | 0.1672 | 0.0036 | -0.0451 | 0.0063 |
| **TF_Lading_GrpM** | 0.1077 | -0.0400 | -0.1047 | -0.0129 | -0.1080 | -0.1386 | 0.1105 | -0.0088 | 0.0090 | 0.0027 |
| **TF_Lading_GrpO** | -0.0879 | 0.0614 | 0.0708 | 0.0086 | -0.0846 | 0.0764 | 0.0828 | -0.0107 | -0.0205 | -0.0184 |
| **TF_Lading_GrpQ** | 0.0879 | -0.0898 | -0.0704 | -0.0008 | 0.0033 | -0.1222 | 0.0674 | 0.0025 | 0.0017 | -0.0217 |
| **TF_Lading_GrpT** | 0.0443 | -0.0342 | -0.0286 | -0.0008 | -0.0309 | -0.0624 | 0.0405 | 0.0167 | -0.0101 | -0.0155 |

**Estimated Correlation Matrix**

| Parameter | TSPCDR | TSP2 | CDRTSP2 | Haz_Env | TSP2Haz_Env | TF_Lading_GrpB | TF_Lading_GrpD |
|---|---|---|---|---|---|---|---|
| **Intercept** | -0.0038 | 0.0104 | -0.0049 | -0.0429 | 0.0183 | 0.3478 | 0.0691 |
| **SMS515** | 0.0316 | -0.0404 | -0.0153 | -0.0277 | 0.0604 | -0.2178 | 0.1122 |
| **SMS516** | 0.0373 | -0.0280 | -0.0118 | -0.0324 | 0.0376 | -0.1656 | 0.0176 |
| **STS** | -0.0157 | -0.0292 | 0.0255 | 0.0100 | 0.0230 | -0.0209 | -0.6945 |
| **JKT1** | -0.0600 | -0.0241 | 0.0414 | 0.0456 | -0.0010 | -0.1124 | 0.1974 |
| **SID** | 0.0345 | 0.0219 | -0.0312 | 0.0108 | -0.0109 | -0.4602 | 0.2313 |
| **TFT1** | 0.0861 | 0.0493 | -0.0866 | -0.0389 | -0.0057 | 0.2854 | 0.5822 |
| **ACCTYP1** | 0.0840 | -0.0322 | -0.0939 | -0.4782 | 0.2932 | -0.0036 | 0.0258 |
| **SEV2** | -0.0585 | -0.2147 | 0.0445 | 0.0689 | 0.1670 | -0.0351 | -0.0423 |
| **TSP** | -0.7215 | -0.8850 | 0.7638 | -0.1610 | 0.2044 | -0.0736 | -0.0457 |
| **TSPCDR** | 1.0000 | 0.5827 | -0.9464 | -0.0920 | -0.0305 | 0.0841 | 0.0427 |
| **TSP2** | 0.5827 | 1.0000 | -0.6733 | 0.3313 | -0.5356 | 0.0629 | 0.0686 |
| **CDRTSP2** | -0.9464 | -0.6733 | 1.0000 | 0.0854 | -0.0005 | -0.0800 | -0.0701 |
| **Haz_Env** | -0.0920 | 0.3313 | 0.0854 | 1.0000 | -0.6837 | -0.0164 | -0.0355 |
| **TSP2Haz_Env** | -0.0305 | -0.5356 | -0.0005 | -0.6837 | 1.0000 | -0.0230 | -0.0075 |
| **TF_Lading_GrpB** | 0.0841 | 0.0629 | -0.0800 | -0.0164 | -0.0230 | 1.0000 | 0.2020 |

| Estimated Correlation Matrix | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Parameter** | **TSPCDR** | **TSP2** | **CDRTSP2** | **Haz_Env** | **TSP2Haz_Env** | **TF_Lading_GrpB** | **TF_Lading_GrpD** |
| **TF_Lading_GrpD** | 0.0427 | 0.0686 | -0.0701 | -0.0355 | -0.0075 | 0.2020 | 1.0000 |
| **TF_Lading_GrpE** | 0.1014 | 0.0639 | -0.0949 | -0.0091 | -0.0120 | 0.7669 | 0.2341 |
| **TF_Lading_GrpF** | 0.1218 | 0.0900 | -0.1149 | -0.0033 | -0.0643 | 0.5652 | 0.2269 |
| **TF_Lading_GrpG** | 0.0161 | 0.0348 | -0.0175 | -0.0143 | -0.0038 | 0.2154 | 0.1635 |
| **TF_Lading_GrpH** | 0.0332 | 0.0240 | -0.0383 | -0.0134 | 0.0089 | 0.3889 | 0.0770 |
| **TF_Lading_GrpK** | 0.0161 | 0.0038 | -0.0159 | -0.0222 | -0.0021 | 0.3585 | 0.0661 |
| **TF_Lading_GrpM** | 0.0253 | 0.0008 | -0.0405 | -0.0477 | 0.0265 | 0.2583 | 0.0962 |
| **TF_Lading_GrpO** | 0.0452 | 0.0142 | -0.0360 | 0.0057 | -0.0018 | 0.1560 | 0.1095 |
| **TF_Lading_GrpQ** | 0.0191 | 0.0216 | -0.0212 | -0.0006 | -0.0028 | 0.2158 | 0.0714 |
| **TF_Lading_GrpT** | 0.0189 | 0.0112 | -0.0143 | 0.0047 | -0.0035 | 0.1053 | 0.0269 |

| Estimated Correlation Matrix | | | | | |
|---|---|---|---|---|---|
| **Parameter** | **TF_Lading_GrpE** | **TF_Lading_GrpF** | **TF_Lading_GrpG** | **TF_Lading_GrpH** | **TF_Lading_GrpK** |
| **Intercept** | 0.3273 | 0.0993 | -0.1257 | 0.2062 | 0.2008 |
| **SMS515** | -0.1134 | -0.0510 | 0.0877 | -0.1160 | -0.1231 |
| **SMS516** | -0.1138 | -0.0127 | 0.0954 | -0.0690 | -0.0773 |
| **STS** | -0.0118 | -0.0266 | 0.0104 | -0.0154 | -0.0199 |
| **JKT1** | -0.0267 | -0.2977 | -0.1161 | -0.1830 | -0.1931 |
| **SID** | -0.4589 | -0.1598 | 0.1144 | -0.2635 | -0.2529 |
| **TFT1** | 0.3065 | 0.2860 | 0.1133 | 0.1767 | 0.1672 |
| **ACCTYP1** | -0.0136 | 0.0139 | 0.0023 | 0.0047 | 0.0036 |
| **SEV2** | -0.0402 | -0.0580 | -0.0522 | -0.0523 | -0.0451 |
| **TSP** | -0.0757 | -0.0710 | -0.0330 | -0.0294 | 0.0063 |
| **TSPCDR** | 0.1014 | 0.1218 | 0.0161 | 0.0332 | 0.0161 |
| **TSP2** | 0.0639 | 0.0900 | 0.0348 | 0.0240 | 0.0038 |
| **CDRTSP2** | -0.0949 | -0.1149 | -0.0175 | -0.0383 | -0.0159 |
| **Haz_Env** | -0.0091 | -0.0033 | -0.0143 | -0.0134 | -0.0222 |
| **TSP2Haz_Env** | -0.0120 | -0.0643 | -0.0038 | 0.0089 | -0.0021 |
| **TF_Lading_GrpB** | 0.7669 | 0.5652 | 0.2154 | 0.3889 | 0.3585 |
| **TF_Lading_GrpD** | 0.2341 | 0.2269 | 0.1635 | 0.0770 | 0.0661 |
| **TF_Lading_GrpE** | 1.0000 | 0.5633 | 0.2109 | 0.3926 | 0.3575 |
| **TF_Lading_GrpF** | 0.5633 | 1.0000 | 0.2793 | 0.3305 | 0.3147 |

| Estimated Correlation Matrix | | | | | |
|---|---|---|---|---|---|
| **Parameter** | **TF_Lading_GrpE** | **TF_Lading_GrpF** | **TF_Lading_GrpG** | **TF_Lading_GrpH** | **TF_Lading_GrpK** |
| **TF_Lading_GrpG** | 0.2109 | 0.2793 | 1.0000 | 0.1304 | 0.1208 |
| **TF_Lading_GrpH** | 0.3926 | 0.3305 | 0.1304 | 1.0000 | 0.2115 |
| **TF_Lading_GrpK** | 0.3575 | 0.3147 | 0.1208 | 0.2115 | 1.0000 |
| **TF_Lading_GrpM** | 0.2695 | 0.2320 | 0.0950 | 0.1458 | 0.1387 |
| **TF_Lading_GrpO** | 0.1548 | 0.2033 | 0.1261 | 0.0935 | 0.0881 |
| **TF_Lading_GrpQ** | 0.2257 | 0.1671 | 0.0662 | 0.1109 | 0.1037 |
| **TF_Lading_GrpT** | 0.1082 | 0.0895 | 0.0354 | 0.0584 | 0.0547 |

| Estimated Correlation Matrix | | | | |
|---|---|---|---|---|
| **Parameter** | **TF_Lading_GrpM** | **TF_Lading_GrpO** | **TF_Lading_GrpQ** | **TF_Lading_GrpT** |
| **Intercept** | 0.1077 | -0.0879 | 0.0879 | 0.0443 |
| **SMS515** | -0.0400 | 0.0614 | -0.0898 | -0.0342 |
| **SMS516** | -0.1047 | 0.0708 | -0.0704 | -0.0286 |
| **STS** | -0.0129 | 0.0086 | -0.0008 | -0.0008 |
| **JKT1** | -0.1080 | -0.0846 | 0.0033 | -0.0309 |
| **SID** | -0.1386 | 0.0764 | -0.1222 | -0.0624 |
| **TFT1** | 0.1105 | 0.0828 | 0.0674 | 0.0405 |
| **ACCTYP1** | -0.0088 | -0.0107 | 0.0025 | 0.0167 |
| **SEV2** | 0.0090 | -0.0205 | 0.0017 | -0.0101 |
| **TSP** | 0.0027 | -0.0184 | -0.0217 | -0.0155 |
| **TSPCDR** | 0.0253 | 0.0452 | 0.0191 | 0.0189 |
| **TSP2** | 0.0008 | 0.0142 | 0.0216 | 0.0112 |
| **CDRTSP2** | -0.0405 | -0.0360 | -0.0212 | -0.0143 |
| **Haz_Env** | -0.0477 | 0.0057 | -0.0006 | 0.0047 |
| **TSP2Haz_Env** | 0.0265 | -0.0018 | -0.0028 | -0.0035 |
| **TF_Lading_GrpB** | 0.2583 | 0.1560 | 0.2158 | 0.1053 |
| **TF_Lading_GrpD** | 0.0962 | 0.1095 | 0.0714 | 0.0269 |
| **TF_Lading_GrpE** | 0.2695 | 0.1548 | 0.2257 | 0.1082 |
| **TF_Lading_GrpF** | 0.2320 | 0.2033 | 0.1671 | 0.0895 |
| **TF_Lading_GrpG** | 0.0950 | 0.1261 | 0.0662 | 0.0354 |
| **TF_Lading_GrpH** | 0.1458 | 0.0935 | 0.1109 | 0.0584 |

| Estimated Correlation Matrix | | | | |
|---|---|---|---|---|
| **Parameter** | **TF_Lading_GrpM** | **TF_Lading_GrpO** | **TF_Lading_GrpQ** | **TF_Lading_GrpT** |
| **TF_Lading_GrpK** | 0.1387 | 0.0881 | 0.1037 | 0.0547 |
| **TF_Lading_GrpM** | 1.0000 | 0.0674 | 0.0743 | 0.0380 |
| **TF_Lading_GrpO** | 0.0674 | 1.0000 | 0.0484 | 0.0265 |
| **TF_Lading_GrpQ** | 0.0743 | 0.0484 | 1.0000 | 0.0317 |
| **TF_Lading_GrpT** | 0.0380 | 0.0265 | 0.0317 | 1.0000 |

