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16. Abstract

Previous research has shown that increased alcohol availability associated with reductions in legal minimum age for purchase of alcoholic beverages resulted in increased alcohol-related traffic crash involvement among young drivers. In the late 1970s, Michigan raised the drinking age from 18 to 21, and Maine from 18 to 20, providing natural experiments reducing alcohol availability. Effects of the raised drinking age on motor vehicle crash involvement were evaluated using a tri-level hierarchical multiple time-series design.

Results revealed a significant 20% reduction in alcohol-related injury-producing crash involvement among 18-20-year-old Michigan drivers directly attributable to the higher drinking age; alcohol-related property damage crashes decreased 17% for this age group. Maine drivers age 18-19 experienced a 20% reduction in alcohol-related property damage crash involvement attributable to the raised drinking age.

It is concluded that the legal minimum drinking age has a significant effect on alcohol-related motor vehicle crash involvement among young drivers. Implications of the findings for beverage alcohol availability theory and public policy concerning the prevention of alcohol-related problems are included.

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1.0 INTRODUCTION

After the repeal of prohibition in 1933, all states established minimum legal ages for purchase and consumption of alcoholic beverages; most states set the minimum drinking age at 21, while a few chose drinking ages between 18 and 20. Little attention was given to these laws over the subsequent three and a half decades. The controversy surrounding the drinking age began in 1970 with passage by the Congress, and subsequent ratification by the states, of the 26th amendment to the U.S. Constitution extending the right to vote in federal elections to citizens between 18 and 21 years of age. A movement to extend the rights and privileges of adulthood to youth aged 18 and over began, and within three years all 50 states extended the right to vote in state elections to 18-year-olds. During this period, 29 states reduced their minimum legal drinking ages (Table 1.1).[1]

Following the reductions in drinking age, considerable controversy emerged in academic, law enforcement, political, and industry circles concerning the wisdom of lowering the drinking age (Michigan Licensed Beverage Association, 1973; Works, 1973; Distilled Spirits Council of the United States, 1973a, 1973b; Bowen and Kagay, 1973; Zylman, 1973, 1974; Douglass, 1974). Uncontrolled analyses of early data were used by some partisans in the political debate to argue that huge increases in youthful alcohol-related motor vehicle crashes occurred after the reduction in drinking age (Michigan Council on Alcohol Problems, 1973). Others argued that the observed crash increases were a result of changes

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[1]Published literature on legal drinking age has provided conflicting information on the number of states that have changed the drinking age. Information on legal drinking age changes provided here was based on a comprehensive survey of all 50 states conducted by Wagenaar (1981).

TABLE 1.1

States Lowering the Minimum Legal Drinking Age: 1970-1975

State	Effective Date	Description of Change
Alabama	7/75	21 to 19 - all beverages
Alaska	9/70	21 to 19 - all beverages
Arizona	8/72	21 to 19 - all beverages
Connecticut	10/72	21 to 18 - all beverages
Delaware	7/72	21 to 20 - all beverages
Florida	7/73	21 to 18 - all beverages
Georgia	7/72	21 to 18 - all beverages
Hawaii	3/72	20 to 18 - all beverages
Idaho	7/72	21 to 19 - wine and distilled spirits; 20 to 19 - beer
Illinois	9/73	21 to 19 - beer and wine only
Iowa	4/72	21 to 19 - all beverages
Iowa	7/73	19 to 18 - all beverages
Maine	6/72	20 to 18 - all beverages
Maryland	7/74	21 to 18 - beer and light wine only
Massachusetts	3/73	21 to 18 - all beverages
Michigan	1/72	21 to 18 - all beverages
Minnesota	6/73	21 to 18 - all beverages
Montana	7/71	21 to 19 - all beverages
Montana	7/73	19 to 18 - all beverages
Nebraska	6/72	20 to 19 - all beverages
New Hampshire	6/73	21 to 18 - all beverages
New Jersey	1/73	21 to 18 - all beverages

State	Effective Date	Description of Change
Rhode Island	3/72	21 to 18 - all beverages
South Dakota	7/72	19 to 18 - 3.2 beer only
Tennessee	5/71	21 to 18 - all beverages
Texas	8/73	21 to 18 - all beverages
Vermont	7/71	21 to 18 - all beverages
Virginia	7/74	21 to 18 - beer only
West Virginia	6/72	21 to 18 - distilled spirits (beer and wine were 18 since 1935)
Wisconsin	3/72	21 to 18 - all beverages except beer which has been 18 since 1933
Wyoming	5/73	21 to 19 - all beverages

in police reporting practices, growth in the population of young drivers, and long-term trends in the incidence of traffic accidents (Zylman, 1974). By the mid-1970s, controlled studies of the effects of lowered drinking ages began to appear both in the United States and Canada. Most of these investigations found significant increases in alcohol-related motor vehicle accidents among young drivers attributable to the lowered drinking age. Several studies also reported increased consumption of alcoholic beverages after the lowered drinking ages went into effect. As the evidence documenting the adverse effects of the lowered drinking age on alcohol-related problems accumulated, the trend toward reducing the drinking age reversed. No states have lowered their drinking age since 1975, and at least 15 states raised their drinking ages between 1976 and 1981 (Table 1.2). Current legal minimum drinking ages in the 50 states as of April 1981 are listed in Table 1.3.

TABLE 1.2

States Raising the Minimum Legal Drinking Age: 1976-1981

State	Effective Date	Description of Change
Florida	10/80	18 to 19 - all beverages
Georgia	9/80	18 to 19 - all beverages
Illinois	1/80	19 to 21 - beer and wine only
Iowa	7/78	18 to 19 - all beverages
Maine	10/77	18 to 20 - all beverages
Massachusetts	4/79	18 to 20 - all beverages
Michigan	12/78	18 to 21 - all beverages
Minnesota	9/76	18 to 19 - all beverages
Montana	1/79	18 to 19 - all beverages
Nebraska	5/80	19 to 20 - all beverages
New Hampshire	5/79	18 to 20 - all beverages
New Jersey	1/80	18 to 19 - all beverages
Rhode Island	7/80	18 to 19 - all beverages
Rhode Island	7/81	19 to 20 - all beverages
Tennessee	6/79	18 to 19 - all beverages
Virginia	7/81	18 to 19 - off-premise beer only

The purpose of this study was to evaluate the effects of returning to higher drinking ages. Maine and Michigan were selected as primary study states because both lowered their drinking age in the early 1970s

TABLE 1.3

Current Minimum Legal Drinking Ages: April 1981

State	Beer		Wine		Distilled Spirits
	3.2% or less alcohol	over 3.2% alcohol	Light	Fortified	
Alabama	19	19	19	19	19
Alaska	19	19	19	19	19
Arizona	19	19	19	19	19
Arkansas	21	21	21	21	21
California	21	21	21	21	21
Colorado	18	21	21	21	21
Connecticut	18	18	18	18	18
Delaware	20	20	20	20	20
District of Columbia	18	18	18	21	21
Florida	19	19	19	19	19
Georgia	19	19	19	19	19
Hawaii	18	18	18	18	18
Idaho	19	19	19	19	19
Illinois	21	21	21	21	21
Indiana	21	21	21	21	21
Iowa	19	19	19	19	19
Kansas	18	21	21	21	21
Kentucky	21	21	21	21	21
Louisiana	18	18	18	18	18
Maine	20	20	20	20	20
Maryland	18	18	18	21	21

State	Beer		Wine		Distilled Spirits
	3.2% or less alcohol	over 3.2% alcohol	Light	Fortified	
Massachusetts	20	20	20	20	20
Michigan	21	21	21	21	21
Minnesota	19	19	19	19	19
Mississippi	18[1]	21	18[1]	21	21
Missouri	21	21	21	21	21
Montana	19	19	19	19	19
Nebraska	20	20	20	20	20
Nevada	21	21	21	21	21
New Hampshire	20	20	20	20	20
New Jersey	19	19	19	19	19
New Mexico	21	21	21	21	21
New York	18	18	18	18	18
North Carolina	18	18	18	21	21
North Dakota	21	21	21	21	21
Ohio	18	21	21	21	21
Oklahoma	18[2]	21	21	21	21
Oregon	21	21	21	21	21
Pennsylvania	21	21	21	21	21
Rhode Island	20	20	20	20	20
South Carolina	18	18	18	18	21
South Dakota	18	21	21	21	21
Tennessee	19	19	19	19	19
Texas	18	18	18	18	18

State	Beer		Wine		Distilled Spirits
	3.2% or less alcohol	over 3.2% alcohol	Light	Fortified	
Utah	21	21	21	21	21
Vermont	18	18	18	18	18
Virginia	18[3]	18[3]	21	21	21
Washington	21	21	21	21	21
West Virginia	18	18[4]	18	18	18
Wisconsin	18	18	18	18	18
Wyoming	19	19	19	19	19

[1]Drinking age is 18 for beer or wine that is 4% or less alcohol by weight.

[2]Prior to December 1976, the age was 18 for females and 21 for males. This sex discrimination was ruled unconstitutional by the U.S. Supreme Court, having the effect of lowering the age to 18 for males [Craig v. Boren, U.S. Okl. 97 S. Ct. 451 (1976)].

[3]Eighteen for on-premise consumption, nineteen for off-premise consumption.

[4]Effective June 1980; beer over 3.2% was illegal in West Virginia before that date.

and returned to their original higher age in the late 1970s. As noted in Table 1.1, Maine lowered its drinking age from 20 to 18, effective June 9, 1972, and returned the legal age to 20, effective October 23, 1977. Similarly, Michigan lowered its drinking age from 21 to 18, effective January 1, 1972, and returned the legal age to 21, effective December 23, 1978. When the drinking age was raised, neither state included a "grandfather clause" whereby young people who could legally drink prior to the increase in drinking age would continue to possess that right. After the raised drinking ages went into effect, young people who previously had the right to purchase alcoholic beverages no longer were legally allowed to do so.

The goals of this investigation were twofold. First, to provide objective information concerning the effect of the legal drinking age to policy-makers and voters who must continue to deal with this issue. A major concern in discussions of public policy on the legal drinking age is the extent to which modifications in the drinking age cause changes in the motor vehicle accident experience of young drivers. Therefore, this investigation emphasized the use of a research design with a high degree of interval validity, and included consideration of potential alternative explanations of the observed relationship between the drinking age and traffic accidents. In addition to the primary focus on motor vehicle accidents, the relationship between drinking age changes and aggregate beverage alcohol sales was also explored. The second goal of the present study was to use naturally occurring experiments with the minimum legal drinking age to test propositions based on emerging theories concerning the impact of beverage alcohol availability on alcohol consumption and alcohol-related public health problems.

2.0 ALCOHOL AND HIGHWAY SAFETY

A major component in the legal drinking age debate has been the impact of modifications of drinking age on alcohol-related motor vehicle collision experience of youth. Recent trends in youthful drinking patterns and the role of alcohol in traffic accidents, especially with reference to young drivers, are discussed below.

2.1 Drinking Patterns

It is well established that most young people in the United States regularly drink alcoholic beverages. Blane and Hewitt (1977) reviewed 120 surveys of adolescent drinking practices (i.e., youth aged 13 to 18) conducted since 1941. They concluded that the prevalence of youthful drinkers (i.e., "have you ever had a drink") was increasing prior to the mid-1960s, and that about 70 percent of junior and senior high school students were consistently identified as drinkers over the 1966 through 1975 period. A similar pattern was revealed for lifetime prevalence of intoxication (i.e., "have you ever been drunk"), which increased from 19 percent prior to 1966 to 45 percent during the 1966 to 1975 time period, remaining stable during the latter ten-year period. Prevalence of self-reported monthly intoxication (i.e., "how often do you become drunk") similarly increased from 10 percent before 1966 to about 19 percent during the 1966 to 1975 period, although the small number of surveys assessing prevalence of monthly intoxication limits the conclusions that could be made concerning trends in recent years. Blane and Hewitt also could not identify trends in drinking frequency among adolescents over the past two decades because of the inconsistent measures of drinking frequency used in various surveys. Their best estimate of average drinking frequency among teenage drinkers age 13 to 18 was three drinking occasions per month.

Note that although these estimates were based on a comprehensive review of 120 surveys, only 14 of those studies used probability samples from clearly defined populations. As a result, estimates of the drinking practices of adolescents in the United States should be used with caution. Nevertheless, many studies over an extended period have indicated that the great majority of adolescents drink regularly and a substantial number also frequently become intoxicated.

The above discussion has been restricted to drinking practices of junior and senior high school youth. The literature on college students, also reviewed by Blane and Hewitt (1977), is even more limited. Existing surveys of college students indicate that the prevalence of drinkers (i.e., "have you ever had a drink") has been continually increasing since World War II. It is estimated that about 89 percent of all college students are drinkers. There are indications that the frequency of intoxication among college students has increased in the past quarter century. Furthermore, those age 18 to 25 consume more beverage alcohol than at any other period in the life cycle, and they drink larger quantities of alcohol per occasion than older drinkers (Blane and Hewitt, 1977; National Institute on Alcohol Abuse and Alcoholism, 1978).

The most recent information concerning youthful drinking practices was provided by the ongoing longitudinal nationwide probability surveys being conducted by Johnston, Bachman and O'Malley (Johnston et al., 1979a, 1979b). They reported that 88 percent of high school seniors surveyed in 1979 were at least occasional users of alcohol, 72 percent reported use within the past month, and 41 percent reported consuming five or more drinks on at least one occasion in the previous two weeks. Furthermore, similar surveys conducted each year since 1975 revealed that, while the prevalence of drinkers has remained stable in recent years, the prevalence of high school seniors who frequently become intoxicated has increased over the past five years (from 37 percent in 1975 to 41 percent in 1979; Johnston et al., 1979b).[2]

These recent data confirm and extend the conclusion Blane and Hewitt made on the basis of their review of surveys conducted prior to 1975. That is, a plateau in the prevalence of drinkers among older adolescents and young adults has apparently been reached, with about 80 to 90 percent identifying themselves as drinkers. However, the prevalence of young people who frequently become intoxicated appears to be increasing, with current data indicating that more than one-third of young people in the United States become intoxicated at least once every 14 days. The experience of frequent intoxication by a sizeable proportion of American adolescents creates the potential for serious mortality and injury outcomes if young drinkers operate motor vehicles while in an alcohol-impaired state.

2.2 Traffic Accidents

Motor vehicle accidents are the leading cause of death among youth aged 15 to 24, claiming 18,900 lives in the United States in 1979 (National Safety Council, 1980). A large number of interacting factors have been identified as causes of traffic accidents.

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[2]These high prevalence rates of frequent intoxication were also found by Wechsler (1979), in his recent surveys of youthful drinking practices.

Intensive investigations of random samples of accidents conducted at Indiana University by the Institute for Research in Public Safety have revealed that vehicular factors (e.g. brake failures, tire blowouts) were a definite cause of the collision in about 5 percent of the cases, and environmental factors (e.g. slick roads, reduced visibility, roadway defects) were a definite cause in about 20 percent of the accidents examined (Institute for Research in Public Safety, 1975). Human direct causes (e.g. excessive speed, tailgating, driver inattention), on the other hand, were documented as a definite cause of the collision in over 80 percent of the accidents. The researchers emphasized the dominant role of human factors in accident causation, and pointed out that even in those cases where a definite vehicular or environmental cause was evident, it was most often a combination of such factors with human error that brought about the collision.

Human errors that cause most collisions are often a direct result of human conditions at the time of the crash (e.g. driver inexperienced, emotionally upset, fatigued, impaired by drugs). The multidisciplinary investigations of causes of traffic collisions mentioned above have revealed that, for samples of all accidents at all times, alcohol-impairment is the human condition most frequently identified as a causal factor in the crash; alcohol impairment was identified as a definite or probable cause in about 7 percent of the collisions investigated (Treat, 1977). It should be emphasized that the accident sample included all motor vehicle accidents at all times of the day/week; as a result, the great majority of the investigated collisions were relatively minor property-damage accidents occurring during daytime rush hours.

The epidemiological literature on the role of beverage alcohol in traffic accidents demonstrates that the role of alcohol increases as the severity of the accident increases. Although only about 10 percent of the drivers in minor property-damage accidents have blood alcohol concentrations (BACs) over .05 percent, about 15 percent of drivers involved in extensive property-damage accidents have BACs of .05 percent or greater, approximately 25 percent of drivers involved in serious injury accidents have BACs of .10 or greater, and the most serious accidents, fatalities, have the highest rates of alcohol impairment, with about one-half of the drivers having a BAC of at least .10 percent (Cameron, 1977; Jones and Joscelyn, 1978). The findings of these studies are supported by studies that include control groups, matched in time and place to samples of accidents. Such studies have found that the relative risk of being involved in a crash accelerates rapidly at BACs over .08 percent (Cameron, 1977; Jones and Joscelyn, 1978).[3]

A variety of individual characteristics (e.g. socio-demographic, attitudinal, personality, socio-environmental) predispose one to human conditions that often lead to driver error, which consequently results in a collision. Of all of the predisposing characteristics, age and sex of driver are consistently among the best predictors of accident involvement (Cameron, 1977). Young drivers (15 to 24), especially males, are overrepresented in all types of traffic accidents in most developed countries. Young drivers have accident rates from 2 to 10 times the rates for drivers of other age groups (Organization for Economic Cooperation and Development, 1975).

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[3]Relative risk is the probability of crash involvement at a particular BAC divided by the probability of crash involvement with a BAC of zero.

A variety of exposure variables have been suggested as explanations for the overrepresentation of youth among accident-involved drivers, especially involvement in more serious injury-producing collisions, such as: (1) driving at more hazardous times/locations (for example, night-time and weekends); (2) more frequent driving with passengers present (increasing the probability of distraction); (3) driving vehicles that are in poorer condition; and (4) more frequent use of two-wheeled vehicles. Although much work remains to be done concerning the effects of differential exposure, studies to date indicate that the overrepresentation of young drivers in the accident-involved population remains, even after a variety of controls on accident exposure (Organization for Economic Cooperation and Development, 1975; Preusser et al., 1975).

In addition to their overrepresentation in all collisions, young drivers also have the highest rates of alcohol-related crashes of any age group (Cameron, 1977; Flora et al., 1978).[4] The high rates of alcohol-related collisions among youth are apparently not due simply to increased driving after drinking. In fact, roadside breath test surveys have revealed that the proportion of youthful drivers with elevated BACs is the same as, or lower than, the proportion of drivers in their 30s or 40s with elevated BACs (Preusser et al., 1975; Wolfe, 1975).

An important explanation of the excessive rates of alcohol-related collision experience of young drivers is the finding that the relative risk of crash involvement at various BAC levels is higher for youth than the relative risk of crash involvement at the same BAC levels of middle-

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[4]Alcohol-related crash rate is here defined as the alcohol-related crash frequency divided by the total crash frequency for the relevant age group.

age drivers (Perrine et al., 1971; Zylman, 1972; Farris et al., 1975). Thus, a young driver with a given BAC level is more likely to be involved in an accident than an older driver at the same level, and the risk of a crash increases more sharply with increasing BAC levels for youth than for drivers of other ages.

The particularly high susceptibility to traffic crashes among youth as compared to older drivers at identical BAC levels may be due to the lack of extensive experience with drinking and driving after drinking among youth. Such an explanation was supported by the work of Hurst (1973) who reported that, among drinkers of all ages, those who drink infrequently have a higher relative risk of crash involvement at a given BAC level than frequent drinkers. Thus, although youth have been characterized as frequent heavy drinkers (Blane, 1979), their recent initiation into regular drinking may not have afforded them sufficient experience with drinking effects and driving after drinking for the development of compensatory actions that reduce the risk of an alcohol-related collision. A second explanation for the particularly serious effect of an elevated BAC on the risk of crash involvement among youth is that alcohol exacerbates the pre-existing impulsiveness and propensity toward risk taking behavior characteristic of adolescents and young adults (Klein, 1971; Pelz and Schuman, 1971; Makela, 1978).

2.3 Summary and Conclusions

The literature on motor vehicle accidents has revealed that, of the multiple environmental, vehicular, and human causes of collisions, human error is the central cause of most traffic accidents. These human errors are frequently a result of the alcohol-impaired condition of the driver. Drinking patterns of young people, characterized by a high prevalence of drinkers who regularly consume large quantities of alcoholic beverages per occasion, and increased sensitivity to impairment at a given BAC level of young drivers as compared to older drivers, combine to make them particularly susceptible to alcohol-related crash involvement. The combination of (1) high rates of motor vehicle collisions regardless of alcohol involvement (reflecting inexperience with driving), with (2) the highest proportion of all accidents involving alcohol of any age group (reflecting inexperience with drinking), indicates that young drinking drivers are an appropriate high-risk target group for the prevention of death and injury resulting from alcohol-related traffic accidents. The legal minimum drinking age has been identified as one potential mechanism that can be used as part of these prevention efforts.

