The Effectiveness of Taxi Partitions:
The Baltimore Case

Prepared for

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University of Tennessee - Knoxville
Knoxville, Tennessee

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Funded by

The Southeastern Transportation Center
With a Grant from
The University Transportation Centers Program
US Department of Transportation

June 1999

Preface

This project builds upon work we began in 1992 to examine the number of taxi driver assaults and homicides. Since that time taxi driver safety has been recognized as a major occupational safety problem. Taxi drivers sustain proportionately more attacks and homicides than most other professionals. Given the seriousness of their problem the taxi industry has sought to protect drivers with a variety of devices, especially partition (shields). Yet the effectiveness of shields to thwart attacks has remained unproven except through anecdotal evidence. This case study represents the first statistical examination of the evidence that taxi partitions do, indeed, protect drivers. Further, the financial benefit in terms of reduced injuries and loss of life more than pays for the investment in shields.

This report includes the following topics:

- the national magnitude of the driver assault and homicide problem,
- alternative protection measures,
- case study information for Baltimore,
- statistical analysis for Baltimore taxi driver assaults for 1991 - 1997,
- benefit-cost analysis for the city-wide mandate for shields in Baltimore,
- applications for geographical information systems analysis.

Copies of the report are available from DeAnna Flinchum (flinchum@utk.edu) and from John Stone (stone@eos.ncsu.edu). We hope that the results of this research will continue to prove valuable to the taxi community.

The authors express their appreciation to the taxi professionals and others who made this work possible:

Steven Richards, Director of STC, University of Tennessee-Knoxville
DeAnna Flinchum, Assistant Director of STC, University of Tennessee-Knoxville
Dan Setzer, Manager, Royal Cab Association, Baltimore, Maryland
Management Information System Department, Baltimore Police Department
Maryland Public Service Commission

Special notes of appreciation go to Gorman Gilbert and Terry Smythe. For many years they have championed the contributions of taxis to public transportation, and they have communicated the special concerns of the taxi industry.

Abstract

This report addresses the controversy concerning the effectiveness of taxi shields (partitions) by using case study and statistical analysis. It answers questions concerning whether or not shields reduce assaults on taxi drivers and by inference taxi driver homicides. Following a city-wide shield mandate in 1996 case study data show that for the City of Baltimore the percentage of shielded taxis rose from about 50% in 1995 to 100% in 1996 for the 1,151 licensed Baltimore cabs. Comparing the 12-month periods before and after the mandate the data shows that assaults on taxi drivers decreased 56%. Data also show that between the years 1991 when only 5% of the cabs had shields and 1997 when all did, assaults decreased 88%. Unless accounted for analytically, confounding factors such as annual changes in city crime rates, robberies, unemployment, and drug use could also contribute to the assault reduction. However, by comparing the assault rate for a shielded taxi association in 1991 with another similar, but unshielded, taxi association eliminates time varying confounding factors. This analysis shows that an unshielded Baltimore taxi driver in 1991 was five times more likely to experience assaults. Using linear regression to account for the time variation of the factors over the period 1991 to 1997, results indicate that reduced driver assaults correlated most highly with percentage taxis shielded. Average case study data, statistical tests and linear regressions show that assaults on taxi drivers are significantly related to shield installation. A related economic analysis yielded a 17-to-1 benefit-to-cost ratio of estimated savings from reduced injuries versus the costs of citywide shield installation. Thus, this study supports the use of shields in Baltimore for the case study licensed taxis. The results also argue for shields elsewhere, such as Baltimore County, and for other cities with conditions similar to those in Baltimore.

Key words: taxi cabs, occupational safety, taxi regulation, public transportation.

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1. Introduction

Problem Statement

In 1995 the taxi driver homicide rate in the United States was 32 homicides per 100,000 workers (71 total homicides) making it the deadliest U.S. profession (Knestaut 1997, 55). The 1996 rate was 23 homicides per 100,000 workers (71 total homicides) showing a 12-month decline of about 30% in the taxi driver homicide rate (CFOI 1997). The 1997 rate was 31 homicides per 100,000 workers (76 total homicides) showing a 12 month increase of about 35% (CFOI 1998). From January to mid-June 1999 there have been 24 total taxi driver homicides in the United States (Smythe 1999). Thus, the national plight of taxi drivers continues.

One of the most intuitively effective, yet controversial countermeasures is a taxi partition or shield. Many taxi drivers, company officials, and transportation professionals believe that taxi shields can counteract the typical taxi assault from behind the driver. Yet, others downplay shields questioning their effectiveness. Drivers are still vulnerable to attacks if the partition is open, if assaults are from side or front windows, or if the driver is out of the vehicle. Anecdotal evidence suggests that while shields may protect drivers they pose a risk for injuries to passengers during taxi accidents (Newman 1998). Furthermore, drivers complain that shields lock the front seat in one position, reduce airflow, driver and passenger comfort, conversation, and tips.

In light of these concerns, taxi professionals ask, “Do shields protect drivers? If so, are shields worth the cost and inconvenience?”

Scope and Objectives

The ultimate goal of this research is to protect drivers. Besides installing shields protection strategies include changing the work environment by controlling service areas and service hours (most assaults occur at night in isolated areas); installing caller ID, surveillance cameras and cashless fare systems. Training drivers in “street smarts” and conflict resolution, better emergency response, local gun control, and responsible media coverage are other strategies (Stone, et al. 1996, 7-8). This study, however, focuses on shields.

In this study it will be assumed that taxi drivers by the very nature of their work must deal with cash and work alone, often at night. Such immutable environmental factors clearly place them at risk, like convenience store and service station operators. Otherwise, changing environmental factors would prove a productive strategy.

Replacing the cash transactions with credit cards is attractive because robbery is the most frequent motive for assaults (Castillo and Jenkins 1994, 130). The cost of the electronic infrastructure to support credit cards, the radio processing delay, and transaction cost, as well as the traditional cash basis of the industry, have limited credit card implementation to relatively few “premium” taxi services. Furthermore, the limited installation of taxi credit card systems, surveillance cameras, and other related equipment like automatic vehicle locators and computer dispatch with caller identification, means that there are no before-and-after data on the effectiveness of these technologies in protecting drivers.

Fortunately the City of Baltimore has kept taxi driver assault data since 1991. Thus, with the advent of a citywide mandate for shields in regulated taxis in August 1996, there is a before-and-after database to analyze shield effectiveness. With the Baltimore data this analysis can focus on the vehicle and how it may be successfully "hardened" (or not) with a shield.

In this study the frequency of assaults will be analyzed. Assaults in this analysis will mean events where drivers are robbed with the use of force. In some cases where drivers are involved in a robbery they are injured, in other cases they are not injured but were mainly threatened with the use of deadly force. Both of these scenarios will be classified as assaults in this analysis. In other instances drivers are assaulted without any intention of being robbed. These cases are usually classified as "assaults" by law enforcement agencies. They will also be included in this analysis. Crimes involving larceny and burglary of items in the vehicle will not be included due to these crimes by definition not involving any use of force on the driver.

This study will not examine how "in telligent transportation systems" like caller id, automatic call back, video cameras, automatic vehicle location and cashless fare media may help. It will not explore how the driver may be trained to avoid life-threatening situations. And it will not analyze the effects of service area characteristics, controversial assailant "profiling", and local police tactics like New York City's Compstat anti-crime program (Dodenhoff 1996) that may protect taxi drivers.

This study makes one implicit assumption. Due to the limited availability of taxi driver homicide data before-and-after an intervention policy has been implemented, it is assumed that assaults on taxi drivers are a proxy measure of taxi driver homicides. Thus, if shields reduce assaults then it can be assumed that they will reduce homicides.

The specific objectives of the analysis are:

> To develop a descriptive case study of taxi driver assaults before-and-after Baltimore officials required taxi shields in August 1996.
> To statistically test the effectiveness of taxi shields while accounting for city-wide economic, population, crime and other confounding factors.
> To estimate the approximate cost of city-wide shield installation and the expected savings from reduced assaults.
> To use geographic information systems methods to identify city sub-areas where assaults occur.

Literature Review

Professionals typically judge the effectiveness of security intervention methods through one of three approaches: expert assessment, behavioral science analysis, and before-and-after evaluation.

Expert assessment relies on professional opinion and intuitive reasoning. Taxi drivers and owners use anecdotal information to justify (or not) the selection of a security device. For example, taxi owners and operators "know" that the most commonly encountered assault scenario has a backseat passenger attacking a driver (Stone, et al. 1996, 5). Thus, they reason that a shield or partition between the front and back seats will reduce driver injuries and deaths. The opinions of taxi professionals are always valuable, and the need for "real life data from the streets" goes without question. However, the validity of opinions are debatable because expert assessment evaluations may be biased for or against a countermeasure and cannot systematically account for a cause and effect relationship. There is no consensus on shields in the taxi profession according to many postings on the Taxi-l discussion group, the international "voice" of the taxi industry (http://www.taxi-l.org/index.html).

Social scientists and criminologists use case study and statistical analysis to evaluate protection measures and scenario avoidance strategies based on critical environmental factors such as dealing in cash and working alone at night (NIOSH 1996; Knestaut 1997; Castillo, et al. 1994). Identifying critical scenario precursors to a crime is necessary to help thwart it, and follow-up evaluation is necessary to determine whether the proposed avoidance or intervention measures are effective. No such systematic follow-up studies have occurred for the taxi industry.

A before-and-after evaluation relies on area-wide driver assault and homicide data that are collected before and after the implementation of a countermeasure. The effectiveness of the countermeasure is typically found by calculating improvements in assault and fatality rates. The before-and-after study may simply compare trends over time (Setzer 1997) or employ traditional statistical tests for significance and correlation. During such an evaluation the analyst must guard against historical effects, maturation, regression artifacts, and data instability that threaten the validity of any conclusion that is made regarding a countermeasure's effectiveness. Up to this time, however, there have been no before and after statistical tests or benefit-cost analyses involving taxi driver protective measures because of the paucity of data.

Methodology

For the first time reasonable before-and-after data are available from a city that has deployed a countermeasure, namely, shields. The City of Baltimore has carefully tracked monthly taxi driver assaults for a decade. During these years the taxi service area remained unchanged, and the number of regulated taxicabs remained constant at 1,151. In August 1996 the City required all its regulated taxis to have shields. Over 400 unregulated "service sedans" were not covered. Thus, the City of Baltimore is an attractive case study with important statistical control factors.

The methodology of this analysis (Figure 1.1) follows five steps. First, it develops a narrative discussion of the Baltimore case study, and it presents quantitative data relating to taxi assault trends and the effect of a 100% shield law. Second, it uses a statistical analysis including a Z-test, odds ratio (OR), and a regression analysis to explore the significance of shields contributing to the observed reduced assaults on taxi drivers. The linear regression addresses the correlation of the following citywide factors: unemployment, robberies, drug arrests, the percentage of city taxis with shields before the shield law, and population. Third, this analysis estimates the annualized installation costs of shields and compares the cost estimate to the expected and observed savings from reductions in robberies and injuries. Fourth, it applies geographic information systems (GIS) methods to identify city sub-areas where driver assaults occur. Fifth, the analysis presents conclusions for the city of Baltimore, and it suggests implications for other cities concerned with taxi shield policies.

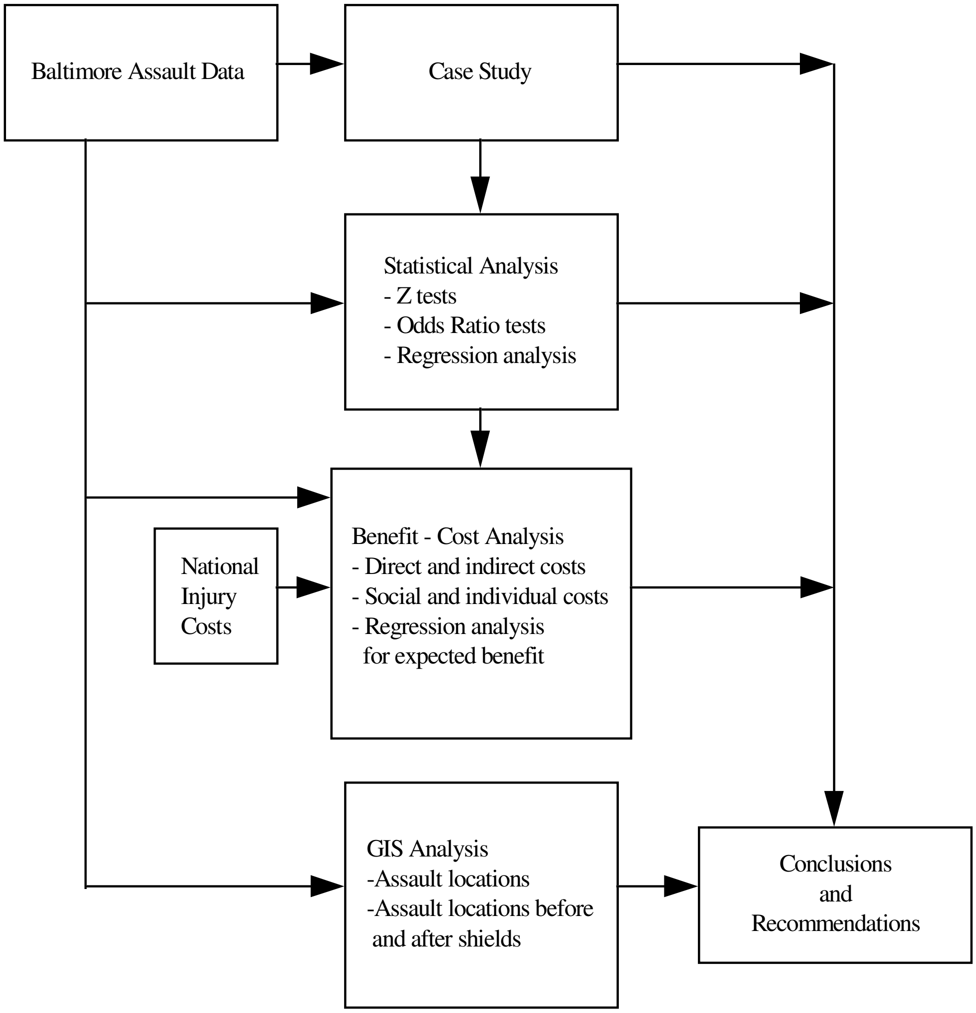


Figure 1.1. Overall Methodology

2. Case Study

Study Area

Baltimore is a port city with a diverse urban and suburban population. It prides itself on its downtown amenities including Harbor Place, the National Aquarium, and Camden Yards baseball stadium. Between 1991 and 1997 the population of Baltimore declined 10% to 657,000. Unemployment and crime have also declined in recent years (Table 2.1 and Figure 2.1). The City covers an area of approximately 85 square miles. The boundaries of the city have not changed for the past 10 years.

Taxi Fleet and Crime Data

The Maryland Public Service Commission (PSC) regulates the taxi industry in Baltimore. From 1946 to 1998 the PSC allowed only 1,151 taxis to serve the City. In late 1998 the PSC authorized 25 additional regulated Baltimore County taxis, which are not part of this study. The taxicabs belong to six taxi associations (Table 2.2).

Associations have different fleet sizes and business practices including contract transportation services and street hail service. A taxi association is a group of one or more companies that either share the same computer support or the same dispatching and administrative support. On August 1, 1996 a PSC ordinance requiring that all city taxi associations be shielded went into effect. In 1995 before the shields Baltimore drivers endured 131 assaults. In 1997 after the shields there were 25 assaults (Table 2.3).