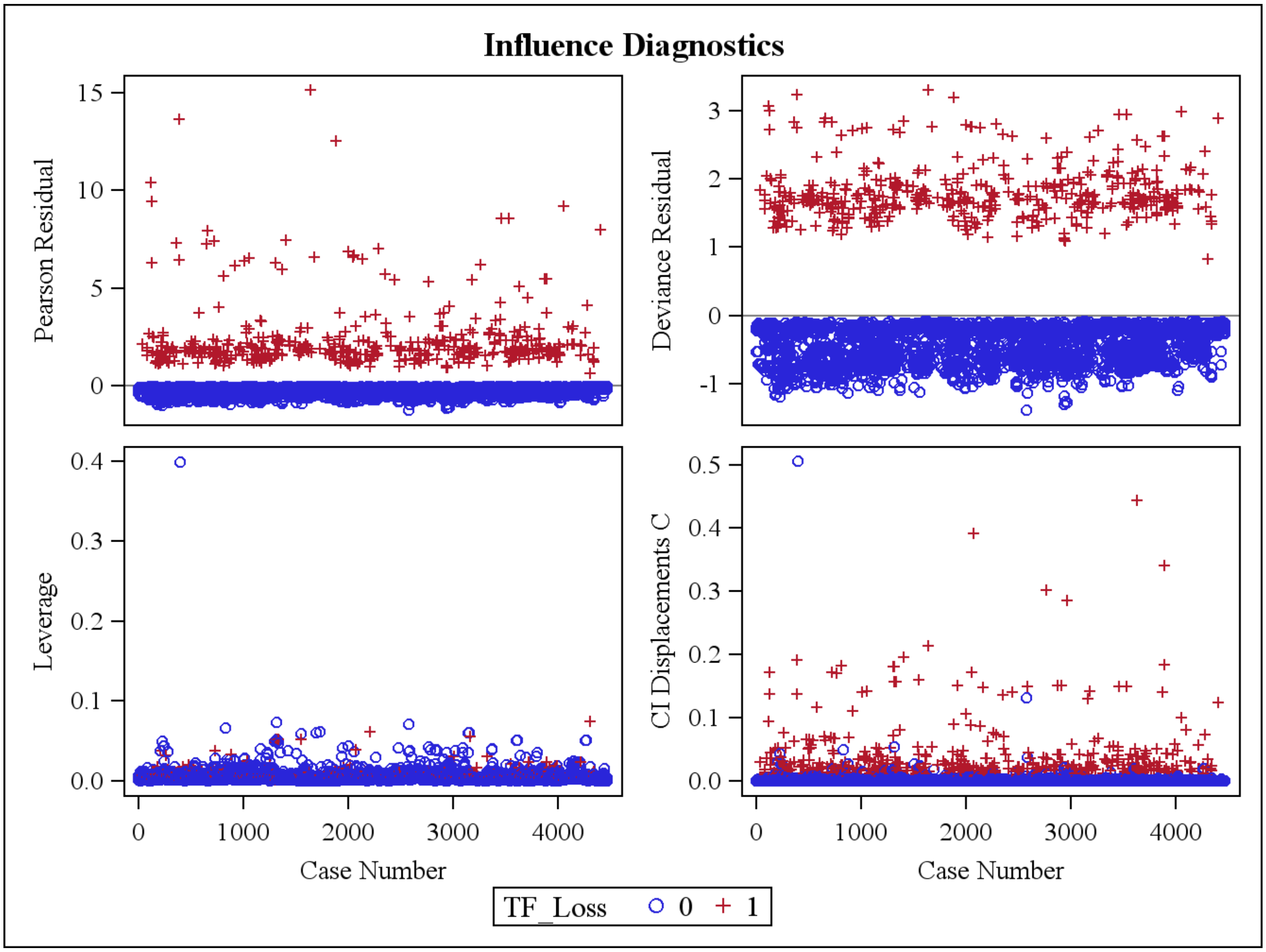
| Partition for the Hosmer and Lemeshow Test | | | | | |
|---|---|---|---|---|---|
| | | **TF_Loss = 1** | | **TF_Loss = 0** | |
| **Group** | **Total** | **Observed** | **Expected** | **Observed** | **Expected** |
| **1** | 448 | 6 | 3.85 | 442 | 444.15 |
| **2** | 447 | 4 | 6.81 | 443 | 440.19 |
| **3** | 451 | 9 | 8.95 | 442 | 442.05 |
| **4** | 447 | 11 | 11.87 | 436 | 435.13 |
| **5** | 447 | 19 | 22.06 | 428 | 424.94 |
| **6** | 447 | 40 | 47.45 | 407 | 399.55 |
| **7** | 447 | 76 | 70.64 | 371 | 376.36 |
| **8** | 447 | 88 | 92.26 | 359 | 354.74 |
| **9** | 447 | 111 | 112.62 | 336 | 334.38 |
| **10** | 439 | 157 | 153.09 | 282 | 285.91 |

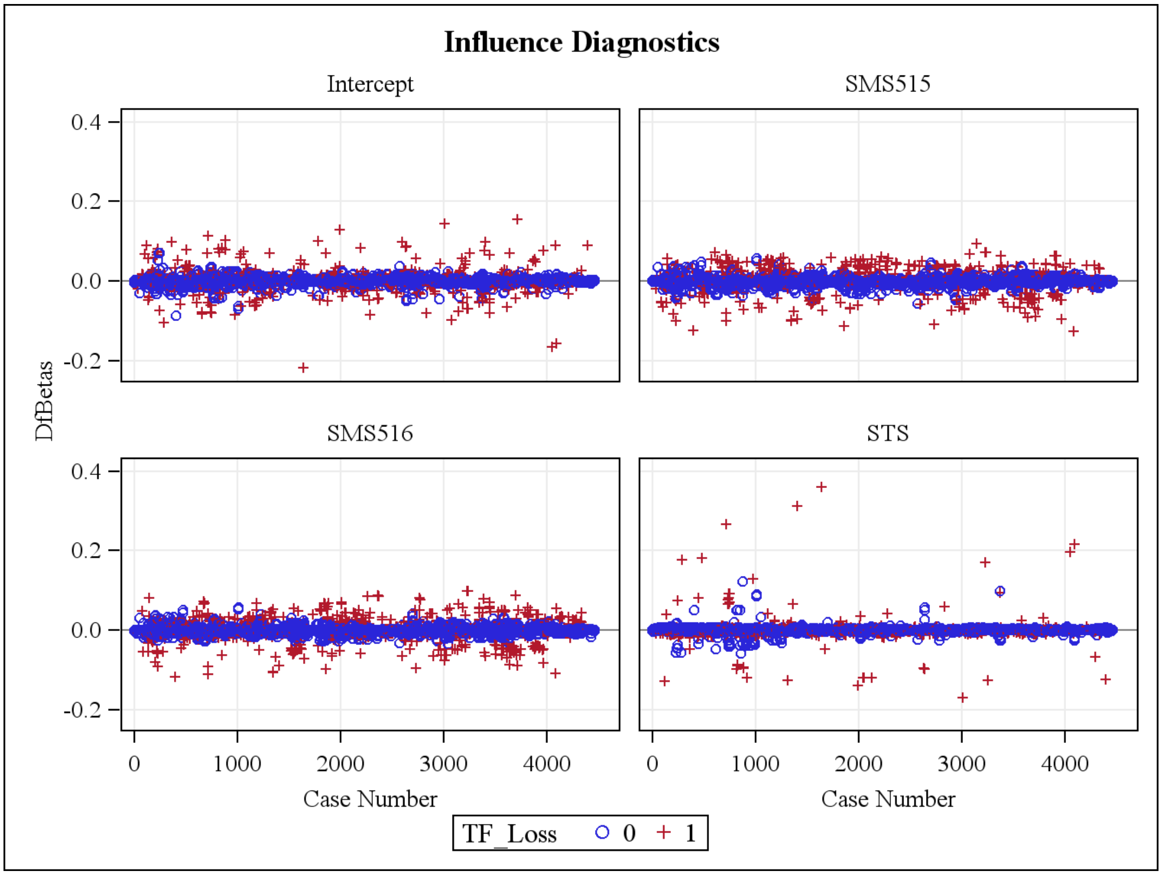
| Hosmer and Lemeshow Goodness-of-Fit Test | | |
|---|---|---|
| **Chi-Square** | **DF** | **Pr > ChiSq** |
| 5.1212 | 8 | 0.7445 |

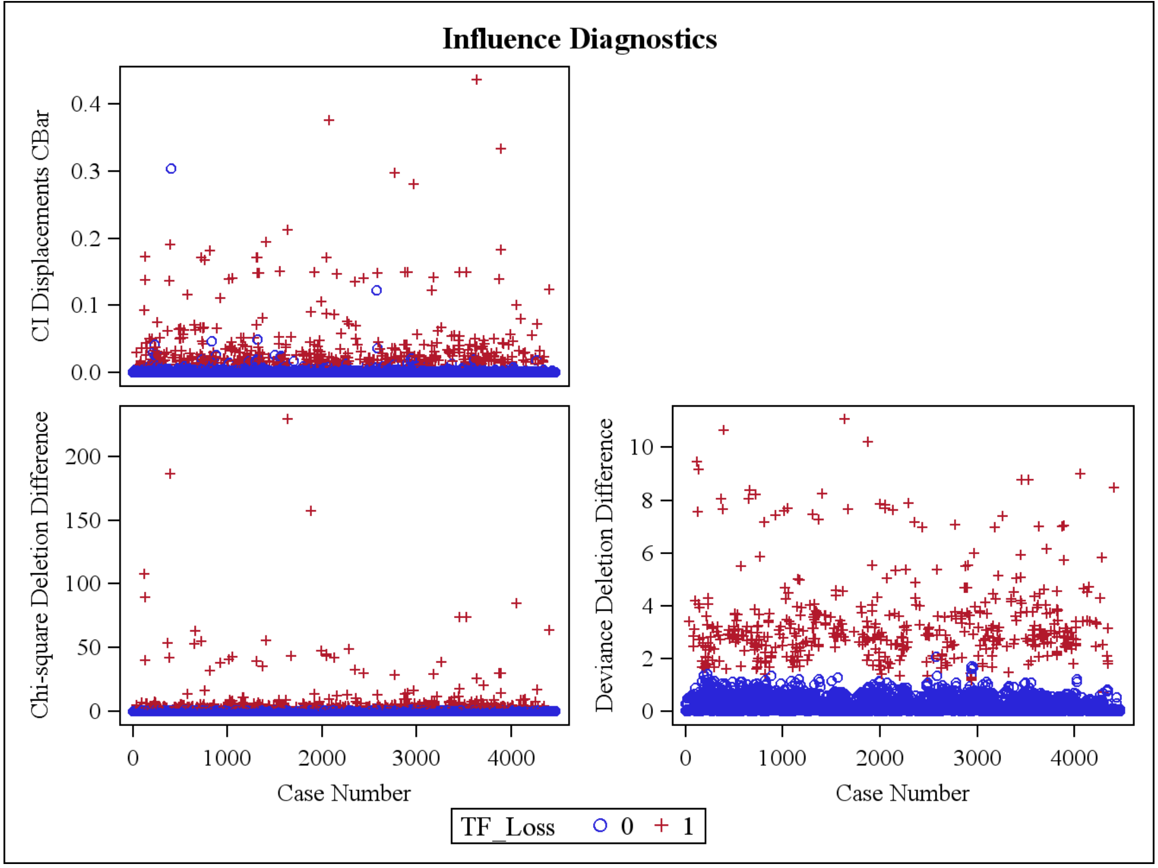
**Classification Table**

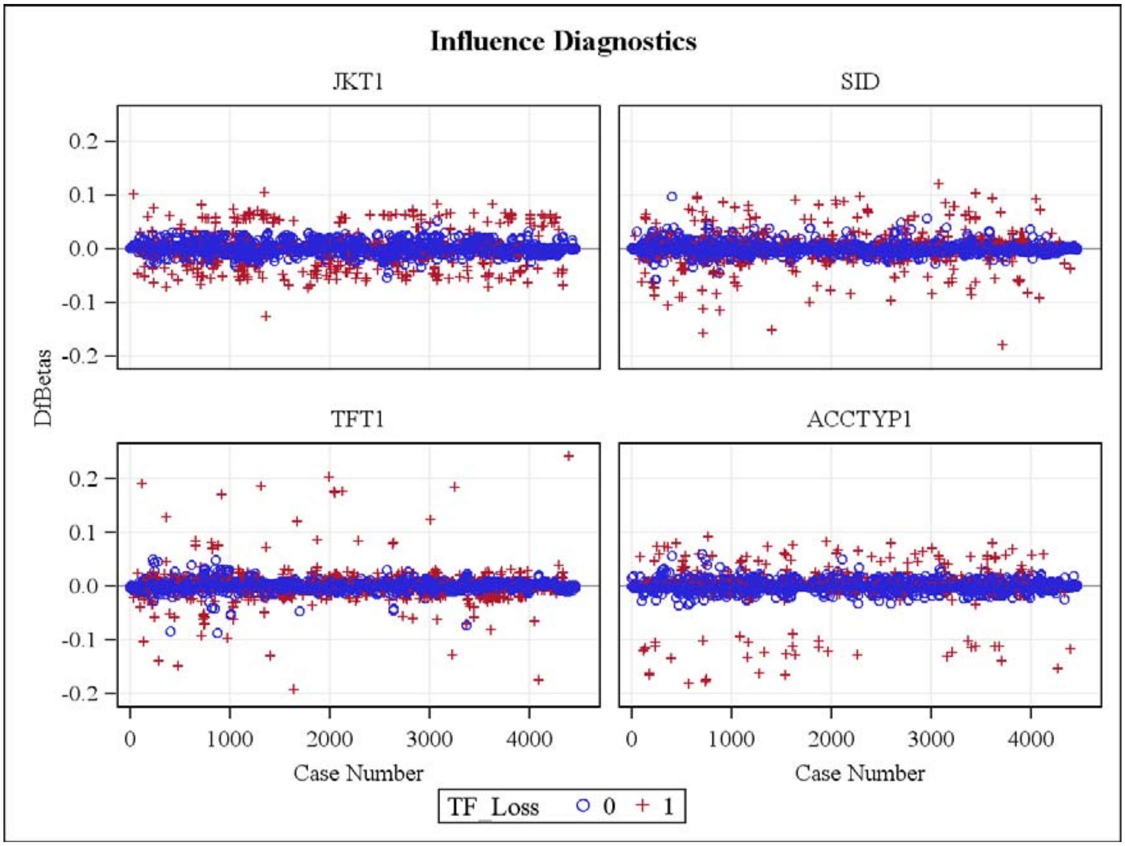
| Prob Level | Correct | | Incorrect | | Percentages | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Event | Non-Event | Event | Non-Event | Correct | Sensitivity | Specificity | False POS | False NEG |
| **0.000** | 521 | 0 | 3946 | 0 | 11.7 | 100.0 | 0.0 | 88.3 | . |
| **0.020** | 503 | 1136 | 2810 | 18 | 36.7 | 96.5 | 28.8 | 84.8 | 1.6 |
| **0.040** | 485 | 1901 | 2045 | 36 | 53.4 | 93.1 | 48.2 | 80.8 | 1.9 |
| **0.060** | 476 | 2085 | 1861 | 45 | 57.3 | 91.4 | 52.8 | 79.6 | 2.1 |
| **0.080** | 467 | 2215 | 1731 | 54 | 60.0 | 89.6 | 56.1 | 78.8 | 2.4 |
| **0.100** | 453 | 2318 | 1628 | 68 | 62.0 | 86.9 | 58.7 | 78.2 | 2.8 |
| **0.120** | 436 | 2501 | 1445 | 85 | 65.7 | 83.7 | 63.4 | 76.8 | 3.3 |
| **0.140** | 416 | 2640 | 1306 | 105 | 68.4 | 79.8 | 66.9 | 75.8 | 3.8 |
| **0.160** | 383 | 2769 | 1177 | 138 | 70.6 | 73.5 | 70.2 | 75.4 | 4.7 |
| **0.180** | 351 | 2954 | 992 | 170 | 74.0 | 67.4 | 74.9 | 73.9 | 5.4 |
| **0.200** | 315 | 3103 | 843 | 206 | 76.5 | 60.5 | 78.6 | 72.8 | 6.2 |
| **0.220** | 278 | 3236 | 710 | 243 | 78.7 | 53.4 | 82.0 | 71.9 | 7.0 |
| **0.240** | 231 | 3387 | 559 | 290 | 81.0 | 44.3 | 85.8 | 70.8 | 7.9 |
| **0.260** | 175 | 3550 | 396 | 346 | 83.4 | 33.6 | 90.0 | 69.4 | 8.9 |
| **0.280** | 145 | 3660 | 286 | 376 | 85.2 | 27.8 | 92.8 | 66.4 | 9.3 |
| **0.300** | 102 | 3741 | 205 | 419 | 86.0 | 19.6 | 94.8 | 66.8 | 10.1 |
| **0.320** | 87 | 3793 | 153 | 434 | 86.9 | 16.7 | 96.1 | 63.8 | 10.3 |
| **0.340** | 82 | 3823 | 123 | 439 | 87.4 | 15.7 | 96.9 | 60.0 | 10.3 |
| **0.360** | 64 | 3843 | 103 | 457 | 87.5 | 12.3 | 97.4 | 61.7 | 10.6 |
| **0.380** | 52 | 3871 | 75 | 469 | 87.8 | 10.0 | 98.1 | 59.1 | 10.8 |
| **0.400** | 39 | 3891 | 55 | 482 | 88.0 | 7.5 | 98.6 | 58.5 | 11.0 |
| **0.420** | 29 | 3912 | 34 | 492 | 88.2 | 5.6 | 99.1 | 54.0 | 11.2 |
| **0.440** | 12 | 3924 | 22 | 509 | 88.1 | 2.3 | 99.4 | 64.7 | 11.5 |
| **0.460** | 10 | 3932 | 14 | 511 | 88.2 | 1.9 | 99.6 | 58.3 | 11.5 |
| **0.480** | 9 | 3933 | 13 | 512 | 88.2 | 1.7 | 99.7 | 59.1 | 11.5 |
| **0.500** | 5 | 3937 | 9 | 516 | 88.2 | 1.0 | 99.8 | 64.3 | 11.6 |
| **0.520** | 4 | 3941 | 5 | 517 | 88.3 | 0.8 | 99.9 | 55.6 | 11.6 |
| **0.540** | 2 | 3941 | 5 | 519 | 88.3 | 0.4 | 99.9 | 71.4 | 11.6 |
| **0.560** | 1 | 3943 | 3 | 520 | 88.3 | 0.2 | 99.9 | 75.0 | 11.7 |

