Institute of Transportation Engineers
Transportation Safety Council

BEFORE-AND-AFTER STUDY TECHNICAL BRIEF

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1. INTRODUCTION

Agencies are required to evaluate the safety effects of a specific improvement to compare its net benefit to other improvement options as well as to justify its implementation at subsequent locations. The typical method of evaluating the safety improvements of a treatment is comparing the crash prevalence associated with the transportation facility before and after the treatment implementation (a before-and-after study). A challenge inherent in these studies is that crashes are random and change from year to year, unlike laboratory experiments in which the analyst can control many extraneous conditions. Other parameters that affect the safety of a facility, such as traffic volume and weather conditions, change over time. Consequently, specific evaluation techniques are required to account for changes in order to estimate the true effects of safety improvements.

The main objective of this technical brief is to provide practitioners with a quick reference on the key considerations and components of a valid before-and-after observational study. This document also serves as a tool to increase the level of understanding of before-and-after study techniques so that they can be more effectively conducted in the future.

By providing better assessment tools and resources to allow practitioners to explicitly consider safety impacts in their decision-making, there has been a positive shift in North American road safety. However, there are cases where local studies and research have employed inferior analysis techniques in before-and-after assessments due to lack of understanding of proper techniques, time or resource constraints and/or budget limitations. As transportation safety practitioners, shortcomings must be identified in before-and-after study methodologies so that good research results are identified and poorly conducted work is not propagated.

This document is not intended to be a prescriptive reference on the methodologies and formulae for completing different types of before-and-after studies. This has been left to more comprehensive documents such as the updated *Highway Safety Manual* and research work available in the public realm and provided in the final section of this brief.

Section 2 of this technical brief outlines the background fundamentals and definitions required to understand the primary components of a before-and-after study, the techniques adopted to conduct such a study and how each technique differs from the others. Section 3 provides an introduction and a brief description of each technique, its requirements, strengths and weaknesses.

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2. BACKGROUND

2.1 Experiments Versus Observational Studies

Experiments are studies that are implemented in a laboratory context. Researchers can intentionally design an experiment in a desired way in order to answer a certain question. However, in observational studies, the parameters of the study cannot be entirely controlled by the researchers. Road safety studies fall into the observational study type because analysts do not have the luxury of designing a test in a laboratory to count the number of accidents. In road safety studies, parameters that may influence the safety of a facility would not necessarily be constant in the before and the after periods. For example, it is conceivable that the traffic volume, weather conditions, traffic regulations and composition of traffic can change over time in any given transportation system.

Observational studies themselves can be categorized into two groups: before-and-after studies and cross-section studies. A before-and-after study is used when it is desired to study the safety implications of a certain improvement or operational change. In an observational before-and-after study, many of the attributes of a facility remain unchanged. For instance, the study of safety implications associated with installing traffic signal controls at an all-way stop-controlled intersection falls under the before-and-after observational study category. In this example, the geometry and other site characteristics of the intersection retain their original configurations.