Table 2.1 Census and Crime Data

Year	Crime Index[a]	Population[b]	Percent Unemployment[c]
1991	85,068	732,493	10.1
1992	90,114	725,479	11
1993	91,920	715,807	10.5
1994	92,783	703,090	8.8
1995	94,855	689,432	8.4
1996	85,982	675,401	8.2
1997	77,595[d]	657,256	9.3

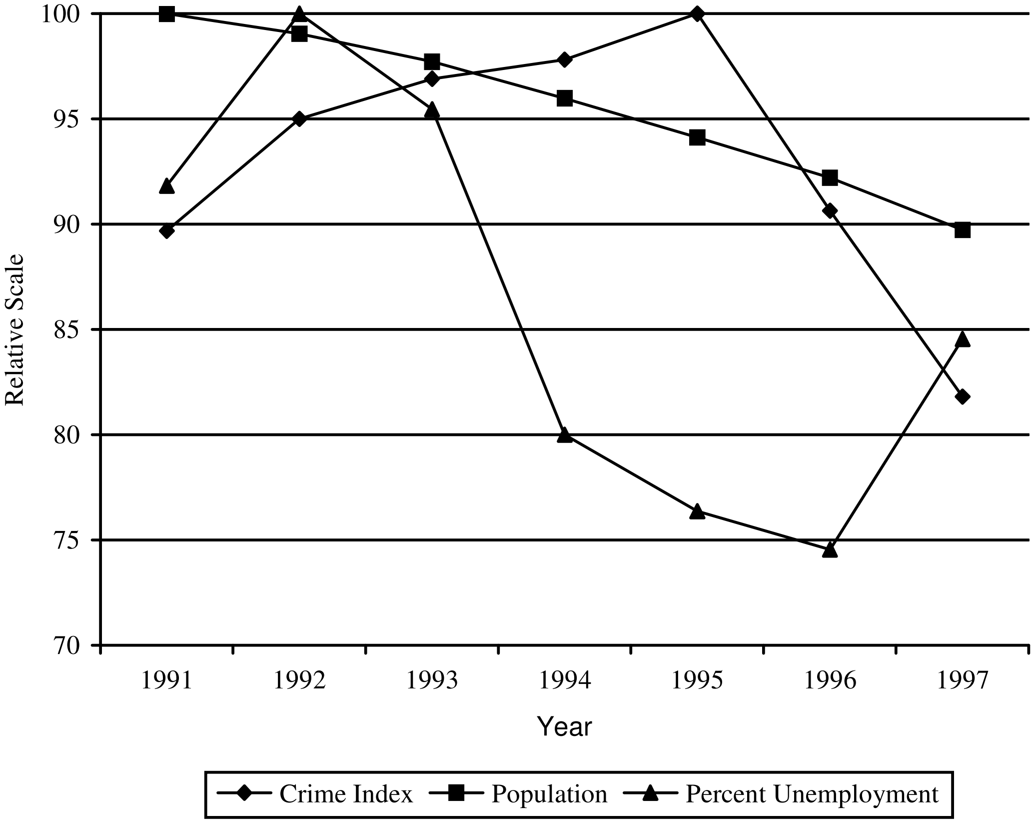
[a] Crime in the US: FBI Uniform Crime Reports, 1991-1997.

[b] US Census, Population Estimates Program.

[c] Bureau of Labor Statistics. "Local Area Unemployment Statistics - Baltimore City" http://www.bls.gov (16 July 1998).

[d] Uniform Crime Reports, 1997 Preliminary Annual Release

Figure 2.1 Baltimore Trends



* To convert Figure values divide each relative scale value by 100 and then multiply it by the largest annual value in the particular series (Table 2.1). For example, for the year 1994 population has a relative scale value of 95.986. Multiplying this value by the largest value for the population series of 732,493, and then dividing by 100 will give the actual population value of 703,090.

Table 2.2 Baltimore Taxi Associations 1991 to 1997

Name	Fleet Size	Type of Service*	% shields 1991*	Year Shielded* (80 % or more)
Yellow Cab	595	Contract, Street Hails	0	1996
Royal Cab	340	Contract, Street Hails	0	1996
Diamond	144	Street Hails	0	1996
Arrow	55	Street Hails	100	1991
ABC	15	Street Hails	0	1996
Independent	2	Street Hails	0	1996
Total	1151	-	-	-

* Dan Setzer, Royal Taxi Association

The number of regulated taxis with shields rose from approximately 5% in 1991 to a monthly average of about 50% in 1995, and to 100% in 1997 (Table 2.3 and Figure 2.2). Each of the six taxi associations experiences different assault rates for any given year. All factors being equal, it should follow that the more taxis an association has, the more assaults it will experience. However, Figure 2.3 does not reflect this relationship between assaults and fleet size.

For example, while the Yellow taxi association maintained the largest taxi fleet, it did not have the highest frequency of assaults in 1991. One possible explanation is that it is a premium service that included more contract business and fewer street fares than the other associations. In contrast Royal taxi association had a higher 1991 assault rate, while serving a more diverse clientele who hail the cab driver from the street or call Royal dispatch for service. Neither Yellow nor Royal was completely shielded in 1991. As a final example, Arrow which is one of the smaller taxi associations and which was shielded in 1991, had a very low assault rate even though it serves street hails in "rough" neighborhoods.

In addition to the City and County taxis that are regulated by the Maryland Public Service Commission (PSC), unregulated sedans also serve the City of Baltimore. The sedans are limited to trips reserved in advance by telephone. The PSC does not allow sedans to take street hails though anecdotal reports say they do to some extent. There are approximately 280 Baltimore County cabs and there are about 400 service sedans in the City of Baltimore (Setzer 1997).

The PSC allows Baltimore City taxis to carry customers originating in the City to other City locations or to areas outside of the City. City taxis cannot take a customer from one of the surrounding counties to Baltimore City. Similarly, County cabs carry County passengers to County or City destinations; yet they cannot pick up fares within the City. The PSC does not require regulated County cabs and unregulated "service sedans" to have shields. Because City taxis only carry City passengers, because the number of City taxis remained constant during the 1991-1997 study period, and because the City of Baltimore taxi service area (city limits) remained unchanged, the statistical analysis can treat Baltimore as a "controlled experiment" for shields. Realistically not all Baltimore contributions to the analysis can be controlled (Table 2.3), but the Baltimore case is adequate for this study.

Furthermore, the regulations of the Maryland PSC and the fact that the Baltimore Police Department keeps monthly records for taxi crimes that occur within the City help to insure that reported taxi assaults involve only customers originating from the City. The implicit assumption we draw from this is that the factors that need to be considered in the regression analysis are only those descriptive factors involving the City of Baltimore that are potentially related to taxi driver assaults, not County factors. These Baltimore factors include the unemployment rate for the City of Baltimore, City crime levels, and the number of City drug arrests, which are potential predictors of criminal activity like driver assaults (Laidlaw 1991; Verhaeghe 1991; Butterfield 1997). The reasoning is that the endogenous conditions in the City and not those in the surrounding counties are what affect the rate of taxi driver assaults. Changes in law enforcement policies and tactics are not included because the percentage change in the total number of full time officers was only 3.9% from 1992 to 1996 (Reaves and Goldberg 1998, 6). Further, during the study period Baltimore did not have an explicit response policy for taxi driver emergencies or a "Compstat" response to neighborhood crime flare -ups (Dodenhoff 1996).

Summary Observations

The foregoing information on taxi associations, PSC regulations, and crime serves as a backdrop for taxi driver assaults. The primary observation for the case study is that monthly data from the Baltimore Police Department showed a 56% reduction in taxi assaults in the 12 months following the shield ordinance in August 1996 compared to the previous 12 months. Figure 2.2 shows, however, that there was a downward trend in assaults even before shields were introduced in August 1996. Similar trends are evident in some of the other possible reasons for the decrease in taxi driver assaults. Figures 2.1 and 2.2 show decreases in population, unemployment, drug arrests, and total robberies. Overall, the Baltimore crime index improved during the same time period taxi driver assaults decreased. Thus, additional analysis is necessary to see if there was a significant statistical reduction in driver assaults as a primary result of shields and to determine what other factors may have also contributed to the reduction.

Table 2.3 Taxi Shield and Baltimore Crime Data

Year	Regulated City Taxis[a]	Taxi Assaults[b]	Shield Implementation Percentage[c]	Total Robberies[b]	Total Drug Arrests[b]	Taxi Driver Homicides[d]
1991	1,151	203	5	11,239	15,485	2
1992	1,151	209	5	12,738	16,735	1
1993	1,151	224	7	12,926	19,359	1
1994	1,151	153	7	11,871	19,011	0
1995	1,151	131	50	10,953	22,642	0
1996	1,151	91	100	10,934	16,603	0
1997	1,151	25	100	9,278	16,934	2

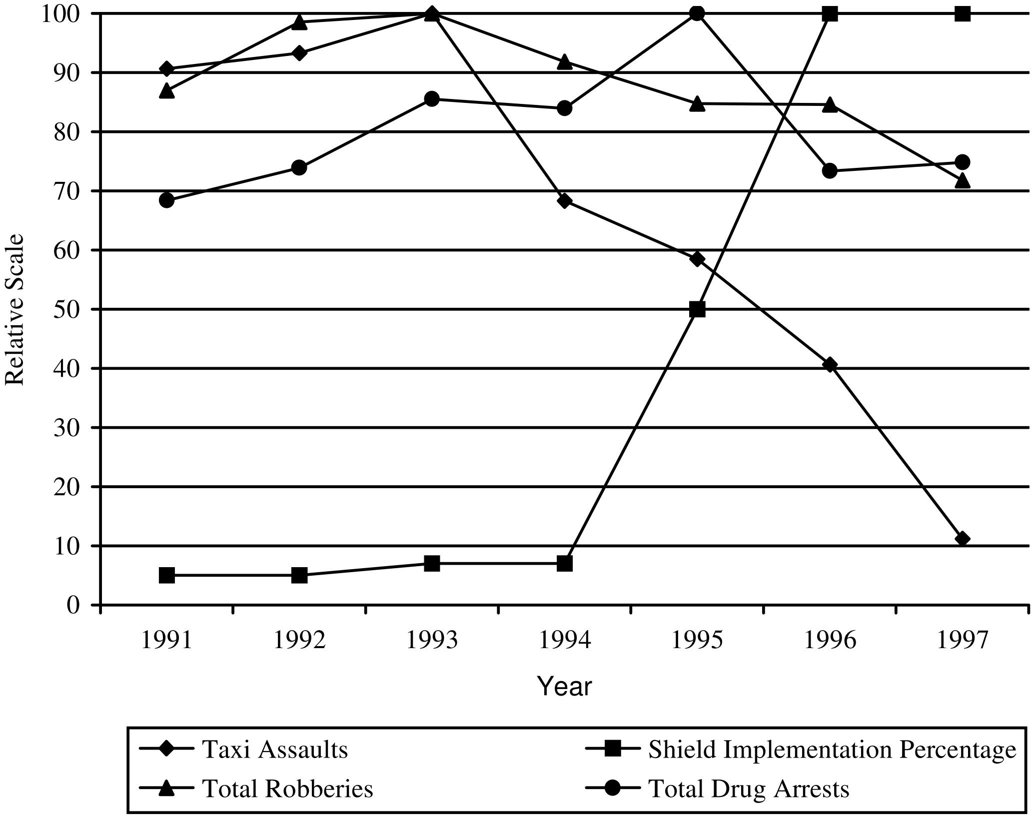
[a] Maryland Public Service Commission. Not published data.

[b] Baltimore Police Department.

[c] Daniel Setzer, Royal Taxi in Baltimore. Estimated average percentage of taxis that were shielded for the year.

[d] Baltimore Sun

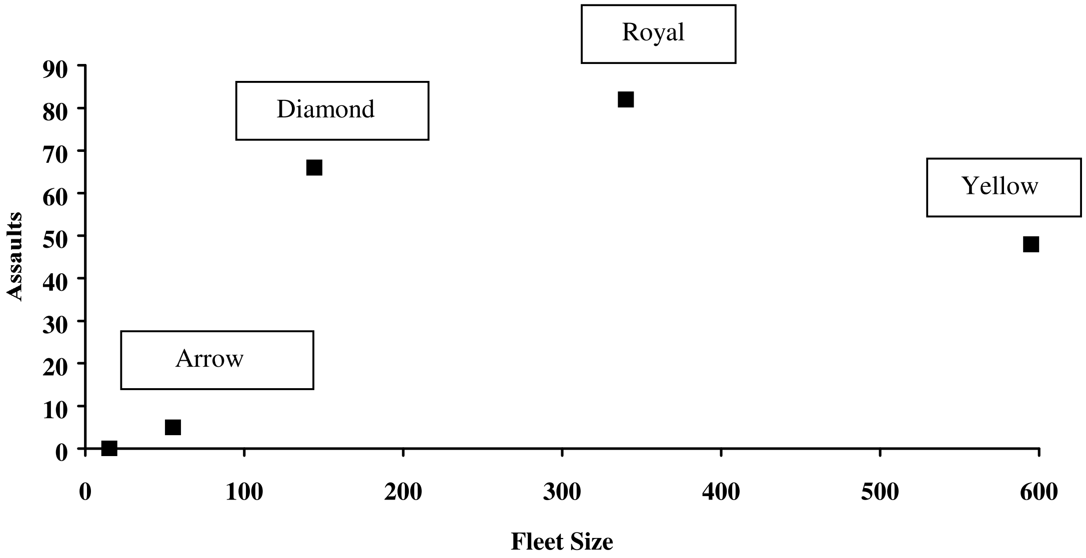
Figure 2.2 Shielded Crime Trends



Note: To convert data points divide each relative scale value by 100 and then multiply it by the largest annual value in the particular series. For example, for the year 1994 total robberies has a relative scale value of 91.838. Multiplying this value by the largest value for the total robberies series of 12,926, and then dividing by 100 will give the original total robberies value of 11,871 for 1994 in Table 2.3.

Figure 2.3 1991 Assaults Versus Fleet Size

Note: The leftmost data point represents both ABC Taxi (15 taxis, 0 assaults) and Independent Tax (2 taxis, 2 assaults).



3. Statistical Analysis

Database

The City of Baltimore Police Department provided data on taxi driver assaults, the number of City robberies of all types and drug arrests (Table 2.3). The data included police reports for each complaint involving a taxi driver, the driver's name, taxi association, location, time, date, type of injury, etc. (Appendix A). Articles from the Baltimore Sun provided additional information regarding the six taxi driver fatalities that occurred in the study time period (Appendix A). The data provided by the Baltimore Police Department does not include driver fatalities if the driver died at the crime scene. Dan Setzer, past president of the Royal Taxi Association, provided estimates of the percent shielding in Baltimore for 1991 to 1997 as well as the victim identifications of city taxi companies as reported in the Baltimore Police database. Census data, unemployment data and crime index information came from national data sources (Table 2.1).

Dependent Variable

The first step in the statistical analysis requires the selection of a dependent variable (Figure 3.1). The choice of a dependent variable is critical to determining if shields are effective. The obvious choice for dependent variable in this study is the number of annual taxi assaults. Note, however, that assaults on drivers can occur while they are inside or outside of their taxis. The Baltimore Police reports do not discriminate between inside or outside assaults, though 70% or more assaults occur inside the vehicle (Stone, et al. 1996, 5). Thus, the analysis may somewhat underestimate the effectiveness of shields when they are used properly, i.e., the driver stays in the taxi and keeps the shield closed.

Other choices of dependent variable could be the number of assaults that occur in the taxi, through unprotected side windows, or through open shields. The ability to categorize assaults according to the type of assault scenario, whether the assault occurred in the taxi or outside of the taxi for example or those due to improper shield use and installation can only be determined through detailed examination of police reports and personal interviews. Such in-depth categorization is beyond the scope of this project. Thus, the annual number of assaults on regulated Baltimore City taxi drivers, as determined from police database files and articles from the Baltimore Sun, will be the measure of shield effectiveness used in the statistical analyses in this report.

Contemporaneous Control Study

The second step in the statistical analysis (Figure 3.1) compares the total number of assaults of two taxi companies with and without shields during the same controlled time period. Instead of just calculating a percentage change between the annual assault rates before and after shields, as in the case study, the statistical analysis uses a Z-test to determine if a significant change has occurred associated with the use of shields. In 1991 contemporaneous data is available on two similar companies. Arrow had shields and Diamond did not (Table 2.2). In 1991, and even today, Arrow and Diamond provide similar street hail and dispatch service with little contract service.