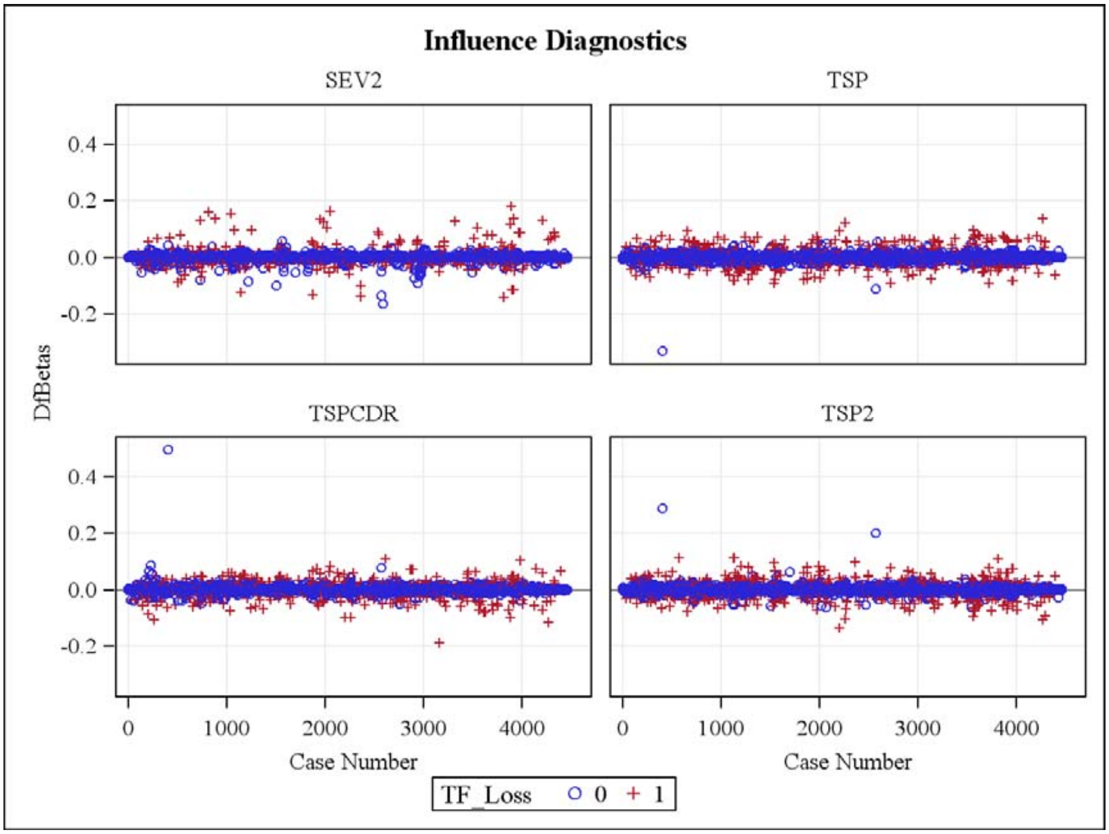
| Classification Table | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Correct | | Incorrect | | Percentages | | | | |
| Prob Level | Event | Non-Event | Event | Non-Event | Correct | Sensi-tivity | Speci-ficity | False POS | False NEG |
| **0.580** | 1 | 3944 | 2 | 520 | 88.3 | 0.2 | 99.9 | 66.7 | 11.6 |
| **0.600** | 1 | 3945 | 1 | 520 | 88.3 | 0.2 | 100.0 | 50.0 | 11.6 |
| **0.620** | 1 | 3945 | 1 | 520 | 88.3 | 0.2 | 100.0 | 50.0 | 11.6 |
| **0.640** | 1 | 3945 | 1 | 520 | 88.3 | 0.2 | 100.0 | 50.0 | 11.6 |
| **0.660** | 1 | 3945 | 1 | 520 | 88.3 | 0.2 | 100.0 | 50.0 | 11.6 |
| **0.680** | 1 | 3946 | 0 | 520 | 88.4 | 0.2 | 100.0 | 0.0 | 11.6 |
| **0.700** | 0 | 3946 | 0 | 521 | 88.3 | 0.0 | 100.0 | . | 11.7 |

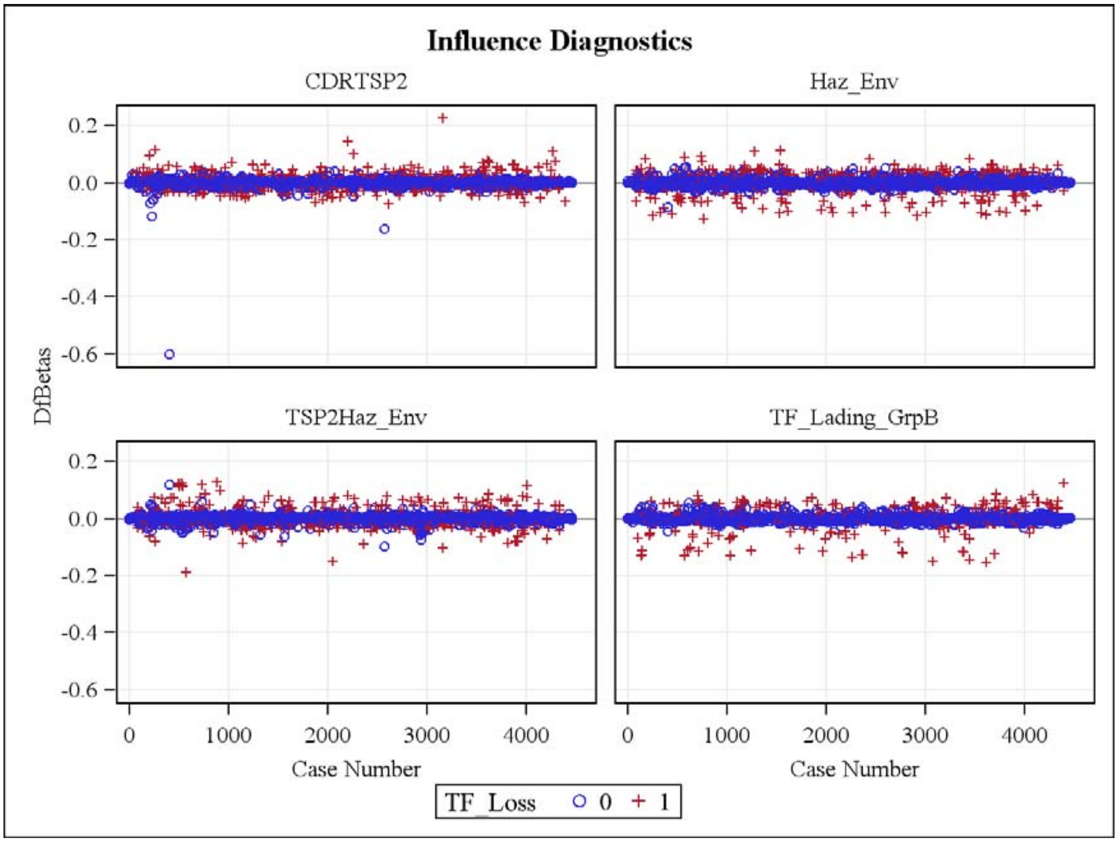


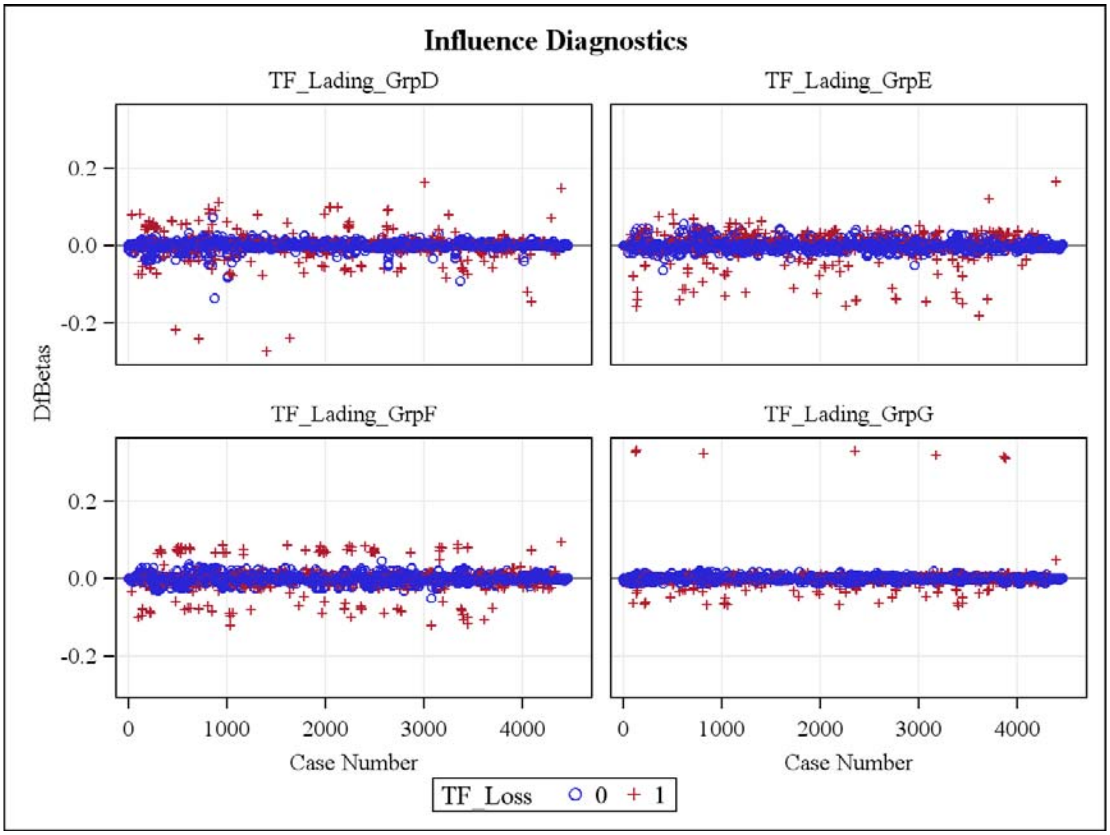

Influence Diagnostics
Intercept
SMS515
SMS516
STS
DfBetas
0.4
0.2
0.0
-0.2
0
1000
2000
3000
4000
Case Number
TF_Loss ○ 0 + 1