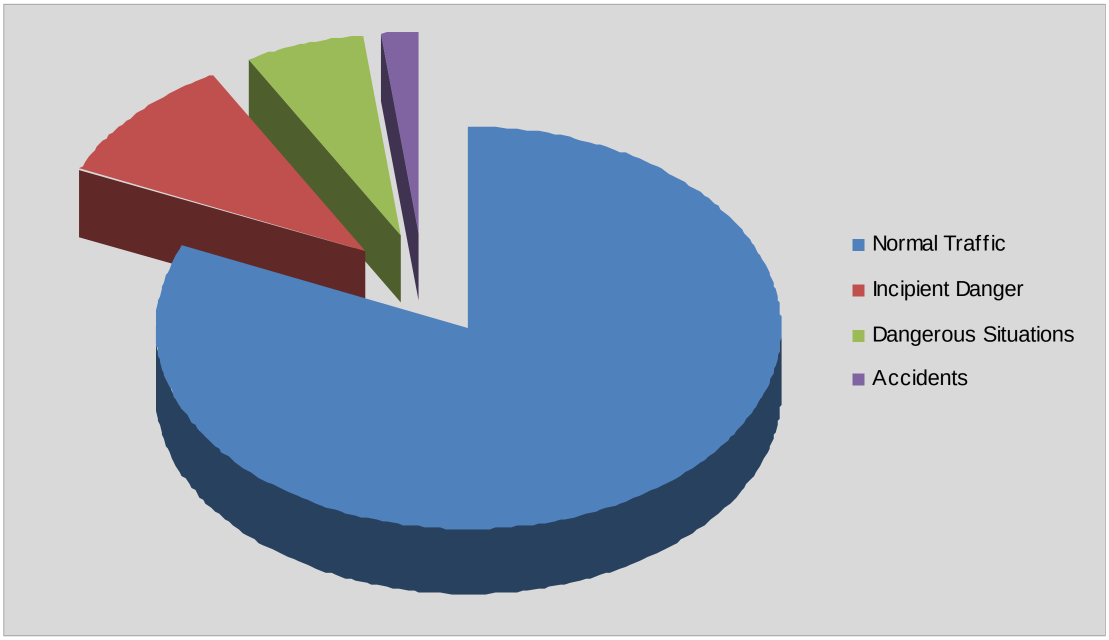
However, in cross-section observational studies, the safety effects of one group of facilities are compared with another group. These two groups of facilities have some common features, and the safety effect of those features that are not in common must be evaluated. The comparison of the safety of a roundabout and a stop-controlled intersection is an example of a cross-section observational study. This technical brief is directed at the techniques that can be utilized for before-and-after observational studies in the context of road safety.

2.2 Definition of Safety

Before any attempt to estimate the level of safety of a transportation facility, safety itself should be defined. It should be noted that two beliefs are associated with road safety: an objective measure and a subjective perception. The objective measure of road safety manifests itself in the number of accidents and their severity. The subjective perception of road safety—referred to as road security—is the degree of safety one feels when traveling within a transportation system. An increase in the security level of a roadway is not necessarily translated into an enhanced level of road safety. In some cases, an increase in security may result in reduced safety because the road user feels safer and become less cautious. For example, if a gravel roadway is paved with asphalt, the average speed is likely to increase, which may result in more accidents.

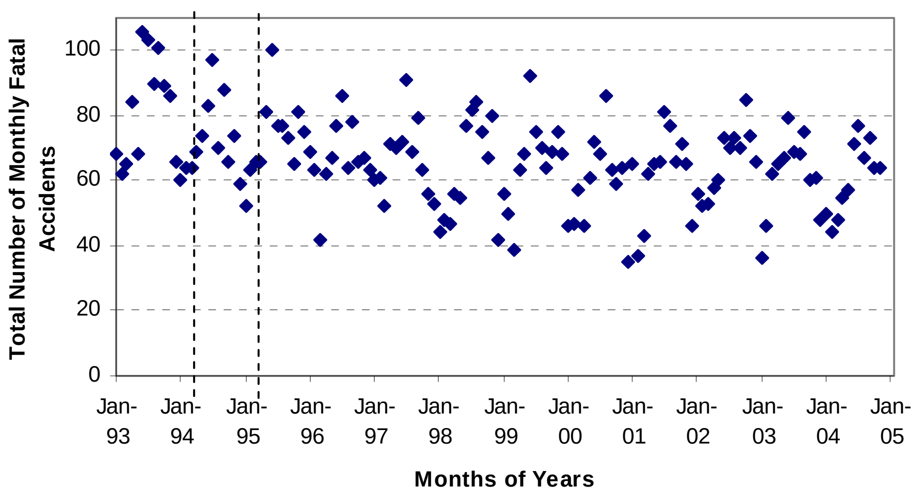
Figure 1 shows the continuum of events in a traffic stream. In this figure, the volume of each situation relates to the corresponding frequency. The number of dangerous situations within a transportation facility is greater than number of accidents per unit of time. Given the fact that events that happen more frequently can be measured more easily, some researchers have tried to define the safety of transportation facilities based on surrogate measures of safety.[1] Accidents are directly proportional to dangerous situations, so safety can be defined in terms of the prevalence of accidents.