The contemporaneous 1991 control study implements the use of the Z-test for proportions (Council, et al. 1980, 74). Arrow, the shielded taxi association, is the test subject, and Diamond, the unshielded company, is the control subject. Differences in fleet size between the two associations are adjusted by the calculation of taxi-days (Table 3.1). For each association the total number of taxi-days is determined for the year. The total number of taxi-days is equal to the fleet size times the number of days in the year. For each association the number of assault taxi-days is found by counting the number of assaults for the year for each association. Since assaults are relatively infrequent, it is reasonable to assume that a taxi driver will endure at most one assault in a taxi-day. If an assault happens and is reported to the police, we assume the driver stops work that day because he or she is either incapacitated or seeks hospital treatment. However, anecdotal evidence suggests that some minor assaults, even robberies, go unreported because the driver cannot afford to take time off. Thus, the analysis may somewhat underestimate the effectiveness of shields.

The Z-test for proportions relies on a normal distribution and compares the proportion of taxi-days involving assaults to the total number of taxi-days for each of the companies. Usually taxi driver assaults are statistically rare events and the occurrence of assaults is considered a Poisson process. Here, however, there are a sufficient number of assaults to assume that a normal distribution exists (Appendix B). The underlying distribution can be considered binomial due to the fact that in a taxi-day the observation of seeing an assault can be either a "success" or a "failure". The large size of the taxi -day samples (52,560 and 20,075) help guarantee that the Z-test for proportions is being properly used. Table 3.2 shows the results of the 1991 Z-test. Appendix B provides details of the Z-test.

As can be seen in Table 3.2, the null hypothesis is that the likelihood of an assault occurring for a shielded company (Arrow) is the same for an unshielded company (Diamond). For this particular contemporaneous study, the null hypothesis is rejected thereby crediting shields for the difference in assault rates between two similar companies during a similar time period.

In addition to the use of the Z-test for proportions another statistical technique is the Odds Ratio test (Sahai and Khurshid 1996). This type of test is also used for controlled case studies, where one of two similar test subjects is treated and the other is not. This test is applied to the same two companies used for the Z-test for proportions test for the year 1991 again with the assumption that Arrow and Diamond are similar. The Odds Ratio Test is different from the Z-test for proportions in that its results are in terms of how many times more likely the unshielded Diamond driver is of being assaulted compared to the shielded Arrow driver. The results of the Odds Ratio test are significant (Table 3.3), and they suggest that in 1991 the occurrence of assaults on drivers in an unshielded Diamond cab was five times greater than in a shielded Arrow cab. Appendix B more fully describes the test.

The major assumption of the contemporaneous study for this analysis is that both the shielded taxi association (Arrow) and the unshielded taxi association (Diamond) are similar in terms of service. This analysis assumes that there only exists a dichotomous risk factor (shielded vs. not shielded) and that no other factors that may affect the assault rates of the two associations are present to any significant extent. In order to test this assumption the statistical analysis implements a Z-test for proportions using assault data from 1997, when both associations were completely shielded. Under such conditions it could be assumed that both associations should incur the same assault rates. The results of the 1997 Z-test (Table 3.4) show that there is not a significant difference between the two taxi associations assault rates, and thus suggests that the assumptions of the 1991 contemporaneous study are correct. Appendix B more fully describes this check of the 1991 contemporaneous tests.

Figure 3.1 Case Study and Statistical Analysis

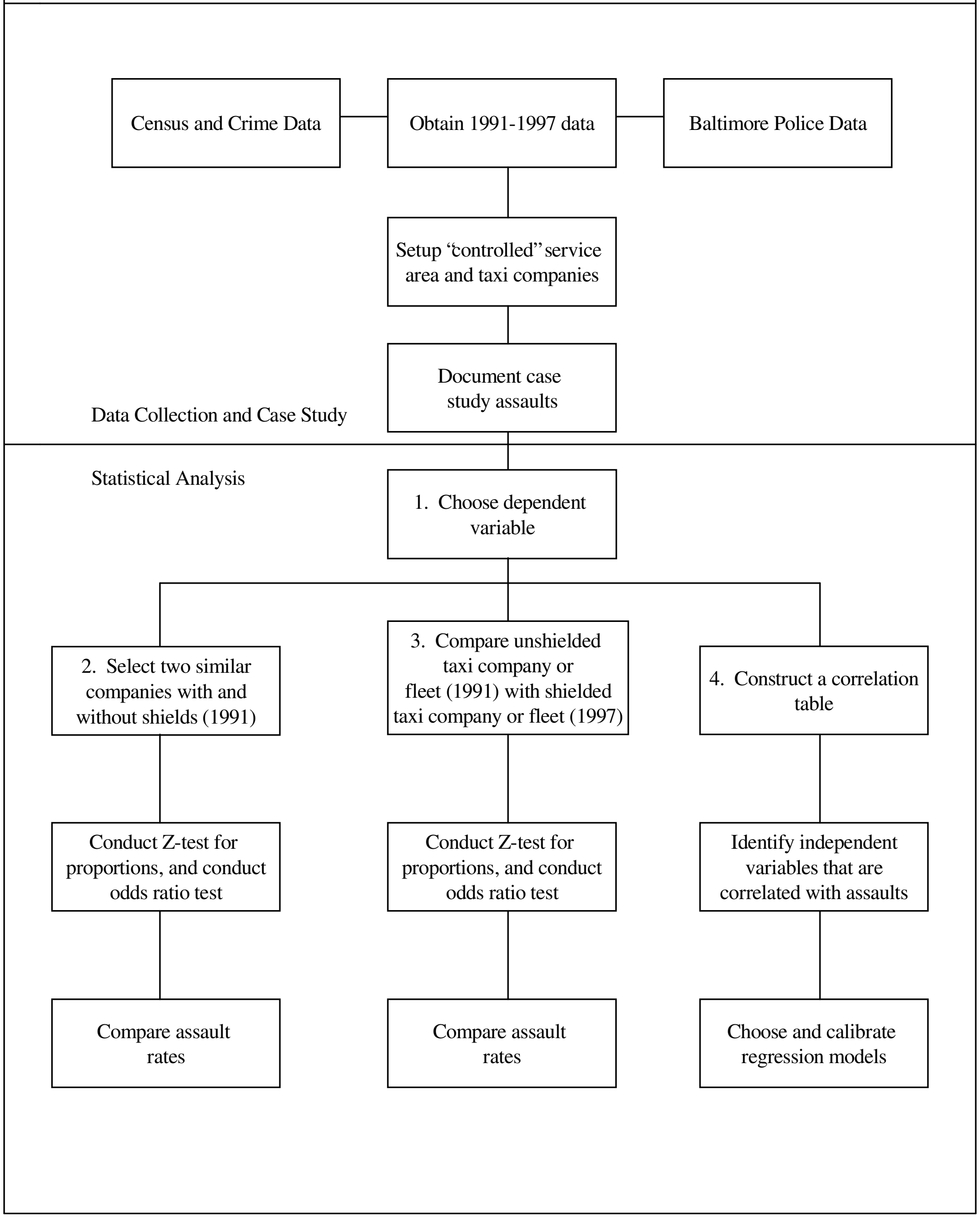


Table 3.1 1991 Before-After Comparison of Two Companies

Taxi Association	Fleet Size	Shields?	1991 Assaults	Assault Frequency Per Day	Taxi Days	Assaults Per Taxi Day

Arrow	55	Yes	5	0.0137	20,075	0.00024907
Diamond	144	No	68	0.1863	52,560	0.00129376

Table 3.2 1991 Z-Test Results for Two Companies

Treatment Versus Control Group

H_o: $P_{control} = P_{treatment}$ H_a: $P_{control} \neq P_{treatment}$ d.f. $\cong \infty$

$Z_{critical} = 1.96$ (two-sided) $\alpha = 0.05$ $Z_o = 3.97$

Table 3.3 1991 Odds Ratio Test Results for Two Companies

Odds Ratio value 5.199 95% Confidence Bounds 2.306 to 11.726

Chi-Square value 15.791 d.f. 1 Prob > = 0.001

Table 3.4 1997 Z-Test Results for Two Companies

Treatment Versus Control Group

H_o: $P_{control} = P_{treatment}$ H_a: $P_{control} \neq P_{treatment}$ d.f. $\cong \infty$

$Z_{critical} = 1.96$ (two-sided) $\alpha = 0.05$ $Z_o = 0.38$

Non-Contemporaneous Before/After Analysis

The third step of the statistical analysis is a non-contemporaneous before/after analysis (Figure 3.1). A suitable period, say 12 to 18 months, before and after the August 1, 1996 mandate could be statistically evaluated. However, there is uncertainty in percentage shield installation before the mandates. The original date for compliance was May 1, 1996, but the PSC extended it to August 1, 1996 at the request of a small group of taxi drivers. During the three-month grace period the percentage of shields was nearly 100%. Furthermore, in anticipation of the original May 1, 1996 mandate for 100% shields, many owners had installed shields. Also, anecdotal information from discussions with taxi owners suggests that 50% or more of the taxis had been shielded since 1995. The transition rates from about 5% in 1991 to 50% in 1995 and from 50% in 1995 to 100% in 1996 are unknown. Thus, this report will avoid analysis of before and after data during the shield installation transition periods. Rather the ‘before mandate” will be defined as 1991 when the entire city fleet had about 5% shields versus 1997 when the entire city fleet had 100% shields.

The comparison of the nearly unshielded 1991 citywide fleet to the 100% 1997 shielded citywide fleet again used the Z-test and Odds Ratio test (Figure 3.1; Tables 3.5-3.7 and Appendix B). Citywide taxi-days and the proportion of taxi-days involving assaults for both 1991 and 1997 are again determined (Table 3.5). Proceeding with a Z-test for proportions, the hypothesis that the assault rates for 1991 and 1997 are the same can be tested. If the hypothesis is true, there is no significant change in assault rates before and after the shield ordinance in 1996. Otherwise, shields can be assumed to make a difference.

Table 3.5 Citywide 1991/1997 Before-After Comparisons

Year	Percent Shields	Number of Taxis	Annual Number of Assaults	Assault Frequency Per Day	Taxi Days	Assaults Per Taxi Day
1991	5%	1,151	203	0.556	420,115	4.83×10^{-4}
1997	100%	1,151	25	0.068	420,115	5.95×10^{-5}

Between 1991 and 1997 the annual assaults dropped from 203 assaults per year to 25 assaults per year (Table 3.5). The results of the Z-test (Table 3.6) show that the 88% drop in assaults between 1991 and 1997 is statistically significant. The results of the Odds Ratio test show that a driver in 1991 was over 8 times more likely to be involved in an assault than a driver in 1997 (Table 3.7). While shields do appear to be the reason, another explanation for the drop could involve "maturation" effects and not the installation of shields. For example, there could have been another trend, such as the decreasing trend in all crimes that has been seen this decade or decreased drug use (arrests). Such effects can be addressed by regression analysis as presented in the next discussion.

Table 3.6 Citywide 1991/1997 Z-test Results

H_o: $P_{1991} = P_{1997}$ H_a: $P_{1991} \neq P_{1997}$ d.f. $\cong \infty$

$Z_{critical} = 1.96$ (two-sided) $\alpha = 0.05$ $Z_o = 11.79$

Table 3.7 Citywide 1991/1997 Odds Ratio Test Results

Odds Ratio value 8.123 95% Confidence Bounds

5.735 to 11.507

Chi-Square value 139.003 d.f. 1 Prob > = 0.001

Linear Regression Analysis

Whether or not the 88% drop in driver assaults between 1991 and 1997 resulted solely from shields, can be determined to some degree by a regression analysis. It is the fourth step in the analysis (Figure 3.1). Since the Z-test indicates that there is a significant change in the number of assaults, then the statistical analysis can proceed to the linear regression in order to determine the relationship between assault rate and other factors. The study of this relationship will involve five independent variables: unemployment rate for Baltimore, total robberies in Baltimore, total drug arrests in Baltimore, Baltimore population, and the percentage of the 1,151 City taxis that are shielded (Tables 2.1 and 2.3 and Appendix C).

Before performing the linear regression the analysis must determine which of the five variables to use in order to insure that there is no "double counting". The cross correlation table (Table 3.8) relates the linear correlation of each variable with the other variables. The top most value in each cell in Table 3.8 is the Pearson correlation value, while the bottom cell value is the probability of getting a numerically larger value of the given Pearson correlation value. Significantly low probabilities allow for the rejection of the null hypothesis that the Pearson correlation value is equal to zero. Consequently, the first row of Table 3.8 shows the independent variables with the most significant Pearson correlation values to the dependent variable annual total assaults. Thus, population, percent taxis shielded, and annual robberies have the highest correlation (0.05 level). Annual unemployment rate shows modest correlation and annual drug arrests show nearly no correlation with annual total assaults. Thus, unemployment rate and drug arrests will be dropped from the analysis.

Subsequent rows indicate whether the dependent variables are correlated among themselves. The second, third, and fifth rows show that percentage shielded taxis, population and robberies are relatively correlated. While percentage shielded taxis shows a high correlation with both annual robberies and population for the years 1991 to 1997, it would more than likely show very little if any correlation in the years previous and subsequent to the study period. In the years before the study period the percentage shielding remained constant at 5%, and in the years after the study the percentage shielding will remain constant at 100%. Total robberies and population would more than likely not be constant during these periods. This suggests that percentage shielding is independent of annual population and robberies, thereby allowing percentage shielding to be used with either of these two factors in the same linear regression model to explain assaults. In order to avoid "double counting" annual robberies and annual population can not be used in the same linear regression model. The choice of final regression model is made below by regressing total assaults against all of the variables both individually and in selected pairs.

In the next step of the regression analysis a series of linear regressions are performed with the variables that are highly correlated with the annual assault rate (Table 3.9). These regressions are carried out individually for percent taxis shielded, total robberies, and annual population versus annual assaults. Regressions are also carried out with allowable combinations of the above variables (Table 3.9). The linear regression with the highest R-square value should be the primary model for explaining changes in annual taxi assault data if the coefficient signs and magnitudes are plausible.

The results of the linear regression (Table 3.9 and Appendix C) show that the model involving population and percentage taxi shielding as the explanatory variables, has the highest R-square value. While the R-square value for this model is high, a lack of fit statistic shows that this two variable model is not any more significant over a single variable model involving only annual population (Appendix B). The same is also found to be true with the two variable model involving percentage shielding and annual robberies (Appendix B). With this model there is no significant improvement with the introduction of annual robberies. Because of this, the set of five regression models to choose from is reduced to three single variable models involving population, robberies, and shields.