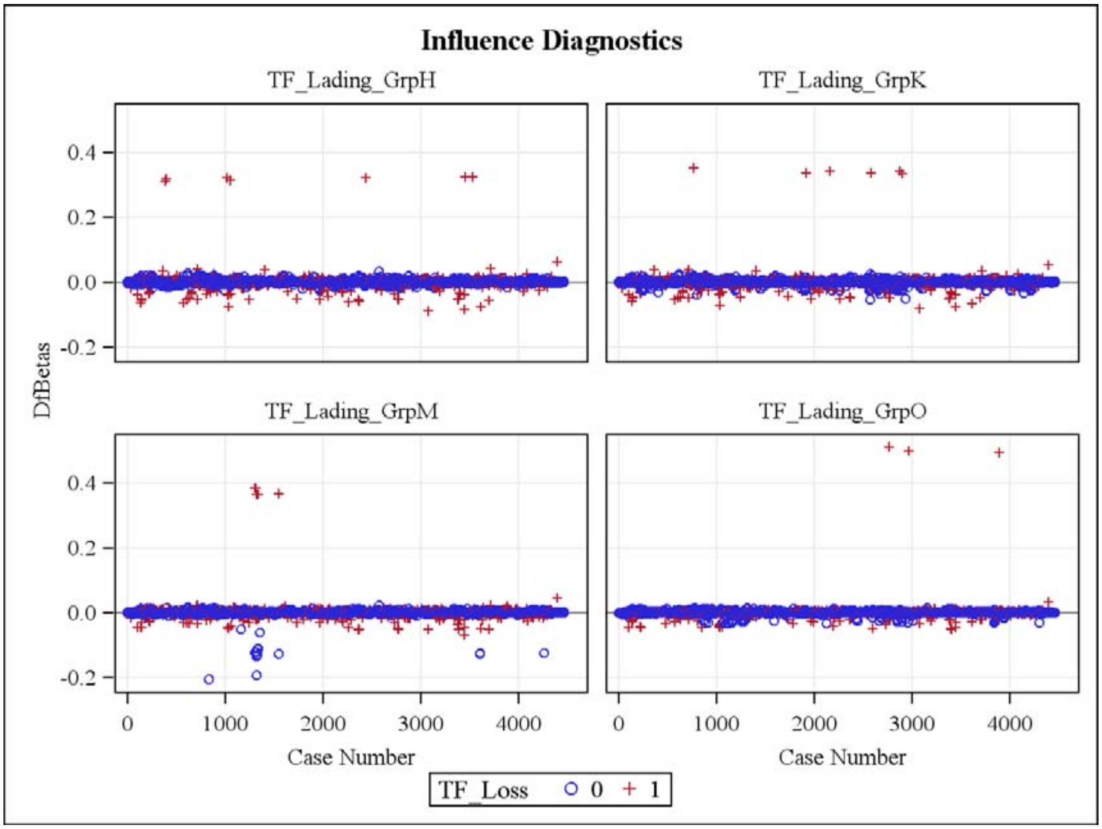

Influence Diagnostics
CI Displacements CBar
0.4
0.3
0.2
0.1
0.0
Chi-square Deletion Difference
200
150
100
50
0
Deviance Deletion Difference
10
8
6
4
2
0
0
1000
2000
3000
4000
Case Number
TF_Loss ○ 0 + 1

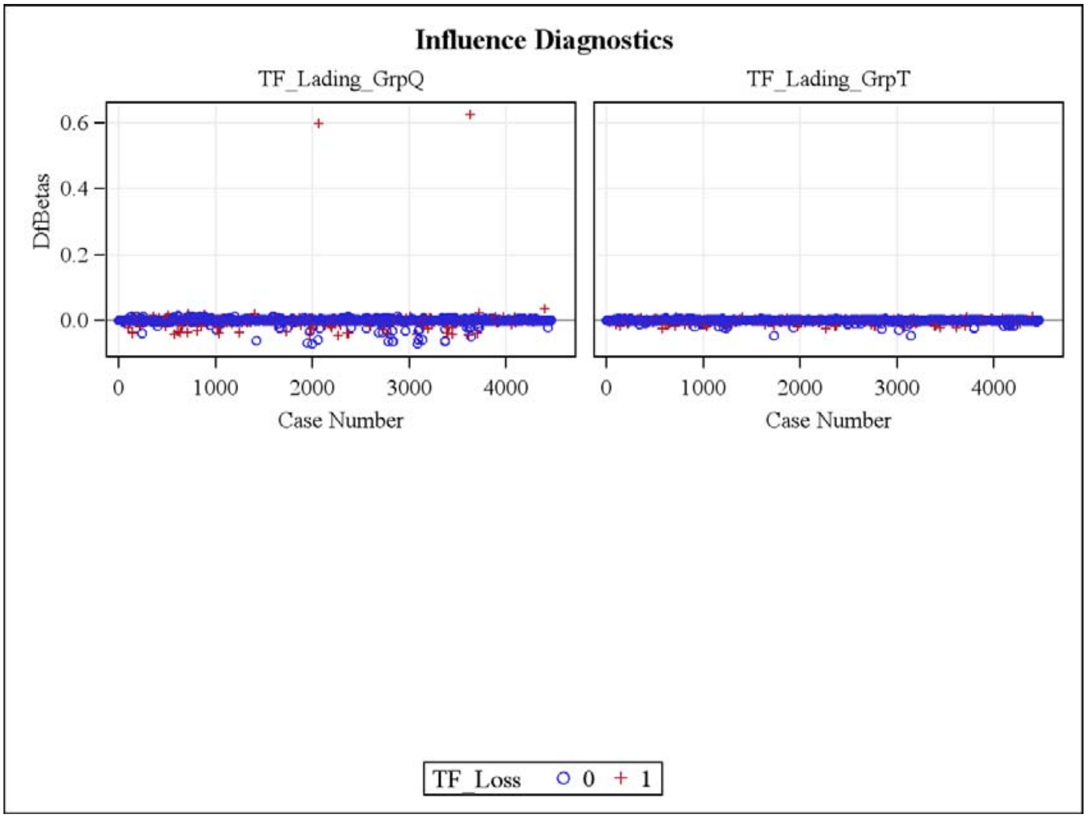

Influence Diagnostics
JKT1
SID
TFT1
ACCTYP1
DfBetas
0.2
0.1
0.0
-0.1
-0.2
0
1000
2000
3000
4000
Case Number
TF_Loss
0
1


Influence Diagnostics
SEV2
TSP
TSPCDR
TSP2
DfBetas
0.4
0.2
0.0
-0.2
0
1000
2000
3000
4000
Case Number
TF_Loss
0
1


Influence Diagnostics
CDRTSP2
Haz_Env
TSP2Haz_Env
TF_Lading_GrpB
DfBetas
0.2
0.0
-0.2
-0.4
-0.6
0
1000
2000
3000
4000
Case Number
TF_Loss
0
1


Influence Diagnostics
TF_Lading_GrpD
TF_Lading_GrpE
TF_Lading_GrpF
TF_Lading_GrpG
DfBetas
0.2
0.0
-0.2
0
1000
2000
3000
4000
Case Number
TF_Loss
0
1


Influence Diagnostics
TF_Lading_GrpH
TF_Lading_GrpK
TF_Lading_GrpM
TF_Lading_GrpO
DfBetas
0.4
0.2
0.0
-0.2
0
1000
2000
3000
4000
Case Number
TF_Loss ○ 0 + 1


Influence Diagnostics
TF_Lading_GrpQ
TF_Lading_GrpT
DfBetas
0.6
0.4
0.2
0.0
0
1000
2000
3000
4000
Case Number
TF_Loss ○ 0 + 1

# Bottom Fittings

| Model Information | |
|---|---|
| **Data Set** | WORK.BFCPR2 |
| **Response Variable** | BF_Loss |
| **Number of Response Levels** | 2 |
| **Model** | binary logit |
| **Optimization Technique** | Fisher's scoring |
| **Likelihood Penalty** | Firth's bias correction |

| | |
|---|---|
| **Number of Observations Read** | 5484 |
| **Number of Observations Used** | 5484 |

| Response Profile | | |
|---|---|---|
| **Ordered Value** | **BF_Loss** | **Total Frequency** |
| **1** | 0 | 5344 |
| **2** | 1 | 140 |

***Probability modeled is BF_Loss='1'.***

| Class Level Information | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Class** | **Value** | **Design Variables** | | | | | |
| **BF_Lading_Grp** | **A** | 0 | 0 | 0 | 0 | 0 | 0 |
| | **D** | 1 | 0 | 0 | 0 | 0 | 0 |
| | **E** | 0 | 1 | 0 | 0 | 0 | 0 |
| | **F** | 0 | 0 | 1 | 0 | 0 | 0 |
| | **J** | 0 | 0 | 0 | 1 | 0 | 0 |
| | **K** | 0 | 0 | 0 | 0 | 1 | 0 |
| | **N** | 0 | 0 | 0 | 0 | 0 | 1 |

| Intercept-Only Model Convergence Status |
|---|
| Convergence criterion (GCONV=1E-8) satisfied. |

| Model Convergence Status |
|---|
| Convergence criterion (GCONV=1E-8) satisfied. |

| Model Fit Statistics | | |
|---|---|---|
| Criterion | Intercept Only | Intercept and Covariates |
| AIC | 1208.387 | 1053.618 |
| SC | 1214.996 | 1159.372 |
| -2 Log L | 1206.387 | 1021.618 |

| Testing Global Null Hypothesis: BETA=0 | | | |
|---|---|---|---|
| Test | Chi-Square | DF | Pr > ChiSq |
| Likelihood Ratio | 184.7683 | 15 | <.0001 |
| Score | 204.9466 | 15 | <.0001 |
| Wald | 164.4706 | 15 | <.0001 |

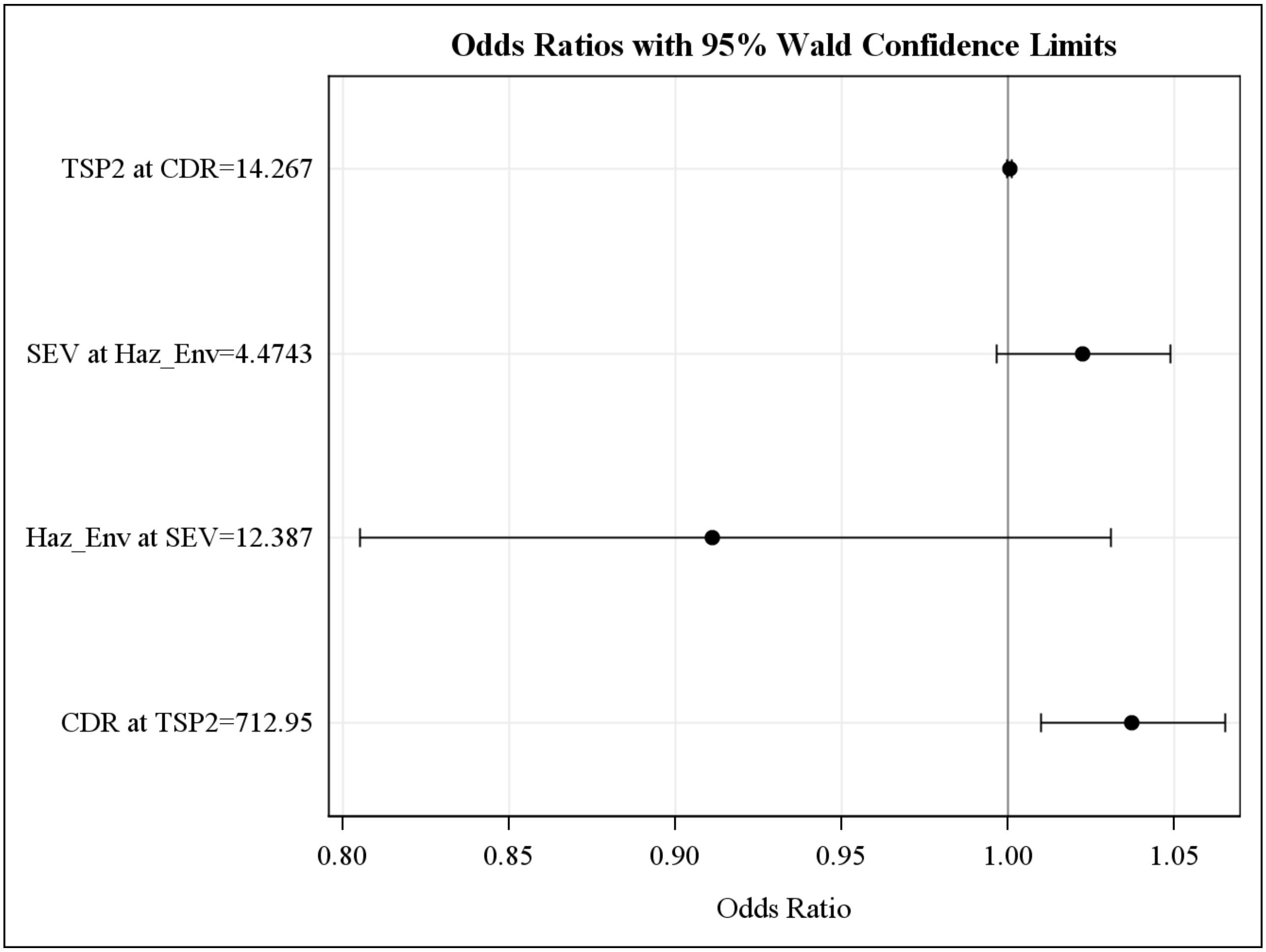
| Type 3 Analysis of Effects | | | |
|---|---|---|---|
| Effect | DF | Wald Chi-Square | Pr > ChiSq |
| JKT | 1 | 14.3077 | 0.0002 |
| STS | 1 | 0.5032 | 0.4781 |
| TSP | 1 | 0.0156 | 0.9006 |
| TSP2 | 1 | 2.5579 | 0.1097 |
| SEV | 1 | 1.6980 | 0.1926 |
| CDR | 1 | 9.0908 | 0.0026 |
| Haz_Env | 1 | 5.7701 | 0.0163 |
| TSP2*CDR | 1 | 8.1470 | 0.0043 |