3.0 ALCOHOL AVAILABILITY AND THE MINIMUM LEGAL DRINKING AGE

3.1 Alcohol Availability

Laws and regulations affecting the availability or accessibility of alcoholic beverages, of which the minimum drinking drinking is one example, have attracted increasing attention in recent years as a strategy for the prevention of alcohol-related problems. As discussed in considerable detail by Beauchamp (1980), since the repeal of prohibition, alcohol-related problems have been viewed as symptoms or consequences of a specific disease called alcoholism. With the emergence of a medical treatment establishment and groups like Alcoholics Anonymous focusing on those addicted to alcohol, individuals experiencing alcohol-related health and social problems were viewed as alcoholic or pre-alcoholic. While the specific etiology of alcoholism remained poorly understood, it was generally thought that those experiencing alcohol-related problems possessed a particular constellation of physiological or psychological traits that made them susceptible to the disease. The concept of alcoholism, by implication, proclaimed alcohol to be non-problematic for society at large, and for most beverage alcohol consumers.

One result of the dominance of the disease concept of alcoholism was a lack of attention to the role of laws and regulations in controlling alcohol use and associated social and health problems. If all alcohol-related problems are a result of the disease of alcoholism, which strikes certain individuals because they have particular traits that most people do not have, then public policy affecting alcohol availability is simply irrelevant when attempting to reduce the prevalence or incidence of alcohol-related problems. If acute public health problems such as accident morbidity and mortality are seen as symptomatic of alcoholism, solutions are focused on defining, identifying, and treating alcoholics, not investigating the effects of controls on alcohol availability. As a result, very little empirical research on the effects of alcohol control laws was conducted in the United States between 1930 and 1970.

One important exception to the absence of inquiry into the alcohol control law area was a series of papers produced by the Moreland Commission of New York State in 1963 (New York State, 1963, 1964; Bacon, 1971). The Commission concluded that, in general, extant beverage control laws did not have beneficial effects in reducing alcohol problems, and recommended relaxing restrictions on the marketing of alcoholic beverages. Although of limited scientific merit, and with admittedly poor data, the Commission's conclusions were accepted for several years, with the result that little detailed examination of beverage control laws was conducted during the subsequent decade.

During the 1970s and early 1980s, alcohol availability issues received increasing research attention, particularly in Europe and Canada, but also in the United States (Bruun et al., 1975; Wong, 1979 Harford et al., 1980; Moser, 1980; Frankel and Whitehead, 1981). Although U.S. studies in the 1970s focused on effects of specific availability changes such as the drinking age, by late in the decade the role of general alcohol availability was receiving more attention. Reports by the federal government discussed the potential of alcohol beverage control laws as one strategy for the prevention of alcohol-related problems (National Institute on Alcohol Abuse and Alcoholism, 1978; Alcohol, Drug Abuse, and Mental Health Administration, 1981). As a result, the role of alcohol availability and alcohol beverage control laws is receiving increasing attention among researchers and policy makers.

Although research on alcohol availability is increasing, a focus on alcoholism and chronic heavy drinking continues. Most recent research on relationships between public policy, alcohol availability, alcohol consumption, and alcohol-related public health problems has used cirrhosis mortality as the dependent variable. The effects of changing alcohol availability by lowering or raising the legal minimum age for purchase of alcoholic beverages is one area where the focus has been on acute alcohol problems, particularly traffic accidents.

3.2 Recent Research on Effects of Changes in Legal Drinking Age

As a result of the drinking patterns of young people, characterized by frequent intoxication, and the high rate of alcohol-related traffic accidents among young drivers, a major issue in the controversy surrounding drinking age has been the impact of changes in legal drinking age upon the incidence of motor vehicle accidents among young drinkers. After many states and Canadian provinces lowered the legal drinking age in the early 1970s, numerous evaluations were conducted of the impact of legal changes on the frequency of involvement in motor vehicle collisions among young drivers. Most of the investigations were based on comparisons between indices of youthful crash involvement before and after a reduction in legal drinking age took effect.

In addition to such pre-change post-change comparisons of crash involvement among youth within the state or province experiencing a reduction in drinking age, numerous studies included an assessment of pre-and-post-legal-change crash involvement for (A) comparison age groups not directly affected by the legal change (such as drivers over age 21), or (B) comparison jurisdictions that had not experienced a contemporaneous change in legal drinking age.

3.2.1 Lowered Drinking Age and Traffic Accidents. Williams et al. (1974) examined fatal traffic accident frequencies among 15-17 and 18-20-year-old drivers in Michigan, Wisconsin, and Ontario, where the legal drinking age had been lowered. Fatal accident frequencies for three years prior to and one year after the legal changes were compared to the contiguous states of Indiana, Illinois, and Minnesota, respectively, where the drinking age had not been lowered during the time period studied.

Significant increases in fatal crash frequencies were found for both the 15-17 and 18-20 age groups in the jurisdictions experiencing a legal drinking age reduction. Separate analyses of single-vehicle and nighttime fatal crashes, of which a large proportion are known to be alcohol-related, revealed larger increases in frequency than analyses of all fatal crashes. The observed increases in fatal crash involvement among youth were substantially larger for Michigan and Ontario than for Wisconsin. The smaller effect for Wisconsin was most likely a result of the less drastic change in the legal availability of alcohol. In Wisconsin prior to the legal change, 18-20-year-olds could legally purchase beer; the new law simply extended that right to all types of alcoholic beverages.

Naor and Nashold (1975) also studied the impact of the Wisconsin legal change upon highway fatalities. Although the frequency of alcohol-related fatalities did increase concomitant with the legal change, the proportion of all fatally injured drivers having elevated blood alcohol levels did not change significantly.[5] Naor and Nashold used the latter finding to argue that the reduced drinking age had no effect on traffic accidents among youth. However, since beer, the beverage of choice among young people, was legally available prior to the drinking age change evaluated, this investigation cannot be considered a valid test of the effects of a lowered legal drinking age.

Cucchiaro et al. (1974) evaluated the impact of reduced drinking age in Massachusetts using monthly time-series of traffic accidents. Traffic accident time-series were examined for the age groups 15-17, 18-20, 21-23, and 24 and over. The 18-20-year-old driving population experienced significant increases in total fatal crashes, alcohol-related fatal crashes, and alcohol-related property damage accidents, after the drinking age was lowered. None of the accident measures changed significantly for the 21-23 and 24-and-over drivers.

Douglass (1974), also using monthly time-series of motor vehicle crash involvement, assessed the impact of reduced drinking ages in Maine, Michigan, and Vermont. Collision involvement of 18-20 or 18-19-year-old drivers in these states was compared with collision involvement of 21-45-year-old drivers within the same state, and with 18-20-year-old drivers in Louisiana, Pennsylvania, and Texas, states which held the drinking age constant over the study period. Time-series analyses revealed significant increases in alcohol-related crash frequencies among the 18-20-year-old population in both Michigan and Maine. No significant increases in alcohol-related crash frequencies among youth were observed in any of the comparison states, nor were there any

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[5] Only fatalities for which a blood alcohol concentration test was administered were used in these analyses.

significant shifts for 21-45-year-old drivers within the experimental states. Douglass suggested that the lack of significant changes in traffic crash frequency in Vermont, which also lowered its drinking age, may have been a result of the relative ease with which 18-20-year-olds in Vermont could obtain alcoholic beverages prior to the reduced drinking age by driving to New York, which has had a drinking age of 18 since 1934.

Douglass and Freedman (1977) replicated some of the earlier analyses, using four years of observations after the legal change. According to the authors, the results demonstrated that the increase in alcohol-related crash involvement among Michigan youth, identified in the 1974 research, persisted over the four years after the reduced drinking age took effect (i.e., 1972 through 1975). Evaluation of the Michigan experience continued with Flora et al.'s (1978) analyses of fatal accidents in Michigan from 1968 through 1976. Although these authors did not use the same analytical techniques as Douglass, the impact of the 1972 reduction in legal drinking age upon alcohol-related traffic accidents among youth was again demonstrated.

An increase in alcohol-related collisions was also reported by Schmidt and Kornaczewski (1975), who examined yearly accident data for Ontario from 1967 through 1971. Although lack of monthly data and the inability to analyze separately only 18-20-year-old drivers made this study a conservative test of the effects of a reduced drinking age, the researchers found a significant increase in crash involvement among 16-19-year-old drivers after the law changed.

Whitehead et al. (1975) examined the crash involvement of 16-20 and 24-year-old drivers in London, Ontario, for the 1968 through 1973 time period. Increases of 150 to 300 percent in alcohol-related crashes among drivers age 18-20 were evident after Ontario's drinking age was lowered.[6] In contrast, 24-year-old drivers experienced only a 20 percent increase in alcohol-related crashes for the first year after the legal change, with their collision frequency returning to the pre-change level the second year after the reduced drinking age took effect. In a followup study, Whitehead (1977) examined an additional two years of collision data. A total of four years of crash involvement data after the reduction in drinking age demonstrated the permanence of the increased alcohol-related collision frequency documented in the 1975 investigation.

Warren et al. (1977) evaluated the impact of reduced drinking ages in Alberta, Manitoba, New Brunswick, and Saskatchewan on traffic fatalities between 1968 and 1975. Only those fatalities for which a blood alcohol concentration test was administered were included in the analyses. Frequency of alcohol-related fatalities for 15-20-year-old drivers before and after a reduction in drinking age were compared within each province. Some increases in fatalities among 15-20-year-old drivers were observed within the study jurisdictions at the time the drinking age was lowered. However, since blood alcohol concentration legally defined as drunk driving was reduced to .08 percent at about the same time that drinking ages were lowered, Warren et al. pointed out that the effects of the .08 legislation were confounded with the effects of lower legal drinking ages. Furthermore, insufficient numbers of pre-change observations were available to control adequately for the stochastic error in traffic fatality time-series. According to Warren

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[6]Police reports were used as indicator of alcohol involvement.

et al., although increases in fatalities among youth occurred after the drinking age was lowered, one is not able to conclude that the increases were due to drinking age changes.

One of the provinces investigated by Warren et al., Saskatchewan, was also studied by Shattuck and Whitehead (1976). After the drinking age was lowered from 21 to 19 in April 1970, 16-20-year-old drivers exhibited 20 to 50 percent increases in alcohol-related crashes.[7] After drinking age was lowered from 19 to 18 in June 1972, 16-18 year old drivers experienced further increases in alcohol-related collision involvement. Thus, two reductions in the legal drinking age were associated with increased alcohol-related crash involvement among both the newly enfranchised drinkers and the underage population.

Bako et al. (1976) examined the frequency of drivers with blood alcohol concentrations of .08 percent or greater among those fatally injured in the province of Alberta. An increase of 118 percent was observed in incidence of alcohol-related fatal collisions among 15-19 year-old drivers after the drinking age was lowered. The researchers concluded that their findings support the argument that lowered drinking ages lead to increased alcohol-related collisions among youth.

The reduction in legal drinking age for beer and wine in Illinois (from 21 to 19) was evaluated by the Illinois Department of Transportation (1977). Comparisons between fatality incidence in Illinois and five control states were used as the basis for the conclusion that the lowered drinking age in Illinois caused a 1.6 percent increase in fatalities among drivers age 19 and 20.

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[7]Police reports were used as indicator of alcohol involvement.

The National Institute on Alcohol Abuse and Alcoholism's Alcohol Epidemiologic Data System (1980) examined annual traffic fatality counts in the 50 states from 1970 through 1978. The authors concluded that ". . .differences in highway fatalities with the change in drinking laws do not appear significantly large." The authors readily admit, however, that their analyses did not adequately control for the effects of several confounding factors that occurred in the 1970s (e.g. fuel shortages, speed limit reductions, etc.).

After Alabama lowered its drinking age from 21 to 19 in 1975, alcohol-related crashes increased significantly among drivers age 18-20, according to Brown and Maghsoodloo (1981). Koch (1981) points out the methodological limitations of Brown and Maghsoodloo's study, and argues that it does not establish a causal connection between the drinking age and crashes, because the study did not include adequate comparisons between alcohol-related and non-alcohol-related crashes and between states that changed the drinking age and those that did not. However, the association between lowered drinking age and increased alcohol-related crashes in Alabama is consistent with the results from studies of other states, and provides additional support for the conclusion that lower drinking ages increase alcohol-related traffic crashes.

Lynn (1981) analyzed annual counts of alcohol-related crashes in Virginia from 1969 through 1979. Drivers age 16-20 experienced an identifiable increase in alcohol-related crash involvement beginning in 1974 when the drinking age for beer was lowered to 18. In contrast, drivers 25 and over experienced a decrease in alcohol-related crashes during the same period. The author concluded that the lowered drinking age was responsible for increased alcohol-related crashes among young drivers in Virginia in the late 1970s, and recommended a gradual return to the 21-year-old drinking age.

It is evident from the literature reviewed here that most of the investigations of the impact of lowered legal drinking ages on motor vehicle collision involvement have found significant increases in crash involvement frequencies among previously underage drivers who acquired the right to drink under the new laws (usually 18-20-year-old drivers). A number of studies have also demonstrated substantial increases in crash involvement among underage drivers (usually 16 and 17 years old) following reductions in minimum drinking age. Consistency of the results leads to the conclusion that lowered drinking ages result in increased highway safety problems among youth.

The view that lower legal drinking ages cause increased youthful crash involvement is not universally held, with Zylman a well-known opponent of a causal interpretation of the observed relationships. Zylman (1973, 1974, 1976, 1977) has criticized several of the studies reviewed above. He argues that observed increases in alcohol-related crash involvement among youth after the drinking age was lowered were not due to the drinking age change, but rather were a result of (1) random fluctuations in traffic accident time-series, (2) the continuation of trends of increasing alcohol consumption (and alcohol-related accidents) among youth evident prior to the legal changes, or (3) increased attention to alcohol-related traffic offenses by law enforcement officers. However, those studies explicitly controlling for both long-term trends and random fluctuations have also found effects of the lower drinking age. Secondly, although Zylman correctly points out the danger in relying on analyses of police-reported alcohol involvement, lowered drinking age effects (although of smaller magnitude than analyses based on police reports) have been observed using alternative measures of alcohol-involvement not influenced by police reporting practices, such as analyses of single-vehicle, nighttime, and weekend crashes.

3.2.2 Raised Drinking Age and Traffic Accidents. In addition to the evaluations of the lowered drinking age, there are several early reports on effects of raising the drinking age. Roy and Greenblatt (1979) compared the number of teenagers charged with driving under the influence of liquor (DUIL) appearing in Massachusetts courts before the legal age was raised with similar data for a one-month period after the drinking age change.[8] Small increases in youthful DUIL arrests were used to conclude that the raised drinking age led to increased drinking-driving problems among youth. This study, however, does not merit serious attention because of the following serious flaws in its design and data analyses: (1) DUIL arrests are an inadequate measure of alcohol-related highway safety hazards because young drivers are more likely than older drivers to be involved in an alcohol-related crash, but less likely to be arrested for DUIL (Organization for Economic Cooperation and Development, 1975);[9] (2) the design is a one-group pretest-posttest, inherently characterized by low internal validity because of its lack of a control group and an extended time-series of observations (Cook and Campbell, 1979); (3) related to the basic

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[8]The Massachusetts legal drinking age was raised from 18 to 20 on April 16, 1979. The pre-post comparison was the number of DUIL arrests in February 1979 versus the number in October 1979.

[9]In addition, subjective considerations are more likely to influence whether a particular drinking-driver is arrested than whether a drinking-driver is crash-involved.

inadequacy of the design is the lack of any statistical control on time-ordered trends, seasonality, or random fluctuations in the frequency of DUIL arrests. As a result, this study provides little useful information concerning the effects of a raised drinking age.

Another study of the higher drinking age in Massachusetts, with substantially better design and analysis methods, was conducted by Hingson et al. (1981). Analyses of fatal crashes among young drivers revealed no permanent effect of the higher drinking age. Self-reports (via telephone interviews) of quantity of alcohol drunk and driving-after-drinking behavior among young people did not change substantially as a result of the new law.

Filkins and Flora (1981), using a partitioned chi-square statistical analysis technique, analyzed youth crash involvement and frequency of arrest for Driving Under the Influence of Liquor (DUIL) in Michigan. Significant reductions both in crash involvement and DUIL arrests among 18-20-year-old drivers were found after the drinking age was raised. The authors concluded that the minimum legal drinking age "clearly influences" the drinking-driving patterns of young people.

Wagenaar (1980, 1981) analyzed a 20% random sample of all reported motor vehicle accidents in the State of Michigan between January 1972 and December 1979. Using a multiple time-series design, the frequency of alcohol-related crashes among young drivers was compared to the frequency of non-alcohol-related crashes, and the crash involvement of young drivers was compared with that of older drivers. Results showed an estimated 18% reduction in alcohol-related crash involvement among young drivers was associated with Michigan's increase in drinking age.

Williams et al. (1981) analyzed fatal crash involvement in nine states that raised the drinking age, comparing them to adjacent states with unchanged drinking ages during the period studied. Eight of the nine states experienced decreases in youth fatal crash involvement after the drinking age was raised. The authors concluded that raising the drinking age in any given state should result in a 28% reduction in nighttime fatal crash involvement among the age group affected by the legal change.

In summary, of the studies conducted to date on the effect of returning to higher drinking ages, most found significant reductions in drinking-driving or alcohol-related crash involvement after states raised the drinking age. The two studies that found no effect of a higher drinking age both examined the experience in Massachusetts. Furthermore, in Williams et al. (1981) study of fatal crashes in nine states, the estimated fatal crash reduction in Massachusetts was only 6%, a non-significant difference. Without further research, it is not clear why the Massachusetts experience with a raised drinking age was different from that in all of the other states examined to date.

3.2.3 Drinking Age and Alcohol Consumption Among Youth. Existing literature on the effects of changing the drinking age on youthful alcohol consumption has focused on three main types of alcohol consumption data: (1) self-reported consumption, (2) perceptions of youthful consumption patterns reported by school officials, and (3) aggregate sales volumes. Wolfe and Chapman (1973a, 1973b) surveyed Michigan high school students in 1971 before the drinking age was lowered, and again in 1973 after the reduction in drinking age, and found substantially increased frequency of drinking, and increased quantity consumed per occasion. According to the authors, the increases were consistent with pre-existing trends in youthful alcohol use, and therefore could not be unambiguously attributed to the lowered legal drinking age.

Smart and Schmidt (1975) conducted a similar before and after survey of Toronto junior and senior high school students. After a reduction in the drinking age, 41 percent of the students reported no change in drinking patterns, 20 percent reported drinking more, 4 percent reported drinking less, and 9 percent indicated that they had started drinking since the drinking age had been reduced. Smart and Schmidt also surveyed college students, the majority of whom reported no change in frequency or quantity of alcohol consumption, although 55 percent did report increased patronization of public drinking establishments since the legal change.

McFadden and Wechsler (1979) surveyed Massachusetts teenagers in 1965, 1970, and 1974. Youthful alcohol consumption increased between 1965 and 1970, when there was no change in the drinking age, as well as between 1970 and 1974, when there was a reduction in the legal age from 21 to 18. The authors also surveyed New England college students in 1977, and found that students from states with a low legal drinking age consumed alcohol more frequently than students from states with a high drinking age.

Rooney and Swartz (1977) surveyed high school students in three selected states with minimum legal drinking ages at 18, and two selected states with drinking ages at 20 and 21, respectively. The samples were not demonstrably representative of the high school age population in the states examined. They found that 42 percent of the responding students in states with the drinking ages at 20 or 21, and 47 percent in states with the drinking age at 18, reported consuming beer once a week or more. Furthermore, students in states with a high drinking age had a lower prevalence of abstainers (19 versus 24 percent), and a higher incidence of alcohol-related problems. The authors concluded that a high drinking age has no beneficial effect in controlling alcohol consumption among young people, and that it may even have adverse effects.

Opposite results were obtained by Maisto and Rachal (1980) in their analyses of a nationwide probability sample of high school students. They found that students in states with a higher legal drinking age were more likely to be abstainers, less likely to be heavy drinkers, and experienced intoxication less frequently than students in states with a lower drinking age. The authors concluded that the legal availability of beverage alcohol, as reflected in the drinking age, is associated with the drinking practices of young people.

Perceptions of school officials have also been used as an indicator of changes in youthful alcohol consumption concomitant with lowering the drinking age. Hammond (1973), questioning 354 Michigan high school principals, found that the majority reported more drinking among 15-17 year-old students after the drinking age was lowered. A similar survey in the Toronto area found that vice-principals reported more drinking among students at school functions after the drinking age was lowered (Smart and Schmidt, 1975).

The third major type of data that has been used to assess the impact of reduced drinking ages on alcohol consumption patterns is aggregate sales volumes. Smart and Schmidt (1975), in a comparison of

Ontario beverage alcohol shipments before and after a reduction in the legal age, found that consumption in the first five months after the legal change was higher than expected on the basis of the pre-change figures. Increased alcohol sales were particularly noticeable for on-premise sales, strengthening the argument that the lowered drinking age was at least a partial cause of the observed changes.

Barsby and Marshall (1977), examining aggregate distilled spirits sales in 25 states, did not identify any significant impact of lowered legal purchase ages on spirit sales. The authors temper their conclusions, however, by noting four limitations of their study. First, any change in distilled spirits consumption by youth following drinking age changes would have to be substantial before the impact would be seen in the aggregate statistics. Second, very little is known about changes in consumption patterns after legal changes; a change in location or quantity consumed per occasion resulting from the lowered drinking age, for example, could have significant adverse health consequences, independent of the total quantity consumed. Third, the analyses applied only to distilled spirits, not beer or wine, which are more popular beverages among young drinkers. Fourth, the time-span covered by the study was short, including only one year before and one year after the legal changes.