Table 3.8 Cross-Correlation of Independent Variables

	Annual Total Assaults	Percent Taxis Shielded	Annual Population	Annual Unemployment Rate	Annual Robberies	Annual Drug Arrests
Annual	1.00000[a]	-0.91766	0.96081	0.67096	0.90330	0.02350
Total Assaults	0.0000[b]	0.0036	0.0006	0.0989	0.0053	0.9601
Percent Taxis	-0.91766	1.00000	-0.92749	-0.63733	-0.80170	-0.07180
Shielded	0.0036	0.0	0.0026	0.1236	0.0301	0.8784
Annual	0.96081	-0.92749	1.00000	0.69342	0.78868	-0.14619
Population	0.0006	0.0026	0.0	0.0840	0.0351	0.7545
Annual	0.67096	-0.63733	0.69342	1.00000	0.57326	-0.36847
Unempl. Rate	0.0989	0.1236	0.0840	0.0	0.1785	0.4160
Annual	0.90330	-0.80170	0.78868	0.57326	1.00000	0.11511
Robberies	0.0053	0.0301	0.0351	0.1785	0.0	0.8059
Annual	0.02350	-0.07180	-0.14619	-0.36847	0.11511	1.00000
Drug Arrests	0.9601	0.8784	0.7545	0.4160	0.8059	0.0

[a] Pearson correlation value
[b] Probability of getting a numerically larger value of the Pearson correlation value

Table 3.9 Regression Models

	R-square
Annual Assaults = -1285.255493 - 0.307030 * Percent Taxis Shielded + 0.002065 * Population	0.9282
Annual Assaults = -1621.382312 + 0.002528 * Population	0.9232
Annual Assaults = -128.352575 - 0.876242 * Percent Taxis Shielded + 0.027203 * Total Annual Robberies	0.9207
Annual Assaults = 206.119123 - 1.484795 * Percent Taxis Shielded	0.8421
Annual Assaults = -450.143927 + 0.052378 * Total Annual Robberies	0.8160
Annual Assaults = -275.329001 + 44.695370 * Percent Unemployment	0.4502
Annual Assaults = 135.353980 + 0.000698 * Total Annual Drug Arrests	0.0006

Taking into consideration the R-square values of the three single variable linear regression models, the best model is found to involve annual population (Table 3.9 and Appendix C). It seems reasonable that as population decreases (as it did for Baltimore) that assaults would decrease. Yet population, per se, is not a “cause” for assaults. In order to test this rationale total annual assaults for the Arrow taxi association were regressed against annual population at the 0.05 significance level (Appendix C). The Arrow taxi association (55 taxis) was completely shielded for the years 1991 to 1997. By regressing the annual assaults for a 100% shielded taxi association against population, the statistical analysis can control for the effects of shielding and focus on annual population effects. As can be seen by the results in Table 3.10 and in Appendix C the model is not statistically significant in explaining the variability of annual taxi assaults for the completely shielded taxi association. Therefore, it is reasonable for this statistical analysis to exclude population from further consideration. The same test was also carried out with Arrow’s annual assaults regressed against annual robberies (Appendix C). Similar results were found for this test (Table 3.10) and annual robberies will be dropped from further consideration.

After excluding the single variable models that involved annual population and annual robberies, the remaining model involves only percentage taxis shielded. The best equation to predict assaults on regulated taxi drivers in Baltimore is thus:

Annual Assaults = 206.119123 - 1.484795 * Percent Taxis Shielded (R-square = 0.84)

As a variable percentage shielding intuitively relates to assaults. Contrary to popular theories (Butterfield 1997; Laidlaw 1991; Verhaeghe 1991), drug arrests and unemployment, at least in Baltimore, are not highly correlated to the total annual frequency of driver assaults (Table 3.9 and Appendix C).

Table 3.10 Regression Model for Annual Assaults: Arrow Taxi Association

	R-square
Annual Arrow Assaults = -26.027763 + 0.000042906 * Population	0.3772
Annual Arrow Assaults = -3.662220 + 0.000671 * Total Annual Robberies	0.1900

Summary Findings

The statistical analysis as outlined in Figure 3.1 carried out contemporaneous and non-contemporaneous analyses as well as a regression analysis. The comparison of the assault rate for the shielded taxi association versus the unshielded association showed that the assault rate of the shielded taxi association was significantly lower than for the unshielded taxi association. Drivers for the unshielded taxi association were also found to be five times more likely to be assaulted compared to their colleagues who worked for a shielded taxi company.

In addition to the contemporaneous analysis, the statistical analysis compared assault rates for the entire city fleet at two different stages of shield implementation. The assault rate for 1991 when the entire city fleet had an average shielding implementation percentage of 5% (only Arrow) was found to be significantly higher than the assault rate in 1997 when 100% shielding was present. The Odds Ratio test as carried out for the years 1991 and 1997 showed that drivers in 1991 were over 8 times more likely to be assaulted than drivers in 1997.

While shields are initially credited for the significant improvements in assaults, other effects could be responsible for the decline. The statistical analysis addressed some possible effects and found that the most reasonable and significant explanatory variable was percentage shielding. The models involving annual population with percentage shielding, and percentage shielding with annual robberies were excluded from consideration due to the results of a lack of fit test. As a result only three linear regression models were considered involving annual population, percentage shielding, and annual robberies. Population was found to have a significant effect but was not further considered by the statistical analysis due to there not being a fundamental causal relation between annual population and annual assaults. Population was also excluded due to the findings of a regression of annual assaults for a 100% shielded taxi association on annual population. The model that regressed annual assaults against annual robberies was found to have a lower R-square value than percent shielding. Therefore, the statistical analysis determined that annual percentage shielding explained the most variability of annual taxi assaults.

4. Benefit-Cost Analysis

Problem Statement

Thus far it has been determined that shields in Baltimore taxis significantly reduce assaults on taxi drivers. Furthermore, shields are the primary reason for reduced assaults compared to other explanations such as reduced crime, drug arrests, and population. Next it will be determined whether or not shields are economically cost beneficial as compared to not installing shields. The cost-benefit analysis will be limited to the following:

- costs of purchasing and installing shields
- financial losses from robberies
- costs associated with assault injury and trauma
- costs involving fatalities

Indirect costs related to low driver morale, productivity, passenger complaints and driver absenteeism will not be fully addressed in this analysis. Benefits are defined as the expected difference between costs with and without shields. Hard to quantify benefits such as improved driver recruitment and retention are not included in this analysis.

Costs

The discussion of costs, as conducted for this analysis, involves three primary categories that are widely acknowledged: direct, indirect, and social costs (Ashford 1976, 328). This analysis is limited in its ability to capture all costs. Breaking down all of the relevant costs according to cost category can help illustrate why this is so.

Direct costs primarily involve balance sheet information. The cost of purchasing and installing shields are included in this category. For this analysis shield installation costs are determined from vendors' estimates. Of all of the three cost categories, direct costs are the easiest to acquire.

Indirect costs include robbery losses, which are available from driver complaints filed with the Baltimore Police. Other indirect costs are not so easily quantifiable. For example, indirect costs such as reduced worker morale and productivity are difficult to determine. Time lost from work, another major indirect cost, may be quantifiable, but Baltimore data are unavailable since taxi drivers are independent contractors who set their own work hours.

The highest costs involved with shields fall under the third cost category, social costs. Primarily, these costs involve trauma expenses, productivity losses, and quality of life losses that are ultimately borne by hospitals and individuals. National average injury cost information (Miller and Cohen 1997, 329-341; Waller, et al. 1994, 921-926) and Baltimore Police injury severity data will be substituted for actual Baltimore driver injury and trauma costs due to the difficulty in obtaining actual injury cost information.

Benefits

This analysis defines benefits as the expected reductions in costs due to shields. The relevant costs are the social and indirect costs. For this analysis an expected reduction in costs represents the difference in expected costs for a given percentage shield scenario less the expected costs associated with an average annual shielding percentage of seven percent. This baseline percentage is used as the base level because it is assumed that from the years 1991 to 1994 those taxi associations that were shielded did so not in anticipation of the 1996 shield ordinance but rather from general safety concerns. Because of this, the 7% shielding in 1994 will be considered as the status quo baseline that would have existed without the shield ordinance. After 1994 the additional shielding of city taxis will be assumed to be the result of the shield ordinance.

Benefit-Cost Ratio

The benefit-cost ratio (B/C) is a measure of the financial feasibility and attractiveness of a given shield scenario. The numerator or benefit contains the difference between the expected indirect and social costs for any two shielding scenarios, and the denominator contains shield costs and installation expenses associated with a given scenario. In equation form for a given year the benefit-cost ratio is expressed as:

$$\frac{B}{C} = \frac{\exp ected \cos ts_{shieldscenario} - \exp ected \cos ts_{baselineshieldingscenario}}{shieldinstallation \cos ts}$$

Methodology

The benefit-cost ratio involves the ratio of expected shielding benefits to expected costs associated with shielding. Due to the annual format of data, expected benefits and costs will be determined annually. As a result, a benefit cost ratio will be determined for selected years and will represent the expected benefits and costs associated with these particular years. Expected annual costs simply involve actual amortized shield installation costs. Expected benefits are the annualized indirect and social costs at 7% shield installation less the annualized indirect and social costs associated with shielding within the range of greater than 7% and less than or equal to 100%. A benefit in this analysis involves a reduction in indirect and social costs that is associated with a given shielding scenario. Such expected benefits can be determined through the use of linear regression techniques. In such a linear model the actual indirect and social costs are regressed on the estimated annual percentage of taxis that are shielded for each particular year. The resulting model can then be used to determine the expected losses for a given shielding scenario. Expected benefits are in turn determined by comparison of a particular shielding scenario outcome with the outcome of the do nothing approach (7% shielding). Any difference between the two estimates is considered an expected benefit.

Expected Costs

In order to determine the expected costs for the years 1991 to 1997, certain steps should be carried out. The first step involves determining the number of shields that are installed during the years 1991 to 1997. Using annual average shield installation percentages from Table 2.3, the fixed number of 1151 taxis, and the assumption that shields are replaced after 10 years, the estimated number of new shields installed for every year *n* can be estimated using the equation:

$$ShieldsInstalled_n = \frac{\left(EstimatedShield\%_n - EstimatedShield\%_{n-1}\right) * 1151}{100}$$

The shield installation percentages given in Table 2.3 represent the average shielding for each year. In order to determine the number of new shields installed for a given year, the percentage of taxis shielded at the end of each of the years needs to be determined. For this analysis it is assumed that the given annual average shielding percentages, with the exception of 1995, represent the percentage of taxis shielded at the end of each respective year (Table 4.1). This is possible due to the assumed constant nature of shield installation for the years 1991 to 1994, and 1996 to 1997. For 1995 it will be assumed that at the end of the year the percentage of taxis with shields will be 100%. It will also be assumed that those shields that were in place before 1991 (5% of total fleet) were fully depreciated by 1990, thereby requiring replacement in 1991. Using the end of year percentage shielding estimates in Table 4.1 and the above formula the number of new shields installed for each year can be established (Table 4.1).

Table 4.1 Estimated End of Year Percentage of Taxis Shielded / Number and Cost of Shields Installed - 1991 to 1997

	1991	1992	1993	1994	1995	1996	1997
Average annual percentage shielding	5	5	7	7	50	100	100
Percentage of taxis shielded by year's end	5	5	7	7	100	100	100
New shields installed	58	0	23	0	1,070	0	0
Shield cost	2,320	2,320	3,240	3,240	46,040	46,040	46,040

After the number of newly installed shields are determined for each year, the total amortized costs of shield installation can be determined for each year from 1991 to 1997 (Table 4.1). The cost of installing a shield is assumed to be $400 (Mause 1996). Each shield is amortized over a ten year period (Manitoba Taxi Board 1990, 18). Maintenance costs are not considered because they are relatively low. The resulting shield cost for each year *n* is estimated using the following equation:

$$ShieldCost_n = \sum_{1991}^{n} \left[\frac{1}{10} \left(NewShieldsInstalled_n * \$400 \right) \right]$$

$$n = 1991, 1992 \ldots 1997$$

After the total shield costs for each year have been determined, the annual costs incurred for injuries, fatalities, and robbery losses can then be estimated. The expected reduction in these injury and robbery costs attributable to shields is the expected benefit. The total injury costs given in Table 4.2 represent losses due to injuries involving shootings, stab wounds, and beatings. This cost category also includes losses associated with fatalities. The final total losses category includes both robbery losses as well as total injury costs. All estimated injury costs are determined using Baltimore Police MIS data as well as national injury cost figures.

The total injury costs associated with driver injuries and fatalities for each year were determined using average injury cost data as given in Miller and Cohen's 1997 report on gunshot and stab wound costs in the United States (Table 4.3). The average cost of beatings as given by Waller, Skelly, and Davis was also used to determine the total injury costs (Table 4.3).

Miller and Cohen categorize gunshot and stab wounds into three different categories according to injury severity; fatal, hospitalization, and emergency department only (Table 4.3). Associated with each level of injury severity in Table 4.3 is a particular average cost that includes medical costs, productivity losses, and lost quality of life. Beatings in this analysis are only assumed to involve the injury severity level of emergency department only.

Table 4.2 Estimated Injury and Robbery Losses

	1991	1992	1993	1994	1995	1996	1997
Gunshot wound(s)	3	2	3	3	0	0	0
Stabbing	6	4	10	6	8	4	0
Beating	10	4	21	23	23	9	7
No injury	182	198	189	121	100	78	16
Fatalities	2	1	1	0	0	0	2
Total	203	209	224	153	131	91	25
Total injury costs (in 12/93 dollars; includes costs associated with fatalities)	6,637,200	3,421,680	4,039,820	942,660	605,660	301,780	5,602,940
Robbery losses	31,059	31,977	34,272	23,409	20,043	13,923	3,825
Total losses (with fatalities)	6,668,259	3,453,657	4,074,092	966,069	625,703	315,703	5,606,765
Total losses (with out fatalities)	968,259	653,657	1,274,092	966,069	625,703	315,703	6,765

Source: Baltimore Police Department

Table 4.3 National Average Total Costs by Injury Type and Severity (12/93 dollars)

Injury type\Injury severity	Fatal	Hospitalization	Emergency department only
Gunshot wound	2,800,000	249,000	73,000
Stabbing	2,900,000	202,000	32,000
Beating	---	---	420

Sources: Miller and Cohen 1997, 335; Waller, et al. 1994, 924

While the frequency of gunshot wounds, stab wounds, and beatings for City of Baltimore taxi drivers are known for each year as determined from the Baltimore MIS (Table 4.2), the injury severity for each assault is not known. Because of the limitations in the data this analysis uses national injury severity occurrence rates (Table 4.4) to establish injury severity frequencies for gunshot wounds and stabbings (Miller and Cohen 1997, 336). Fatalities are established using newspaper reports, and do not require the use of national injury severity occurrence rates. Multiplying the frequencies of stabbings and gunshot wounds in Table 4.2 against their respective national average injury severity occurrence rates in Table 4.4 yields an estimate of the distribution of injuries according to degree of severity for each injury type category (Tables 4.5 and 4.6).

Table 4.4 National Injury Severity Frequency by Injury Type, 1992

Injury type\Injury severity	Hospitalization	Emergency department only	Total
Gunshot wound	46,800	34,500	81,300
Stabbing	34,800	110,100	144,900

Source: Miller and Cohen 1997, 336

Table 4.5 Estimated Injury Severity Frequency for Stabbings, 1991 to 1997

	1991	1992	1993	1994	1995	1996	1997
Fatality	1	0	0	0	0	0	0
Hospitalization	1	1	2	1	2	1	0
Emergency department only	5	3	8	5	6	3	0

Sources: Baltimore Sun, Baltimore Police Department, Miller and Cohen 1997, 336

Table 4.6 Estimated Injury Severity Frequency for Gunshot Wounds, 1991 to 1997

	1991	1992	1993	1994	1995	1996	1997
Fatality	1	1	1	0	0	0	2
Hospitalization	2	1	2	2	0	0	0
Emergency department only	1	1	1	1	0	0	0

Sources: Baltimore Sun, Baltimore Police Department, Miller and Cohen 1997, 336

The injury severity frequencies in Tables 4.5 and 4.6 multiplied by the national average costs in Table 4.3 give an estimate of the total injury costs for each year as listed in Table 4.2. As can be seen in Table 4.7 the majority of the injury costs for the years 1991 to 1993 and 1997 are dominated by costs associated with fatalities. According to Miller and Cohen's findings the high cost associated with fatalities is largely due to the the losses incurred due to pain, suffering, and lost quality of life.

The total robbery losses given in Table 4.2 are determined by multiplying the average robbery loss by the total number of assaults for a particular year. It is assumed for this analysis that every assault involved some kind of robbery loss. The average robbery loss was found by determining the mean amount of cash stolen, based on nine complaints filed by Royal Cab association drivers. It is assumed that the complaints for the most part are randomly selected, and are representative of all driver losses in the City of Baltimore. The average amount of cash stolen was determined to be $153.