| Type 3 Analysis of Effects | | | |
|---|---|---|---|
| **Effect** | **DF** | **Wald Chi-Square** | **Pr > ChiSq** |
| **SEV*Haz_Env** | 1 | 8.0248 | 0.0046 |
| **BF_Lading_Grp** | 6 | 56.9025 | <.0001 |

| Analysis of Maximum Likelihood Estimates | | | | | | |
|---|---|---|---|---|---|---|
| **Parameter** | | **DF** | **Estimate** | **Standard Error** | **Wald Chi-Square** | **Pr > ChiSq** |
| **Intercept** | | 1 | -2.3275 | 3.2833 | 0.5025 | 0.4784 |
| **JKT** | | 1 | -0.8730 | 0.2308 | 14.3077 | 0.0002 |
| **STS** | | 1 | -5.2546 | 7.4073 | 0.5032 | 0.4781 |
| **TSP** | | 1 | 0.00328 | 0.0263 | 0.0156 | 0.9006 |
| **TSP2** | | 1 | 0.000846 | 0.000529 | 2.5579 | 0.1097 |
| **SEV** | | 1 | -0.0275 | 0.0211 | 1.6980 | 0.1926 |
| **CDR** | | 1 | 0.0578 | 0.0192 | 9.0908 | 0.0026 |
| **Haz_Env** | | 1 | -0.2307 | 0.0960 | 5.7701 | 0.0163 |
| **TSP2*CDR** | | 1 | -0.00003 | 0.000010 | 8.1470 | 0.0043 |
| **SEV*Haz_Env** | | 1 | 0.0111 | 0.00392 | 8.0248 | 0.0046 |
| **BF_Lading_Grp** | **D** | 1 | 0.3864 | 1.1245 | 0.1181 | 0.7311 |
| **BF_Lading_Grp** | **E** | 1 | 1.7277 | 0.2664 | 42.0498 | <.0001 |
| **BF_Lading_Grp** | **F** | 1 | 1.7051 | 0.3310 | 26.5384 | <.0001 |
| **BF_Lading_Grp** | **J** | 1 | 2.7727 | 0.9190 | 9.1030 | 0.0026 |
| **BF_Lading_Grp** | **K** | 1 | 1.5623 | 0.4157 | 14.1269 | 0.0002 |
| **BF_Lading_Grp** | **N** | 1 | 0.9318 | 0.3887 | 5.7454 | 0.0165 |

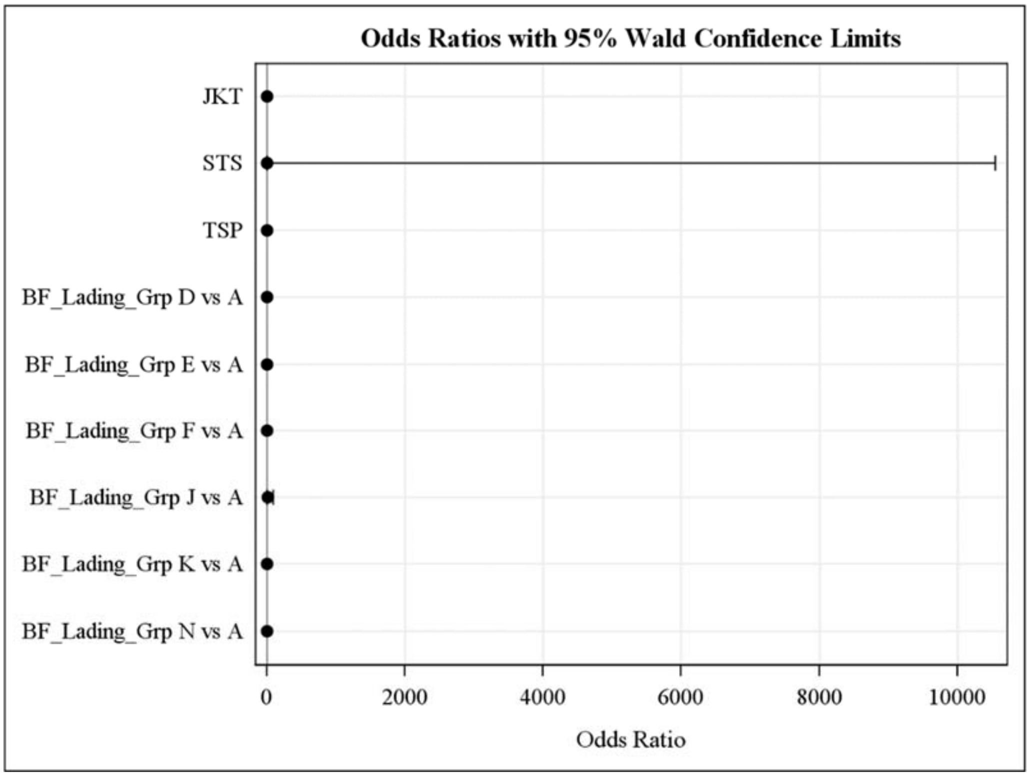
| Association of Predicted Probabilities and Observed Responses | | | |
|---|---|---|---|
| **Percent Concordant** | 81.0 | **Somers' D** | 0.622 |
| **Percent Discordant** | 18.8 | **Gamma** | 0.624 |
| **Percent Tied** | 0.2 | **Tau-a** | 0.031 |
| **Pairs** | 748160 | **c** | 0.811 |

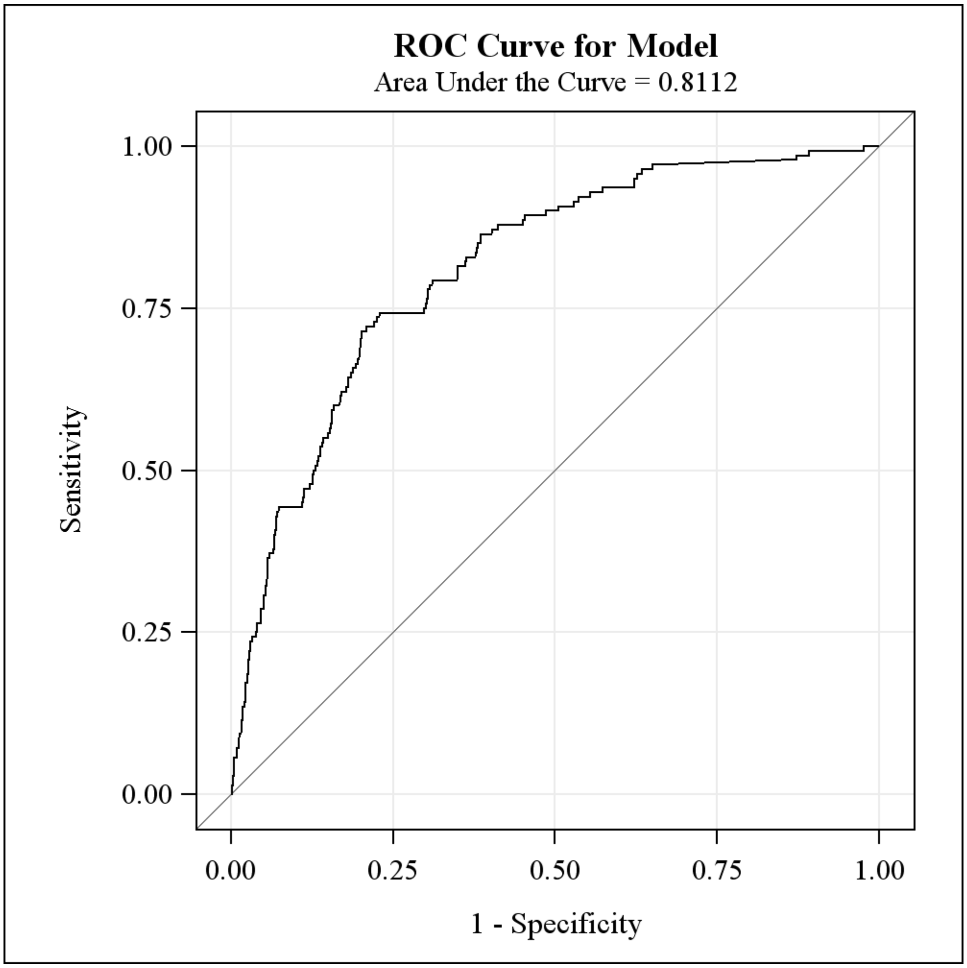
| Odds Ratio Estimates and Wald Confidence Intervals | | | |
|---|---|---|---|
| **Label** | **Estimate** | **95% Confidence Limits** | |
| TSP2 at CDR=14.267 | 1.000 | 1.000 | 1.001 |
| SEV at Haz_Env=4.4743 | 1.022 | 0.997 | 1.049 |
| Haz_Env at SEV=12.387 | 0.911 | 0.805 | 1.031 |
| CDR at TSP2=712.95 | 1.037 | 1.010 | 1.065 |



| Parameter Estimates and Wald Confidence Intervals | | | | |
|---|---|---|---|---|
| **Parameter** | | **Estimate** | **95% Confidence Limits** | |
| **Intercept** | | -2.3275 | -8.7626 | 4.1076 |
| **JKT** | | -0.8730 | -1.3254 | -0.4207 |
| **STS** | | -5.2546 | -19.7726 | 9.2634 |
| **TSP** | | 0.00328 | -0.0482 | 0.0548 |
| **TSP2** | | 0.000846 | -0.00019 | 0.00188 |
| **SEV** | | -0.0275 | -0.0690 | 0.0139 |
| **CDR** | | 0.0578 | 0.0202 | 0.0954 |
| **Haz_Env** | | -0.2307 | -0.4190 | -0.0425 |
| **TSP2*CDR** | | -0.00003 | -0.00005 | -9.35E-6 |
| **SEV*Haz_Env** | | 0.0111 | 0.00342 | 0.0188 |
| **BF_Lading_Grp** | **D** | 0.3864 | -1.8175 | 2.5904 |
| **BF_Lading_Grp** | **E** | 1.7277 | 1.2055 | 2.2499 |
| **BF_Lading_Grp** | **F** | 1.7051 | 1.0564 | 2.3538 |
| **BF_Lading_Grp** | **J** | 2.7727 | 0.9715 | 4.5739 |
| **BF_Lading_Grp** | **K** | 1.5623 | 0.7476 | 2.3770 |
| **BF_Lading_Grp** | **N** | 0.9318 | 0.1699 | 1.6937 |

| Odds Ratio Estimates and Wald Confidence Intervals | | | | |
|---|---|---|---|---|
| **Effect** | **Unit** | **Estimate** | **95% Confidence Limits** | |
| **JKT** | 1.000 | 0.418 | 0.266 | 0.657 |
| **STS** | 1.000 | 0.005 | <0.001 | >999.999 |
| **TSP** | 1.000 | 1.003 | 0.953 | 1.056 |
| **BF_Lading_Grp D vs A** | 1.000 | 1.472 | 0.162 | 13.335 |
| **BF_Lading_Grp E vs A** | 1.000 | 5.628 | 3.338 | 9.487 |
| **BF_Lading_Grp F vs A** | 1.000 | 5.502 | 2.876 | 10.525 |
| **BF_Lading_Grp J vs A** | 1.000 | 16.001 | 2.642 | 96.917 |
| **BF_Lading_Grp K vs A** | 1.000 | 4.770 | 2.112 | 10.772 |
| **BF_Lading_Grp N vs A** | 1.000 | 2.539 | 1.185 | 5.440 |


Odds Ratios with 95% Wald Confidence Limits
JKT
STS
TSP
BF_Lading_Grp D vs A
BF_Lading_Grp E vs A
BF_Lading_Grp F vs A
BF_Lading_Grp J vs A
BF_Lading_Grp K vs A
BF_Lading_Grp N vs A
0
2000
4000
6000
8000
10000
Odds Ratio


ROC Curve for Model
Area Under the Curve = 0.8112
1.00
0.75
0.50
0.25
0.00
Sensitivity
0.00
0.25
0.50
0.75
1.00
1 - Specificity

**Estimated Correlation Matrix**

| Parameter | Intercept | JKT | STS | TSP | TSP2 | SEV | CDR | Haz_Env | TSP2CDR |
|---|---|---|---|---|---|---|---|---|---|
| Intercept | 1.0000 | -0.1025 | -0.9896 | -0.0331 | 0.0547 | -0.0856 | 0.0454 | -0.0952 | -0.0613 |
| JKT | -0.1025 | 1.0000 | 0.0563 | 0.0054 | -0.0365 | 0.0267 | -0.0924 | 0.0289 | 0.0968 |
| STS | -0.9896 | 0.0563 | 1.0000 | -0.0009 | -0.0233 | 0.0203 | -0.0383 | 0.0157 | 0.0475 |
| TSP | -0.0331 | 0.0054 | -0.0009 | 1.0000 | -0.8785 | -0.1803 | -0.4684 | -0.2672 | 0.4433 |
| TSP2 | 0.0547 | -0.0365 | -0.0233 | -0.8785 | 1.0000 | -0.0886 | 0.6452 | 0.0872 | -0.7409 |
| SEV | -0.0856 | 0.0267 | 0.0203 | -0.1803 | -0.0886 | 1.0000 | -0.2408 | 0.6827 | 0.2978 |
| CDR | 0.0454 | -0.0924 | -0.0383 | -0.4684 | 0.6452 | -0.2408 | 1.0000 | -0.2158 | -0.8308 |
| Haz_Env | -0.0952 | 0.0289 | 0.0157 | -0.2672 | 0.0872 | 0.6827 | -0.2158 | 1.0000 | 0.2194 |
| TSP2CDR | -0.0613 | 0.0968 | 0.0475 | 0.4433 | -0.7409 | 0.2978 | -0.8308 | 0.2194 | 1.0000 |
| SEVHaz_Env | 0.0786 | -0.0172 | -0.0103 | 0.2090 | -0.0833 | -0.7890 | 0.1171 | -0.8150 | -0.2098 |
| BF_Lading_GrpD | 0.8309 | 0.0822 | -0.8565 | 0.0034 | 0.0148 | -0.0057 | -0.0012 | -0.0120 | -0.0239 |
| BF_Lading_GrpE | -0.0604 | 0.4235 | -0.0143 | 0.0156 | -0.0283 | 0.0138 | -0.0053 | 0.0081 | 0.0371 |
| BF_Lading_GrpF | -0.0016 | -0.2183 | -0.0363 | 0.0370 | -0.0080 | 0.0200 | 0.0561 | -0.0171 | -0.0485 |
| BF_Lading_GrpJ | -0.0223 | -0.0382 | 0.0011 | 0.0457 | -0.0503 | -0.0108 | -0.0070 | 0.0242 | 0.0290 |
| BF_Lading_GrpK | -0.0238 | -0.1632 | -0.0062 | 0.0931 | -0.0745 | -0.0103 | -0.0704 | -0.0036 | 0.0561 |
| BF_Lading_GrpN | -0.0657 | 0.2186 | 0.0191 | 0.0204 | -0.0626 | 0.0541 | -0.0841 | 0.0286 | 0.0827 |