Douglass and Freedman (1977) avoided the last two design limitations of Barsby and Marshall's study by examining the monthly aggregate sales of draft beer, packaged beer, wine, and distilled spirits in Michigan over an eight year period. A statistically significant increase in draft beer sales was associated with lowering the drinking age. The authors attributed the shift in draft beer sales to the lowered drinking age, since no other confounding factors were identified that could have plausibly accounted for the observed relationship. No significant shifts were identified for any of the other beverage categories.

Smart and Goodstadt (1977) discussed a study conducted by Smart and Finley in which per capita beer consumption in ten Canadian provinces was examined. Eight provinces that lowered their drinking ages were compared with two that had not changed during the study period. Although increased beer sales were evident in the pre/post comparisons for three provinces experiencing a reduction in the drinking age, the increases were similar in magnitude to the experience of the two control provinces. Moreover, beer sales decreased in the other five provinces. Smart and Goodstadt conclude that the study's findings do not allow any general conclusion as to the effect of lowered drinking ages on total beer sales.

Finally, Smart (1977) compared sales of beer, wine, and distilled spirits in 25 states which reduced the drinking age with 25 states with unchanged drinking ages. Although no significant differences between the states were identified for wine or distilled spirits, increases in beer sales were about six percent greater in the states with lowered drinking ages than states with an unchanged legal age.

3.2.4 <u>Summary and Conclusions</u> A review of the literature on effects of changed legal drinking ages clearly indicates that there is an inverse relationship between the minimum age for purchase and consumption of alcoholic beverages and alcohol-related motor vehicle crash involvement among young drivers. In contrast, the literature concerning effects of changing the legal drinking age on beverage alcohol consumption among youth has significant methodological limitations and provides inconsistent results.

3.3 Model of Effects of the Legal Drinking Age

The impact of legal drinking age changes on traffic crash involvement is not direct, but rather is mediated by a variety of intervening variables. A model of the mechanism through which changes in legal drinking age cause changes in traffic crash involvement is presented in Figure 3.1. It is proposed that changes in legal drinking age influence drinking behavior and alcohol-related crash involvement by causing: (A) changes in social norms concerning youthful drinking, (B) changes in marketing activities of the beverage alcohol industry, and (C) changes in availability of alcohol to the target age group. Drinking norms change due to the symbolic function of the law (Bonnie, 1980; Mosher, J. F., 1980); that is, a reduction in legal drinking age may be perceived as an indicator that alcohol use is acceptable or even encouraged for young people. As a result, new patterns of drinking are established; young people who were non-drinkers or only occasional drinkers before the lowered drinking age experience increased social pressure to drink, as more of their friends and associates increase their drinking, and as they participate in more social situations in which beverage alcohol is an integral part. Such changes in drinking norms, according to the model, result in increased drinking among 18-20-year-olds after a reduction in drinking age. A higher drinking age is expected to have opposite effects, symbolizing society's disapproval of youthful drinking, causing the reduction or elimination of certain drinking patterns (bar and tavern drinking, for example), and causing a reduction in social pressure to drink, since alcohol is present in fewer social situations. Empirical support for these propositions is provided by Maisto and Rachal (1980), who analyzed data on a nationwide sample of high school students and found that youth in states with higher legal drinking ages report less peer approval of drinking and less perceived drinking among peers than students in states with lower drinking ages.

Marketing activities of the beverage alcohol industry are also expected to depend on legal drinking age. One would expect a low drinking age to result in advertising campaigns and location/design of drinking outlets oriented toward the youthful drinking population (for example, locating additional establishments with entertainment near college campuses). A higher drinking age is expected to reduce such marketing practices designed to encourage youthful drinking.

Changing the legal drinking age also results in altered availability of beverage alcohol to the affected population. The concept of beverage alcohol availability has numerous dimensions and has been defined in many ways (for example, physical availability, economic availability, and legal availability). For present purposes availability will be broadly defined as the ease with which alcoholic beverages can be obtained. On an individual level, availability of alcohol is an inverse function of total costs (monetary and non-monetary) of physically obtaining alcohol. These costs include: (A) nominal price of alcoholic beverages, (B) search costs involved in obtaining alcohol, such as value of the time expended and costs of any transportation required, and (C) risks associated with obtaining alcohol, a function of the perceived magnitude of potential disutilities accompanying attempts to acquire and use alcohol, and the perceived probability of experiencing such disutilities.

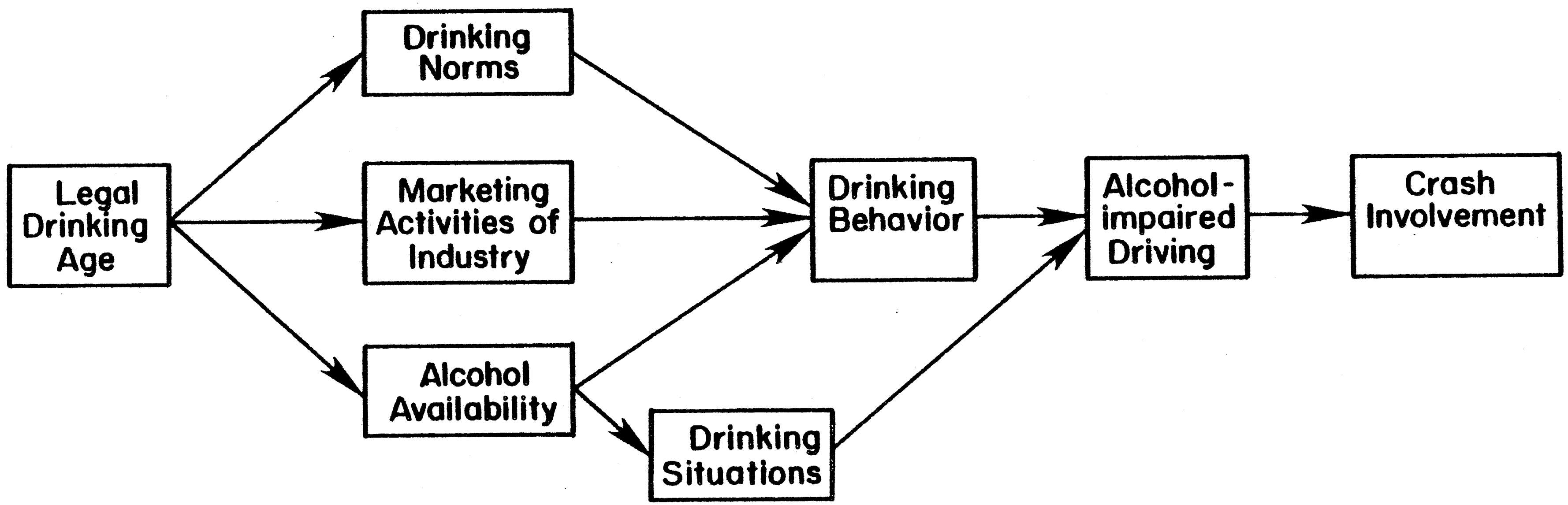

Figure 3.1 Model of the Impact of Changes in the Legal Drinking Age on Motor Vehicle Crash Involvement

Social policy at the aggregate level, such as a change in legal minimum drinking age, is expected to influence a number of the components of total cost of obtaining alcohol by underage individuals. The nominal cost of alcohol may increase with a raised drinking age as a result of a premium charged by those who supply alcohol illegally to underage drinkers. A raised drinking age is likely to increase the search costs (since there are fewer suppliers), and increase the risks associated with apprehension and processing by the law enforcement system.

The legal drinking age does not totally determine the availability of alcohol to underage drinkers, since numerous other aspects of both public policy and the private market of alcoholic beverages influence availability. What is argued here is simply that the legal drinking age is a significant influence on the ease with which alcoholic beverages can be obtained by young drivers. Support for this proposition is provided by cross-sectional surveys of high school students, which have revealed that young people residing in states with lower legal drinking ages are more likely to report that they can "obtain alcoholic beverages when they want them" than youth in states with higher drinking ages (Maisto and Rachal, 1980).

Returning to the overall model in Figure 3.1, increased or decreased frequency of alcohol consumption and quantity consumed per drinking occasion, caused by changed social norms, marketing activities, and alcohol availability, are expected to increase or decrease the amount of alcohol-impaired driving, and consequently, increase or decrease the frequency of alcohol-related collision involvement among drivers in the affected age group. Maisto and Rachal (1980) provide preliminary findings concerning the effect of such factors intervening between a legal drinking age change and alcohol-related crash involvement outcomes. Their analyses led to the conclusion that there was less alcohol consumed less frequently by students in states with higher drinking ages than in states with lower drinking ages. Furthermore, questions on driving after drinking revealed that students in states with higher drinking ages report less frequent driving after drinking than students in states with lower drinking ages.

In addition to the impact of changes in availability of alcohol on the quantity-frequency of alcohol consumed, changes in availability resulting from legal drinking age modifications are also likely to lead to important changes in the situations in which drinking takes place. Lowering the drinking age results in increased drinking in bars and taverns by the age group. Since private automobiles are likely to be the usual mode of transportation to and from such public drinking places, lowering the drinking age can be expected to increase the frequency of driving after drinking among the 18-20 age group. With regard to the effect of a raised drinking age, supporters of the lowered age have argued that raising the legal age of drinking will cause replacement of bar and tavern drinking with drinking in automobiles while driving, increasing the alcohol-related crash risk of the age group. An alternative plausible hypothesis is that a raised drinking age will result in a larger proportion of the drinking by 18-20-year-olds occurring at private parties. Since, in contrast to a public drinking house, participants are not as likely to be compelled to leave at a specific hour and drive home, the incidence of alcohol-related crashes might be lower with a raised drinking age. This hypothesis remains plausible even if one assumes that a raised drinking age has no impact on the overall quantity-frequency of alcohol consumed.

In short, changes in legal drinking age, according to the model presented in Figure 3.1, are expected to result in changes in drinking norms, industry marketing practices, alcohol availability, and the situations in which drinking takes place, all of which influence drinking-driving behavior of the 18-20-year-old age group. Note that this model illustrates plausible mechanisms by which the legal drinking age influences alcohol-related crash involvement frequencies. Several other socio-cultural, political, social-psychological, and situational exogenous variables are likely to have a causal impact on all of the variables in the system depicted in Figure 3.1. The purpose of the model is not to provide a comprehensive theory concerning drinking behavior and driving behavior, but only to indicate the potential causal factors mediating the impact of legal drinking age changes on the frequency of traffic accidents among youth. Although empirical evidence for the specific intervening variables postulated here is scant, early results of surveys of youthful drinking practices generally support the model (Maisto and Rachal, 1980). Further research examining the specific causal mechanisms through which legal changes influence crash outcomes is necessary.

3.4 Specific Research Questions

The core purpose of this investigation was to determine the effect of raising the minimum legal alcohol purchasing age on the frequency of alcohol-related crash involvement among young drivers. It could be argued that the raised drinking age also affected alcohol-related crash involvement among underage drivers (16-17), since the altered norms, marketing practices, and availability of beverage alcohol resulting from a changed drinking age may also influence drinking behavior of the proximal peers of the directly affected age group. It is reasonable to suppose that changed marketing practices and social norms concomitant with changes in drinking age would alter the visibility and acceptability of using alcohol among 16-17-year-olds as well as 18-20-year-olds. Furthermore, the availability of alcohol to 18-20-year-olds is likely to influence the ease with which youth age 16-17 obtain alcoholic beverages, since a prime source of alcohol for 16-17-year-old drinkers is likely to be older friends and associates with greater access to alcohol. Therefore, the effect of the raised drinking age on alcohol-related crash involvement of 16-17-year-old drivers was also analyzed. Because of the indirect nature of the impact of the legal drinking age on the collision experience of underage drinkers, however, the magnitude of the effect on underage drinkers was expected to be smaller than the effect on 18-20-year-old drivers. Furthermore, the impact on underage drinkers was expected to evolve over a longer period of time after a legal change than the impact on 18-20-year-old drivers, since a large portion of the effect of legal changes on underage drinkers is due to prior changes in drinking norms and practices among 18-20-year-olds.

A differential effect magnitude was also expected between a lowered and raised drinking age. It is usually much easier to change a person's pattern of behavior (here, alcohol consumption and drinking-driving) by adding new behaviors, without requiring a change in existing habits and established behavioral patterns, than it is to change personal behavior by requiring one to change or eliminate already established behavioral patterns. Consequently, one would expect a lowered drinking age, allowing (and perhaps encouraging) new drinking patterns to supplement pre-existing drinking or non-drinking patterns, to have a noticeably greater effect than a raised drinking age, restricting already established drinking patterns that have become a part of one's day-to-day activities. In short, it is easier to learn a new behavior than to unlearn an old one. Therefore, results of this research, in conjunction with results of previous research on effects of the lower drinking age, were used to determine whether raising the drinking age has the same magnitude of effect as lowering the legal age; that is, whether raising the drinking age reduced alcohol-related crash involvement as much as lowering the drinking age increased crash involvement.

A major intervening variable between legal drinking age change and crash involvement shown in Figure 3.1 is drinking behavior. One mechanism by which the drinking age is expected to influence alcohol-related crash involvement is by reducing the total quantity of alcoholic beverages consumed by young drivers, and as a result reducing alcohol-impaired driving. Therefore, another goal of the present investigation was an assessment of the extent to which the raised drinking age affected aggregate sales of alcoholic beverages.

4.0 METHODS

This chapter describes the methods selected to measure effects of changes in legal drinking age in Maine and Michigan. Methodological issues discussed include: (1) the quasi-experimental design used, (2) operationalization of the dependent variables (i.e., traffic crash involvement and alcohol consumption), (3) overall design validity of the study, and (4) time series statistical data analysis techniques.

4.1 Research Design

The preferred design for inferring a causal relationship is the true experimental design in which the subject population is randomly assigned to two or more treatment conditions. In the present study this would mean comparing young drivers randomly assigned to a condition of legal availability of beverage alcohol (lower drinking age), to young drivers randomly assigned to a condition of no legal availability of beverage alcohol (higher drinking age). Since such random assignment was impossible, a quasi-experimental design had to be used (Campbell and Stanley, 1966; Cook and Campbell, 1976, 1979). Of the numerous quasi-experimental designs in use, the nonequivalent multiple time-series design rules out the largest number of plausible alternative explanations for a postulated causal relationship. The design involves a comparison of a series of observations over time expected to be affected by the intervention, with comparison series not expected to be affected. In this research, the postulated causal relationship is between changing alcohol availability (i.e., changing the legal drinking age) and traffic accidents. The design, as implemented in the present investigation, can be diagramed in its simplest form as shown in Figure 4.1, where each O_i represents the number of crash involvements in a particular month, I represents raising the drinking age, n_1 is the number of monthly observations before the drinking age was raised, and n_2 is the number of monthly observations after the drinking age was raised. The second row in the design diagram represents a comparison time series, not influenced by the intervention included in the first row.

Although the simple diagram shown in Figure 4.1 depicts only one experimental and one comparison series, multiple measures of motor vehicle crash involvement and multiple comparison groups were included in the design. The broadest of the three levels of comparison included in the design was analyses of four different states (Figure 4.2), two that had raised the drinking age in the late 1970s (Maine and Michigan), and two with no such legal changes (New York with a consistent drinking age at 18 and Pennsylvania with a consistent drinking age at 21). Within each state comparisons were made between young drivers directly affected by the drinking age change and their proximal peers not the focus of the legal change (Figure 4.3). Since in Maine the drinking age was increased from 18 to 20, the crash involvement experience of 18-19-year-olds was compared to that of 20-21-year-olds, the two-year age cohort most similar to the focal 18-19 group, and yet were legally enfranchised drinkers throughout the study period. Similarly in Michigan, drivers age 18-20, the focus of the drinking age increase from 18 to 21, were compared to the three-year cohort 21-23.

In addition to the core experimental and comparison age groups, drivers age 16-17 were examined to assess any possible "trickle-down" effect of raising the drinking age. Finally, the crash involvement experience of older drivers (22-45 in Maine and 24-45 in Michigan) was

$$O_1 \quad O_2 \quad O_3 \cdots O_{n_1} \quad I \quad O_{n_1+1} \quad O_{n_1+2} \quad O_{n_1+3} \cdots O_{n_1+n_2}$$

$$O_1 \quad O_2 \quad O_3 \cdots O_{n_1} \quad I \quad O_{n_1+1} \quad O_{n_1+2} \quad O_{n_1+3} \cdots O_{n_1+n_2}$$

Figure 4.1 Non-equivalent Multiple Time-series Design

Experimental States Raising the Drinking Age		Comparison States with Unchanged Drinking Age	
Maine	Michigan	New York	Pennsylvania

Figure 4.2 First Level of Research Design Comparisons

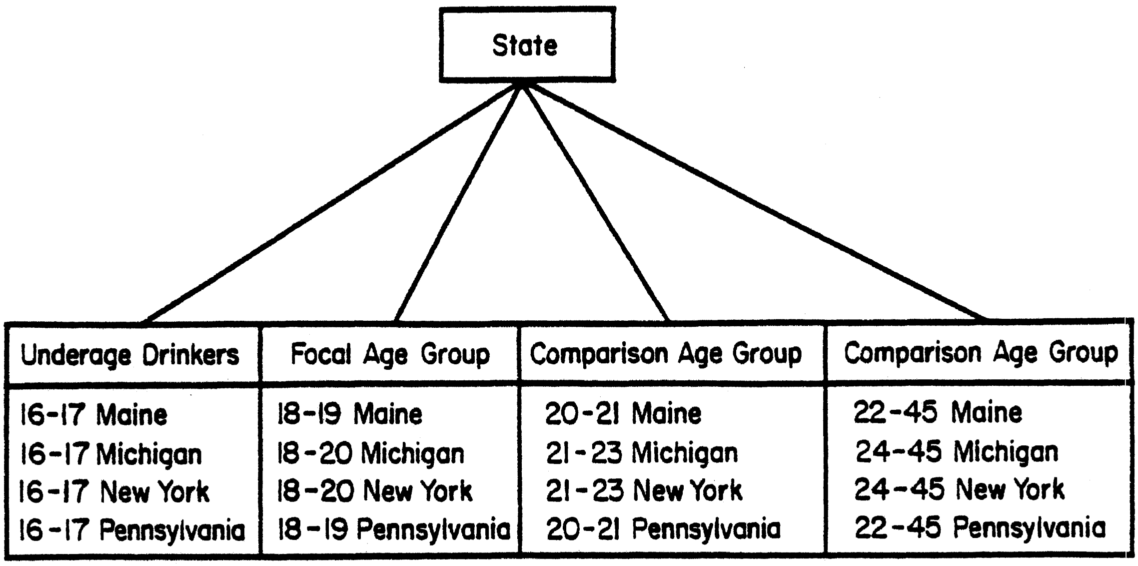

Figure 4.3 Second Level of Research Design Comparisons

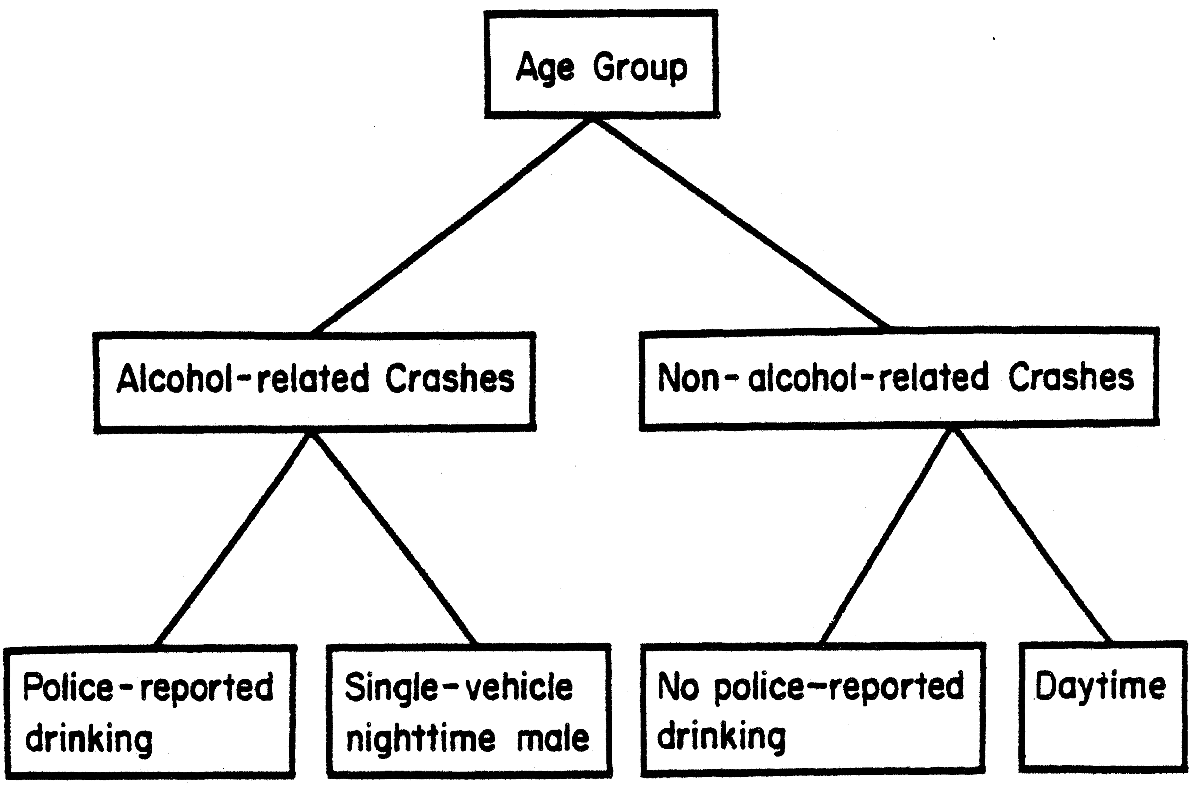

Figure 4.4 Third Level of Research Design Comparisons

analyzed to provide further comparisons with the crash experience of young drivers. The four age groups were analyzed for both the states that changed the drinking age as well as those that did not.