After the determination of the annual total losses in Table 4.2 the next step is to establish a statistical model that can be used to determine the expected losses. Expected losses are required in order to determine the benefit-cost ratio as discussed in Section 4.4. A statistical model would also assist with the consideration of different annual shielding scenarios.

The statistical model used in this analysis involves the use of linear regression techniques. The formation of an expected costs model follows the same procedure that was carried out in Chapter 3. This analysis will also consider the same explanatory variables that were considered in Chapter 3 (Tables 2.1 and 2.3).

Table 4.7 Estimated Injury Costs According to Injury Severity, 1991 to 1997 (12/93 dollars)

	1991	1992	1993	1994	1995	1996	1997
Gunshot wounds							
Fatality	2,800,000	2,800,000	2,800,000	0	0	0	5,600,000
Hospitalization	498,000	249,000	498,000	498,000	0	0	0
Emergency department only	73,000	73,000	73,000	73,000	0	0	0
Stabbings							
Fatality	2,900,000	0	0	0	0	0	0
Hospitalization	202,000	202,000	404,000	202,000	404,000	202,000	0
Emergency department only	160,000	96,000	256,000	160,000	192,000	96,000	0

Beatings	4,200	1,680	8,820	9,660	9,660	3,780	2,940

The first step taken in the formation of a linear regression model involves determining whether or not the explanatory variables are correlated with the dependent variable, which in this case involves the total annual losses listed in Table 4.2. This analysis used the Pearson correlation statistic as a measure of linear correlation. The Pearson correlation values for this analysis are listed in Table 4.8.

Table 4.8 Pearson Correlation Values for Total Annual Losses

	Average % shielding	Population	Unemployment	Robberies	Drug Arrests
Total annual losses	-0.20715[a]	0.29097	0.66702	-0.13411	-0.55625
(includes fatalities)	0.6558[b]	0.5267	0.1017	0.7744	0.1947
Total annual losses	-0.87878	0.81093	0.42882	0.80516	0.21964
(no fatalities)	0.0092	0.0269	0.3371	0.0289	0.6361

[a] Pearson correlation value

[b] Probability of getting a numerically larger value of the Pearson correlation value

None of the explanatory variables are able to satisfy the 0.05 significance level assumed in Chapter 3 (Table 4.8). A possible explanation for this could involve the inclusion of costs associated with fatalities. As can be seen in Table 4.7 the total losses for some years are dominated by costs associated with fatalities. The occurrence of fatalities during the study period varies anywhere from two to no fatalities per year. If it is assumed that the occurrence of fatalities is constant at two per year, then it can be further assumed that the occurrence of fatalities is independent of any explanatory factors. While this is not necessarily a valid conclusion it is a necessary step for this benefit-cost analysis.

With the subtraction of costs associated with fatalities more explanatory variables become highly correlated with the dependent variable (Table 4.8). As can be seen in Table 4.8 percentage shielding, population, and annual robberies are highly correlated with the adjusted total annual losses. Based on the results of Table 3.8 population and annual robberies are also highly correlated. As a result the allowable combinations of explanatory variables for inclusion in the cost model are: percentage shielding, population, annual robberies, percentage shielding / population, and percentage shielding / annual robberies.

With the identification of explanatory variables suitable for the linear regression model, the next step is to regress the adjusted annual losses against all the five variable combinations mentioned earlier. The results of these regressions are presented in Table 4.9.

Table 4.9 Regression Cost Models

	R-square
Total Losses = -177359 - 6292.055179 * Percent Taxis Shielded + 97.271488 * Total Annual Robberies	0.8006
Total Losses = 1353272 - 8732.381895 * Percent Taxis Shielded - 0.463361 * Population	0.7724
Total Losses = 1018645 - 8468.120693 * Percent Taxis Shielded	0.7723
Total Losses = -8206652 + 12.708174 * Population	0.6576
Total Losses = -2488056 + 278.045026 * Total Annual Robberies	0.6483

As can be seen in Table 4.9 the cost models with two explanatory variables do not offer significant improvements over the single variable model involving percentage shielding. As a result this analysis will use the linear regression model that included percentage shielding. This model was also found to have residuals that were normally distributed, thereby satisfying one of the requirements necessary for the use of a linear regression model.

Expected Benefits

The expected benefits due to shield installation are based upon demonstrated reductions in robbery losses and injury costs. In order to determine the expected benefits for each year this analysis established an estimated relationship between shield installation and total costs by regressing total annual losses (without fatalities) against percentage shields installed (Table 4.9). The resulting equation evaluated at two different shielding scenarios determines the expected reduction in losses (benefits) from shields. The first scenario involves implementation of shields according to percentages presented in Table 2.3. The second scenario involves maintaining the 1994 (do-nothing) shield installation percentage of 7% for the years 1995 through 1997. This analysis focuses on the years 1995 through 1997 for both scenarios because most shielding occurred during those years. Table 4.10 displays the expected losses for the years 1995 through 1997 for both shielding scenarios. The expected benefits are the differences in total cost for each year under the different shielding scenarios.

Dividing the expected benefit for each year by the shield cost for each year yields the benefit-to-cost ratio. The highest ratio occurs in the two years with the highest shield implementation. These results indicate that shields generate benefits in excess of their costs.

Table 4.10 Expected benefits and costs for 1995 to 1997

	1995	1996	1997
Shielding scenario (ordinance)	50%	100%	100%
Expected losses (ordinance)	$595,239	$171,833	$171,833
Shielding scenario (no ordinance)	7%	7%	7%
Expected losses (no ordinance)	$959,368	$959,368	$959,368
Expected benefit (ordinance vs. no ordinance	$364,129	$787,535	$787,535
Shield cost (ordinance)	$46,040	$46,040	$46,040
Benefit-to-cost ratio	7.909	17.105	17.105

Summary Results

As can be seen with the given set of assumptions, the benefits of shields are greater than the costs associated with shield installation (Table 4.10) by a ratio of 17 to 1. These benefits are even realized in 1995 when the estimated average shielding percentage for the entire fleet was 50%.

The benefit-to-cost ratios for the years 1996 and 1997 have even more significant improvements over 1995.

5. Geographic Information System Analysis

Introduction

The statistical and regression analyses used citywide data, however, crime tends to concentrate in sub-area neighborhoods. Thus, attempts to better explain taxi assaults might be found by taking into consideration differences in taxi service areas rather than averaging data across an entire city. For example, taxi assaults may be concentrated in "poor" neighborhoods, or assaults may occur in major activity centers or the suburbs. Conceivably the characteristics of neighborhoods or taxi service areas are better predictors of taxi assaults than citywide characteristics.

To explain this idea we used geographic information systems (GIS) analysis to plot taxi assaults for 1991 in the City of Baltimore (Figure 5.1). Clustering of assault events in Figure 5.2 is observed in relation to census block groups. Each plotted point represents the address given in the police report for that assault. Each block group has associated with it unique GIS-based socioeconomic values that can be used with statistical techniques to possibly explain the frequency at which taxi assaults occur there. Due to the borders of the census block groups being streets, some plotted assaults fall on more than one census block group border making it difficult to uniquely assign assaults to individual block groups. This problem can be somewhat resolved by using census tracts as the backdrop for the occurrence of assaults. Merging of similar socioeconomic census block groups can also be done to deal with assaults falling on more than one census block group border. The details of such an analysis will be left for future research.

In addition to the development of models explaining the relationship between assaults and particular explanatory variables, a GIS analysis can also be used as a preventive measure. Figure 5.1 shows taxi assaults plotted on the City of Baltimore street network for 1991. Figure 5.3 shows a small area within Figure 5.1. The area as illustrated in Figure 5.3 can pinpoint specific street addresses where assaults may have taken place, as well as the type of injury that previous drivers experienced there. Such figures as Figures 5.1 and 5.3 could be updated and distributed on a daily or weekly basis to alert taxi drivers to areas to be careful in. They can also be the basis of New York City "Compstat" police tactic s to prevent crime.

Figure 5.1 1991 Assaults on Taxi Drivers by Baltimore Street Location

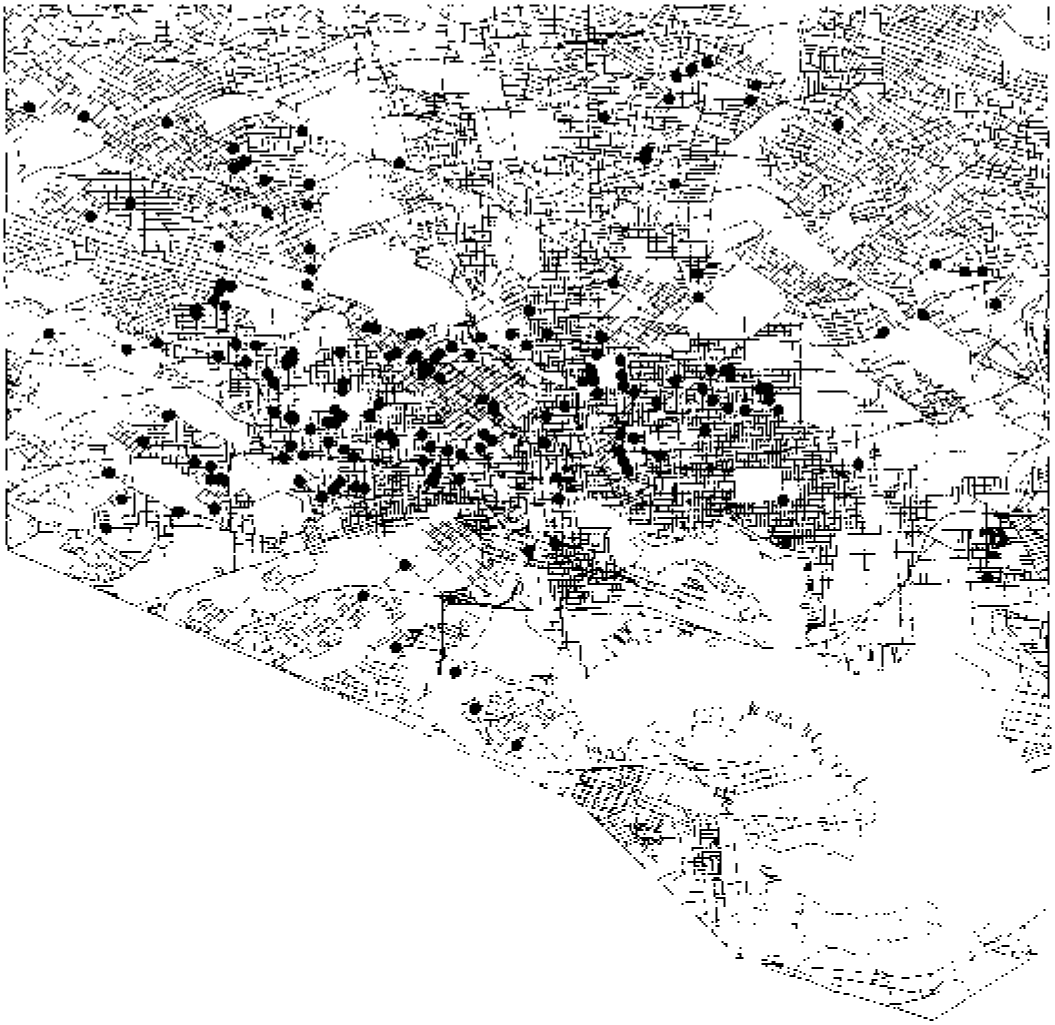


Figure 5.2 1991 Assaults on Taxi Drivers by Baltimore Census Block Groups

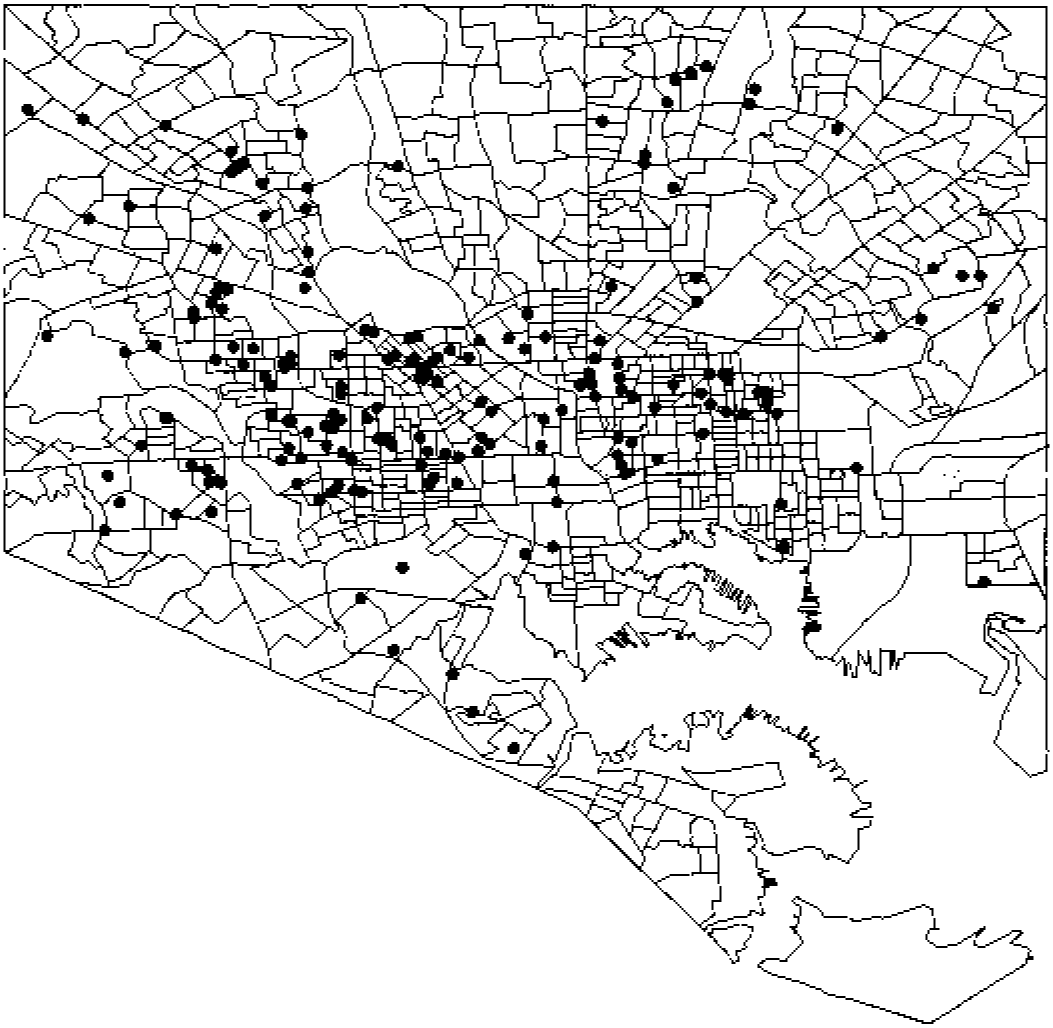
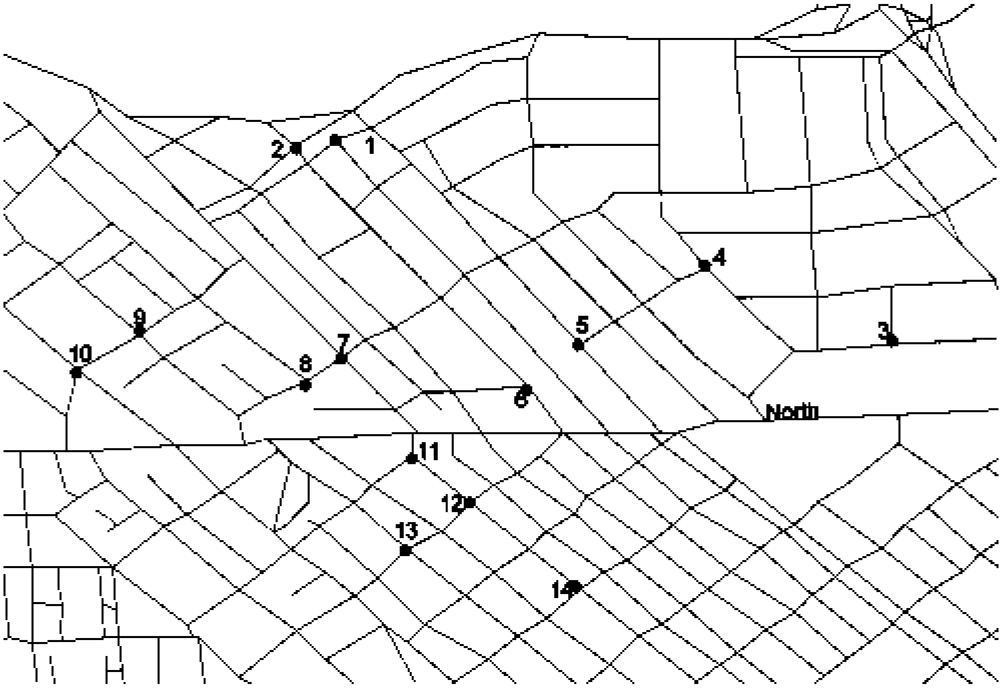