**Estimated Correlation Matrix**

| Parameter | SEVHaz_Env | BF_Lading_GrpD | BF_Lading_GrpE | BF_Lading_GrpF |
|---|---|---|---|---|
| Intercept | 0.0786 | 0.8309 | -0.0604 | -0.0016 |
| JKT | -0.0172 | 0.0822 | 0.4235 | -0.2183 |
| STS | -0.0103 | -0.8565 | -0.0143 | -0.0363 |
| TSP | 0.2090 | 0.0034 | 0.0156 | 0.0370 |
| TSP2 | -0.0833 | 0.0148 | -0.0283 | -0.0080 |
| SEV | -0.7890 | -0.0057 | 0.0138 | 0.0200 |
| CDR | 0.1171 | -0.0012 | -0.0053 | 0.0561 |
| Haz_Env | -0.8150 | -0.0120 | 0.0081 | -0.0171 |
| TSP2CDR | -0.2098 | -0.0239 | 0.0371 | -0.0485 |
| SEVHaz_Env | 1.0000 | 0.0049 | -0.0030 | -0.0164 |
| BF_Lading_GrpD | 0.0049 | 1.0000 | 0.2121 | 0.1202 |
| BF_Lading_GrpE | -0.0030 | 0.2121 | 1.0000 | 0.4110 |
| BF_Lading_GrpF | -0.0164 | 0.1202 | 0.4110 | 1.0000 |

| Estimated Correlation Matrix | | | | |
|---|---|---|---|---|
| **Parameter** | **SEVHaz_Env** | **BF_Lading_GrpD** | **BF_Lading_GrpE** | **BF_Lading_GrpF** |
| **BF_Lading_GrpJ** | 0.0233 | 0.0337 | 0.1694 | 0.1542 |
| **BF_Lading_GrpK** | 0.0096 | 0.0792 | 0.3282 | 0.3572 |
| **BF_Lading_GrpN** | 0.0027 | 0.1135 | 0.5169 | 0.2916 |

| Estimated Correlation Matrix | | | |
|---|---|---|---|
| **Parameter** | **BF_Lading_GrpJ** | **BF_Lading_GrpK** | **BF_Lading_GrpN** |
| **Intercept** | -0.0223 | -0.0238 | -0.0657 |
| **JKT** | -0.0382 | -0.1632 | 0.2186 |
| **STS** | 0.0011 | -0.0062 | 0.0191 |
| **TSP** | 0.0457 | 0.0931 | 0.0204 |
| **TSP2** | -0.0503 | -0.0745 | -0.0626 |
| **SEV** | -0.0108 | -0.0103 | 0.0541 |
| **CDR** | -0.0070 | -0.0704 | -0.0841 |
| **Haz_Env** | 0.0242 | -0.0036 | 0.0286 |
| **TSP2CDR** | 0.0290 | 0.0561 | 0.0827 |
| **SEVHaz_Env** | 0.0233 | 0.0096 | 0.0027 |
| **BF_Lading_GrpD** | 0.0337 | 0.0792 | 0.1135 |
| **BF_Lading_GrpE** | 0.1694 | 0.3282 | 0.5169 |
| **BF_Lading_GrpF** | 0.1542 | 0.3572 | 0.2916 |
| **BF_Lading_GrpJ** | 1.0000 | 0.1286 | 0.1201 |
| **BF_Lading_GrpK** | 0.1286 | 1.0000 | 0.2403 |
| **BF_Lading_GrpN** | 0.1201 | 0.2403 | 1.0000 |

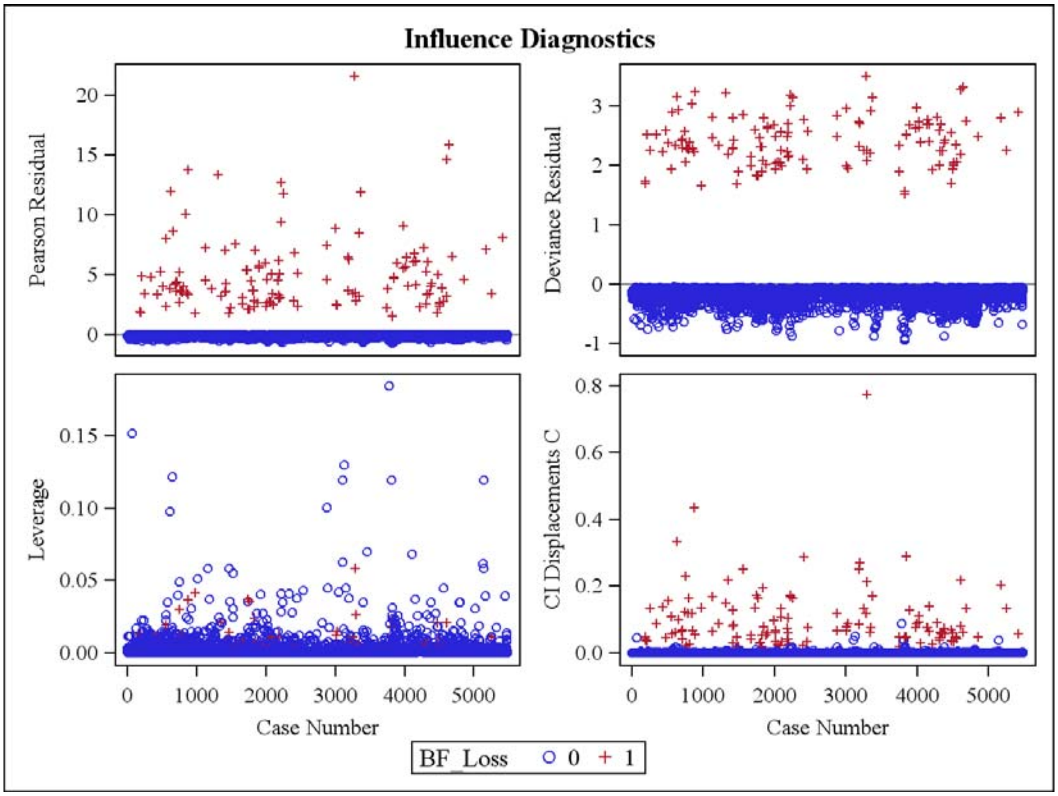
| Partition for the Hosmer and Lemeshow Test | | | | | |
|---|---|---|---|---|---|
| | | **BF_Loss = 1** | | **BF_Loss = 0** | |
| **Group** | **Total** | **Observed** | **Expected** | **Observed** | **Expected** |
| **1** | 548 | 1 | 1.53 | 547 | 546.47 |
| **2** | 212 | 2 | 0.94 | 210 | 211.06 |
| **3** | 1056 | 1 | 5.58 | 1055 | 1050.42 |
| **4** | 548 | 6 | 4.32 | 542 | 543.68 |
| **5** | 548 | 5 | 7.12 | 543 | 540.88 |
| **6** | 549 | 11 | 9.82 | 538 | 539.18 |

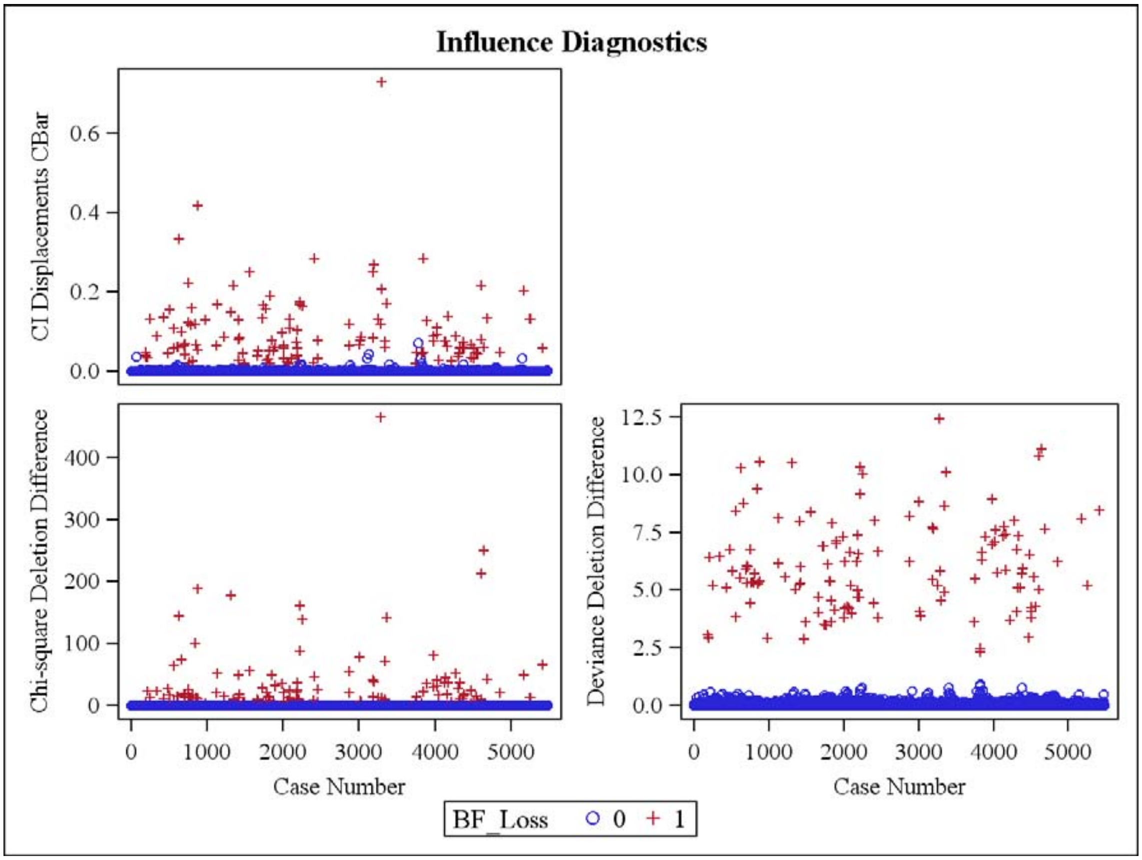
| Partition for the Hosmer and Lemeshow Test | | | | | |
|---|---|---|---|---|---|
| | | BF_Loss = 1 | | BF_Loss = 0 | |
| Group | Total | Observed | Expected | Observed | Expected |
| **7** | 548 | 10 | 14.40 | 538 | 533.60 |
| **8** | 548 | 21 | 18.63 | 527 | 529.37 |
| **9** | 548 | 31 | 33.81 | 517 | 514.19 |
| **10** | 379 | 52 | 50.66 | 327 | 328.34 |

| Hosmer and Lemeshow Goodness-of-Fit Test | | |
|---|---|---|
| Chi-Square | DF | Pr > ChiSq |
| 8.5866 | 8 | 0.3784 |

| Classification Table | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Correct | | Incorrect | | Percentages | | | | |
| Prob Level | Event | Non-Event | Event | Non-Event | Correct | Sensi-tivity | Speci-ficity | False POS | False NEG |
| **0.000** | 140 | 0 | 5344 | 0 | 2.6 | 100.0 | 0.0 | 97.4 | . |
| **0.020** | 112 | 3321 | 2023 | 28 | 62.6 | 80.0 | 62.1 | 94.8 | 0.8 |
| **0.040** | 83 | 4399 | 945 | 57 | 81.7 | 59.3 | 82.3 | 91.9 | 1.3 |
| **0.060** | 63 | 4672 | 672 | 77 | 86.3 | 45.0 | 87.4 | 91.4 | 1.6 |
| **0.080** | 39 | 5034 | 310 | 101 | 92.5 | 27.9 | 94.2 | 88.8 | 2.0 |
| **0.100** | 31 | 5135 | 209 | 109 | 94.2 | 22.1 | 96.1 | 87.1 | 2.1 |
| **0.120** | 26 | 5189 | 155 | 114 | 95.1 | 18.6 | 97.1 | 85.6 | 2.1 |
| **0.140** | 17 | 5224 | 120 | 123 | 95.6 | 12.1 | 97.8 | 87.6 | 2.3 |
| **0.160** | 12 | 5260 | 84 | 128 | 96.1 | 8.6 | 98.4 | 87.5 | 2.4 |
| **0.180** | 8 | 5287 | 57 | 132 | 96.6 | 5.7 | 98.9 | 87.7 | 2.4 |
| **0.200** | 8 | 5303 | 41 | 132 | 96.8 | 5.7 | 99.2 | 83.7 | 2.4 |
| **0.220** | 6 | 5311 | 33 | 134 | 97.0 | 4.3 | 99.4 | 84.6 | 2.5 |
| **0.240** | 2 | 5321 | 23 | 138 | 97.1 | 1.4 | 99.6 | 92.0 | 2.5 |
| **0.260** | 2 | 5332 | 12 | 138 | 97.3 | 1.4 | 99.8 | 85.7 | 2.5 |
| **0.280** | 2 | 5334 | 10 | 138 | 97.3 | 1.4 | 99.8 | 83.3 | 2.5 |
| **0.300** | 1 | 5337 | 7 | 139 | 97.3 | 0.7 | 99.9 | 87.5 | 2.5 |
| **0.320** | 0 | 5337 | 7 | 140 | 97.3 | 0.0 | 99.9 | 100 | 2.6 |

| Classification Table | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Correct | | Incorrect | | Percentages | | | | |
| Prob Level | Event | Non-Event | Event | Non-Event | Correct | Sensi-tivity | Speci-ficity | False POS | False NEG |
| **0.340** | 0 | 5341 | 3 | 140 | 97.4 | 0.0 | 99.9 | 100 | 2.6 |
| **0.360** | 0 | 5343 | 1 | 140 | 97.4 | 0.0 | 100.0 | 100 | 2.6 |
| **0.380** | 0 | 5344 | 0 | 140 | 97.4 | 0.0 | 100.0 | . | 2.6 |