Within each state-age group combination, alcohol-related crash involvement was compared with non-alcohol-related crash involvement (Figure 4.4). Since the raised drinking age was expected to affect the frequency of alcohol-related crashes and have no effect on the frequency of non-alcohol-related crashes, comparison of these two classes of accidents indicated whether observed changes in crash frequencies were due to the drinking age changes or other coincident factors.

In short, the full tri-level hierarchical design involved the following comparisons: (1) states that raised the drinking age were compared with states with unchanged drinking ages; (2) within each state, crash involvement experience of young drivers was compared to that of older drivers; and (3) within each state and age group combination, the frequency of alcohol-related crash involvement was compared to the frequency of non-alcohol-related crash involvement. Each dependent variable in the full design matrix was analyzed for an extended time series of observations, using the statistical modeling methods described in section 4.4.

4.2 Operationalization and Data Collection

4.2.1 Definition of Variables. The core dependent time-series variables were measures of the monthly frequency of alcohol-related and non-alcohol-related motor vehicle crash involvement for the states and age groups included in the research design. Two indicators of alcohol-related crashes and non-alcohol-related crashes were analyzed. The first is based on information provided by police officers investigating traffic accidents. Accident report forms in many states include an indication of the officer's judgement concerning whether or not the driver had been drinking at the time of the crash. Some states, for example Michigan, include a separate dichotomous forced-choice item on the statewide standardized accident report requiring the investigating officer to identify the driver as non-drinking or drinking. The data resulting from such an item is a reasonably good indicator of the involvement of alcohol in a crash. In contrast, other states, such as New York, have police officers identify factors contributing to the crash, selected from a list of possible factors, of which alcohol consumption is one of 40 possible choices. The resulting data are a less adequate indicator of alcohol-related crash involvement because, although alcohol use interacts with many other crash causes, an officer must select one factor as the primary cause of the crash. For example, an officer might select "driver fell asleep" or "unsafe speed" as factors contributing to a crash, rather than "alcohol involvement," when in fact heavy drinking may have been the prior cause of falling asleep or speeding.

To provide a consistent indicator of alcohol-related crashes for comparison across states, and to control for reliability and validity problems in police-reported alcohol-involvement in some states, an indirect indicator of alcohol-related crashes was also analyzed. The alternative indicator involved separate analyses of male drivers involved in single-vehicle nighttime crashes. Previous research has shown that a majority of single-vehicle nighttime male crashes involve drinking drivers (Douglass, 1974). Daytime crashes were used as an indirect indicator of non-alcohol-related crashes for comparison with single-vehicle nighttime male crashes.

4.2.2 Crash File Construction. Data collection efforts were aimed at the acquisition of complete crash records for all crash-involved drivers reported to police authorities in each of the four states between January 1972 and December 1979. A census of all reported crashes was successfully obtained for Maine, Michigan, and Pennsylvania. Files for the State of New York were subset prior to acquisition. Two subset files were obtained; the first included all crashes occurring between January 1975 and December 1979 in which alcohol was reported (by the investigating police officer) to have been a contributing factor; the second New York subset file contained all single-vehicle crashes involving male drivers, also for the 1975-1979 period. Thus, both indicators of alcohol-related crashes were available, but no indicators of the frequency of non-alcohol-related crashes were analyzed for the State of New York.

Variables used from the original crash data files acquired from the states included: (1) police officer's judgement concerning whether or not the driver had been drinking; (2) type of vehicle (i.e. automobile, pickup truck, motorcycle, heavy truck, etc.); (3) age of driver; (4) sex of driver; (5) time of day the crash occurred; (6) severity of the crash (i.e., seriousness of injuries and property damage resulting from the crash); (7) and number of vehicles involved in the crash. The operational definition of most of these variables, for example age/sex of driver and time of crash occurrence, is straightforward and comparable across states. However, there were some differences in the definition of type of vehicle, number of vehicles involved in the crash, and reported alcohol-involvement. The definitions desired for this investigation are briefly discussed here, and specific items in each state's datasets are discussed in sections 4.2.2.1 through 4.2.2.4.

The vehicle type variable was simply used to exclude a variety of miscellaneous traffic units included in comprehensive crash files. The goal was to include drivers of automobiles, pickup trucks, and motorcycles, but exclude from the dependent variables drivers of a variety of miscellaneous traffic units such as farm tractors, snowmobiles, busses, and heavy trucks.

A single-vehicle crash for the purposes of this study was defined as a crash involving one vehicle in transport. Thus, one moving vehicle striking an automobile stopped in traffic is not a single-vehicle crash, while one vehicle striking a parked vehicle is a single-vehicle crash. Moving vehicles striking pedestrians or bicyclists were also not considered single-vehicle crashes, since pedestrians and bicyclists are moving traffic units and frequently cause the crash.

The desired operational definition of police-reported drinking behavior was the officer's simple judgement whether or not the driver had been drinking at the time of the crash, not a much more complex judgement by the officer concerning the extent to which alcohol consumption was a primary or contributory cause of the crash. Furthermore, results of chemical tests for the presence of alcohol in a drivers body were not used as an indicator for the incidence of alcohol-related crashes because only a small fraction of all drinking drivers involved in crashes are chemically tested for alcohol.

The datasets acquired from the several states had a variety of data structures and file formats, and therefore required different processing protocols. Details for each state follow.

4.2.2.1 Michigan. The State of Michigan, Department of State Police has routinely supplied The University of Michigan Highway Safety Research Institute (HSRI) with comprehensive crash data files since 1964. The data were originally formatted in a hierarchical structure, and were reformatted into rectangular files, with one record for each motor vehicle occupant, for use on the HSRI Automated Data Access and Analysis System (ADAAS). Because almost three quarters of a million drivers are involved in reported motor vehicle crashes in Michigan each year, 20% random samples of all crashes were selected for each year from 1972 through 1977, for use in HSRI's earlier research on Michigan's legal drinking age. To reduce data processing costs, these available files were used for the Michigan baseline time period for the present investigation. For 1978 and 1979, census files of all reported crashes in Michigan were constructed and used as the basis for the dependent variables used in this study. Because the 1972-1977 files contained only 20% of all crashes, the resulting crash frequencies for these years were multiplied by five to make them comparable to the 1978 and 1979 census data.

All of the Michigan datasets were filtered to include only drivers of passenger cars, trucks, and motorcycles. Excluded from analysis were the drivers of busses, farm and construction machinery, and other miscellaneous vehicles.

The Michigan crash files included nominal missing data rates on such variables as police-reported drinking, age of driver, and type of vehicle. Missing data rates for the 1978 Michigan file are shown in Table 4.1.

TABLE 4.1
Missing Data Rates for State of Michigan: 1978

Variable	Percentage Missing
Police-reported Had Been Drinking	8.7%
Driver Sex	0.0%
Driver Age	2.9%
Vehicle Type	4.7%
Time of Crash	0.0%
Month of Crash	0.0%

Driver records with missing data on any of the variables required by the research design were excluded from analysis. As noted earlier, the drinking involvement item on the statewide Michigan accident report form requires the investigating officer to make a decision about drinking for every driver of every crash-involved vehicle. As a result, the missing data rate is low compared to other states. The exact phrasing of the "had been drinking" item on the Michigan accident report form is: "Driver had taken alcohol or drugs" or "Driver had not taken alcohol or drugs". "Unknown" is coded in the data files only when the investigating officer leaves this item blank.

4.2.2.2 Maine. The State of Maine, Department of Transportation provided state accident data in a hierarchical format which was reformatted for use on the HSRI system. Unfortunately, the original Maine files did not contain the necessary information to link specific driver records with the corresponding record containing information on the vehicle they were driving at the time of the crash. As a result, miscellaneous vehicles could not be filtered out, and the Maine data used in the time-series analyses included all types of vehicles recorded in the original files.

The condition-of-driver variable was coded using the following six categories: (1) Apparently Normal, (2) Had Been Drinking, (3) Under Influence-Liquor, (4) Under Influence-Drugs, (5) Asleep, and (6) Fatigued. Any driver identified and "had been drinking" or "under influence-liquor" was considered a drinking driver for this study.

No unusual missing data problems were identified for the variables required for this research (see Table 4.2). Those cases missing information or with code values undefined for any of the required variables were excluded from subsequent analyses.

TABLE 4.2
Missing Data Rates for State of Maine: 1979

Variable	Percentage Missing
Condition of Driver	0.0%
Driver Sex	0.6%
Driver Age	1.2%
Time of Crash	0.0%
Month of Crash	0.0%

4.2.2.3 New York. New York motor vehicle crash involvement data were obtained from the New York Division of Alcohol Abuse and Alcoholism. Two sets of files were obtained for the 1975 through 1979 period. The first contained all crash involved drivers for which the investigating police officer indicated that alcohol was a contributing causal factor in the crash. The second set of files included all single-vehicle crashes involving male drivers. As a result, time series of police-reported alcohol-related crashes and single-vehicle nighttime male crashes were analyzed, but the frequency of all daytime crashes or crashes with no police-reported drinking were not available. The frequency of daytime single-vehicle male crashes was used as an indicator of non-alcohol-related crashes.

The frequency of police-reported alcohol-related crashes was relatively low in these New York data. About 3% of all 1979 New York crash-involved drivers were coded with alcohol as an apparent factor in the accident, while about 9.5% of all 1979 Michigan crash-involved drivers were coded as "had been drinking." Part of the difference is due to the nature of the item used to code alcohol involvement. As noted earlier, in Michigan the question put to the officer filling out the accident report is simply whether the driver had been drinking at all. In New York the investigating officer must make the more complex judgement that alcohol involvement was a contributory cause of the crash. Alcohol-involvement is one of 40 possible causative factors from which the officer must select two which he/she believes are the most important causative factors in the crash. Frequently immediate causes such as "excess speed" or "failure to yield" are coded rather than the alcohol-impaired condition of the driver, which often is the underlying cause of immediate driver errors that result in crashes.

Information on the type of vehicle involved in reported crashes was not included in the data files provided by New York. As a result, all vehicle types were included in the final time-series variables. Inclusion of all vehicle types in the analyses was not expected to affect the results since over 92% of all crashed vehicles in New York were automobiles, light trucks, or motorcycles (vehicle types which were the focus of this investigation).

An important change in crash reporting procedures in New York affected interpretation of the data. In September 1978 the minimum dollar amount of property damage for mandatory crash reporting was increased from $250 to $400. As a result, the number of recorded property damage crashes decreased.

Missing data rates for the New York crash variables are shown in Figure 4.3. Note that the lack of any missing data on the drinking variable was due to the nature of the variable. The choice "None" (i.e., no apparent causative factors) precludes the need for a missing data code. About 65% of all crash-involved drivers in New York had no apparent causal factor recorded.

TABLE 4.3
Missing Data Rates for State of New York: 1979

Variable	Percentage Missing
Police-reported Alcohol as a Causative Factor	0.0%
Driver Sex	4.5%
Driver Age	4.5%
Time of Crash	0.0%
Month of Crash	0.0%

Finally, since New York City is an unusual crash reporting jurisdiction, the final time-series variables were constructed in two sets. The first set of variables consisted of crashes occurring in the entire state, as was done for the other three states. The second set of variables were constructed excluding all crash reports from New York City.

4.2.2.4 Pennsylvania. A census of all reported motor vehicle accidents in the state of Pennsylvania from January 1972 through December 1979 was obtained from the Pennsylvania Department of Transportation. An important characteristic of the Pennsylvania data was changes in the criteria for reporting a crash which occurred between 1972 and 1979. Prior to June 30, 1977, local police departments were not required to use a statewide standardized accident report form, nor were they required to submit the reports to the State Department of Transportation. Beginning July 1, 1977, a uniform statewide reporting form was adopted and local police departments were required to submit these reports to the Pennsylvania Department of Transportation. At the same time the minimum reporting criteria for drivers involved in an accident also changed. Before June 30, 1977, drivers involved in any crash resulting in damage amounting to $200 or more had to report the crash to the local police department. After this date only accidents resulting in a vehicle being towed from the scene of the crash required reporting. Personal injury accidents always required reporting, both before and after these changes.

As a result of these data collection system changes, the frequency of reported injury crashes increased (all injury crashes were now reported to the state office on standard forms), and the frequency of reported property damage crashes decreased substantially (because property damage crashes were only reported if a vehicle was towed from the scene). Such effects of reporting system changes were controlled in the time-series analyses reported in Chapter 5.

Since the data received from Pennsylvania contained all reported accidents, the data were subset to include only drivers of passenger cars, light trucks (pickups, vans, etc.), and motorcycles. Due to incompatibilities between computer systems approximately 5 crashes per year were deleted from analyses. Since this very small data loss was a random occurrence it was not expected to affect the results.

As was the case in the other states, rates of missing data for Pennsylvania were quite low; the rates for calendar 1979 are shown in Table 4.4.

TABLE 4.4
Missing Data Rates for State of Pennsylvania: 1979

Variable	Percentage Missing
Alcohol as Causative Factor	0.6%
Driver Sex	1.3%
Driver Age	4.6%
Vehicle Type	3.6%
Time of Crash	0.7%
Month of Crash	0.0%

The police-reported drinking variable in Pennsylvania was coded much like New York. The investigating officer must identify alcohol as a causative factor in the accident, selected from a list of 91 possible causes. As a result, the percentage of all crashes reported as alcohol-involved was very low (2.6% in 1979). Also, note that the alcohol item in the Pennsylvania data indicated that the officer judged alcohol to be a causal factor in the accident; this alcohol item could not be linked to a particular driver involved in the accident. As a result, time-series were constructed of the frequency of Pennsylvania drivers involved in alcohol-related accidents, not the frequency of drinking drivers involved in crashes, as was done for the other three states in the present investigation.

4.2.3 Beverage Sales and Beverage Control Law Enforcement. In addition to the primary emphasis on traffic crash dependent variables, additional analyses were conducted of aggregate alcoholic beverage sales and data on the enforcement of the higher drinking age. Data on aggregate monthly beer, wine, and distilled spirits wholesale distribution in the State of Maine were obtained from the Maine Bureau of Alcoholic Beverages. The figures for monthly wholesale distribution of wine, draft beer, and package beer in the State of Michigan were obtained from the Michigan Beer and Wine Wholesalers Association. Data on wholesale monthly draft and package beer distribution in the State of New Hampshire and the United States as a whole, used for comparison with the Maine and Michigan results, were obtained from the U. S. Brewers Association. In addition to the analyses of aggregate beverage sales, annual frequencies of citations for selling or allowing minors to consume alcoholic beverages were briefly examined. Annual frequencies of such citations brought before the Administrative Court in the State of Maine from 1971 through 1979 were provided by the Maine Department of Public Safety, Bureau of Liquor Enforcement. Similar data for the State of Michigan for the period from 1970 through 1980 were provided by the Michigan Liquor Control Commission.

4.3 Research Design Validity

There are numerous potential threats to the validity of conclusions reached in any research. These can be categorized in a number of ways, the most frequent being the dichotomization of internal and external validity originally presented by Campbell and Stanley (1966). However, the present discussion is structured after the more comprehensive discussion of validity presented in Cook and Campbell's (1979) recent volume. Cook and Campbell present four major categories of research design validity: (1) statistical conclusion validity, (2) internal validity, (3) construct validity, and (4) external validity.

4.3.1 Statistical Conclusion Validity. Statistical conclusion validity is concerned with the possibility that random error and/or the inappropriate use of statistical tests may invalidate research conclusions. Statistical conclusion validity is essential to establish that there is in fact a covariation between the operationalizations of the concepts under investigation. Since covariation is the most basic prerequisite for establishing a causal relationship, one must first establish a valid covariation or statistical relationship prior to conducting a causal analysis.

There are a variety of threats to statistical conclusion validity. First, inadequate power of the statistical tests used may invalidate one's conclusion that no covariation is present. This threat to statistical conclusion validity was minimized by a number of design features in the present investigation. Since there is a direct relationship between sample size and power, a large number of observations over an extended period of time surrounding the intervention point were used in estimating the statistical relationships. Power was also increased by refraining from the use of very low levels of Type I error probability as the criterion for a statistically significant relationship, since power is directly related to the level of Type I error probability chosen.

Statistical conclusion validity was strengthened by the use of the most sensitive statistical methods available that could be appropriately applied to the data. For this reason, the present study was designed to meet the requirements of the recently developed Box-Jenkins transfer function methods (Box and Tiao, 1975; Box and Jenkins, 1976).

Finally, statistical conclusion validity can often be substantially increased by explicitly taking into account in the data analyses as many systematic components of the total variance in the dependent measures as possible, and thus reducing the error variance. As is discussed in Section 4.4 on the data analysis methods, extensive effort was expended to identify systematic components of the total variance in each dependent time series prior to an assessment of the statistical significance or magnitude of drinking age effects.

A second threat to statistical conclusion validity is the violation of the assumptions of the procedures used. This threat to validity is minimized by explicitly noting the assumptions accompanying the statistical procedures, the robustness of the procedures to a violation of those assumptions, and an assessment of the extent to which the assumptions are violated. Further discussion of the assumptions underlying the procedures used in this investigation, and an analysis of the extent to which the assumptions were met, can be found in Section 4.4.

A third threat to statistical conclusion validity is the analysis of multiple tests. Examining multiple tests increases the probability of making a Type I error; that is, it increases the probability of falsely concluding that covariation exists.[10] This threat to validity can be avoided either by explicitly making adjustments in the critical significance levels to account for the number of tests conducted (for example, using Bonferroni multiple t-tests; Dunn and Clark, 1974), or by concluding that true covariation exists only on the basis of a pattern of results rather than on the basis of one or two "significant" findings among a large number of tests conducted. In the present investigation, conclusions were made on the basis of the pattern of results over a number of tests, rather than one or two isolated statistically significant results. Furthermore, the significance criterion chosen for this study was the more conservative .01 probability level, rather than .05.

A low level of reliability in the measures constitutes a fourth threat to statistical conclusion validity. The result of low levels of reliability is an inflation of standard errors and a consequent reduction in the ability to detect covariations that may exist. In other words, low reliability reduces the power of the statistical procedures. The main control over this threat in the present study was the use of aggregate outcome measures, rather than measures based on particular drivers, accidents, or data collection sub-systems (such as a single community or county). The impact of random irregularities over time in the data collection systems of particular local jurisdictions was decreased when the data were aggregated at the state level. The result of statewide aggregation was a reduction in the effect of numerous random measurement errors occurring at the local level;

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[10]For example, if one sets the critical significance level at .05, one would expect to find five "significant" results in any 100 tests conducted, simply as a result of chance.

consequently, systematic patterns in the series were more easily discernable in the aggregated data.

A fifth threat to statistical conclusion validity identified by Cook and Campbell (1979:44) is "random irrelevancies in the experimental setting," that is, the random error in the observations due to all of the other influences upon the frequency of accidents that are not explicitly brought into the analyses.[11] It should be noted that a large number of other causes of crash frequency, although not explicitly identified, were controlled in the analyses by specification of systematic trend, seasonal, and other autocorrelation components in the dependent variables. In addition to the components of the series that reflect causal influences, part of the random component in each series is due to other omitted causal influences. The differential operation of these other factors across jurisdictions is suppressed by using aggregate data across a large number of jurisdictions. As in any research, there always remains, however, a random component due to omitted causes of the phenomenon under study. This random error over time, along with other random error due to measurement error, provides the basis for an assessment of the statistical significance of the effects of the legal interventions.[12]

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[11]Major exogenous factors with known effects on reported frequency of crashes include the fuel shortage and national maximum legal speed limit reduction of early 1974, and changes in criteria for reporting crashes. Known effects of such factors were explicitly controlled in the time-series models before assessing the drinking age impact.

[12]The model of statistical inference used in this research was an econometric or time-series model, where statistical significance of an intervention parameter is assessed by comparing its size with the size of the total random component in the dependent variable. The purpose of statistical inference was to separate the systematic effects from the random component, not generalizations to a specified population. For additional discussion of this issue, see Berk and Brewer (1978).