Figure 5.3 Example Avoidance Area



Incident #	Company	Date	Address	Injury
1	Royal	91/02/24	1000 Hendler Lane	None
2	Diamond	91/05/05	1100 Cloverdale Road	None
3	Citizen	91/07/27	800 Lennox Street	None
4	Diamond	91/09/05	2200 Brookfield Avenue	None
5	Royal	91/08/21	2300 Eutaw Place	None
6	Diamond	91/08/31	1100 Clendenin Street	None
7	Diamond	91/04/06	1400 Whitelock Street	None
8	Delli	91/09/03	1500 Whitelock Street	None
9	Diamond	91/08/18	2500 Woodbrook Avenue	None
10	Royal	91/06/01	2600 Pennsylania Avenue	None
11	Royal	91/02/17	500 Baker Street	None
12	Arrow	91/04/16	500 Gold Street	None
13	Diamond	91/07/23	2200 Division Street	None
14	Diamond	91/03/15	500 Presstman Street	None

6. Conclusions, Recommendations, and Future Work

Problem Review

The analysis of shields regarding the impact they have on taxi driver assaults is both a criminological and an epidemiological analysis. The installation of shields has the potential to lower the frequency of taxi driver assaults. In addition, other confounding factors can affect the frequency of taxi driver assaults. In order to determine the extent to which shields are effective in improving taxi driver safety, we conducted both a statistical and a benefit-cost analysis.

The goal of the statistical analysis is to establish the impact shields have on assaults while taking into consideration other factors. A statistical analysis for an analysis such as ours should involve two major steps. First, it should be established whether or not shielded taxi fleets have significantly fewer assaults than unshielded taxi fleets. This can be carried out with retrospectively designed experiments that use statistical tests such as the Z-Test for proportions and Odds Ratio. The second step of the statistical analysis deals with the limitations of the first step through the establishment of a linear regression model. The establishment of a linear regression model allows for the consideration of confounding factors. The linear regression model in this analysis considered such factors as annual drug arrests, annual robberies, percentage shielding, population, and unemployment.

After demonstrating the relationship between shielding and taxi driver assaults, the analysis should conduct a benefit-cost analysis. Such an analysis is conditional on the demonstrated effectiveness of shields. The goal of the benefit-cost analysis is to determine whether the benefits of shields are greater than the costs of shield installation. Annual losses such as robbery losses and costs incurred for injuries and fatalities are considered in the establishment of a cost model. These total annual losses are regressed against percentage shielding and other explanatory variables for each of the years in a study period. The resulting linear regression cost model can then be used to determine the expected benefits for every year of the study period. If percentage shielding is included as an explanatory variable in the resulting cost model, different shielding scenarios can then be compared in order to establish the expected benefits associated with shield installation.

This analysis carried out a statistical analysis as well as a benefit-cost analysis in order to determine the effectiveness of shields. Some of the problems incurred included lack of data and the inability of the linear regression models to explain a significant portion of the variability in the given data. These were dealt with through the establishment of assumptions, and in the case of the benefit-cost analysis not including fatality costs in the cost model. The primary difficulty in this analysis involved lack of data with regards to annual shield installation percentages, proper shield use, and the issue of underreporting of assaults. Other lack of data are associated with driver injury and robbery losses. Passenger injury loss data are also hard to come by.

Conclusions

The use of statistical tests and linear regression techniques helped to establish the effectiveness of shields in the reduction of taxi driver assault frequencies. The benefit-cost analysis also helped justify the costs of shield installation. Specifically, our analysis established the following conclusions with regards to shields and the frequency of assaults:

- The results of the before/after studies show that shields reduce assaults. Excluding the population effect, shield implementation from 1991 to 1997 explains reductions in total citywide assaults. This conclusion is also supported through further analysis. The contemporaneous control study suggests that the difference in taxi assault rates as witnessed between two taxi associations in Baltimore is more than likely due to the installation of shields. According to the results of this analysis a driver of an unshielded taxi is more likely of being assaulted than a driver of a shielded taxi.

- The percentage of taxis that are shielded is the single most important factor that determines how many assaults occur in a year. The results of the linear regression show that shield installation is the most significant reason explaining the reduction in the number of annual taxi assaults. While population also showed a strong relationship with the frequency of assaults, further analysis suggested that such a relationship might in fact not exist as witnessed by the occurrence of assaults for a taxi association that was completely shielded.

- The benefits of shields that come in the form of reduced injury and robbery losses substantially exceed the costs of shield installation as shown by the benefit-cost analysis.

- The final cost model excluded the losses associated with the six homicides that occurred during the study time period.

Recommendations

It is recommended that shields be implemented in cities with population and crime characteristics similar to those experienced in Baltimore before shields were fully implemented.

In addition to the factors associated with citywide conditions, factors such as taxi fleet size and types of taxi services can have an impact on the frequency of taxi driver assaults. Therefore, it is recommended that shields be mandated in cities that have annual assault frequencies, fleet size, and taxi services similar to Baltimore’s. The combined requirements of similar citywide factors and of a similar taxi fleet are necessary due to the following argument. In the case of Baltimore, the injury costs were the most significant component of the annually incurred losses. For a city with very few violent assaults, the installation of shields may not be justified by the reduction in injury costs if there are no homicides. For smaller fleets the amortized shield costs may not be justified with the expected benefits associated with shield installation.

Future Work

At the current time, cities that experience assaults on taxi drivers have several options to choose from in their attempt to curb future assaults. This analysis addressed one proposed solution that has been available for several decades. While further work is required in the study of safety shield effectiveness, other potential solutions also deserve attention. Methods such as the use of credit cards for fares, automatic vehicle location (AVL), in-vehicle cameras and silent alarms are solutions that have the potential to protect drivers. Yet none separate the driver from physical threat.

In addition to this analysis of taxi partition effectiveness, further research needs to address the possibility of taxi assaults being centered in city sub-areas. Some police departments in the United States are currently using geographic information systems (GIS) to pinpoint areas for focused police response. Such a procedure could be applied to the taxi industry. The effectiveness of such an implementation should be addressed in future work.

Ultimately any research into the feasibility of proposed countermeasures requires good data. The data used for this research allowed for the use of statistical techniques in establishing shield effectiveness. The data made available by the Baltimore Police Department MIS has even more potential. Each record in the taxi driver assault database has associated with it a complaint form. Complaints provide more information regarding each individual assault. This in tandem with field data collection efforts could yield even further insight into the dynamics of shields and assaults on drivers.

With the ongoing data collection efforts of the Baltimore Police Department and other law enforcement agencies in the United States, data for future analysis will become more available. This is important due to the fact that this study only covered a time period from 1991 to 1997 when all crimes were in decline. If in the future, crime trends should go up the data made available by the Baltimore Police department will assist in determining the effectiveness of shields during times of more intense criminal activity.

Data collected from other cities will allow for establishing the impact city fleet size and citywide factors have on assault frequency. In addition, additional data collection efforts can further establish the impact that different taxi services have on assault frequencies.

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Appendix A

Summary News Articles and Baltimore Police Data

Baltimore Sun Fatality News Articles Summaries

"Cabbie's Slaying Among Three Reported in Baltimore" Saturday, June 1, 1991, News Section.
Summary: Stabbed to death, 11 inch butcher knife, robbery apparent motive. Occurred on Thursday night, May 30, 1991. Victim age 56. Diamond Cab #31. 2900 block of West Belvedere Avenue near Pimlico. Wounded in the neck and face. Died at the scene. Male passenger in front seat.

"Man and Woman Are Charged in Slaying of Baltimore Cabdriver" Thursday, October 10, 1991. News Section. Roger Twigg .
Summary: Shot to death, .38 caliber handgun. Occurred on Tuesday night October 8, 1991. Victim age 44. Sun Cab driver. Died at the scene. 5000 block Denview Way. Shot three times in the back, one time in the chest.

"Cabbie Found Slain After Taxi Crashes Near Hillendale" Saturday, February 22, 1992.
Summary: Shot in the back of the head. Occurred on Friday night February 21, 1992. Checker Cab driver. Dragged from the vehicle and robbed after the crash. 6600 block of English Oak Road.

"No Title"
Summary: Shotgun blast to the head. Occurred on August 31, 1993. GI Veterans Cab driver. Age 48. Victim of robbery. Pronounced dead at the scene. 2800 blockof N. Dukeland Street. GI Veterans is a member of the Royal taxi association.

"Second Cabdriver in Two Weeks Is Fatally Shot" June 10, 1997. Peter Hermann.
Summary: Shot in the head. Robbery motive. Died on Monday June 9, 1997. Royal Cab driver. Two suspects, one shot fired shattering the passenger side window. One shot to the head. Died of his injuries several hours later. 1600 North Calhoun Street.

"Cabdriver Shot Last Week Dies; Third in Four Weeks" June 24, 1997. Sun Staff writer.
Summary: Shot from inside the cab. Robbery motive. Died on Monday June 23, 1997. Yellow Cab driver. 70 year old victim. Leeds Street and Palormo Avenue.

Baltimore Police Data

The table that follows was taken from a database provided by the Baltimore Police department. The complete table is made up of 1362 records involving complaints filed with the Baltimore Police department. All of the records were classified as involving taxicabs or services deemed similar to those provided by taxicabs. The entire table was made available in an Access database format.

CCN	BEAT	RA	CRIME	VICTID	VICTSRA	VICTINJ	DATE	TIME	PREMC DE	ADDRESS	SUSP SRA
	221	C149	3A	DIAMON	1240	7	91/01/0	2220	74	1100 ORLEANS ST	1230
	811	C616	3A	COUNTY	1137	3	91/01/0	0550	74	5100 DICKEY HILL RD	1240
	711	D736	3A	ROYALC	1235	7	91/01/0	1615	74	1200 LEXINGTON ST W	1230
	824	F863	3A	DIAMON	1228	3	91/01/0	0210	74	0300 BEECHFIELD AV S	1220
	314	D130	3A	CHECKE	1230	7	91/01/0	1730	74	0400 OLIVER ST E	1228
	531	B550	3A	ROYALC	1254	7	91/01/1	0525	74	2500 LOYOLA SOUTHW	1240
	615	D638	3A	ROYALC	1258	7	91/01/1	0040	74	4700 DELAWARE AV	1235
	613	C631	3A	DIAMON	1226	7	91/01/1	0125	74	4200 REISTERSTOWN RD	1230
	636	C644	4E	FLEPHI	1248	7	91/01/1	1200	74	6136 REISTERSTOWN RD	1245
	323	E316	3A	ROYALC	1228	7	91/01/1	1545	74	1500 CHASE ST E	1230
	314	A128	3A	DIAMON	1252	7	91/01/1	2015	74	1800 ENSOR ST	12
	525	I428	3A	JIMMYS	1133	7	91/01/1	2253	74	4100 WILSBY AV	1223
	135	C511	3A	DIAMON	1245	7	91/01/1	0030	74	2200 MT ROYAL TR	1225
	144	A139	3A	DIAMON	2231	7	91/01/1	0240	74	0010 EAGER ST E	1220
	514	F408	3A	DIAMON	1252	2	91/01/1	2000	74	3000 REESE ST	1219
	632	E654	3A	ADALMO	1234	7	91/01/1	2200	74	7000 FIELDCREST RD	1216
	331	A305	3B	GIVETE	1234	7	91/01/1	0315	74	1600 GAY ST N	1228
	314	J127	3A	ROYALC	1256	7	91/01/1	0100	74	1700 GREENMOUNT AV	1220
	315	B312	3A	GIVETE	1243	7	91/01/2	1451	74	1400 BROADWAY N	1224
	712	B716	3A	DIAMON	1228	7	91/01/2	0355	74	0900 FRANKLIN ST W	1224
	712	B730	3A	ROYALC	1233	7	91/01/2	0400	74	1000 BENNETT PL	1221
	436	G353	3A	OVERLE		7	91/01/2	0023	74	5925 RADECKE AV	1220
	433	B348	3A	OVERLE	1132	2	91/02/0	2151	74	5100 CEDGATE RD	1217
	925	A926	3A	GIVETE	1232	6	91/02/0	0625	74	1800 CHERRY HILL RD	1219
	434	C349	3A	OVERLE	1145	7	91/02/0	2330	74	5200 FRANKFORD AV	1225
	534	D559	3A	ROYALC	1260	7	91/02/0	1045	74	2400 GARRISON AV W	1223
	811	A616	3A	DIAMON	1240	7	91/02/0	0150	74	4500 WINDSOR MILL RD	1225
	715	C759	3A	ROYALC		7	91/02/1	1555	74	1300 FULTON AV N	1220
	631	F635	3A	ROYALC	2141	7	91/02/1	1400	74	3800 HOWARD PARK AV	1230
	222	A166	3A	ROYALC	1253	7	91/02/1	0435	74	0200 COLVIN ST	1220
	331	D405	3A	ROYALC	1248	7	91/02/1	0400	74	2200 NORTH AV E	1220
	331	G306	3A	ROYALC	1245	7	91/02/1	0335	74	2300 FEDERAL ST	1220
	735	J604	6D	DIAMON	1148	7	91/02/1	0430	74	2010 ASHBURTON ST	
	615	F638	6C	GOLDEN	1148	7	91/02/1	1130	74	4408 PARK HEIGHTS AV	1225
	144	H131	3A	ROYALC	2142	7	91/02/1	1300	74	1100 HARGROVE AL	1140
	732	B701	3A	ROYALC	1230	7	91/02/1	1815	74	0500 BAKER ST	1225
	523	M442	3A	DIAMON	1238	7	91/02/1	0245	74	5656 THE ALAMEDA	1218

Appendix B

Z-Test and Odds Ratio Computations

The analysis of shielded and unshielded taxis using the Z-Test for proportions and the odds ratio test is an attempt at determining whether there is an association between a dichotomous risk factor (shielded taxi vs. unshielded taxi) and a dichotomous condition state (assault vs. no assault). In this study of the association between shielding and assaults, a prospective sampling design was implemented. With such a sampling method, observations are made of a shielded and an unshielded taxi association in 1991, and of the entire Baltimore city taxi fleet in 1991 (unshielded year) and in 1997 (shielded year). The frequency of assaults is observed for both associations and years.

In the case of the two taxi associations in 1991, each was classified according to whether or not it was exposed or unexposed to a particular risk factor. For this analysis the dichotomous risk factor involves the taxis of a taxi association either being shielded or not shielded. Drivers in a shielded taxi association would not be exposed to attacks from the rear of the vehicle unless the shield was open. Unshielded taxi drivers are at risk for attacks from the rear passenger area. For both shielded and unshielded taxi associations there is still the potential for attacks from the driver's side window. Because of this and because police data make no such distinction, the dichotomous condition state will include assault scenarios from the rear passenger area and the driver's side window.