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100
200
300
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Deviance Deletion Difference
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7.5
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3000
4000
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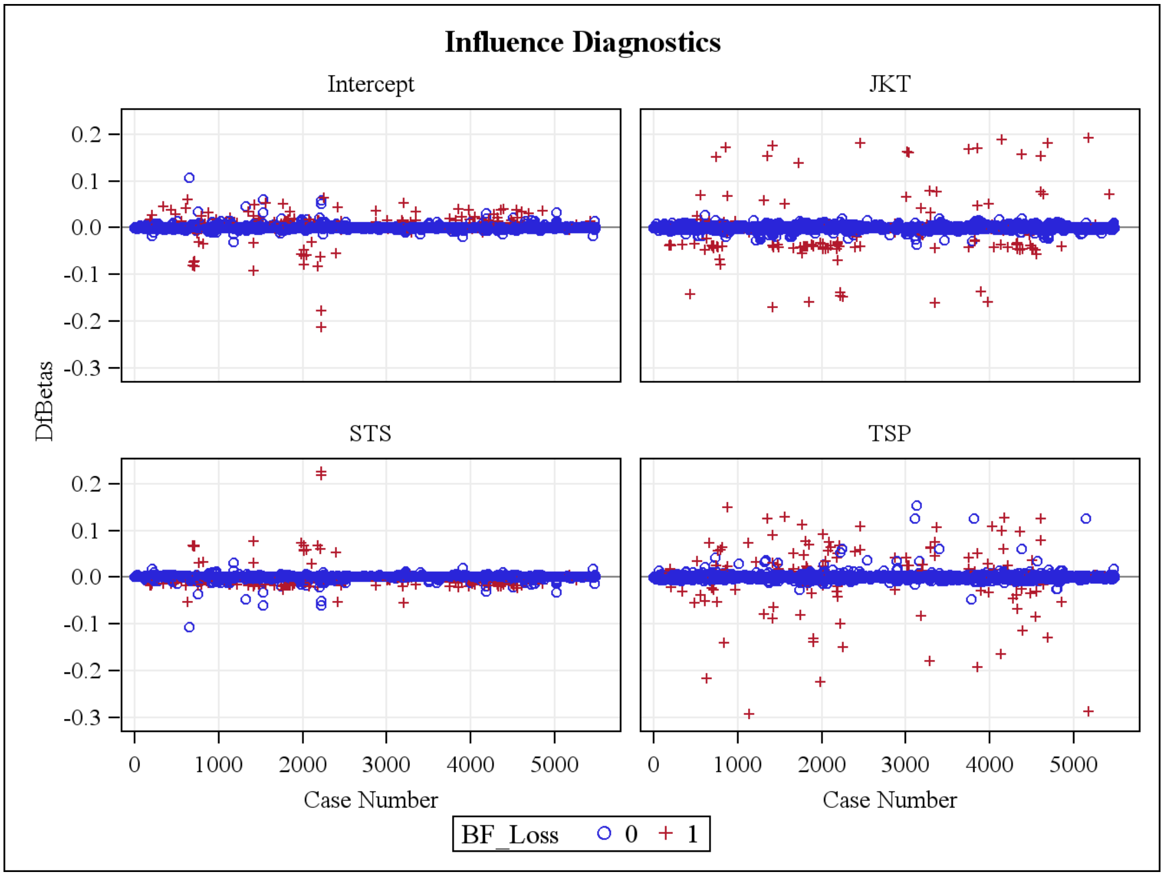
Case Number
BF_Loss ○ 0 + 1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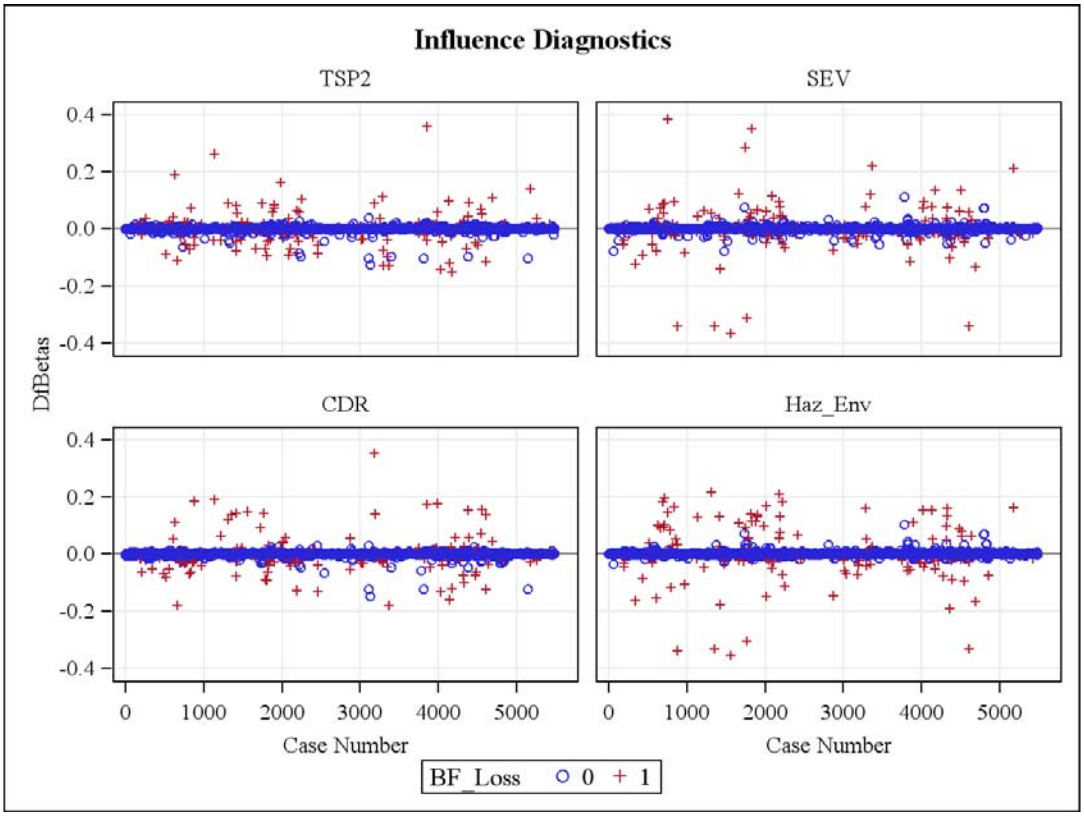
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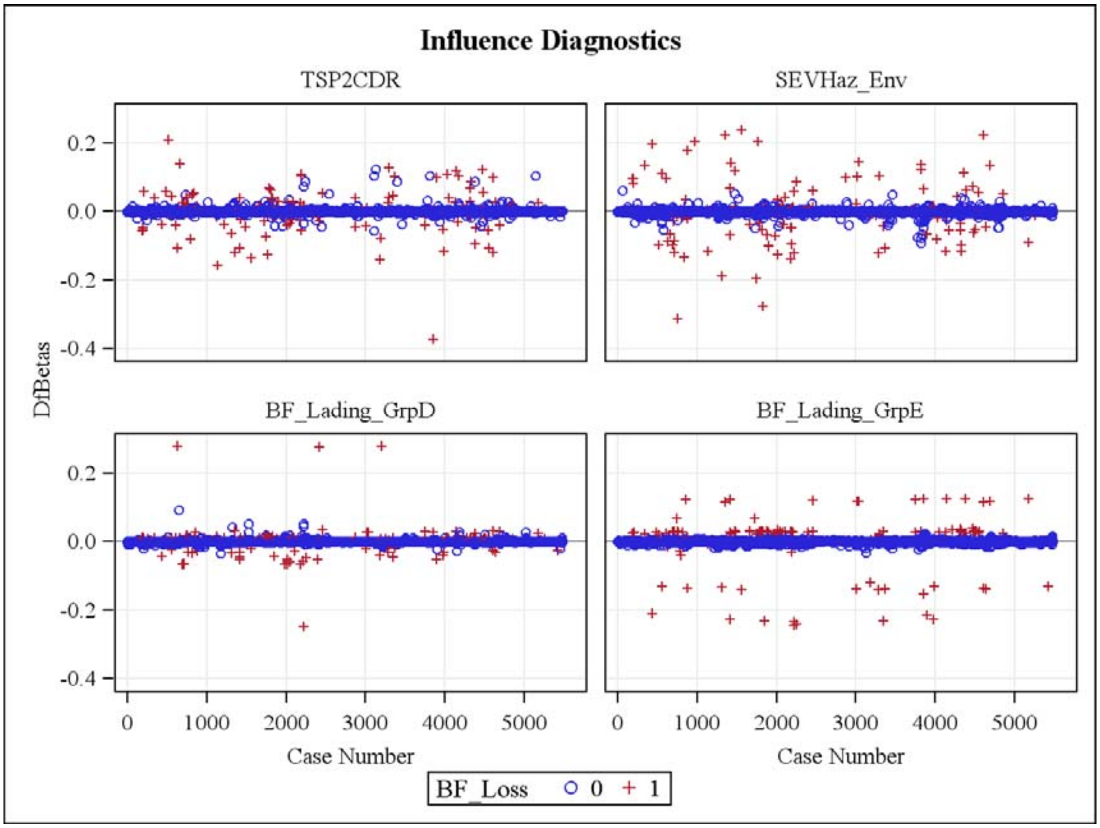
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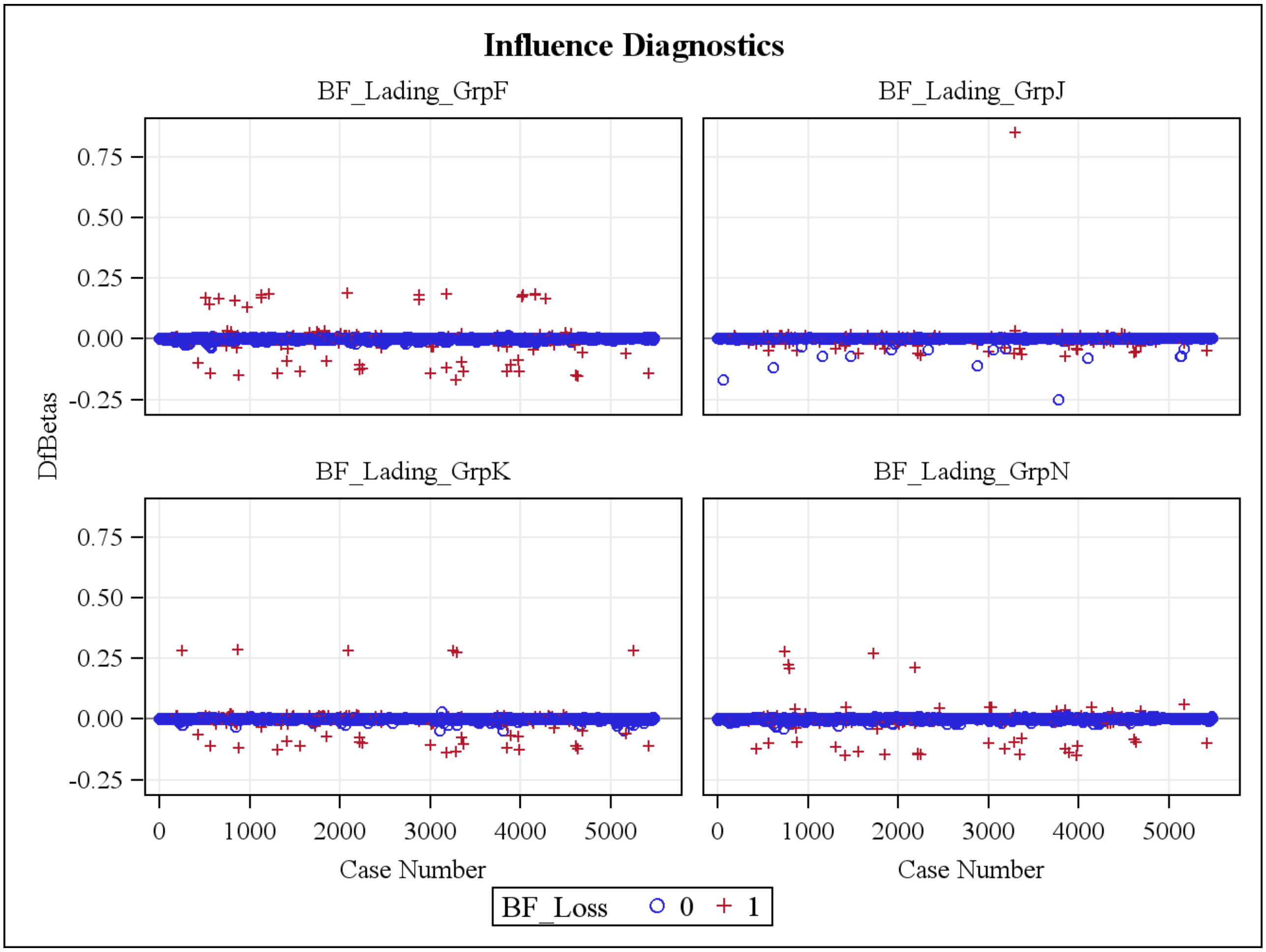
+ 1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BF_Lading_GrpJ
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0.00
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3000
4000
5000
Case Number
BF_Loss
○ 0
+ 1

# Appendix D
## Uncertainty Surrounding CPR

All estimates/predictions in the study are accompanied by uncertainty. The methods and the final models were chosen to limit and, to the extent possible, minimize this uncertainty, but it cannot be eliminated.