Figure 1. The Continuum of Events.



Unfortunately, randomness of accidents is also one of the primary characteristics of safety, which makes the evaluation of a safety treatment more challenging. Figure 2 shows the number of total monthly fatal accidents in Ontario, Canada, from the period between January 1993 and December 2004. If a random year is selected from this figure, one is not able to determine a specific trend in the number of accidents among different months. Similarly, if a random month is selected, as can be seen from 1993 to 1994, the number of accidents decreased from 106 to 83. However, in 1995, it increased to 100. As with any transportation facility, accident occurrences are random; this must be explicitly recognized in any effort to measure safety performance.

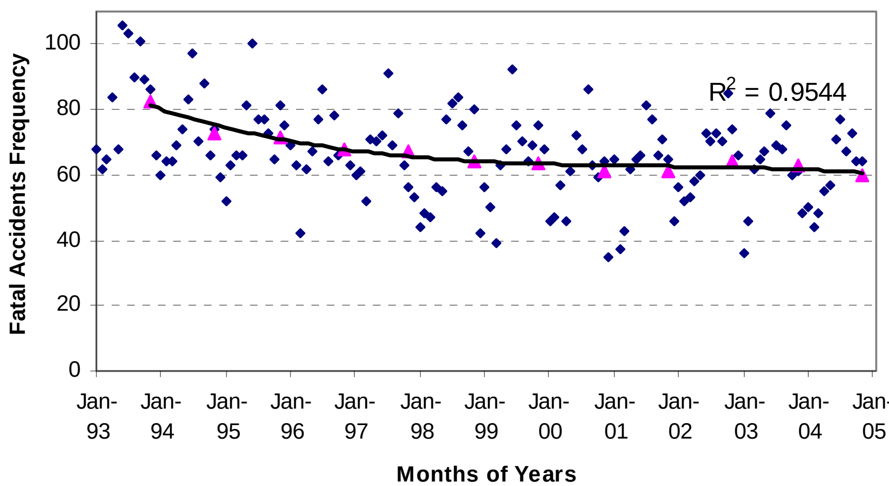
Figure 2. Number of Monthly Fatal Accidents from January 1993 to December 2004 in Ontario, Canada.



The squares in Figure 3 represent the same number of fatal accidents that were shown in Figure 2. The triangles in Figure 3 correspond to the annual average monthly fatal accidents from 1993 to 2004. During this 12-year period, the annual average monthly fatal accidents follow a general trend. This simple example illustrates that the safety of a facility is different than the number of accidents, which is a random variable.

Safety is an attribute of a facility that is believed to be the same over time if all influencing parameters (such as environment, users, volumes, etc.) remain unchanged. Consequently, the safety of a facility can be defined as an expected accident frequency or, more formally, "the number of accidents, or accident consequences, by kind and severity, expected to occur on the facility during a specified period."[2]

Figure 3. Number of Monthly Fatal Accidents and Annual Average Monthly Fatal Accidents from January 1993 to December 2004 in Ontario, Canada.



2.3 Target Accidents

Having established that the expected accident frequency is the foundation and starting point of road safety analysis, attention must be turned to the specific types of accidents that are expected to be affected following the implementation of a proposed or existing treatment—the safety improvement plan. In any before-and-after study, accidents can be grouped into two categories as they relate to the treatment:

- target accidents that can be materially affected by the treatment; and
- comparison accidents that are not affected by the safety treatment.[3]

The differentiation and determination of which accident types belong to either of the above categories is a challenge. In general, this division will not be definitive. A firm understanding of the contributory factors in specific accident types is required to reduce the likelihood that comparison accidents are analyzed as target accidents and vice versa.

2.4 Causal Factors Explained

The safety performance of a transportation facility changes over time. Two groups of causal factors affect the safety performance of these facilities. The first are those that are recognized, measured, understood and can be explained by models. The second group of factors are those that are not recognized, not measured, or not understood. These latter causal factors have to be implicitly understood in a valid before-and-after study.