Units

The variable of interest in the Z-Test and Odds Ratio analyses is the "taxi-day". A taxi-day represents the use of a taxi for one full day, and it is used in this analysis as both a frequency count of the dichotomous condition state, as well as a measure of sample size. If a taxi association, for example, has seven taxis that are in use everyday for a year (365 days), then there would have been 2,555 "taxi-day" observations. Taxi-day observations in this case are proportional to exposure but should not be confused with the two risk factor categories mentioned earlier. It is assumed every taxi is used every day. No adjustment is made for a taxi being out of service for maintenance, which would reduce some what the taxi-days. Also, no adjustment is made for the near 24-hour, two-shift use of some taxis, which would "lengthen" the taxi-day and increase the exposure of drivers. The point to be made, however, is that there are a large number of taxi-day observations (represented by sample size *n*) thus insuring the required existence of a normal distribution (Council, et al. 1980, 74).

A taxi-day will be classified as either involving an assault or no assault on the taxi driver that rented a taxi on a particular day. If, for example, the taxi association with seven taxis experienced two assaults during the course of the year, then that association experienced two assault taxi-days, and 2,553 non-assault taxi-days. For this analysis, it is assumed that any one taxi driver can only endure one assault in a given day. In many cases the driver is incapacitated for several days following a violent assault. It is assumed that the taxi association has extra contract drivers to take his or her place in the days following an assault, thereby keeping the taxi in full service.

In order for the taxi-day observations to be considered normally distributed, the probability of assault occurring for any trial (*p*) times the sample size of *n* independent trials should be greater than or equal to approximately 5 assaults (Council, et al. 1980, 101). This must occur with a large *n*. While *p* may never be known, it can be estimated by dividing the total observed assaults by the total observations or trials (taxi-days). By checking to make sure that there are approximately 5 or more observed assaults in the following Z-Tests, then it can be determined whether or not the assumption that the observed binomial distribution approaches a normal distribution is true. If the observed frequency is less than 5, then the assumed distribution is approaching a Poisson distribution which would make the Z-Test for proportions an inappropriate test.

Input for Z-Test and Odds Ratio Test

The determination of the input data for the statistical tests requires establishing the fleet size for the two taxi associations (Arrow and Diamond) and the total city taxi fleet size in the years 1991 and 1997. The fleet size for the shielded taxi association (Arrow) in 1991 was 55 taxis, while for the unshielded taxi association (Diamond) in 1991 it was 144 taxis. The fleet sizes for both associations remained constant for the years 1991 to 1997. The size of the city taxi fleet was constant for the years 1991 to 1997 at 1,151 taxis.

After determining the fleet sizes, the frequency of assaults for the associations in 1991 and the frequency of assaults for the years 1991 and 1992 need to be established. Using the Baltimore Police MIS database records, these two sets of assault frequencies were found and are listed as follows.

Table B-1

Taxi Association (1991)	Fleet Size	Taxi-day observations	1991 Assaults	Assault Taxi Days	Non-Assault Taxi Days
Arrow (shielded)	55	55 * 365 = 20,075	5	5	20,070
Diamond (unshielded)	144	144 * 365 = 52,560	68	68	52,492

Table B-2

Year	Fleet Size	Taxi-day observations	Assaults	Assault Taxi Days	Non-Assault Taxi Days
1991	1,151	1,151 * 365 = 420,115	203	203	419,912
1997	1,151	1,151 * 365 = 420,115	25	25	420,090

As was mentioned earlier, in order for the normal distribution assumption to be correct the product of *np* should be greater than or equal to 5. While the true probability *p* is not known, it can be estimated by dividing the total observed assault taxi-days by the total taxi-day observations. The product of np can then be estimated with the observed frequency of assault taxi days. The required frequency of 5 assaults exists for all of the dichotomous risk factor states (Arrow vs. Diamond; 1991 vs. 1997). Therefore it can be reasonably assumed that the underlying binomial distributions for both Z-Tests are approximately normally distributed.

Z-Test Statistic

The Z-Test statistic is formulated as follows (Council, et al. 1980, 74):

$$Z = \frac{P1 - P2}{\sqrt{P(1-P)\left(\frac{1}{N1} + \frac{1}{N2}\right)}}$$

where $P1 = \frac{X1}{N1}$, $P2 = \frac{X2}{N2}$

$$P = \frac{X1 + X2}{N1 + N2} = \frac{N1P1 + N2P2}{N1 + N2}$$

$X1$ and $X2$ in this case represents the assault taxi-days for Arrow and Diamond, respectively, or the assault taxi-days for 1991 and 1997, respectively. $N1$ and $N2$ represent the total number of taxi-day observations for Arrow and Diamond, respectively, or the total number of taxi-day observations for 1991 and 1997, respectively.

Odds Ratio Test

The Odds Ratio test as carried out for this analysis implements a 2 x 2 display of the input data. The Odds Ratio statistic was only determined for two time periods: the contemporaneous analysis involving the taxi associations Arrow and Diamond in 1991, and the non-contemporaneous analysis involving the citywide fleet in 1991 and 1997.

Table B-3

	Diamond (unshielded)	Arrow (shielded)	Total
Assault Taxi-days	A	B	$M1$
Non-Assault Taxi-days	C	D	$M2$
Total Observations	$N1$	$N2$	

Odds Ratio: $\hat{OR} = \frac{AD}{BC}$

Results

The test of association between the dichotomous risk factor and the dichotomous condition state involves using the Z-Test for proportions. In the case of the two taxi associations in 1991, the input data is used to estimate the proportion of assault taxi-days for the shielded and unshielded taxi associations, as well as for the overall proportion:

$$\hat{P}shielded = \frac{5}{20075} = 0.00024907$$

$$\hat{P}unshielded = \frac{68}{52560} = 0.00129376$$

$$\hat{P}overall = \frac{20075(0.00024907) + 52560(0.00129376)}{20075 + 52560}$$
$$= 0.00100503$$

The Z statistic is

$$Z = \frac{0.00129376 - 0.00024907}{\sqrt{0.00100503(0.99899497)(0.00004981} + 0.00001903)}$$

$$Z = 3.97$$

In the case of the city taxi fleet for the years 1991 and 1997, the input data is used to estimate the proportion of assault taxi-days for the 1151 taxis of the city taxi fleet in 1991 and 1997, as well as for the overall proportion:

$$\hat{P}1991 = \frac{203}{420115} = 0.00048320$$

$$\hat{P}1997 = \frac{25}{420115} = 0.00005951$$

$$\hat{P}overall = \frac{420115(0.00048320) + 420115(0.00005951)}{420115 + 420115}$$
$$= 0.00027135$$

The Z statistic is

$$Z = \frac{0.00048320 - 0.00005951}{\sqrt{0.00027135(0.99972865)(0.00000238 + 0.00000238)}}$$

$$Z = 11.79$$

After the Z Test results have shown a significant difference between the shielded and unshielded taxi associations, then the Odds Ratio (OR) test is performed.

Table B-4

	Diamond (unshielded)	Arrow (shielded)	Total
Assault Taxi-days	68	5	73
Non-Assault Taxi-days	52492	20070	72562
Total Observations	52560	20075	

The estimated Odds Ratio is calculated as follows:

$$\hat{OR} = \frac{(68)(20070)}{(5)(52492)}$$

$$= 5.199$$

The citywide 1991/1997 Odds Ratio is calculated as follows:

Table B-5

	1991 (5% shielding)	1997 (100% shielding)	Total
Assault Taxi-days	203	25	228
Non-Assault Taxi-days	419912	420090	840002
Total Observations	420115	420115	

$$\hat{OR} = \frac{(203)(420090)}{(25)(419912)}$$

$$= 8.123$$

Arrow and Diamond Taxi Associations

The use of Arrow and Diamond taxi associations for the Z-test for proportions and the Odds Ratio test was primarily based upon the Arrow taxi association being 100% shielded in 1991 while the Diamond taxi association was assumed to have very few shields in place. In addition to the dichotomous risk factor (shielded vs. not shielded) another potential difference between any two taxi associations involves some taxi associations primarily conducting contract business and others conducting street hail business. It is assumed that smaller taxi associations primarily conduct street hail business, therefore both Arrow and Diamond taxi associations would more than likely be street hail business taxi associations. Even with these experimental controls, there is still the potential for differences to exist between the two associations. In order to test for such a difference a Z-test for proportions was conducted for both associations in 1997 when both associations had 100% shielding. The following results show that both taxi associations, in contrast to 1991's Z-test for proportions, have no significant difference in assault rates thereby suggesting that both associations were controlled for appropriately in the previous tests.

Table B-6

Taxi Association (1997)	Fleet Size	Taxi-day observations	1997 Assaults	Assault Taxi Days	Non-Assault Taxi Days
Arrow	55	55 * 365 = 20,075	3	3	20,072
Diamond	144	144 * 365 = 52,560	6	6	52,554

$$\hat{P}arrow = \frac{3}{20075} = 0.00014944$$

$$\hat{P}diamond = \frac{6}{52560} = 0.00011416$$

$$\hat{P}overall = \frac{20075(0.00014944) + 52560(0.00011416)}{20075 + 52560}$$
$$= 0.00012391$$

$$Z = \frac{0.00014944 - 0.00011416}{\sqrt{0.00012391(0.99987609)(0.00004981} + 0.00001903)}$$

$$Z = 0.382$$

Appendix C

Regression Analysis

Proposed Explanatory Variables

In an attempt to explain the year to year variation in total annual assaults from 1991 to 1997 in Baltimore, a linear regression analysis was conducted. The explanatory variables used in this analysis were established on the basis of factors that are believed to have an impact on the frequency of all crime. Several of these variables are listed in the FBI's Crime in the United States, an annual report of crime from participant law enforcement agencies across the United States. These probable factors range from population density to the level of law enforcement. This regression analysis will address some of the FBI's crime factors as well as other factors that have been proposed. The only non-exogenous factor that will be included in this analysis is the average percentage shielding. This is included to determine whether or not shielding can fully or partially explain the downward trend in annual assaults during the course of the study period.

The first factor considered in this analysis deals with population levels in the City of Baltimore. Population as an explanatory category in the FBI's Crime in the United States includes such factors as population density, degree of urbanization, population composition, and resident mobility. With regards to population density and degree of urbanization, researchers are interested in any potential differences in the frequency of occupational homicide occurring in both highly and lowly populated areas (NIOSH 1992, 4). Past research in the area of taxi assaults and population did not establish a relationship between the two (Stone, et al. 1992, 4). With regards to population composition others have proposed that changing age group distributions are one reason for the decline of crime in the United States during the 1990's (Thomas 1997). This analysis will only consider area population in the City of Baltimore, and not other factors dealing with population. This is done in order to limit the scope of the overall analysis. All population figures used in this analysis (Table 2.1) only involve the City of Baltimore and not any surrounding counties that are included in the U.S. Census' Metropolitan Statistical Area for Baltimore.

The second factor addressed deals with another FBI explanatory category involving economics. This category covers such matters as median income, poverty level, and job availability (Crime in the United States 1996, iv). Job availability, measured in terms of unemployment, is believed by some to be positively correlated with burglaries (Verhaeghe 1991). Recessions often are paired with high unemployment. Some believe that during recessions cab drivers are more likely to serve more crime prone areas (Laidlaw 1991). If we assume that unemployment is positively correlated with economic recession, and that recession causes drivers to take greater risks, then increases in the assaults of taxi drivers can potentially be explained by the local unemployment rate. The use of unemployment rate as an explanatory variable can also address the theory reported by Verhaeghe. This analysis will only address the unemployment factor under the FBI's economic category.

Another factor that is not mentioned by the FBI, but is listed as a potential explanatory variable by others deals with drug use, in particular the infamous street drug "crack" cocaine. In a 1997 Justice Department report it was found that there is a relationship between increases in crack use and increases in homicide rates (Butterfield 1997). If we assume that crack use is associated with changes in homicide rates as well as in changes in violent assault rates, then by capturing "crack" use the analysis can explain for some if not all of the assaults on taxi drivers. One available variable that is potentially correlated with crack use is the frequency of annual drug arrests. The frequency of drug arrests in this analysis includes both misdemeanors and felonies as reported by the Baltimore police department. This analysis will use drug arrests as a potential explanatory variable with the additional assumption that changes in the annual drug arrest figures for the City of Baltimore are largely due to increases or decreases in drug use, and not in improved policing strategies.

While the majority of factors so far are of an independent explanatory nature, the next potential variable is often labeled in other crime analyses as the dependent variable. Such a variable for this analysis are the annual robberies reported in the City of Baltimore. The total annual robberies used in this analysis include highway, commercial, oil station, convenience store, and bank robberies. Taxi driver robberies are not included in these annual robbery figures. Another potential and similar explanatory variable involves the annual crime index as published in the FBI's Crime in the United States. The crime index includes several other crimes that do not logically connect with taxi driver assaults, such as forcible rape and nonnegligent manslaughter. This analysis instead chooses to use only total annual robberies, in an attempt to incorporate a crime similar in nature to the assault of taxi cab drivers. This stems from the majority of assaults on taxi drivers involving robbery as a primary motive (Stone, et al. 1996, 5; Knestaut 1997, 55). This is much the case with the 1,036 assaults used in this analysis. Of the 1,036 assaults addressed in this analysis for the years 1991 to 1997, 1,034 involved robbery.

Explanatory Variables Selection

After the explanatory variables have been proposed for analysis, they should then be verified for whether or not they exhibit a linear relationship with annual taxi assaults (Papacostas and Prevedouros 1993, 317). This can be accomplished by plotting the annual assaults versus each of the five independent variables (Figures C-1 to C-5). As can be seen annual robberies, percentage implemented shielding, and population exhibit linear relationships with annual assaults. Unemployment and drug arrests do not exhibit linear relationships.