4.3.2 Internal Validity. After a high degree of statistical conclusion validity has been achieved, that is, after the existence of covariation between operationalizations of the concepts of interest has been established, the question as to whether the covariation is plausibly indicative of a truly causal relationship has to be addressed. Establishing the causal nature of observed covariations between operationalizations is the domain of internal validity. There are a large number of potential threats to the internal validity of an investigation and each threat should be explicitly considered and ruled out as a plausible explanation of the observed covariation. Through the successive ruling out of potential alternative explanations for observed covariations, one's confidence in inferring a causal relationship on the basis of the observed covariation is strengthened. Although from an epistemological point of view one can never actually prove the existence of a causal relationship, demonstrating the implausibility of potential alternative explanations, for all practical purposes, functions to establish the causal hypothesis as true until it can be disproved by new evidence. For these reasons, as many potential alternative explanations of observed relationships between the measure of beverage alcohol availability (i.e., legal drinking age) and measures of motor vehicle accidents as possible were analyzed before dismissing them as implausible explanations of observed covariations.

One potential alternative explanation of an observed relationship between legal drinking age changes and measures of accidents is that the proposed causal relationship is reversed, that is, changes in accident frequency bring about changes in the legal drinking age rather than vice-versa. This threat to internal validity was ruled out in the present design by the time-ordered nature of the measurements. A cause must precede in time its effects, and since the measures of the changes in legal drinking age precede the measures of accidents, the argument that the causal relationship is reversed was discarded.

A second major threat to internal validity is history, a contemporaneous event that may be the true cause of the observed effect. For example, one might argue that any downward shifts in accidents among youth after the increase in legal drinking age were due to the moderate gasoline shortage (and increased gasoline prices) of the late 1970s, and the resultant decrease in miles driven. The plausibility of such explanations of observed shifts in the dependent series was reduced by specific features of the research design. The use of quasi-control groups, consisting of the affected age group's older peers not affected by the drinking age change, and comparison states that have not altered their drinking age, permitted an assessment of the validity of alternative explanations, of which the gasoline shortage is one example. Such contemporaneous historical events would most likely affect all age groups in all four states, not just 18-19 or 18-20-year-olds in Maine and Michigan, and the effects of such factors would be observed in the comparison dependent variables.

A third threat to internal validity is maturation, gradual developmental changes in the dependent variables simply due to the passage of time. The time-series design used in the present research rules out this threat by including a series of observations prior to the intervention, permitting a determination of whether the post-intervention observations were simply the continuation of a pre-intervention maturational trend. It should be noted that a gradual trend in the dependent series can be attributed to maturational effects or to the effects of some omitted variables such as economic or population growth or decline; in any case, observed trends in the dependent variable series were explicitly taken into account in the data analyses.

A fourth potential threat to internal validity is instrumentation, a change in the measuring instrument occurring coincident with the intervention. That is, the process by which accident frequencies are measured may have changed at the same time point as legal changes in drinking age, and may account for any observed shifts in the series at the point of the legal changes. This argument is not a plausible alternative explanation of the proposed causal relationship because multiple comparison groups were included that would also have experienced basic changes in measurement process. Such changes in measurement process cannot be used to explain differential shifts in frequency of accidents for the 18-19 or 18-20 age groups as compared to age groups presumably unaffected by legal drinking age changes. The time-series nature of the design also reduces the plausibility of attributing observed changes in crash involvement at the time the drinking age was raised to instrumentation changes. With a large number of observations over an extended period of time prior to the intervention, a substantial instrumentation change exactly at the point of the intervention is less plausible.

Regression to the mean is another often mentioned threat to internal validity. Regression to the mean is a particular problem if an intervention is implemented exactly at a point at which the dependent series is at a very high or a very low point, since the subsequent observations will tend to be closer to the mean of the series simply by chance, regardless of any intervention effect. For example, if the drinking age was raised at precisely that point in time when alcohol-related traffic accidents among youth were at their highest level in years, one would expect the level of accidents to fall somewhat after that unusually high point. Such a regression effect could be mistaken as the effect of the drinking age change. Such an argument is not a threat to the internal validity of the present design for several reasons. First, a long series of observations was available prior to the interventions, facilitating determination of the exceptionality of the observations immediately prior to the interventions. Second, and perhaps more important, the data analysis techniques used to assess shifts in the series were based on all of the observations in the series, rather than relying only on observations immediately prior to and immediately after the intervention. Furthermore, the analysis methods take into account seasonality and autocorrelation regularities in the series, ensuring that the intervention effect identified was independent of effects due simply to the particular time points at which the interventions were implemented.

The sixth and seventh potential threats to internal validity are selection and mortality. That is, particular characteristics of the subjects selected for study, and particular characteristics of those subjects who drop out of the study, may invalidate the results. One type of selection threat occurs when differences in the kinds of subjects in the experimental and control groups account for differences in the post-intervention measures between the two groups, rather than an impact of the intervention. This alternative explanation was not a threat in the present design because the criterion for establishing an intervention effect was not simply differences in the post-intervention observations between experimental and comparison groups, but rather differences in the shifts found within the experimental and the control dependent series. However, when intervention effects are assessed by examining shifts within each of the series, selection and mortality may threaten internal validity if the composition of the experimental group changes substantially at the point at which the intervention was implemented, thus providing a plausible alternative explanation of observed shifts in the series. The composition of the experimental group does change over time with the addition of new drivers who attain the age of 18 and dropping out of individuals who attain the age of 20 or 21. This change in composition of the group, however, occurs gradually, with only a small proportion of the total experimental population changing from month to month. Furthermore, these changes in composition of the experimental groups are primarily due to a stable aging process that cannot be influenced by the intervention or extraneous factors. Thus, it was highly implausible that changes in the composition of experimental groups accounted for observed shifts in the dependent variables.

There are three threats to internal validity which involve interaction with selection of particular threats already discussed. First, selection-maturation refers to a differential maturational trend across the experimental and control groups. This was not a threat to internal validity for the same reasons that the main effect of maturation was not a threat, namely, the long series of observations available prior to the interventions, and the data analysis methods used, which explicitly take into account any maturational trends in each group's series of observations.

The second interaction threat to internal validity is the interaction of selection and history. It is possible that each experimental group experienced a different "local" history, and this differentially experienced contemporaneous event is actually the cause of shifts observed in the series concomitant with drinking age interventions. For example, two contemporaneous events, the moderate gasoline shortage and price increases of the late 1970s, and the ban on non-returnable beverage containers in Michigan and Maine (increasing the cost of alcoholic beverages), may have had a differential impact on the various age groups. One could conceivably argue that both of these contemporaneous events had an influence upon youth but not adults. Since youth may have less discretionary disposable income available, and since these contemporaneous events increased the cost of both driving and drinking, the ban on non-returnable beverage containers and the 1979 fuel shortage/price increases may explain why there were reduced alcohol-related accidents for youth and no such shifts for older age cohorts during 1979. If it is true that the increased cost of fuel and alcoholic beverages influenced the drinking and driving patterns of youth more than the drinking and driving patterns of older cohorts, the major fuel shortage and price increases of early 1974 should also have had a greater impact on young drivers. However, the time-series analysis results presented in Appendix B reveal that the 1974 fuel shortage/price increases did not affect young drivers more than older drivers. This finding reduces the plausibility of the argument that the increased fuel prices in the late 1970s account for the larger reductions in accidents observed for young drivers than older drivers.

The final interaction with selection that is a potential threat to internal validity is selection-instrumentation. This threat could obtain if alterations in the procedures for reporting alcohol-related accidents occurred only for accidents involving youth. The instrumentation change could then account for shifts in accident frequencies specific to this age group. This threat to internal validity is the argument most frequently used by those who favor lower drinking ages, to discredit observed covariations between drinking age changes and the frequency of collisions among young drivers. The argument is that with a lowered legal age police officers are more vigilant in reporting the presence of alcohol in crashes involving young drivers, and conversely, officers report fewer crash-involved young drivers as "had been drinking" when a high drinking age is in effect. Although the extent of any such police reporting bias has not been documented, the selection-instrumentation challenge to internal validity was controlled through the use of a second, indirect indicator of alcohol-related crashes as discussed in Section 4.2 (i.e., single-vehicle nighttime male crashes). It is highly unlikely that reporting of the driver's sex, the time of the crash, or the number of vehicles involved, would change at the time of the drinking age modifications, either for young drivers or for older cohorts.

Cook and Campbell (1979) also point out the potential threat to internal validity of the "diffusion or imitation of treatments," where there is contamination of comparison groups as a result of their experiencing a portion of the intervention. Diffusion of the interventions was possible in the present design for the 16-17 age group, since a major change in the level of availability of alcoholic beverages for the 18-19 or 18-20 age group indirectly changes the level of alcohol availability for the 16-17 age group. As a result, the interventions may have an impact on the 16-17-year-old cohort as well as the focal 18-19 or 18-20 age groups. Diffusion of the intervention to 16-17-year-olds was no threat to the present investigation since other comparison age groups, whose levels of alcohol availability were not affected by the interventions, were included in the design. Effects of drinking age changes on the 16-17 age group were directly assessed along with the impact upon 18-19 or 18-20-year-olds.

In summary, the goal in designing this research was to obtain valid conclusions as to whether reductions in availability of beverage alcohol, as represented by raising the drinking age, cause substantial reductions in the frequency of alcohol-related accidents. The first step was to establish that there was a true covariation between changes in availability and changes in accident frequency, achieved by assuring the statistical conclusion validity of observed shifts in the accident time series. The second step was to rule out extraneous hypotheses, those other than the causal hypotheses under investigation, that could plausibly explain the covariations observed. The result was high internal validity and a high level of confidence that the covariation observed represents a causal relationship between the particular operationalizations of alcohol availability and alcohol-related accidents. The next validity issue was whether the causal relationship established between the particular measures was, in fact, indicative of a causal relationship between the broader constructs of interest, namely, alcohol availability and alcohol-related traffic accidents. The relationship between the operationalizations or measures used and the theoretical constructs of interest is in the domain of construct validity.

4.3.3 Construct Validity. Construct validity answers the question, given the established causal relationship between the operationalizations used (i.e., high internal validity), do the operationalizations adequately reflect the concepts of interest? The first threat to construct validity is inadequate explication of constructs prior to their operationalization. Clear specification of the concepts of interest is an important aid for obtaining measures that are appropriate to the concepts under study.

A second threat to construct validity is labeled "mono-operation bias" by Cook and Campbell (1979:65). Mono-operation bias refers to the use of only a single operationalized measure of each concept. The use of single indicators prevents an assessment of convergent validity, that is, the extent to which different measures of the same concept produce the same result. Mono-operation bias was reduced in the present research through the use of multiple indicators of each concept. As discussed in Section 4.2, the traffic crash dependent variable measures include frequency of police-reported "had not been drinking" crash-involved drivers, frequency of police-reported accident-involved drivers where the driver "had been drinking," and an indirect measure of alcohol-related accidents based on previous research (i.e., single-vehicle nighttime male crashes). Furthermore, two categories of crash involvement were examined, frequency of property damage crash involvement and frequency of injury or fatal crash involvement. Use of such multiple indicators of traffic accidents and alcohol-related traffic accidents permitted an assessment of convergent validity. The measure of changes in alcohol availability was based on the effective date of the legal changes, and was accepted as a valid measure on the basis of face validity.

A threat to construct validity closely related to mono-operation bias is "mono-method bias" (Cook and Campbell, 1979:66). It refers to the reduction in construct validity that occurs if all the measures of a concept are based on the same data collection technique. The most difficult concept to measure in the present investigation, alcohol-related accidents, was measured using two methods. The "had been drinking" measure is based on judgements of investigating police officers, while the single-vehicle nighttime male indicator was empirically constructed on the basis of demographic characteristics of the driver and circumstances surrounding the collision.

There are three threats to construct validity that are potential reactive effects of the experimental situation. The first threat occurs if subjects within the various experimental conditions guess what the researcher's hypothesis is and act in such a manner to confirm (or contradict) that hypothesis. The second threat is "evaluation apprehension" (Cook and Campbell, 1979:67) on the part of the experimental subjects, where, as a result of the subjects' awareness of being evaluated, behave in a socially desirable manner. The third reactive effect that may threaten construct validity is the expectation of the experimenter. If the experimenter's expectations are communicated to the subjects under investigation or those who collect data, distortions in the subjects' behavior or the data collected may result. The experiment examined here was a natural part of the social environment, not imposed on the social system by outside researchers, and thus was unlikely to create reactive effects. However, a form of the third threat, experimenter's expectations, could threaten construct validity if expectations of police officers, who are responsible for collection of data on traffic accidents, influence reported frequencies of "had been drinking" crashes. This threat is minimized by use of measures over which the police had little control and were thus unlikely to be distorted by such subjective factors (i.e., single-vehicle nighttime male crashes).

Another threat to construct validity is somewhat obscurely labeled "confounding constructs and levels of constructs" by Cook and Campbell (1979:67). This source of invalidity occurs when there is implementation of only a small number of all possible levels of the intervention variable, and/or measurement of only a subset of all possible levels of the outcome variable. Invalid conclusions may result if the effect (or lack of effect) observed is due to the fact that only particular levels of the intervention are administered, or only a portion of the potential range of the outcome variables is measured. In the present design, the full range of possible values for the outcome variables was examined and the independent variable was a dichotomy (beverage alcohol legally available to an age group versus beverage alcohol not legally available to that age group). One could argue that the concept of alcohol availability is continuous and the present design only examines two of many possible levels of alcohol availability. If one accepts this very reasonable argument, it must be noted that the two levels of availability examined are at widely divergent points of the availability continuum. Although a detailed examination of the pattern of impact of marginal changes in availability of beverage alcohol was not possible, conclusions concerning the impact of a major change in availability upon motor vehicle accidents, the purpose of the present investigation, could be validly reached.

4.3.4 External Validity. External validity answers the question, given that one can confidently conclude that there is a causal relationship between the focal constructs, to what extent is this causal relationship generalizable across persons, settings, and times? The first major threat to external validity is the interaction of selection and treatment. That is, the plausibly causal relationship that has been established may only apply to the particular atypical population analyzed. The selection of a target population of all accident involved youth in four states, analyzing a census of all reported crashes, reduced this constraint on generalizability.

There are two major limitations on the populations to which findings can safely be generalized. First, since the analyses were limited to the aggregate of all reported crash involved youth in the four states, no generalizations can be made to particular youth subpopulations. For example, without specific analyses of particular subgroups based on socio-demographic or social-psychological variables, one cannot determine the differential impact of changes in legal availability of beverage alcohol upon particular types of youth. Although the overall impact was determined, this overall impact may be the result of differing impacts on particular subgroups of the total youth population. Second, because the analyses were based solely on the population in Maine, Michigan, New York, and Pennsylvania, the generalizability of the results is, strictly speaking, limited to these states. It must be recognized that generalizing to other states is based on one's judgement as to the similarity between those states and the states examined here, rather than based on explicit features of the research design. Since the jurisdictions studied include large heterogeneous states, generalization to numerous similar states and provinces can reasonably be made.[13]

The interaction of setting and treatment is a second basic threat to external validity. This limitation on generalizability occurs when the intervention effects observed are due to implementation of the interventions in a particular socio-cultural setting. Since the present investigation assessed the effects of changing legal drinking age in only one socio-cultural setting, one cannot necessarily generalize the results to widely different states or countries. However, the experimental setting was not substantially atypical of a number of industrialized states, and some generalization can plausibly be made, if it is done with caution, recognizing that one is generalizing by inference, not on the basis of explicit features of the research design.

A third major threat to external validity is the interaction of history and treatment. If intervention effects occur only under the particular historical circumstances present when the interventions were

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[13]One important difference between states, potentially limiting generalizability, is the degree to which the state is isolated from contiguous states with different drinking ages. For example, a raised drinking age is likely to have less impact in a state with a long border with a state that retains a lower drinking age because young drinkers may drive to the neighboring state to obtain alcohol. Such a situation is an example of the operationalized measure, a legal change in drinking age, not reflecting a major change in the construct of interest, alcohol availability. Since only a marginal change in alcohol availability occurs after a legal drinking age change in such circumstances, less effect on alcohol-related collisions might be expected.

implemented, the generalizability of the findings is limited. Comparing the results of this investigation of the raised drinking age with earlier studies of the lowered drinking age substantially reduced this threat to external validity. Since the differential impact of lowered drinking age in the early 1970s and raised drinking age in the late 1970s was examined, the plausibility of the argument that particular historical circumstances interacted with the drinking age intervention in both cases, bringing about both observed shifts, was greatly reduced. However, the drinking age changes were implemented in a particular historical period, and the extent to which similar results would occur during different time periods is unknown. For example, the Vietnam war, the military draft, and associated youth protest activities of the late 1960s and early 1970s may have facilitated the move to a lower age of majority (including drinking age). The movement to raise the drinking age may be affected by the frequently discussed conservative drift of the United States in the late 1970s and early 1980s. One can only speculate as to the effect of larger socio-historical developments on the interaction between drinking age public policy and motor vehicle accidents.

In summary, it is evident that a number of features of the design of this investigation, such as (1) appropriate use of sensitive statistical procedures, (2) use of long series of observations for multiple measures, and (3) analyses of multiple comparison groups, increase the validity of the findings. The high levels of statistical conclusion validity and internal validity of this study facilitate the establishment of a causal relationship between changes in the legal availability of beverage alcohol, as measured by modifications in the drinking age, and traffic accidents, as measured by the frequency of collisions. The levels of design validity for construct and external validity were somewhat lower, however, and broad generalizations to related concepts and other populations and settings should be made with care. In particular, the conceptualization and measurement of alcohol-involvement in traffic crashes requires further development. As Cook and Campbell (1979) pointed out, construct and external validity are, in the final analysis, matters of replication. Therefore, replication of the present investigation in other states, using various measures of the concepts and using the sensitive design and data analysis features used here, would strengthen the conclusion that there exists a general causal relationship between beverage alcohol availability and the frequency of alcohol-related public health problems.

4.4 Data Analysis Methods

Ordinary least squares regression and other commonly used statistical procedures assume independent observations, that is, no serial correlation between the observations. Since a series of observations on the same unit over time are very likely to be autocorrelated, violating the assumption of independence required for the use of standard statistical procedures, alternative data analysis strategies are necessary. One such approach is the modeling strategy of Box and Jenkins (1976) and Box and Tiao (1975). The Box-Jenkins approach involves modeling the autocorrelation in time-series variables to produce unbiased estimates of error variance in the presence of serially correlated observations.[14] Recent methodological developments

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[14]Reid provides evidence of the superiority of the Box-Jenkins methodology by applying five different time-series analysis and

in the use of transfer functions along with the Auto-Regressive Integrated Moving Average (ARIMA) modeling strategy make these techniques the best currently available for the analysis of time-series quasi-experiments (Box and Tiao, 1975; Hibbs, 1977; McCleary and Hay, 1980). The techniques identify a wide variety of patterns in dependent time-series variables, provide a sensitive test of intervention effects, and allow for the analysis of a variety of intervention effect patterns.[15]

The first step in the Box-Jenkins intervention analysis strategy is the identification or specification of a parsimonious Auto-Regressive Integrated Moving Average (ARIMA) model for each dependent time-series variable. The ARIMA model is commonly called the "noise model" since its purpose is to isolate all of the aspects of the stochastic autocorrelation structure of the series, and provide a benchmark for the assessment of intervention effects. The ARIMA model accounts for the variance in the dependent series that is due to identifiable trend,

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forecasting techniques to 113 different series. In the great majority of the applications, the Box-Jenkins techniques produced the smallest residual error variances. The Box-Jenkins techniques performed especially well with long series characterized by seasonal components (cited in Kendall, 1973:125-127). Other assessments of time-series analysis techniques generally support the superiority of the Box-Jenkins methods (see Vigderhous, 1977 for a brief review).

[15]See Glass, Willson and Gottman (1975:44) for a description of possible intervention effect patterns. The purpose of the data analyses in this investigation was to determine the impact of changes in legal drinking age on each dependent variable. After the effects of legal changes on each variable were determined through the statistical procedures described below, the effects were compared across those measures expected to be influenced by the legal change and those not expected to be influenced by the intervention. The present section discusses procedures used to determine the effect on each isolated dependent time-series; the comparison of these effects across experimental and comparison age groups, as called for in the design, is discussed in Chapter 5.0 on results of the statistical analyses.

seasonal, and other autocorrelation patterns in the data. The residual "white noise" or random error variance then permits a sensitive test of the statistical significance of intervention effects.