To assist in placing the appropriate weight on the estimates for decision-making purposes, it can be worthwhile to examine a confidence interval around key CPRs.

A large-sample 95% confidence interval for s prediction is given by

$$\left(L^{\mathrm{lo}} = \hat{L} - 1.96\hat{\sigma}_L, L^{\mathrm{hi}} = \hat{L} + 1.96\hat{\sigma}_L\right) \tag{15}$$

This transforms to a confidence interval for P of

$$\left(\frac{e^{L^{\mathrm{lo}}}}{1+e^{L^{\mathrm{lo}}}}, \frac{e^{L^{\mathrm{hi}}}}{1+e^{L^{\mathrm{hi}}}}\right) \tag{16}$$

When comparing two CPRs, if one falls within the confidence interval around the other, then the two estimates are not statistically distinct, i.e., there is no evidence that the true CPRs for those two cars are actually different.

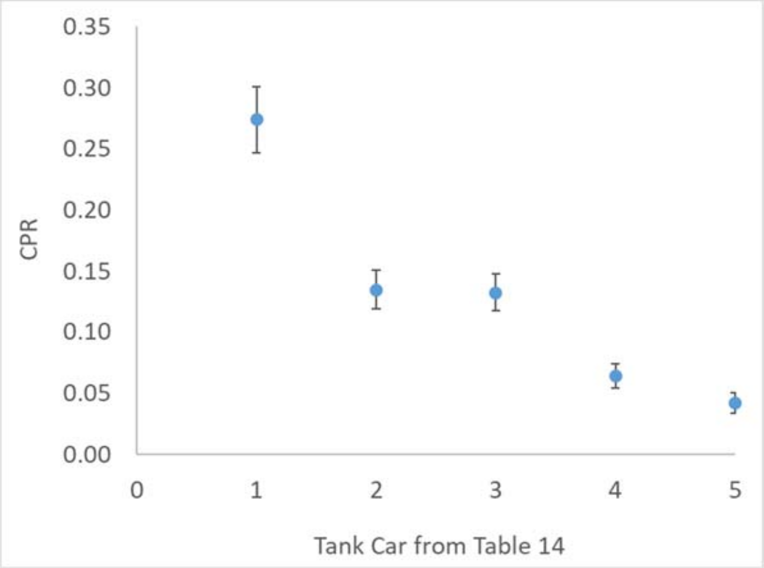
Table 12 provides examples.

Table 12
CPR Estimates and Associated Confidence Intervals for Five Tank Car Configurations

| | Car | Estimated Mainline CPR | Lower 95% Confidence Bound | Higher 95% Confidence Bound |
|---|---|---|---|---|
| 1 | 111A100W1, 7/16" tank, no jacket, bottom fittings, 119" ID | 0.274 | 0.239 | 0.293 |
| 2 | 111A100W1, 7/16" tank, jacket, bottom fittings, 119" ID | 0.134 | 0.119 | 0.151 |
| 3 | CPC-1232, 1/2" tank, no jacket, half-height head shield, top fittings protection, bottom fittings, 119" ID | 0.132 | 0.117 | 0.148 |
| 4 | CPC-1232, 7/16" tank, jacket, full head shield, top fittings protection, bottom fittings, 119" ID | 0.064 | 0.054 | 0.074 |
| 5 | DOT-117, 9/16" tank, jacket, full head shield, top fittings protection, bottom fittings, 119" ID | 0.042 | 0.034 | 0.050 |

Figure 9 shows the same data, and makes clear that cars 2 and 3, for which the CPRs fall within each other's confidence intervals, are not statistically significantly different in CPR, but the CPR differences between all other pairings are statistically significant.

Figure 9
CPRs for Five Tank Cars, with 95% Confidence Intervals



## Appendix E
## Calculation of the FRA Accident Data Compatibility Multiplier

Tank cars are entered in TCAD when they experience damage to tank-car-specific features in an accident. Therefore, if the fraction (cars releasing lading)/(cars in the database) is calculated, this results in an estimate of the probability of lading loss, conditional on being in the database, i.e., being damaged.

However, such an estimate is not particularly useful in a broader risk assessment or cost-benefit analysis. It cannot be connected to accident rate data, for example. If the denominator can be converted into the number of tank cars derailed in FRA-reportable accidents, on the other hand, then the resulting probability estimate can be combined with published FRA accident rates. Such a conversion would account for tank cars that are derailed in reportable accidents, but not damaged on the tank, jacket, fittings, or head shield. Also, tank cars that are in TCAD but derailed in accidents that did not meet the FRA cost threshold for reporting would also be accounted for.

Two approaches to estimating the adjustment, which takes the form of a multiplicative factor referred to as the FRA multiplier, are explored below.

The first approach uses a sample of data from Burlington Northern Santa Fe Railway (BNSF) covering the period 2000-2010. In this dataset, it was known that each record corresponded to an FRA-reportable accident, and that these were all of the tank cars derailed in FRA-reportable accidents on the BNSF system in that period. All data were for mainline accidents. These data were compared to data in TCAD that were associated with accidents on BNSF.

The maximum likelihood estimator (MLE) of the ratio between BNSF/FRA and TCAD loss probability estimates is calculated using equation (17):

$$\hat{M} = \frac{\mathrm{CPR}_{FRA}}{\mathrm{CPR}_{SP}} = \frac{\mathrm{L}_{\mathrm{FRA}}/\mathrm{N}_{\mathrm{FRA}}}{\mathrm{L}_{\mathrm{SP}}/\mathrm{N}_{\mathrm{SP}}} \qquad (17)$$

where:

$\hat{M}$ = estimated FRA multiplier
$\mathrm{L}_{\mathrm{FRA}}$ = number of tank cars with lading loss in FRA-reportable accidents,
$\mathrm{N}_{\mathrm{FRA}}$ = number of tank cars derailed in the FRA-reportable accidents.
$\mathrm{L}_{\mathrm{SP}}$ = number of tank cars with lading loss in the TCAD data, and
$\mathrm{N}_{\mathrm{SP}}$ = number of tank cars in the TCAD data

The (100-α)% large sample asymptotic confidence interval of estimated multiplier can be expressed as:

$$\exp(\ln \hat{M} \pm z_{1-a/2} SE) \tag{18}$$

where

$$SE = \sqrt{\frac{1}{L_{FRA}} - \frac{1}{N_{FRA}} + \frac{1}{L_{SP}} - \frac{1}{N_{SP}}} \tag{19}$$

Data for the BNSF mainline accidents in 2000-2010 were as follows:

| | BNSF Records Known to Be FRA-Reportable | All TCAD BNSF Records |
|---|---|---|
| Cars with loss, L | 115 | 66 |
| Cars in dataset, N | 470 | 355 |
| CPR, L/N | 0.245 | 0.186 |

The estimated FRA multiplier for mainlines arising from this procedure is

$$\hat{M} = \frac{CPR_{FRA}}{CPR_{SP}} = \frac{L_{FRA}/N_{FRA}}{L_{SP}/N_{SP}} = 1.32 \tag{20}$$

with a corresponding 95% confidence interval is (1.01, 1.72). The 99% confidence interval is (0.92, 1.88). Note that the value of one falls within the 99% interval, but not the 95% interval. The P-value for a test of difference from one is 0.046. Whether there is statistically significant evidence that the mainline multiplier is different from one is dependent on the analyst's selection of significance level. At 5% significance level, the multiplier appears to be greater than one. At 1% significance level, no difference is found.

It was decided to consider this analysis as insufficient evidence of a multiplier different from one, for the following reasons:

1) The p-value is borderline,
2) The form of the confidence interval is defensible for sufficiently large sample sizes, and incurs some uncertainty at moderate sample sizes,
3) It is unclear how representative BNSF data for the whole rail industry, and
4) The observations are not, strictly speaking, independent, since some come from the same accident.

A second approach was to attempt to assign a FRA-reportable status to a larger group of cars in TCAD for 2000-2010. Some railroads indirectly inform the Tank Car Safety Project when an accident was reported to FRA by using the same report submission number for their FRA report and for information provided to the Project. Tank cars identified this way, damaged in mainline accidents, broke down as follows:

| | TCAD Records Known to Be FRA-Reportable | All TCAD Mainline Records for the Period |
|---|---|---|
| Cars with loss, L | 303 | 376 |
| Cars in dataset, N | 1,310 | 1,699 |
| CPR, L/N | 0.231 | 0.221 |

For this dataset,

$$\hat{M} = \frac{\mathrm{CPR}_{FRA}}{\mathrm{CPR}_{SP}} = \frac{\mathrm{L}_{\mathrm{FRA}}/\mathrm{N}_{\mathrm{FRA}}}{\mathrm{L}_{\mathrm{SP}}/\mathrm{N}_{\mathrm{SP}}} = 1.05. \tag{21}$$

The corresponding 95% confidence Interval is (0.91, 1.19). The confidence interval contains the value one. Therefore, even at 95% confidence, there is no evidence of a difference between the loss ratios from FRA-reportable TCAD accidents and all of TCAD for mainlines. This result reinforces the earlier conclusion that the mainline FRA multiplier should be set at 1.

The previous study, RA-05-02 [Ref. 4], provided separate FRA multipliers for mainline/siding and yard/industrial track types. In this study the track type variable was included in the regressions directly, and found to be insignificant on its own. Therefore, it was deemed adequate to use appropriate train speeds and derailment sizes for the two different track types, and let those differences drive any difference in CPRs.

It is still possible that the degree of correlation between an accident being FRA-reportable and that accident causing TCAD-recordable damage could differ between track types. Further work could be done to resolve this. Also, the magnitude of multipliers and the need for multipliers could change over time so the term has been kept in the model in case such a need arises.

Note that the FRA multiplier does not have any bearing on comparisons among car configurations, as the percent difference between CPRs for different cars remains the same no matter what multiplier is used.

# Appendix F
## Comparison of TWP-17 and RA-05-02 CPR Estimates

Table 13 compares the CPR estimates derived in this study to those for the same cars using the RA-05-02 formulas. Note that TWP-17 CPRs are consistently lower. This could be due to a number of factors that cannot be verified. The distribution of accident environments has probably changed over time. The robustness of materials and/or designs that are lumped under one term in this study, such as "TC-128" or "head shield", may have generally improved over time. In any event, the lower rates of release are validated by the broader data in the Tank Car Safety project database; note that the mainline FRA multiplier is 1.0.

Table 13
TWP-17 CPRs and RA-05-02 CPRs for Selected Tank Cars
Under Average Mainline Derailment Conditions

| Car Specification | Head and Shell Thickness (in.) | Jacket | Head Shield | Top Fittings Protection | Bottom Fittings | Shell Inside Diameter (in.) | TWP-17 CPR | RA-05-02 CPR | Difference |
|---|---|---|---|---|---|---|---|---|---|
| 111A100W1 | 0.4375 | No | No | No | Yes | 119 | 0.274 | 0.353 | -0.079 |
| 111A100W1/3 | 0.4375 | Yes | No | No | Yes | 119 | 0.134 | 0.207 | -0.073 |
| 111A100W1/2 | 0.4375 | No | No | No | No | 119 | 0.265 | 0.310 | -0.045 |
| 111A100W1/2/3 | 0.4375 | Yes | No | No | No | 119 | 0.130 | 0.170 | -0.040 |
| 111A100W2 | 0.5625 | No | No | Yes | No | 100.625 | 0.201 | 0.202 | -0.001 |
| 111A100W1 | 0.4375 | Yes | Full | Yes | Yes | 119 | 0.064 | 0.150 | -0.086 |
| 111A/S100W1 | 0.500 | No | Half | Yes | Yes | 119 | 0.132 | 0.241 | -0.109 |
| 117R100W | 0.4375 | Yes | Full | No | Yes | 119 | 0.126 | 0.188 | -0.062 |
| 117R100W | 0.4375 | Yes | Full | Yes | Yes | 119 | 0.064 | 0.150 | -0.086 |
| 117R100W | 0.500 | Yes | Full | No | Yes | 119 | 0.106 | 0.176 | -0.070 |
| 117R100W | 0.500 | Yes | Full | Yes | Yes | 119 | 0.052 | 0.137 | -0.085 |
| 117J100W | 0.5625 | Yes | Full | Yes | Yes | 119 | 0.042 | 0.126 | -0.084 |
| 112J340W | 0.625 | Yes | Full | Yes | No | 118.75 | 0.033 | 0.076 | -0.043 |
| 105J300W | 0.5625 | Yes | Full | Yes | No | 118.75 | 0.040 | 0.086 | -0.046 |
| 105A500W | 0.779 | Yes | No | Yes | No | 102 | 0.040 | 0.073 | -0.033 |
| 105J500W | 0.797 | Yes | Full | Yes | No | 102 | 0.031 | 0.060 | -0.029 |
| 112J500I | H1.03 / S0.89 | Yes | Full | Yes | No | 115.34 | 0.017 | 0.049 | -0.032 |
| 105J600I | H1.136/S0.98 | Yes | Full | Yes | No | 106 | 0.016 | 0.047 | -0.031 |