According to the two groups of causal factors, change in safety performance from the before period to the after period can be disaggregated into four components: treatment effect, exposure effect, trend effect and random effect.[4] All of these effects are explained in the following sections.

2.4.1 TREATMENT EFFECT

The treatment effect is the change in safety performance of a transportation facility caused by implementation of a specific treatment. In a before-and-after study, the treatment effect must be isolated from the other causal factors to determine the net improvement/deterioration in terms of safety performance. The net safety benefits/costs of the treatment are obtained by finding and comparing the answers to the following two questions:

- What would have been the safety performance of the facility in the after period had the treatment not been applied?
- What is the safety performance of the treated facility in the after period?

To answer the first question, the causal factors outlined in the following three subsections must be fully quantified and isolated. The second question needs to recognize the importance of the target accident discussion in the preceding section.

2.4.2 EXPOSURE EFFECT

The exposure effect is caused by change in traffic volume and patterns on a facility. Traffic volume and accident frequencies have a direct relationship. Therefore, it is conceivable that the accident frequency of a facility increases as traffic volume increases and vice versa. This effect could be significant if the remedial action applied to the facility significantly changes the operations or capacity of the facility, such as placing an intersection under traffic signal control or providing a two-way left-turn lane on a specific road section.

2.4.3 TREND EFFECT

The trend effect is due to causal factors that are not recognized, measured and understood. For example, traffic composition (such as a higher/lower percentage of trucks or pedestrians), driver composition (in terms of behavior, age, etc.), enforcement level, weather conditions, etc. can be changed from the before period to the after period.

2.4.4 RANDOM EFFECT

The random effect occurs because of a phenomenon referred to as regression-to-the-mean bias in statistics. In practice, there is a tendency to select facilities with high accident frequency or rates for safety treatments. However, if the selection is made based on a short-term high prevalence of accidents, a lower accident rate would be expected in the after period, even if no improvement had been implemented.

Based on the definition of the above four effects, it can be concluded that even if no safety treatment had been applied to the facility, it would have been likely to observe a change in accident frequency from the before to the after periods. Consequently, analysts must recognize the impact of each of these effects on their evaluation results and must employ techniques that seek to minimize or account for these extraneous effects. Properly designed studies extract the treatment effect from the total change in safety performance in order to assess if the safety or operational treatment has resulted in a safety improvement or deterioration.

The following section is a summary of four common before-after study approaches with specific attention to their ability to address and control for the exposure, trend and random effects noted above.

3. BEFORE-AND-AFTER STUDY APPROACHES

The following is an overview of the four most commonly used approaches to perform a before-and-after study in order to evaluate the performance of a safety improvement plan or an operational change on a transportation facility: naïve before-and-after study, before-and-after study with yoked comparison, before-and-after with comparison group and before-and-after study with Empirical Bayes approach.

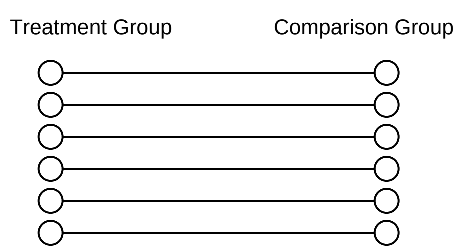
3.1 Naïve Before-and-After Study

The naïve before-and-after study is the simplest technique for this kind of observational study. In this approach, accident counts in the before period are used to predict the expected accident rate and, consequently, expected accident counts if the safety treatment had not been implemented. The change in accident counts between the before and the after conditions is considered the treatment effect. The effect of the passage of time on the safety of a facility is ignored; this technique is unable to separate the treatment effect from the other effects described in Section 2.4. The application of this technique in real-world projects is not recommended.

3.2 Before-and-After Study with Yoked Comparison

In the before-and-after study with yoked comparison, the treated facility and untreated facility are referred to as the treatment site and comparison site, respectively.[5] In this technique, a group of similar facilities is selected so that there is a one-to-one correspondence between each member of the comparison group and the treatment group. This requires that the treatment site be similar to the comparison site. For instance, if the treated facility is an intersection, the comparison site should be a similar intersection with respect to area type (commercial business district, urban, rural), intersection type (three-legged or four-legged), traffic control (signalized, two-way stop-controlled, etc.), geometric design and traffic volume. The comparison site should not have undergone any geometric change or traffic control improvement during the before and after periods.[6] A graphical representation of the treatment and comparison groups is provided in Figure 4.