Since traffic accident time-series often contain large seasonal components, the general multiplicative seasonal model was applied to each dependent series. The general seasonal ARIMA model is shown in equation one,

$$z_t = \frac{(1 - \Delta_1 B^s - \ldots \Delta_Q B^{sQ})(1 - \theta_1 B - \ldots \theta_q B^q)u_t + \alpha}{(1 - \Gamma_1 B^s - \ldots \Gamma_P B^{sP})(1 - \phi_1 B - \ldots \phi_p B^p)(1 - B^s)^D (1 - B)^d} \qquad (1)$$

where p is the order of the auto-regressive process, d is the degree of non-seasonal differencing, q is the order of the moving-average process, P is the order of the seasonal auto-regressive process, D is the degree of seasonal differencing, Q is the order of the seasonal moving average process, s is the seasonal span, Γ_1 to Γ_P are the seasonal auto-regressive parameters, ϕ_1 to ϕ_p are the regular auto-regressive parameters, Δ_1 to Δ_Q are the seasonal moving-average parameters, θ_1 to θ_q are the regular moving-average parameters, u_t is the random (white noise) error component, α is a constant, and B is the backshift operator such that $B(z_t)$ equals z_{t-1}. It is important to realize that the ARIMA model is not based on a theory concerning the causes of the dependent series. It is a model to describe the nature of the ongoing regularities in the series due to any number of (most likely unidentified) causes. The ARIMA model for each variable, therefore, must be empirically determined by an examination of a series of observations of that particular variable.

Initial specification of an ARIMA model for a particular series was made on the basis of a visual examination of a plot of the raw series and the autocorrelation and partial autocorrelation functions estimated from the series observations. The raw time-series plot provided initial information as to trend and seasonal characteristics of the series, facilitating the identification of differencing factors and the seasonal span. Differencing refers to the calculation of a new series by subtracting each observation from a previous one in the same series. For example, the first difference is $z_t - z_{t-1}$, the first seasonal difference with a seasonal span of 12 is $z_t - z_{t-12}$; the second difference is the first difference of the first differences. Differencing is used to obtain a series with a constant mean or overall level, an assumption of ARMA models. The plot of the raw series was also visually examined for constant variance across the series; if the variance appeared non-constant, appropriate transformations were performed before proceeding.[16]

Theoretical autocorrelation and partial autocorrelation functions corresponding to various ARIMA models have been described by Box and Jenkins (1976). In the present study, a preliminary ARIMA (p,d,q) (P,D,Q)s model was identified for each series on the basis on an examination of the estimated autocorrelations and partial autocorrelations, assessing the degree to which the actual autocorrelations fit one of the theoretically expected patterns. The simplest model that could plausibly account for the behavior of the series was selected.

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[16]Range-mean plots can also be used to check for non-constant variance.

A first-order moving average, first-order seasonal moving average model on the seasonally differenced series was identified for the majority of the dependent variables.[17] In terms of the general model in equation one, the specific baseline model for most of the series is shown in equation two.

$$(2) \qquad z_t = \frac{(1-\Delta_1 B^{12})(1-\theta_1 B)u_t + \alpha}{1 - B^{12}}$$

The variance of several series was roughly proportional to the mean; therefore, they were logarithmically transformed before proceeding with model identification.

After an ARIMA model of the series was identified, transfer functions representing hypothesized effects of the raised drinking age were added to the ARIMA noise model. The general form of the transfer function is shown in equation three,

$$(3) \qquad y_t = \frac{(\omega_0 - \omega_1 B - \ldots \omega_s B^s)}{(1 - \delta_1 B - \ldots \delta_r B^r)}(I_{t-b})$$

where ω_0 to ω_s and δ_1 to δ_r specify the manner in which the "input" or independent variable I_t influences the "output" or dependent variable y_t, B is the backshift operator such that $B(z_t)$ equals z_{t-1}, I_t is either a step function with the value zero before the intervention and

[17]A plot of each time series and the final identified model is shown in Appendices A, B, C, D, G, I, J, and K.

one thereafter, or a pulse function with the value one for the month in which the intervention begins and zero otherwise, and b is a delay parameter indicating the length of lag or "dead time" between the intervention and the initial effects of the intervention (Hibbs, 1977:149).

The main intervention of interest in the present investigation was the increase in drinking age. In addition, since several reports found that the fuel shortage, national maximum legal speed limit reduction, and related factors of early 1974 resulted in a reduction in motor vehicle crashes (Borg et al., 1976; Burritt et al., 1975; Carpenter, 1974, 1975; Chu and Nunn, 1976; Dart, 1977; Kahane, 1975; Klein et al., 1976; O'Day et al., 1975; Seila et al., 1977; Tofany, 1975; United States Department of Transportation, 1978; Wiorkowski and Heckhard, 1977), a transfer function representing the effects of this major exogenous influence on the frequency of traffic accidents was included in the analyses of those variables exhibiting a substantial decrease in frequency in early 1974. Other major shifts in the dependent variables, due to reporting changes or other historical events, were controlled by including additional transfer functions where appropriate. All of the exogenous factors were modeled with simple forms of the general transfer function model shown in equation three.

Two specific forms of the general transfer function model were used in the present investigation, a temporary impact model ($\frac{\omega}{1 - \delta B} P_t$ where ω is the shift or change in level component, δ is the auto-regressive "memory" component, and P_t is defined as a pulse function), and an abrupt permanent impact model (ωI_t with I_t defined as a step function).[18] Using the Box-Jenkins nomenclature, these models are labeled as rsb (1,0,0) and rsb (0,0,0), where r is the order of the auto-regressive component, s is the order of the shift or change in level component, and b is the amount of delay or dead time after the beginning of the intervention before any impact is expected. No delay parameter b was included in the analyses because the initial effects of the legal changes were expected in the month immediately following the change in drinking age.[19] The impact patterns assessed by the models are shown in Figures 4.5 through 4.10. All of the major changes in the dependent time series variables were modeled with simple shift transfer functions (Figures 4.7 and 4.8) except the increase in draft beer sales in Michigan following the 1972 reduction in drinking age, which was best explained by a temporary impact model (Figure 4.10).

After the order of the ARIMA component was identified on the basis of a plot of the raw data and autocorrelation and partial autocorrelation functions, and the appropriate transfer function components were added, preliminary estimates of the parameters of the identified model were calculated on the basis of the raw data plot and the estimated autocorrelations. These preliminary estimates were input

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[18]Techniques for specifying the form of the transfer function model on the basis of cross correlations between input and output series (following similar principles as outlined above for the specification of ARIMA models), have been proposed (Box and Jenkins, 1976; Haugh and Box, 1977). However, these procedures require the variance of the input series to be similar in magnitude to the variance of the output series. Since this investigation involved dummy input variables and output accident variables with large variances, such empirical transfer function identification procedures could not be used. Instead, transfer function models were specified a priori on the basis of theoretical expectations, and assessed within an hypothesis testing framework.

[19]Immediate effects of the higher drinking ages were hypothesized because previous research had identified immediate effects of both lowered (Douglass, 1974) and raised (Wagenaar, 1980) drinking age.

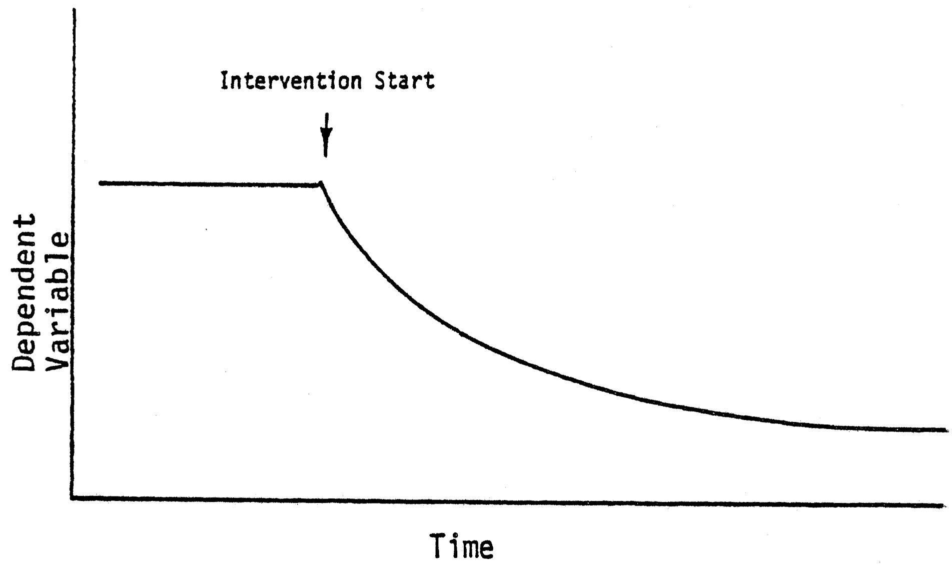

Figure 4.5 Negative Impact Pattern Estimated by the rsb (1,0,0) Transfer Function Model with a Step Function Input

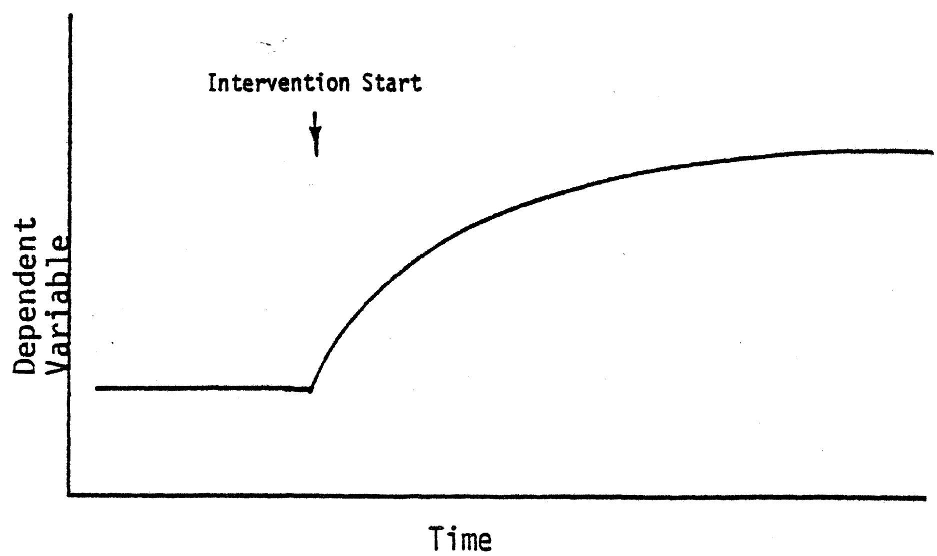

Figure 4.6 Positive Impact Pattern Estimated by the rsb (1,0,0) Transfer Function Model with a Step Function Input

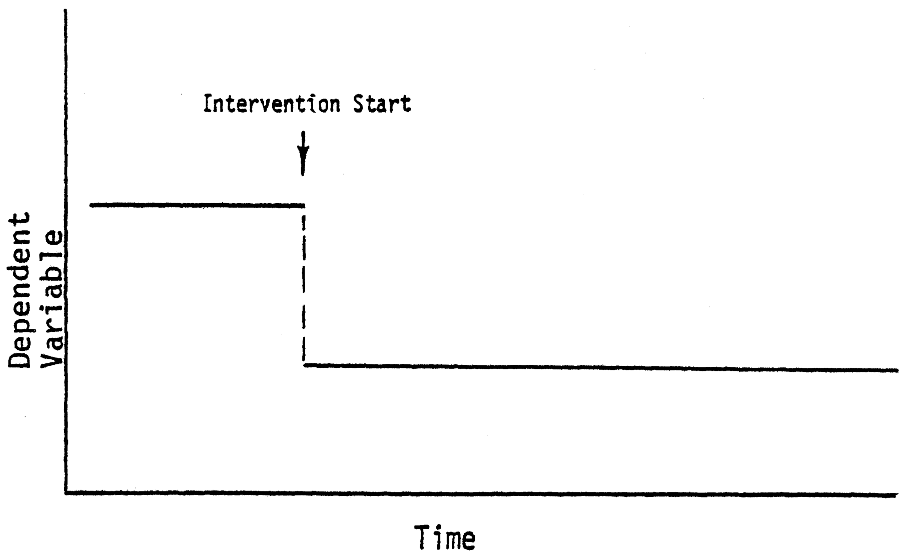

Figure 4.7 Negative Impact Pattern Estimated by the rsb (0,0,0) Transfer Function Model with a Step Function Input

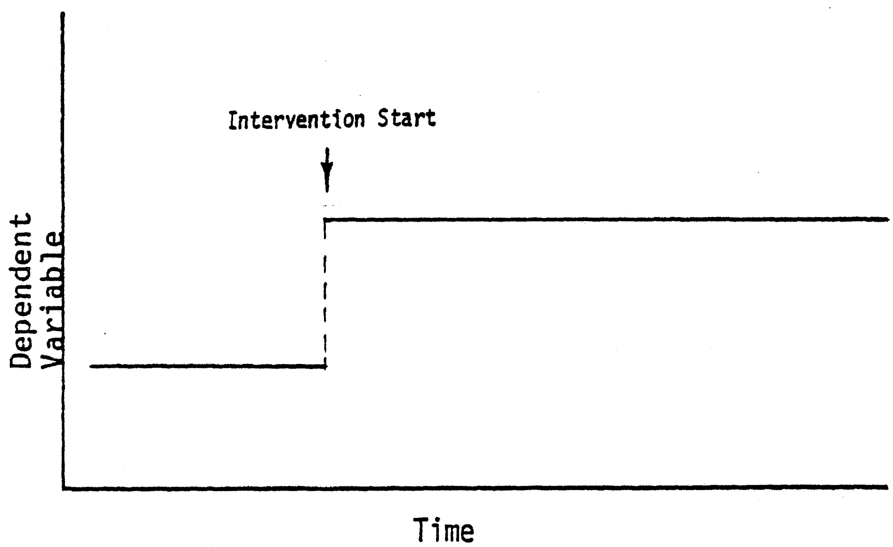

Figure 4.8 Positive Impact Pattern Estimated by the rsb (0,0,0) Transfer Function Model with a Step Function Input

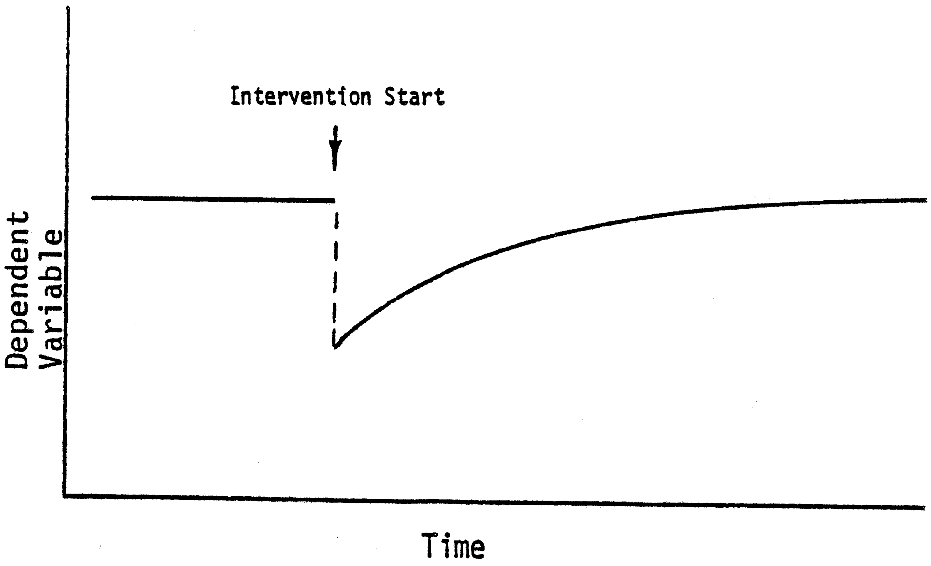

Figure 4.9 Negative Impact Pattern Estimated by the rsb (1,0,0) Transfer Function Model with a Pulse Function Input

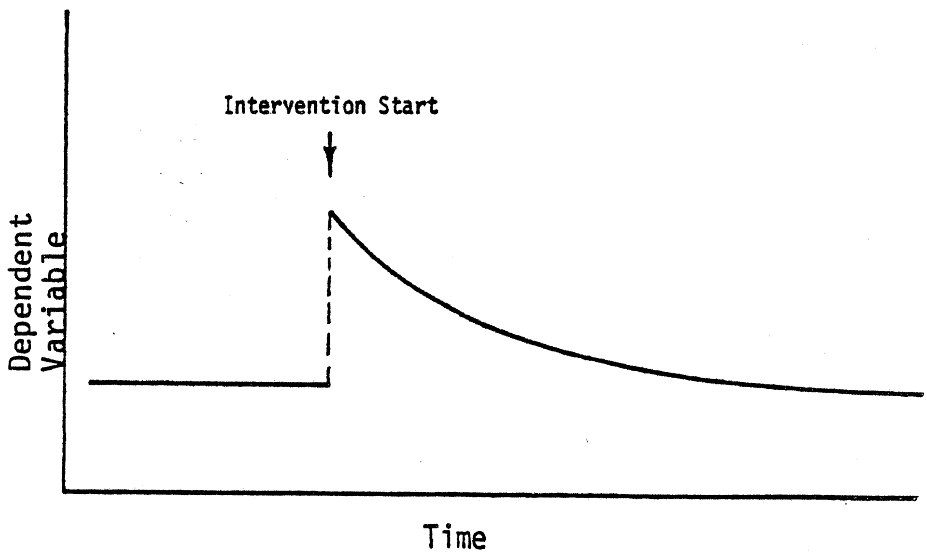

Figure 4.10 Positive Impact Pattern Estimated by the rsb (1,0,0) Transfer Function Model with a Pulse Function Input

as starting values for the computer estimation program BMDQ2T (Liu, 1979). Since the models are intrinsically non-linear, BMDQ2T uses the Gauss-Marquardt method to obtain maximum likelihood estimates of the parameters. The unconditional least squares (i.e. backcasting) estimation algorithm was used rather than conditional least squares because seasonal moving average models were being estimated; Box and Jenkins (1976) recommend unconditional least squares estimation for such models.

Perhaps the most important step in the Box-Jenkins modeling strategy follows the initial estimation of a model. The estimated model must be evaluated with regard to its parsimony and its ability to account for all of the autocorrelation patterns in the original series. There are several considerations in assessing model adequacy. First, the estimated parameters should meet the conditions of stationarity-invertibility required for the particular model under consideration (Box and Jenkins, 1976). Second, the estimated parameters of the ARIMA component should be significantly different from zero. Third, the correlations among the parameters should not be excessive, indicating redundancy in the model specified. Fourth, the overall "flatness" of the autocorrelation function of the residuals should be documented by a non-significant Q-statistic (Box and Pierce, 1970; Ljung and Box, 1976). Fifth, the autocorrelation function should not reveal significant correlations at the first few lags or the first seasonal lag. Sixth, parameter estimates should be interpretable in terms of theoretical expectations and known characteristics of the dependent variable.

Inadequacies in the combined ARIMA/transfer function model, detected when evaluating the estimation results, were used to guide re-specification of the model. After re-specification, maximum likelihood estimates were obtained, and the revised model was evaluated according to the above criteria. If the model was still inadequate, the specification, estimation, and evaluation steps were repeated again; if more than one model was adequate by these criteria, the model with the lowest sum of squared deviations from the fitted model was selected. The values of the transfer function parameter estimates, along with unbiased estimates of their standard errors, were used to determine the existence of effects of the interventions, and where intervention effects were evident, to assess the direction and magnitude of the impact in terms of the number of crashes apparently caused by or prevented by the intervention.

All of the specific models fit to the series were variations of the underlying model which views a particular time series as a realization of a general discrete linear stochastic process (Nelson, 1973:30-33). In modeling a time-series as a realization of a discrete linear stochastic process, one assumes that: (1) the time-series is stationary and characterized by a constant mean, i.e., the series does not exhibit a substantial trend or change in overall level, (2) all random errors (u_t in equation one) are drawn independently from the same distribution over time and thus are characterized by constant variance, and (3) the autocovariances are constant over time, depending only on the extent of lag between the observations. If one adds the assumption of normally distributed errors, what is referred to as strict stationarity is achieved. The assumption of a stationary mean or level in the original series is not strictly required, because the model remains appropriate provided stationarity is obtained after using the appropriate differencing factors on the original series. If a stationary level is obtained after differencing, the series is said to exhibit "homogeneous non-stationary behavior" (Box and Jenkins, 1976:11).

An important strength of the Box-Jenkins modeling strategy is that an assessment of the extent to which the assumptions underlying the analyses are met is explicitly included in the model building process. Thus, after each particular model was specified and estimated, the residuals were examined to ensure that they displayed the characteristics of white noise (i.e., were independently and identically distributed with constant variance).[20] Evidence that the assumptions of the model were met increased the validity of the findings.

In summary, the data analysis strategy was as follows. First, an ARIMA noise model was specified on the basis of a plot of the raw series and the estimated auto- and partial autocorrelation functions. Second, transfer functions for the major exogenous factors were added to the noise model and the combined noise and intervention model was estimated. The combined model was evaluated and the specification, estimation, and evaluation process was repeated until an adequate model was obtained. The statistical significance and magnitude of the transfer function parameter estimates were used to identify the impact of a legal change in drinking age on that particular time series dependent variable. The data analysis strategy was repeated for each dependent variable, and the results, as called for in the research design, were compared across (1) indicators of alcohol-related accidents and indicators of non-alcohol-related accidents, (2) experimental age groups (youth under 20 or 21)

[20]A more general discussion of the importance of examining residuals to ensure that assumptions are not violated is provided by Draper and Smith (1966).

and comparison age groups (drivers over 20 or 21), and (3) states that changed their drinking age (Michigan and Maine) and states that did not (New York and Pennsylvania).