Figure C-1 Total Assaults Versus Unemployment

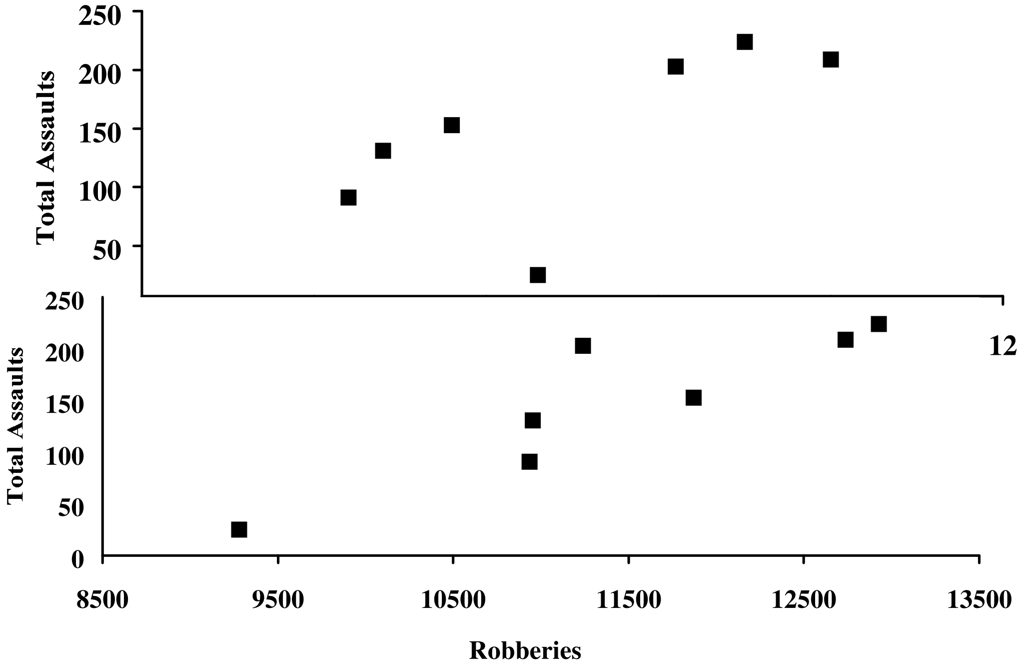


Figure C-2 Total Assaults Versus Total Robberies

Figure C-3 Total Assaults Versus Drug Arrests

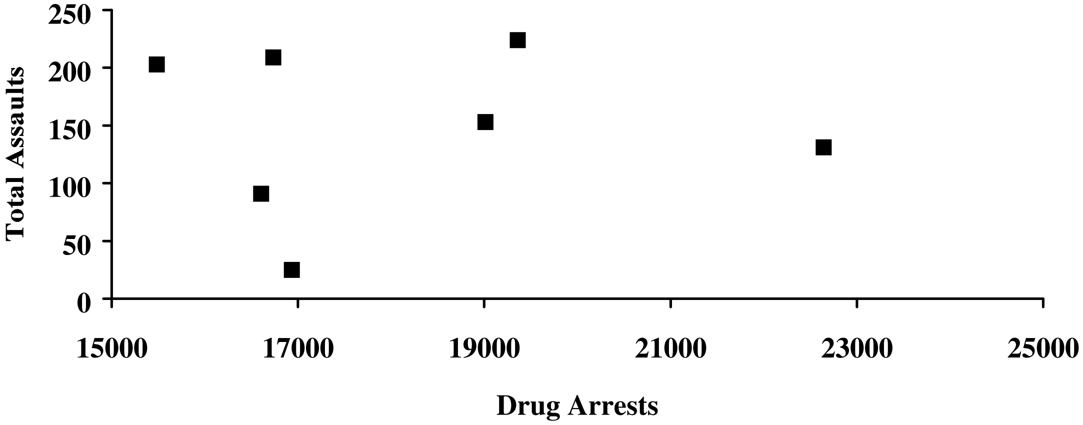


Figure C-4 Total Assaults Versus Percentage Shielding

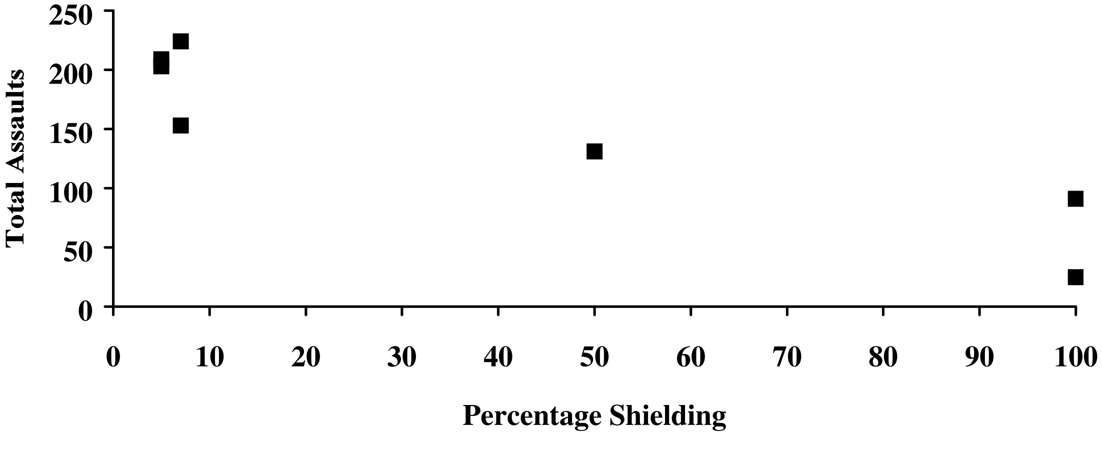
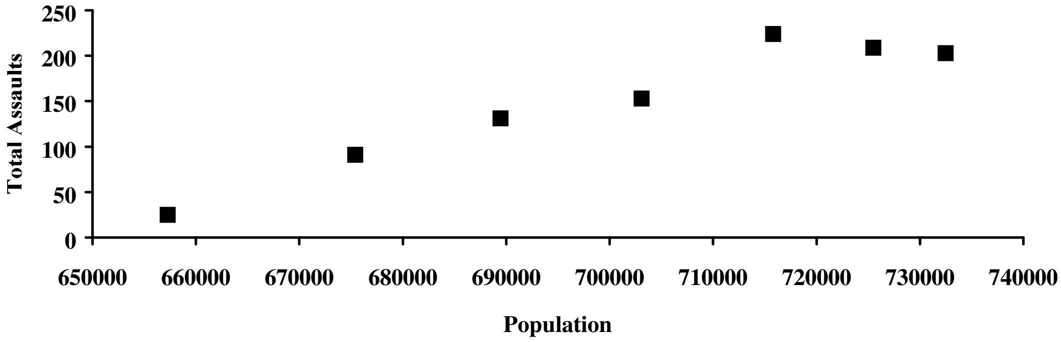


Figure C-5 Total Assaults Versus Population



In order to quantify the linear relationship between the independent variables and annual assaults a correlation table was created (Table 3.8). The statistics listed in Table 3.8 are Pearson correlation values. The observed linear relationships from Figures C-1 through C-5 are reflected by the Pearson correlation values, with annual robberies, percentage implemented shielding, and population showing the most significant correlation values with annual assaults (0.05 significance level). With both the results of the plots and the correlation table the final variables for use in the linear regression are determined.

While the above three variables have been determined to exhibit a linear correlation with annual assaults, it is also important to determine whether or not they are highly correlated between themselves (Papacostas and Prevedouros 1993, 317). Using the same correlation table as before for the three selected variables, it is observed that each of the three variables are highly correlated with each other. As a result, none of the variables can be used in combination with each other in a linear regression model. If the percentage shielding were reconsidered in terms of its correlation with annual population and robberies, then it could be assumed that the variables can be combined in pairs, with the exception of annual population and annual robberies. The correlation between percentage shielding and the other two variables is assumed to not be significant based on the following explanation. Percentage shielding for several years before the study period remained constant at five percent. More than likely percentage shielding will remain constant at 100% for the years following the study period. If data were to be collected for all three time periods (previous, current, and future) then it would probably be determined that percentage shielding does not exhibit any correlation with annual population and annual robberies. It can be assumed that percentage shielding is independent of the other two variables. Because of this, percentage shielding will be used in combination with the other two variables annual population and annual robberies in the linear regression models that are formed.

As a result of the above selection process the following explanatory variable combinations will be regressed against annual assaults: percentage shielding and annual population, percentage shielding and annual robberies, percentage shielding, annual population, and annual robberies.

Linear Regression Models

After the appropriate explanatory variables have been determined, the linear regression models based on the different combinations of the three selected variables are then created. With there being a total of five potential regression models there is a need to establish which of the five is the most significant in terms of its ability to explain the variation of the data. This analysis will first determine which of the five models meet a predetermined statistical significance criterion. Those that meet this criterion are then ranked on the basis of the percentage of the overall variability that they are able to explain (R-square value).

The statistical significance of any regression model is first established with the F-statistic, which in this case is equal to the ratio of the mean square for the model to the mean square error. This analysis used a 0.05 significance level for the selection of statistically significant regression models. Based on this first criterion all of the five proposed regression models were found to be significant (Table C-1).

After all of the regression models have been tested for statistical significance, they are then ranked based on the percentage of the total variability that the models are able to explain. This measure is called the R-square statistic. The higher the R-square value the better the model. Tables 3.9 and C-1 show the R-square values for each of the five models. Based on this criterion the preliminary best model involves the multiple variable linear regression of annual assaults on annual population and percentage shielding (Tables 3.9 and C-1).

Table C-1 F-test and R-square values

	F value	Prob > F	R-square
Annual Assaults = -1285.255493 - 0.307030 * Percent Taxis Shielded + 0.002065 * Population	25.849	0.0052	0.9282
Annual Assaults = -1621.382312 + 0.002528 * Population	60.064	0.0006	0.9232
Annual Assaults = -128.352575 - 0.876242 * Percent Taxis Shielded + 0.027203 * Total Annual Robberies	23.231	0.0063	0.9207
Annual Assaults = 206.119123 - 1.484795 * Percent Taxis Shielded	26.666	0.0036	0.8421
Annual Assaults = -450.143927 + 0.052378 * Total Annual Robberies	22.167	0.0053	0.8160

Lack of Fit Tests

Among the five regression models that are considered in this analysis there are multiple and univariate linear regression models. In order to determine whether or not the multiple linear regression models are appropriate for use in explaining the variability of annual assaults, a series of lack of fit tests were conducted. These tests were carried out by first determining the error sums of squares, as well as the error degrees of freedom for all multiple and univariate linear regression models (Table C-2). After the error sums of squares are determined, the differences in error sums of squares among the five models can then be determined. These differences are determined between the multiple variable regression models and the single variable regression models (Table C-3). The differences are only found between models that share a common variable such as between the multiple variable models involving percentage shielding and population, and the single variable models involving population and percentage shielding. The results of this step are shown in Table C-3. As can be seen in Table C-3 there are four different scenarios. Each one represents the addition of a second variable to a single variable model. If the F value in Table C-3 is significant, it means that the addition of the second variable made a significant contribution to the resulting model. If an F value in Table C-3 is not significant it means that the resulting multiple variable model is not worth considering. With each of the F test statistics having 1 degree of freedom in the numerator, and 4 degrees of freedom in the denominator, the critical F value at the 0.05 significance level is found to be equal to 7.71. As can be seen in Table C-3 both multiple variable models are connected with F-tests' that failed to reject the null hypothesis of no significant difference. Failing to reject the null hypothesis suggests that the addition of the second variable will not significantly improve the ability of the current model to explain the annual frequency of assaults. As a result it can be properly assumed that none of the proposed multiple variable linear regression models should be considered in this analysis. With this under consideration the analysis will only consider the three single variable models involving percentage shielding, annual robberies, and annual population.

Table C-2 Lack of Fit Tests - Error Sums of Squares

Linear Regression Model	Error Sums of Squares	Error Degrees of Freedom	Mean Square Error
Percentage Taxis Shielded Annual Population	2241.63537	4	560.40884
Percentage Taxis Shielded Annual Robberies	2474.27228	4	618.56807
Annual Population	2398.72129	5	479.74426
Annual Robberies	5744.84918	5	1148.96984
Percentage Taxis Shielded	4928.67214	5	985.73443

Table C-3 Error Sums of Squares Differences and F Test Values

Difference Combination	Difference Sums of Squares	Mean Difference Sums of Squares	F Value (numerator 1d.f./denominator 4 d.f.)
Percentage Shielding + Annual Population | Annual Population	157.08592	157.08592	0.2803
Percentage Shielding + Annual Population | Percentage Shielding	2687.03677	2687.03677	4.7948
Percentage Shielding + Annual Robberies | Annual Robberies	3270.5769	3270.5769	5.2873
Percentage Shielding + Annual Robberies | Percentage Shielding	2454.39986	2454.39986	3.9679

Linear Regression Assumptions

With linear regression models there are certain assumptions that are made that need to be satisfied in order for the linear regression models to be valid. These assumptions are that the residuals are normally distributed and that they have a common variance (Steel, et al. 1997, 261). In order to test the first assumption of normally distributed residuals there is the Shapiro-Wilk test (Steel, et al. 1997, 567). The results of the test can be seen in Table C-4. All of the linear regression models failed to reject the null hypothesis of a normally distributed population. The Shapiro-Wilk tests for all of the models show that the normal distribution assumption cannot be rejected, thereby satisfying the first assumption for these models.

Table C-4 Shapiro-Wilk Test for Normalcy

	W:Normal	Prob < W
Annual Assaults = -1285.255493 - 0.307030 * Percent Taxis Shielded + 0.002065 * Population	0.956343	0.7984
Annual Assaults = -1621.382312 + 0.002528 * Population	0.964333	0.8617
Annual Assaults = -128.352575 - 0.876242 * Percent Taxis Shielded + 0.027203 * Total Annual Robberies	0.963385	0.8545
Annual Assaults = 206.119123 - 1.484795 * Percent Taxis Shielded	0.920237	0.4890
Annual Assaults = -450.143927 + 0.052378 * Total Annual Robberies	0.828239	0.0780

With regards to the second assumption of a common variance there are not enough data points for the conducting of F-tests. The only exception is with the regression model involving percentage shielding. In the years 1991 and 1992 there was an estimated 5% shielding, in the years 1993 and 1994 there was an estimated 7% shielding, and in 1996 and 1997 there was 100% shielding. Therefore for these three shield implementation percentages there are two data points each . Using the estimated means from the linear regression model (percentage shielding only Table C-1) the variances at each of the three percentage shielding levels can be calculated using data from Table 2.3. Dividing the largest of the three variances by the smallest variance, an F-statistic with a numerator d.f. of 1 and a denominator d.f. of 1 can be determined. In this case the largest F-statistic was found to be equal to 21.05. At the 0.05 significance level the F-statistic critical value is 161.4. Therefore, for this regression model involving only percentage shielding it can be reasonably assumed that the population variances are equal. Due to the limited number of data points, this is the only model that this assumption can be tested for.

Discussion

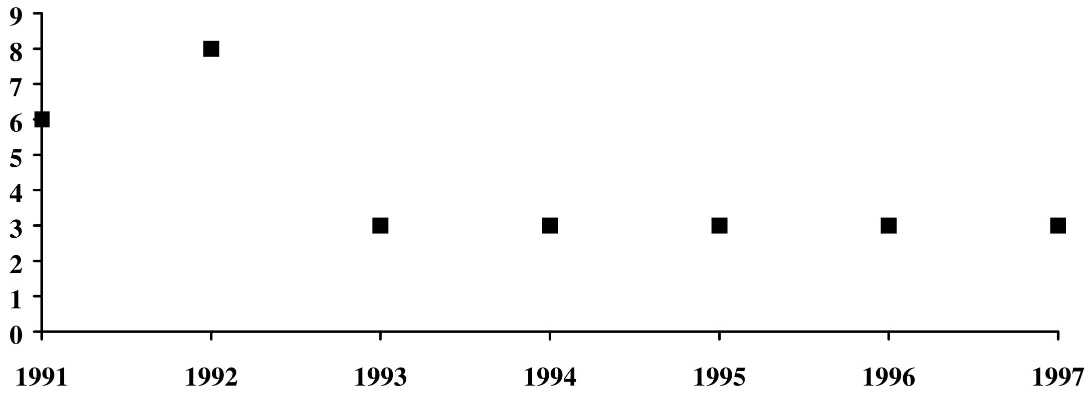
The final result of the regression analysis is a set of regression models that are statistically significant and that reasonably meet the necessary assumptions of being normal distributed and of having a common variance. Of the three regression models selected previously, the model with the highest R-square value involves annual population (Tables 3.9 and C-1). As seen in Table C-4 this regression model can be properly assumed to be normally distributed.

As a check of the relationship between percentage shielding, annual population, and annual robberies, another set of linear regressions were carried out using the annual assaults of a taxi association (Arrow) that was completely shielded during the study period from 1991 to 1997. This is the same association that was used in the contemporaneous study. By regressing the annual assaults of the Arrow taxi association against annual robberies and annual population, it can be further checked which of the explanatory variables best explains the frequency of assaults on taxi drivers. As can be seen in Table C-5 the regression of annual assaults for the Arrow association against annual population and annual robberies shows no significant relationship for either single variable linear regression model (0.05 significance level). Figure C-6 shows the annual assaults for the Arrow taxi association versus each of the years of the study. The relatively constant nature of the annual assaults for the Arrow taxi association is one reason for the inability of either annual population or annual robberies in being able to explain the annual frequency of assaults for the association. Because of this, this analysis will conclude that the linear regression model that includes the single explanatory variable percentage shielding is the best linear regression model for the explanation of annual assaults.

Table C-5 Arrow Taxi Association

Explanatory Variable	F value	Prob > F	R-square
Annual Population	3.029	0.1423	0.3772
Annual Robberies	1.173	0.3283	0.1900

Figure C-6 Arrow Taxi Association Annual Assaults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