Figure 4. Yoked Comparison.



Source: Harwood, D.W. et al. “Safety Effectiveness of Intersection Left- and Right-Turn Lanes.” *Transportation Research Record*, No. 1840 (2003): 131–139.

In this method, it is hoped that the unknown causal factors should affect the comparison group in the same manner that they influence the treatment group. Therefore, the change in the number of accidents from the before period to the after period, had the treatment sites been left unimproved, would have been in the same proportion as the matching comparison site. Under this assumption, the accident frequency at each treatment site in the before period is multiplied by the ratio of after-to-before accidents at the comparison site to predict the expected number of accidents in the after period at the treated site without the improvement.[7] This approach has better theoretical grounds than the naïve before-and-after study technique; however, it still suffers from three main issues:

- It makes use of only one comparison site, and it is conceivable to have different estimates when other comparison sites are used. Consequently, the findings based on the evaluation of the facility will be variable with relatively wide confidence limits.
- It is unable to address the issue known as regression-to-the-mean bias. If the treatment site is chosen based on the fact that the agency has observed high accident counts in a short term, the accident frequency will likely be lower in the after period even if no treatment is applied. However, this method cannot identify whether the lower accident frequency is due to the treatment or the intrinsic randomness of accidents.
- It is unable to deal with cases where the comparison site has no history of accident occurrences.[8]

A before-and-after study was performed with yoked comparison in the state of Illinois to evaluate the effectiveness of continuous shoulder rumble strips (CSRS).[9] The target accidents in this study were single-vehicle run-off-the-road accidents. The author selected 55 treatment sites and 55 comparison sites. The selected yoked comparison sites in this study were freeway sections adjacent and upstream to the treatment sites.

Tables 1 and 2 illustrate the time series of the accident counts in the before and after periods. As shown, the durations of the before and after periods are similar to each other in this study.

Table 1. Before Period Accidents for Treatment and Yoked Comparison Groups.

	Before Period						
Years	1987	1988	1989	1990	1991	1992–93	Total
Treatment	276	644	863	596	310	112	2801
Comparison	240	515	646	521	259	107	2288

Source: Griffith, M. "Safety Evaluation of Continuous Rolled-In Rumble Strips Installed on Freeways." *Transportation Research Record*, No. 1665 (1999): 28–34.

Table 2. After Period Accidents for Treatment and Yoked Comparison Groups.

	After Period						
Years	1990	1991	1992	1993	1994	1995	Total
Treatment	70	391	500	534	255	145	1895
Comparison	112	462	460	454	212	133	1833

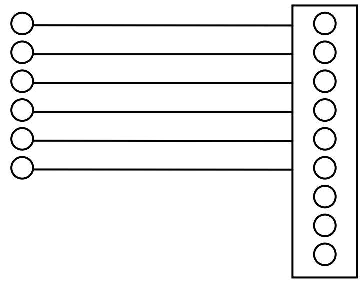
Source: *Safety Evaluation of Rollen-In Continuous Shoulder Rumble Strips Installed on Freeways*. Highway Safety Information System Summary Report, FHWA-RD-00-32. Washington, DC, USA: Federal Highway Administration, U.S. Department of Transportation, 1999.

The researcher found that the CSRS treatments contributed to an 18.3-percent reduction in target accidents.[10]

3.3 Before-and-After Study with Comparison Group

The rationale behind the before-and-after study with comparison group is the same as the yoked comparison technique; however, in this approach there is no need for a one-to-one matching between members of the comparison group and the treatment group. The philosophy is that the larger the comparison group, the better the assessment. A graphical representation of the treatment and comparison group for this method is provided in Figure 5.

Figure 5. Comparison Group.



Source: Harwood, D.W. et al. "Safety Effectiveness of Intersection Left- and Right-Turn Lanes." *Transportation Research Record*, No. 1840 (2003): 131–139.