5.0 FINDINGS

Results are presented in three sections. Section 5.1 presents the findings of the main study, the effect of the drinking age on traffic crashes. Section 5.2 discusses analyses of aggregate alcoholic beverage sales in several states, where the effects of the drinking age and other public policy changes were evaluated. Finally, section 5.3 examines data on beverage control law enforcement activities and the role of enforcement when using the minimum drinking age as an alcohol-related problem prevention strategy. In each of these sections, the main findings are discussed and summarized in tabular form. Additional information on the data and statistical models used is provided in the appendices.

5.1 Effects of the Raised Drinking Age on Motor Vehicle Crash Involvement

Results of the time-series modeling of crash involvement in Michigan, Maine, New York, and Pennsylvania are summarized in Tables 5.1 through 5.12 below. Shown for each dependent variable is the estimated average change in monthly frequency of driver crash involvements after a change in drinking age was implemented. As noted in the tables, some series were logarithmically transformed to reduce heteroscedasticity, that is, variation over time in the series variance. In such cases, the parameter estimates refer to the log of crash frequency, and cannot be directly interpreted as the change in number of crash-involved drivers per month. In addition to the time-series model estimates, the summary tables include the t-ratio for the estimates, and the estimates calculated as percentage change between actual crash involvement frequencies after the implementation of the raised drinking age and the frequency expected had there been no change in drinking age.[21]

The reader is encouraged to concentrate on the percent figures, comparing changes in alcohol-related crash involvement with changes in non-alcohol-related crash involvement, and comparing changes in crash involvement for young drivers with the figures for older drivers. The t-ratios identify those shifts in crash involvement that are statistically significant (indicated in the tables with footnotes). Note that the results summarized in Tables 5.1 through 5.12 were extracted from comprehensive models for each time-series dependent variable. The estimates, therefore, represent the net change in crash involvement associated with raising the drinking age, controlling for the effects of long-term trends, seasonal cycles, and other major factors affecting the frequency of reported crash involvement, including motor fuel shortages, maximum speed limit changes, and modifications in criteria for reporting a crash. Taking into account these factors produced models which in most cases explained well over 50% of the variance in the dependent variables. A plot of each time series, the complete model developed for each series, and an estimate of goodness of fit between each model and the data (i.e. the adjusted R-square statistic) are shown in the appendices.

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[21]Percent change figures were based on the first 12 months after an increase in drinking age, and were calculated as follows:

$$(100)\frac{12\omega}{\left(\sum_{i=1}^{12} f_i\right) - 12\omega} = \text{percent change}$$

where ω is the shift in the frequency of driver crash involvement estimated by the time-series model, and f_i is the actual monthly frequency of crash involvement.

5.1.1 Michigan. Net changes in property damage crash involvement associated with the December 1978 increase in drinking age in Michigan are summarized in Table 5.1. The following findings emerge. First, alcohol-related crash involvement decreased significantly for drivers age 18-20, the target of the increase in drinking age (see Appendix B, Figure 10); non-alcohol-related crash involvement also decreased significantly for this age group, but the magnitude of the decrease is only half as large as the decrease in alcohol-related crashes. Subtracting the percent decrease in general non-alcohol-related crash involvement from the percent decrease in alcohol-related crashes produces a net reduction of 11 to 22 percent in alcohol-related property damage crash involvement attributable to implementation of the higher drinking age. The 11 to 22 percent reduction represents 725 to 1,617 fewer young Michigan drivers involved in alcohol-related property damage crashes over the first 12 months with the higher legal age than would have been expected had the drinking age not been increased. The conclusion that the raised drinking age is responsible for these observed crash reductions is strengthened by the results for the older age groups; drivers age 21-23 and 24-45 exhibited no significant change in crash involvement, in contrast to 18-20-year-olds, the target of the drinking age change.

A second major finding was that there was no observed effect of the raised drinking age on the frequency of property damage crashes among 16- and 17-year-old drivers. Although police-reported alcohol-related crashes decreased significantly, crashes with no police-reported drinking decreased by about the same amount; as a result, the decrease

TABLE 5.1
Time-series Model Estimates of Changes in Property-damage-only Crash Involvement Associated With Raising the Legal Minimum Drinking Age in Michigan

Type of Crash	Age of Driver			
	16-17	18-20	21-23	24-45
Alcohol-related Indicators				
Police-reported Drinking				
Estimate	-21.4	-208.2	-7.6	44.9
T-ratio	3.0[1]	7.2[1]	0.5	1.2
Percent	-14.7	-34.0	-1.7	3.8
Single-vehicle Nighttime Male				
Estimate	-34.9	-129.4	-31.2	-20.7
T-ratio	2.6	5.1[1]	2.3	0.5
Percent	-15.5	-24.0	-8.8	-2.5
Non-alcohol-related Indicators				
No Police-reported Drinking				
Estimate	-400.2	-0.1[2]	-0.1[2]	-0.1[2]
T-ratio	3.7[1]	3.0[1]	2.4	2.3
Percent	-13.3	-12.2	-10.4	-9.5
Daytime				
Estimate	-324.2	-539.9	-315.5	-1186.7
T-ratio	3.4[1]	2.9[1]	2.0	2.4
Percent	-13.3	-12.8	-9.6	-10.0

[1]P<0.01, two-tailed test.
[2]Series logarithmically transformed to reduce heteroscedasticity; estimate based on transformed series.

in alcohol-related crashes cannot be attributed to the drinking age increase.

A third trend evident in Table 5.1 is that the parameter estimates for non-alcohol-related crash indicators for all age groups are negative and have relatively large t-ratios, even if not significant at the .01

level. Furthermore, all of these estimated crash reductions are in the 10 to 13% range. Reduced economic activity in Michigan in 1979 is the likely cause of the uniform reduction in general non-alcohol-related crash frequency across all age groups.

The effect of a raised drinking age was also evident from analyses of injury and fatal crash involvement in Michigan (Table 5.2). Police-reported alcohol-related accidents among 18-20-year-olds decreased 28 percent when the drinking age was raised; single-vehicle nighttime male crashes decreased 22 percent. Daytime injury and fatal accidents also decreased significantly for this age group but the magnitude of the decrease was only half as large as the decrease in nighttime crashes. If one subtracts the 11 percent decrease in daytime accidents from the 22 percent decrease in single-vehicle nighttime male crashes, an 11 percent reduction in alcohol-related accidents remains attributable to the raised drinking age. Since there was no significant change in crashes with no police-reported drinking, the 28 percent reduction in police-reported alcohol-related accidents also can be considered an estimate of the effect of the drinking age change. In short, raising the drinking age resulted in an 11 to 28 percent reduction in alcohol-related injury/fatal motor vehicle crash involvement. This 11 to 28 percent reduction represents 373 to 1,726 fewer young drivers involved in injury/fatal crashes over the first 12 months after the drinking age increase than would have been expected had the law not been changed. The conclusion that these reductions are due to the drinking age is strengthened by finding no significant reductions in alcohol-related or non-alcohol-related crashes among drivers age 21-23 or 24-45. In fact, results for drivers age 24-45 indicate increased alcohol-related crash involvement, in contrast to the decreases evident for 18-20-year-old drivers. Although the increases among drivers age 24-45 were not significant at the .01 level, examination of the time-series plots reveals higher alcohol-related injury/fatal crash involvement in 1979 than previous trends would lead one to expect (see Appendix B, Figures 25 and 27).

TABLE 5.2
Time-series Model Estimates of Changes in Injury/Fatal Crash Involvement Associated With Raising the Legal Minimum Drinking Age in Michigan

Type of Crash	Age of Driver			
	16-17	18-20	21-23	24-45
Alcohol-related Indicators				
Police-reported Drinking				
Estimate	-20.2	-143.8	9.6	88.2
T-ratio	2.5	4.6[1]	0.6	2.3
Percent	-16.8	-27.8	2.5	8.7
Single-vehicle Nighttime Male				
Estimate	-12.7	-63.0	9.3	38.6
T-ratio	2.3	3.6[1]	1.3	2.4
Percent	-12.6	-21.5	5.1	9.8
Non-alcohol-related Indicators				
No Police-reported Drinking				
Estimate	-100.8	-160.4	-60.3	-263.0
T-ratio	2.5	1.8	0.8	1.0
Percent	-8.5	-7.8	-3.8	-4.8
Daytime				
Estimate	-73.2	-187.7	-53.0	-219.9
T-ratio	2.1	3.0[1]	0.8	1.0
Percent	-7.7	-10.9	-4.0	-4.4

[1]P<0.01, two-tailed test.

As was the case for property damage crashes, no significant effect of the raised drinking age on injury and fatal crash involvement among Michigan drivers age 16-17 was found.

5.1.2 Maine. Effects of the raised drinking age on less serious, property damage crashes in Maine are shown in Table 5.3. Drivers age 18-19 experienced a significant 16.8 percent reduction in police-reported alcohol-related property damage crash involvement, and a 21.5 percent reduction in single-vehicle nighttime male crashes (the significant decreases are evident in Appendix A, Figures 10 and 12, where the 12-month moving average levels off after the drinking age was raised, in contrast to the previous long-term upward trend). In contrast, drivers age 18-19 showed no significant change in non-alcohol-related property damage crash involvement, measured either by police reports or daytime crashes. In addition, no significant changes in any of the four crash time series were observed for drivers age 21-22 or 22-45 in Maine. A significant reduction in alcohol-related property damage crashes for young drivers in Maine at the time the drinking age was raised, with no comparable reductions in either non-alcohol-related crashes among young drivers in Maine, or alcohol-related crashes among older drivers in Maine, indicates that raising the drinking age apparently caused the observed reduction in alcohol-related property damage crash involvement. The 16.8 to 21.5 percent reduction represents 61 to 90 fewer young drivers involved in alcohol-related property damage accidents the first year with the higher drinking age than expected on the basis of previous trends.

Although the time-series model estimates indicate reductions in alcohol-related property damage crashes among drivers age 16 and 17, the

TABLE 5.3
Time-Series Model Estimates of Changes in Property-damage-only Crash Involvement Associated With Raising the Legal Minimum Drinking Age in Maine

Type of Crash	Age of Driver			
	16-17	18-19	20-21	22-45
Alcohol-related Indicators				
Police-reported Drinking				
Estimate	-0.3[2]	-5.1	-3.0	-7.0
T-ratio	1.4	3.7[1]	1.5	1.8
Percent	-24.4	-16.8	-10.5	-6.9
Single-vehicle Nighttime Male				
Estimate	-2.8	-7.5	-0.9	1.1
T-ratio	2.2	3.5[1]	0.5	0.2
Percent	-15.9	-21.5	-3.6	14.9
Non-alcohol-related Indicators				
No Police-reported Drinking				
Estimate	5.8	-19.8	-12.5	-28.8
T-ratio	0.5	1.2	0.6	0.3
Percent	3.0	-6.4	-4.8	-1.9
Daytime				
Estimate	3.5	-10.8	-8.0	-31.4
T-ratio	0.3	0.7	0.5	0.3
Percent	2.2	-4.3	-3.6	-2.3

[1]$P<0.01$, two-tailed test.
[2]Series logarithmically transformed to reduce heteroscedasticity; estimate based on transformed series.

estimates were not significant using the .01 probability level chosen for this study. However, the small monthly crash counts for 16-17-year-olds in Maine, and the resulting large random component in the time series may mask the effect of the raised drinking age on underage drinkers. Examination of the raw frequency plots (Appendix A, Figures 2 and 4) indicated a decline in crash involvement among underage drinkers for the first year after the drinking age was raised; however, the crash frequency series resumed the long-term upward trend in 1979.

Analyses of serious crashes, that is, those involving at least one injury or fatality, revealed no significant shifts in alcohol-related crash involvement among Maine drivers age 18-19 (Table 5.4). Similarly, there were no measurable changes in the frequency of serious crashes for Maine drivers age 22-45, and no changes in non-alcohol-related serious crash involvement among Maine drivers age 20-21. However, 18-19-year-old drivers were involved in 24% more daytime serious crashes after October 1977 than previous trends indicate would be expected.[22] Maine drivers age 20-21 experienced a significant increase in alcohol-related crashes, averaging 4.9 drivers per month (21.4%) for the police-reported drinking series, and 2.4 drivers per month (14.2%) for the single-vehicle nighttime male series.

A significant increase in serious daytime crash involvement among 18-19-year-old drivers in Maine, with no significant change in serious single-vehicle nighttime male crash involvement, might indicate that the raised drinking age prevented an increase in single-vehicle nighttime male crash involvement that would have occurred had there been no legal change. Such a conclusion is strengthened by finding a significant increase in alcohol-related crash involvement for drivers age 20-21, the proximal peers of the focal age group. In addition, although serious single-vehicle nighttime male crash involvement among drivers age 18-19 showed no statistically significant change, the time-series model estimation results indicate an 18.4% decrease when the drinking age was

[22]Note that daytime crash involvement for 18-19-year-olds and 20-21-year-olds decreased significantly in 1979, as was the case in Michigan (see Appendix A, Figures 15 and 23).

TABLE 5.4
Time-series Model Estimates of Changes in Injury/Fatal Crash Involvement Associated With Raising the Legal Minimum Drinking Age in Maine

Type of Crash	Age of Driver			
	16-17	18-19	20-21	22-45
Alcohol-related Indicators				
Police-reported Drinking				
Estimate	2.7	1.9	4.9	3.2
T-ratio	1.6	0.8	2.8[1]	0.8
Percent	30.5	7.9	21.4	3.5
Single-vehicle Nighttime Male				
Estimate	0.4	-3.2	2.4	2.5
T-ratio	0.3	1.4	2.8[1]	0.9
Percent	2.8	-18.4	14.2	4.4
Non-alcohol-related Indicators				
No Police-reported Drinking				
Estimate	0.8	-1.8	-1.4	-18.3
T-ratio	0.2	0.2	0.2	0.7
Percent	1.1	-1.5	-1.4	-3.5
Daytime				
Estimate	2.1	19.0	5.7	-26.4
T-ratio	0.5	4.4[1]	1.1	1.0
Percent	3.2	24.0	7.2	-5.4

[1] $P<0.01$, two-tailed test.

raised. Because the magnitude and direction of the estimated (non-significant) change in single-vehicle nighttime male crashes among drivers age 18-19 is consistent with hypothesized drinking age effects, one might interpret the results as evidence that Maine's raised drinking age affected serious crash involvement. Given the tenuousness of the argument concerning single-vehicle nighttime male and daytime serious crashes, and no changes in serious police-reported drinking crashes or serious crashes with no police-reported drinking, the safest conclusion is that there was no clearly demonstrable effect of Maine's raised drinking age on injury and fatal alcohol-related crash involvement among 18- and 19-year-old drivers.

As in Michigan, there was also no effect of the raised drinking age on injury/fatal crash involvement among 16-17-year-old Maine drivers.

5.1.3 New York. The same time-series analysis strategy used for Maine and Michigan was applied to New York, to determine whether youthful alcohol-related crash involvement in that state decreased significantly at the time either Maine or Michigan raised the legal minimum drinking age. If New York, which did not change its drinking age, showed decreases in crash involvement similar to Maine or Michigan, one might conclude that observed crash reductions in the experimental states were due to some factor unrelated to the raised drinking age.[23]

Estimated changes in New York property damage crash involvement beginning November 1977 (when Maine raised the drinking age) are summarized in Table 5.5. There were no significant changes in any of the crash involvement categories for 18-20-year-old drivers, in contrast to Maine, where 18-19-year-old drivers experienced significant reductions in alcohol-related property damage crashes beginning in November 1977. Note that the parameter estimates for single-vehicle nighttime male and daytime single-vehicle male crashes were negative for all age groups, and were significant for drivers 21-23 and 24-45. Furthermore, the reported crash reductions were substantial, ranging

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[23]As noted earlier, the New York crash data were analyzed twice, first including the entire state as was done for other study states (Appendix C), and second, excluding New York City from the statewide totals (Appendix K). Exclusion of New York City did not appreciably change the results, and results discussed here are based on the statewide totals excluding New York City.

from 30 to 52%. This pattern of lower than expected reported property damage crash involvement across all age groups for both daytime and nighttime single-vehicle male driver crashes was a result of an important change in crash reporting criteria, mentioned earlier in section 4.2.2.3. After September 1978, any crash causing property damage of $400 or more had to be reported; prior to this date, any crash causing $250 or more in damage had to be reported. This instrumentation change, occurring within the first year after the October 1977 drinking age change in Maine, apparently caused the significant reduction in reported property damage crashes identified in the New York time-series models.

Estimated changes in New York injury and fatal crash involvement, concomitant with Maine's increase in drinking age, are shown in Table 5.6. As with property damage crashes, there were no significant changes in any crash category for 18-20-year-old drivers. The other three age groups experienced significant increases in police-reported alcohol-involved crashes. Because of the nature of the New York reporting system concerning alcohol-related crashes,[24] the frequency of reported alcohol-related crashes using this indicator is probably quite sensitive to increased public interest in the alcohol-related crash problem. In recent years, more media and public policy attention has been given to the alcohol/highway safety issue, and as a result, observed increases in police-reported alcohol-related serious crash involvement may very well be due to improved reporting of the involvement of alcohol in New York crashes.

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[24]Refer to section 4.2.2.3 for details.

TABLE 5.5
Time-series Estimates of Changes in Property-damage-only Crash Involvement in New York After October 1977, When Maine Raised the Legal Minimum Drinking Age

Type of Crash	Age of Driver			
	16-17	18-20	21-23	24-45
Alcohol-related Indicators				
Police-reported Drinking				
Estimate	0.2	3.5	1.6	12.0
T-ratio	0.2	2.1	0.9	2.5
Percent	3.1	12.7	6.9	15.3
Single-vehicle Nighttime Male				
Estimate	-0.7[2]	-0.3[2]	-0.4	-0.7[2]
T-ratio	3.7[1]	1.5	6.7[1]	4.1[1]
Percent	-52.3	-23.7	-29.5	-47.8
Non-alcohol-related Indicator				
Daytime Single-vehicle Male				
Estimate	-0.3[2]	-0.3[2]	-0.4[2]	-0.6[2]
T-ratio	2.5	1.9	3.7[1]	4.7[1]
Percent	-28.8	-22.9	-32.3	-45.1

[1]P<0.01, two-tailed test.
[2]Series logarithmically transformed to reduce heteroscedasticity; estimate based on transformed series.

The New York time-series models also included estimates of shifts in crash involvement beginning January 1979, for comparison with the Michigan findings. Results for property damage crashes are summarized in Table 5.7. No significant reductions in property damage alcohol-related crash involvement occurred among New York 18-20-year-old drivers in 1979, in contrast to significant decreases in Michigan. This finding provided further support for the hypothesis that the crash reductions in Michigan were a direct result of the higher drinking age, not other more

TABLE 5.6
Time-series Model Estimates of Changes in Injury/Fatal Crash Involvement in New York After October 1977, When Maine Raised the Legal Minimum Drinking Age

Type of Crash	Age of Driver			
	16-17	18-20	21-23	24-45
Alcohol-related Indicators				
Police-reported Drinking				
Estimate	5.3	5.4	21.5	27.5
T-ratio	4.0[1]	0.4	5.0[1]	2.8[1]
Percent	18.1	3.1	18.0	7.3
Single-vehicle Nighttime Male				
Estimate	5.6	-3.4	-5.3	7.9
T-ratio	1.7	0.4	0.6	0.5
Percent	10.5	-1.3	-3.0	2.3
Non-alcohol-related Indicator				
Daytime Single-vehicle Male				
Estimate	-3.4	-0.1	-1.0	-32.7
T-ratio	0.7	0.0	0.2	7.1[1]
Percent	-3.9	-0.5	-0.9	-8.9

[1]$P<0.01$, two-tailed test.

general nationwide factors influencing crash involvement during this period.

The only significant time-series model estimates in Table 5.7 were for single-vehicle nighttime male crashes among drivers age 21-23, and daytime single-vehicle male crashes among drivers age 18-20. In both of these cases, the significant positive time-series model estimates were a result of the leveling off a pre-existing downward trend in crash frequency (see Appendix K, Figures 18 and 12).

Table 5.8 shows estimated changes from pre-existing trends in New York serious crash involvement in 1979. Again, no significant decreases

TABLE 5.7
Time-series Model Estimates of Changes in Property-damage-only Crash Involvement in New York After December 1978, When Michigan Raised the Legal Minimum Drinking Age

Type of Crash	Age of Driver			
	16-17	18-20	21-23	24-45
Alcohol-related Indicators				
Police-reported Drinking				
Estimate	2.0	-1.5	4.2	2.1
T-ratio	1.6	0.8	1.9	0.5
Percent	34.6	-4.7	16.4	2.6
Single-vehicle Nighttime Male				
Estimate	0.0[2]	0.3[2]	0.3[2]	0.1[2]
T-ratio	0.1	1.7	7.2[1]	0.0
Percent	3.0	35.0	35.0	6.2
Non-alcohol-related Indicator				
Daytime Single-vehicle Male				
Estimate	0.0[2]	0.4[2]	0.0[2]	0.1[2]
T-ratio	0.2	3.1[1]	0.0	0.6
Percent	2.0	46.2	4.1	7.2

[1]$P<0.01$, two-tailed test.
[2]Series logarithmically transformed to reduce heteroscedasticity; estimate based on transformed series.

in injury/fatal crash frequency for 18-20 drivers was found, in contrast to the Michigan results, providing further evidence that Michigan's crash reductions among youth were due to the increase in drinking age.