In this evaluation approach, the facilities in the comparison group do not have to be exactly similar to the facilities in the treatment group. However, it is important that a close agreement exist with regard to accident history at the treatment and comparison sites in the before period. This approach resolves the first issue associated with the before-and-after study with the yoked comparison; however, it is unable to address the phenomenon of regression-to-the-mean bias. Also, it should be noted that this technique is similar to the yoked comparison approach in that it cannot determine the treatment effectiveness if accident counts in either the before or the after period in the comparison group equal zero. This situation is unlikely to occur due to having a group of comparison sites rather than only one single comparison site for each specific treatment site.

The Insurance Corporation of British Columbia (ICBC) launched the STOP Sign In-Fill Program in 1998 to reduce the frequency and severity of accidents in residential areas in the greater Vancouver, British Columbia, Canada, regional district. The effectiveness of the program was evaluated using an observational before-and-after study with comparison groups to determine whether the program had been effective. This program promoted the idea that STOP signs should be installed at every second intersection in residential neighborhoods.[11]

One of the unique features of this study was the fact that the intersections treated in this study had not been selected based on their accident frequencies, but on the basis of a general rule that a STOP sign should be installed at every second intersection. Consequently, the effect of the regression-to-the-mean phenomenon was minimal in this project.

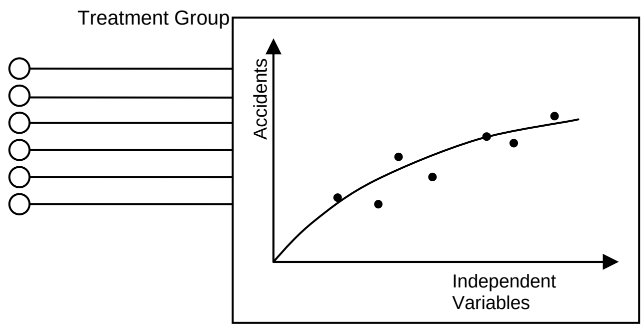
The project study area consisted of 22 zones including 380 intersections. The treatment of intersections had been completed in 1999, 2000, 2001, or 2002 in order to provide the analysts with adequate time for a thorough before-and-after study. The accident data associated with each intersection were extracted from the ICBC database. The comparison group in this study was a collection of 133 existing two-way stop-controlled intersections located in the 22 study zones.

The research found that the total accidents and severe accidents were reduced by 52.8 and 66.9 percent, respectively. It should be noted that the researchers also conducted a before-and-after study with yoked comparison. They found that the total and severe accidents were reduced by 44.8 and 61.1 percent, respectively.[12]

3.4 Before-and-After Study with the Empirical Bayes Approach

In practice, there is a tendency to select facilities with high accident rates for safety treatments. However, if the selection is made based on a short-term high prevalence of accidents, a lower accident rate would be expected in the after period, even if no improvement had been implemented. As previously explained, this phenomenon is well known in statistics as regression-to-the-mean bias. To properly account for the effect of regression to the mean, the Empirical Bayes approach is used. The Empirical Bayes method is a statistical approach to determine the appropriate weighting to place on each relevant factor to estimate accident outcomes for a treatment group. The Empirical Bayes method determines a smoothed value for expected accidents and eliminates the randomness element of accidents. In this evaluation approach, safety performance functions (SPFs) are used to estimate accident frequencies had the treatment not been applied. SPFs are regression models that explain the relationship between accident frequency and some explanatory variables such as traffic volume on the facility. A number of SPFs already have been developed by researchers and jurisdictions to estimate accident frequencies on different facilities. A graphical representation of the treatment and comparison function for this method is provided in Figure 6.

Figure 6. Empirical Bayes Approach.



Source: Harwood, D.W. et al. "Safety Effectiveness of Intersection Left- and Right-Turn Lanes." *Transportation Research Record*, No. 1840 (2003): 131–139.

In the Empirical Bayes approach, the accident frequency in the after period if the treatment had not been applied is predicted using accident prediction models or SPFs developed for a reference group and the observed accidents in the before period. The reference group is similar to the comparison group introduced in other methods. Consequently, the reference group consists of similar facilities that have not undergone any improvements from the before to the after periods.

The safety effects of roundabout conversions in the United States were investigated using the Empirical Bayes approach. The researchers analyzed 23 intersections in seven states: Colorado, Florida, Kansas, Maine, Maryland, South Carolina and Vermont. All of these intersections were converted to roundabouts between 1992 and 1997. Among the 23 intersections, 19 had been stop-controlled, while the remainder were signalized.[13]

The researchers employed accident prediction models prepared for signalized intersections and those developed for rural stop-controlled intersections.[14,15] However, new regression models were calibrated for urban stop-controlled intersections based on data from Toronto, Canada, and the states of Maryland and Florida. Using these models, the frequency of accidents during the before period was calculated. For 23 intersections converted to roundabouts, the total accidents and the injury accidents were reduced by 40 percent and 80 percent, respectively.[16]

4. SUMMARY

The main objective of this technical brief is to provide a quick reference for practitioners to understand the requirements for conducting a valid before-and-after study. Properly conducted before-and-after studies can be used to quantify and assess the safety improvements of a particular treatment on different transportation facilities.

This brief describes four common methodologies for conducting before-and-after studies for transportation facilities as well as their benefits and shortcomings. The naïve before-and-after study is the simplest technique for this kind of study. Within this methodology, the effect of passage of time on the safety of a facility is ignored, which is an unreasonable assumption in terms of statistical validity. The application of this technique in real-world projects is not recommended.

The most statistically rigorous method of the four reviewed is the Empirical Bayes technique. There is general consensus among researchers and practitioners regarding the superiority of this technique, and it is recommended for use in all circumstances where the data and required SPFs are available. The next preference is to perform a before-and-after study with comparison groups. However, if the number of facilities is limited in the comparison group, the yoked comparison is the next best analysis choice.

The decision to use one analysis methodology versus another ultimately is in the hands of the transportation practitioner undertaking the before-and-after study. This brief provides an understanding of the merits of each method to weigh into the decision process where data availability, resources, time constraints and other decisive factors are a reality.

Table 3 is a summary of the abilities of each of the four before-and-after study methods to address the primary causal factors attributed to a change in safety performance.

Table 3. Summary of Before-and-After Study Application.

Methodology	**Ability to determine or account for:**			
	Treatment Effect	**Exposure Effect**	**Trend Effect**	**Random Effect**
Before-and-After with Empirical Bayes	Yes	Yes	Yes	Yes
Before-and-After with Comparison Group	Yes	Yes	Yes	No
Before-and-After with Yoked Comparison	Yes	Yes	Potential	No
Naïve Before-and-After Study	Yes	Potential	No	No

Table 4 shows the data requirements of each technique and briefly states the weaknesses and strengths associated with each approach.

Table 4. Data Requirements, Strengths and Weaknesses.

Technique	Data Requirements	Strengths	Weaknesses
Before-and-After with Empirical Bayes	Accident counts in the before and the after periods Safety performance functions that suit the facility and the type of target accidents	Has a concrete theoretical background and is the preferred approach by researchers Addresses the issue of regression-to-the-mean bias	Safety performance functions do not exist for all facilities being analyzed
Before-and-After with Comparison Group	Accident counts in the before and the after periods for the treatment and comparison sites A comparison group that is in conformity with the treatment group in the before period	The treatment sites and comparison group sites need to be similar, but a one-to-one pairing is not required	Does not address regression-to-the-mean bias Conformity check between treatment group and comparison group is required in the before period
Before-and-After with Yoked Comparison	Accident counts in the before and the after periods A comparison group that has a one-to-one similarity with the treatment group	Simple to carry out Fewer data requirements	Has to be a one-to-one match between treatment and comparison sites; therefore different estimates are obtained when other comparison sites are used Does not address regression-to-the-mean bias
Naïve Before-and-After	Accident counts in the before and the after periods	Simple to carry out Few data requirements	Does not address regression-to-the-mean bias Does not account for exposure and trend effects over time

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