Significant increases in police-reported alcohol-involved crashes for three of the four age groups might be due to improved police reporting of alcohol involvement, the suggested explanation of the increased frequency of police-reported alcohol-involved property damage crashes in New York identified with the November 1977 time-series model parameter. Unlike the pattern of results in Table 5.6, however, Table

TABLE 5.8
Time-series Model Estimates of Changes in Injury/Fatal Crash Involvement in New York After December 1978, When Michigan Raised the Legal Minimum Drinking Age

Type of Crash	Age of Driver			
	16-17	18-20	21-23	24-45
Alcohol-related Indicators				
Police-reported Drinking				
Estimate	11.2	23.7	31.1	56.8
T-ratio	7.0[1]	2.3	6.6[1]	5.0[1]
T-ratio	7.0[1]	2.3	6.6[1]	5.0[1]
Percent	33.1	11.9	21.2	13.7
Single-vehicle Nighttime Male				
Estimate	3.2	32.7	24.3	59.6
T-ratio	0.9	3.6[1]	2.6	4.6[1]
Percent	5.2	12.2	14.0	17.5
Non-alcohol-related Indicator				
Daytime Single-vehicle Male				
Estimate	1.1	7.0	4.0	7.6
T-ratio	0.2	1.0	1.0	1.5
Percent	1.2	4.7	3.7	2.2

[1]$P<0.01$, two-tailed test.

5.8 reveals that the more reliable alcohol-related indicator, single-vehicle nighttime male crash involvement, also exhibited significant increases for the 21-23 and 24-45 age groups, and an estimated increase for 18-20-year-olds that was significant at the less conservative .05 level. The pattern of consistently positive point estimates, with five of the eight significant at the .01 level, suggests that a real increase in injury/fatal alcohol-related crash involvement occurred in 1979 among New York drivers.

5.1.4 <u>Pennsylvania</u>. Crash involvement in Pennsylvania from 1972 through 1979 was also analyzed, for comparison with the Michigan and

Maine results. The police-reported alcohol indicator was not well suited for this research. Few crashes were identified as alcohol-related, and for those that were, the alcohol item applied to the accident, and could not be linked to particular drivers. As a result, frequencies of police-reported alcohol-involved crashes were not analyzed in detail, although a plot of each time series is included in Appendix D. Instead of detailed analyses of frequencies of crashes with no police-reported alcohol involvement, the total frequency of crash-involvement was examined.

Results, shown in Table 5.9, indicated that Pennsylvania drivers experienced no change in property damage crash involvement in 1977, at the time Maine raised its drinking age and experienced a significant decrease in alcohol-related property damage crash involvement among young drivers. Again, a state without a drinking age change, Pennsylvania, experienced no significant change in youth crash involvement at the time a state that raised its drinking age, Maine, experienced significant decreases in alcohol-related crashes.

Analyses of Pennsylvania injury crashes revealed no significant changes beginning in 1977 for any of the crash category/age group combinations (Table 5.10).

When Michigan raised its drinking age and experienced significant decreases in alcohol-related property damage crash involvement among young drivers, Pennsylvania showed no change in alcohol-related property damage crash involvement among youth (Table 5.11). Daytime property damage crashes in Pennsylvania among drivers of all ages were down 9 to 17% in 1979, however. Similar reductions in non-alcohol-related crashes across all age groups were found in Michigan, indicating that some more

TABLE 5.9
Time-series Model Estimates of Changes in Property-damage-only Crash Involvement in Pennsylvania After October 1977, When Maine Raised the Legal Minimum Drinking Age

Type of Crash	Age of Driver			
	16-17	18-19	20-21	22-45
Alcohol-related Indicator				
Single-vehicle				
Nighttime Male				
Estimate	0.2	-17.2	-12.7	-77.1
T-ratio	0.0	0.8	0.8	1.6
Percent	0.1	-8.9	-7.3	-12.6
Non-alcohol-related Indicator				
Daytime				
Estimate	-0.1[1]	-0.0[1]	-0.1[1]	-0.0[1]
T-ratio	1.9	0.5	0.7	0.3
Percent	-12.2	-3.4	-4.8	-2.1
Total				
Estimate	-0.1[1]	-0.1[1]	-0.0[1]	-0.0[1]
T-ratio	1.7	0.8	0.5	0.3
Percent	-10.6	-5.0	-2.9	-2.0

[1]Series logarithmically transformed to reduce heteroscedasticity; estimate based on transformed series.

general factor affecting crash frequencies in multiple states, such as reduced economic activity in 1979, may be the cause of reduced non-alcohol-related crash involvement. Further support for such an argument can be found in the Maine results, where non-alcohol-related property damage crash involvement also decreased significantly in 1979 (see Appendix A). Of the four states analyzed here, only New York did not exhibit obvious decreases in non-alcohol-related property damage crash involvement in 1979.

TABLE 5.10
Time-series Model Estimates of Changes in Injury/Fatal Crash Involvement in Pennsylvania After October 1977, When Maine Raised the Legal Minimum Drinking Age

Type of Crash	Age of Driver			
	16-17	18-19	20-21	22-45
Alcohol-related Indicator				
Single-vehicle				
Nighttime Male				
Estimate	0.1[1]	-0.0[1]	-0.2[1]	-0.0[1]
T-ratio	0.7	0.1	2.1	0.5
Percent	-7.5	-0.6	-14.8	-3.4
Non-alcohol-related Indicator				
Daytime				
Estimate	20.8	31.7	-6.0	133.7
T-ratio	0.5	0.5	0.1	0.5
Percent	3.1	3.7	-0.7	2.8
Total				
Estimate	-34.5	25.1	-76.5	170.1
T-ratio	0.5	0.3	1.2	0.5
Percent	-3.5	1.9	-5.7	2.6

[1]Series logarithmically transformed to reduce heteroscedasticity; estimate based on transformed series.

Analyses of serious crash involvement in Pennsylvania revealed no significant changes in 1979 for any of the crash category/age group combinations (Table 5.12). Finding no change in alcohol-related serious crash involvement among Pennsylvania youth in 1979, when Michigan had significant decreases in youthful serious alcohol-related crash involvement strengthens a causal interpretation of the drinking age/crash association observed in Michigan.

5.1.5 Discussion of Crash Findings. The time-series model estimates represent the net shift in the frequency of crash involvement

TABLE 5.11
Time-series Model Estimates of Changes in Property-damage-only Crash Involvement in Pennsylvania After December 1978, When Michigan Raised the Legal Minimum Drinking Age

Type of Crash	Age of Driver			
	16-17	18-19	20-21	22-45
Alcohol-related Indicator				
Single-vehicle				
Nighttime Male				
Estimate	-11.8	-20.7	12.7	42.4
T-ratio	0.7	1.0	0.8	0.9
Percent	-11.0	-10.8	8.4	8.4
Non-alcohol-related Indicator				
Daytime				
Estimate	-0.2[2]	-0.2[2]	-0.2[2]	-0.1[2]
T-ratio	3.8[1]	3.1[1]	3.3[1]	2.1
Percent	-16.6	-14.4	-16.5	-9.1
Total				
Estimate	-0.2[2]	-0.1[2]	-0.1[2]	-0.1[2]
T-ratio	3.3[1]	2.6	2.5	1.3
Percent	-13.9	-10.7	-10.2	-5.5

[1]P<0.01, two-tailed test.
[2]Series logarithmically transformed to reduce heteroscedasticity; estimate based on transformed series.

associated with increases in the legal minimum drinking age in Maine and Michigan, independent of the effects of long-term trends, seasonal cycles, and other factors. Alcohol-related property damage crash involvement among young drivers after an increase in drinking age was significantly lower than previous trends would lead one to expect in both Maine and Michigan. Significant reductions in alcohol-related property damage crash involvement were not found for older drivers within either experimental state, or for young drivers in the two comparison states that did not change the drinking age. Furthermore,

TABLE 5.12
Time-series Model Estimates of Changes in Injury/Fatal Crash Involvement in Pennsylvania After December 1978, When Michigan Raised the Legal Minimum Drinking Age

Type of Crash	Age of Driver			
	16-17	18-19	20-21	22-45
Alcohol-related Indicator				
Single-vehicle				
Nighttime Male				
Estimate	0.0[1]	0.1[1]	0.1[1]	0.1[1]
T-ratio	0.5	0.7	1.1	1.9
Percent	3.9	5.1	4.6	9.0
Non-alcohol-related Indicator				
Daytime				
Estimate	-52.6	-20.3	-8.3	64.1
T-ratio	1.2	0.3	0.2	0.2
Percent	-8.5	-2.6	-1.2	1.5
Total				
Estimate	-104.0	-27.7	-91.3	108.0
T-ratio	1.6	0.4	1.4	0.3
Percent	-11.3	-2.2	-7.4	1.7

[1]Series logarithmically transformed to reduce heteroscedasticity; estimate based on transformed series.

identified reductions in non-alcohol-related property damage crashes during this period were less than half the magnitude of the decrease in alcohol-related crashes. The same analyses applied to serious (i.e. injury and fatal) alcohol-related crash involvement demonstrated significant reductions among young drivers associated with the higher drinking age in Michigan, with no clear effect observed in Maine. Analyses of older drivers in Michigan and young drivers in the comparison states revealed no significant reductions in alcohol-related serious crashes. The most plausible explanation of this pattern of findings is that raising the legal drinking age caused significant reductions in alcohol-related property damage crash involvement among young drivers in both Michigan and Maine, and caused significant reductions in serious crash involvement in Michigan.

5.2 Effects of Raised Drinking Age on Beverage Alcohol Sales

In addition to analyses of crash involvement discussed above, aggregate alcoholic beverage sales were examined to identify whether the drinking age has a noticeable effect on the beverage alcohol market in Maine or Michigan. Beverage sales data for the United States as a whole were used as a comparison time-series. Finally, sales data for New Hampshire were also examined to assess whether observed reductions in Maine beverage sales were due to increased cross-border purchases rather than a reduction in actual consumption of alcoholic beverages.

5.2.1 Michigan. Results of analyses of aggregate beverage distribution in Michigan are summarized in Table 5.13 with a plot of each time series and detailed modeling results shown in Appendix H. Application of the iterative model building strategy to wine distribution in Michigan resulted in the model shown in Appendix H, Figure 1. Time-series modeling estimation results show that, controlling for the unexplained significant increase in October 1970, there were no significant changes in wine sales in 1972, after the drinking age was lowered, or 1979, after the drinking age was raised.

The final model for total beer distribution is shown in Figure H.2. From Table 5.13, it is evident that no significant change in total beer sales occurred in 1972, and a significant decrease of 5,384 kiloliters per month in total beer sales occurred beginning in January 1979, when a

TABLE 5.13
Time-series Model Estimates of Changes in Average Monthly Beverage Alcohol Sales in State of Michigan

Type of Beverage	Intervention	
	January 1972: Michigan Lowered Drinking Age	January 1979: Michigan Raised Drinking Age
Draft Beer		
Estimate	1321.4	1600.2
T-ratio	6.3[1]	11.9[1]
Percent	18.9	19.8
Package Beer		
Estimate	1049.2	-7658.7
T-ratio	0.6	4.3[1]
Percent	1.9	-11.5
Total Beer		
Estimate	1462.0	-5383.5
T-ratio	0.8	3.0[1]
Percent	2.4	-7.3
Wine		
Estimate	165.9	86.8
T-ratio	1.2	0.7
Percent	0.2	0.1

[1]$P<0.01$, two-tailed test.

mandatory beverage container deposit law and the raised drinking age went into effect.

Since package beer (Appendix H, Figure 3) accounts for more than three-fourths of all beer distributed in Michigan, the time-series model is very similar to the model for total beer. Again, no significant shift in package beer sales in 1972 was observed. However, a significant decrease in package beer sales of 7,659 kiloliters per month occurred over the January 1979 through October 1980 period.

The large one-month drop in wholesale package beer distribution in October 1978, evident in the time-series plot, was most likely a result of wholesale and retail dealers reducing their purchases in an attempt to eliminate their inventory of nonreturnable containers before the December deadline when the mandatory deposit law went into effect.

The 1979-80 decrease in package beer distribution is substantially larger than the decrease in total beer sales, leading one to suspect that part of the decline in package beer sales was offset by an increase in draft beer sales, which is confirmed by separate analyses of the draft beer series. Time series analyses produced the model of draft beer sales shown in Appendix H, Figure 4. An additional step function for 1980 was added to the model because draft beer sales increased substantially in 1980 over and above the increase in 1979. The results reveal a significant temporary increase in draft beer sales beginning in January 1972, when the drinking age was lowered. The effect dissipated by the end of 1972, however, and no significant permanent shift in draft beer sales associated with the lowered drinking age was observed (note the pattern of the 12-month moving average in Appendix H, Figure 4).

Results for 1979 and 1980 indicate dramatic increases in draft beer sales in Michigan. Distribution in 1979 was 1,600 kiloliters per month higher than expected given baseline patterns; the first 9 months of 1980 exhibited an additional 1,194 kiloliter per month increase. In spite of the large increases in draft beer distribution, total beer distribution was down significantly for 1979-80 because package beer, which decreased in 1979-80, accounts for over three-fourths of all beer distributed in the State of Michigan.

The significant increase in draft beer distribution in 1972, immediately after the drinking age was reduced from 21 to 18, can be interpreted as a result of the sudden expansion in the population of legal drinkers. Why the positive shift in draft beer sales rapidly decayed is not clear. One might speculate that the effect of the reduced drinking age was a sudden experimentation with consumption of draft beer, with the novelty wearing off after the first year, followed by a return to drinking patterns practiced before the drinking age was lowered. This argument seems less plausible, however, given the permanent significant increases in alcohol-related public health problems, such as traffic collisions, following reductions in drinking age.

A plausible hypothesis is that other exogenous factors, unrelated to the lowered drinking age, caused draft beer sales to decrease in 1973. Since youth age 18-20 constitute only a fraction of the total beer drinking population, a substantial increase in consumption by the 18-20 age group could be easily masked by a small reduction in consumption by all other drinkers. Therefore, the significant increase in aggregate draft beer sales in 1972, concomitant with the lowered drinking age, may be offset by a small reduction in consumption among all drinkers in 1973, due to other unidentified factors.

The substantial decrease in package beer distribution in 1979-80, when the drinking age was raised and non-returnable containers were banned, also has multiple explanations. Although the raised drinking age may account for a portion of the decrease, the magnitude of the decrease suggests that other factors, affecting the entire population of package beer consumers, were operating. One such factor is the mandatory container deposit law implemented in Michigan the same month the drinking age was raised. One result of the container law was a 10 percent increase in the real price of package beer.[25] The price jump and the inconvenience of returnable containers may explain the decrease in sales. In addition to reduced consumption of package beer resulting from its increased cost (both direct monetary costs and in terms of inconvenience), some consumers residing near Michigan's borders may have shifted their package beer purchases to retailers in bordering states. However, since most of Michigan's population does not reside near the state's borders, they do not have easy access to adjoining states with non-returnable containers where lower package beer prices prevail. As a result, it would appear that cross-border purchases do not account for the entire decrease in package beer sales in Michigan. This is not to say cross-border purchase of beer does not account for a significant portion of the observed decrease in Michigan package beer sales, since the densely populated metropolitan Detroit area is less than an hour drive from the Ohio border, where non-returnable containers are sold. In 1981 the Michigan Commerce Department announced a crackdown on persons crossing the State's borders to purchase package beer, arguing that a smuggling "epidemic" was harming Michigan business (Detroit Free Press, 1981).[26]

Given substantial increases in draft beer distribution during the same period, it appears that a number of beer drinkers shifted some of

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[25]Real price refers to price in constant dollars, controlling for the effects of inflation.

[26]The political debate surrounding the implementation of the mandatory container law included discussion as to whether the beverage industries were justified in raising prices; it is simply noted here that retail prices did, in fact, increase.

their consumption from package to draft beer. Michigan's economic recession, with associated unemployment and reductions in disposable income, may have contributed to the shift to less expensive draft beer.[27]

Michigan's raised drinking age may have had a larger effect in reducing package beer consumption among youth than draft beer consumption because the law did not prohibit young people age 18-20 from patronizing public drinking establishments; only purchase and consumption of alcoholic beverages were prohibited. In a crowded bar or tavern a legal drinker might easily purchase alcoholic beverages for friends under age 21. As a result, draft beer sales may be higher than expected if those under 21 were not allowed to frequent public drinking establishments. In addition, part of the increased draft beer sales in 1979-80 may be a result of an increased number of "kegger" parties among 18-20-year-olds, where a legal drinker purchases a keg of draft beer for consumption off-premise at a party attended by underage drinkers.

5.2.2 Maine. Results of analyses of aggregate beverage alcohol distribution in Maine are summarized in Table 5.14, and a plot of each time series and detailed modeling results are shown in Appendix G. Application of the iterative model building strategy to the Maine beer distribution time series resulted in the model shown in Appendix G, Figure 2. Controlling for long-term trends and seasonal cycles, there was no significant change in beer sales associated with the reduction in

[27]A telephone survey of a random sample of Michigan bars, taverns, and restaurants revealed that draft beer has a significantly lower retail price than than any other on-premise alcoholic drink. Depending on region of the state, retail price of draft beer was 17 to 40 percent lower than on-premise package beer, usually the second least expensive drink (Douglass et al., 1980).

drinking age. However, there was a significant decrease in total beer sales averaging 1,114 kiloliters per month (11.8%) after the drinking age was raised. The lower than expected sales after November 1977 are clearly evident in the time series plot.

TABLE 5.14
Time-series Model Estimates of Changes in Average Monthly Beverage Alcohol Sales in State of Maine

Type of Beverage	Intervention	
	June 1972: Maine Lowered Drinking Age	November 1977: Maine Raised Drinking Age
Total Beer		
Estimate	179.4	-1114.2
T-ratio	1.1	6.8[1]
Percent	2.6	-12.9
Wine		
Estimate	-14.2	46.9
T-ratio	0.7	2.5
Percent	-4.1	10.2
Spirits		
Estimate	-23.3	25.7
T-ratio	1.2	1.3
Percent	-3.7	3.6

[1]P<0.01, two-tailed test.

No change in wine sales at the time the drinking age was lowered was identified. As shown in Table 5.14, the model estimation results indicate an increase in wine sales of 10.2% after the drinking age was raised in late 1977; the increase is significant at p<.05, but not at p<.01, the significance level selected for this study. Consistent with the marginal significance of the estimate, examination of the wine sales plot (Appendix G, Figure 1) indicates that wine sales after October 1977 were not dramatically different than expected, given the long-term upward trend in wine sales.

The time series model for spirits sales in Maine (Appendix G, Figure 3) revealed no measurable changes associated with either lowering or raising the legal drinking age.

One might conclude, on the basis of these findings, that the raised drinking age in Maine resulted in significantly reduced alcohol consumption among youth, since sales of beer, the beverage of choice among young drinkers, decreased significantly after the raised drinking age was implemented. Although the interrupted time-series design employed here is characterized by high internal validity, a serious threat to a causal interpretation of the findings remaining is contemporaneous history, that other events occurring at about the same time as the raised drinking age may account for the observed decrease in beer sales. As in Michigan, the major confounding historical factor is a mandatory beverage container deposit law, implemented in Maine in January 1978, just two months after the higher drinking age went into effect (Maine, State of, 1977). Inconvenience of returnable containers, along with substantial increases in the price of canned and bottled beer may have caused the reduction in beer sales. Reduced sales, in turn, may have been due to reduced consumption and/or a shift from purchasing beer in Maine to purchases in neighboring states, particularly New Hampshire, where beer prices are substantially lower. Beer prices have traditionally been lower in New Hampshire than Maine because of lower tax rates. Maine's taxes on beer include excise tax of 25 cents per gallon and general sales tax of 5 percent; in contrast, New Hampshire has a 15 cent per gallon excise tax on beer and no sales tax (Distilled Spirits Council of the United States, 1980). According to the Maine state officials, the beer price differential has widened noticeably since implementation of the mandatory deposit law, with Maine residents increasingly purchasing the lower-priced New Hampshire beer.[28]

5.2.3 New Hampshire and United States as Comparison Jurisdictions. The only change in alcohol distribution associated with lowered drinking ages in the two focal states of this investigation, Maine and Michigan, was a temporary increase in draft beer sales in Michigan in the first year after the lower drinking age was implemented. When the drinking age was raised, however, there were significant decreases in total beer sales in both Maine and Michigan. In Michigan, where beer sales were also examined separately for draft and package beer, the decrease in total beer sales in 1979-80 was due to a substantial decrease in sales of package beer, while sales of draft beer increased.

Interpretation of the changes in beer sales at the time these two states raised the drinking age is complicated by a major confounding historical factor in both states, implementation of mandatory beverage container deposit laws at about the same time the higher drinking ages went into effect.

In an attempt to separate the effects of the drinking age change and the beverage container deposit law, beverage sales in the State of New Hampshire were analyzed. New Hampshire is the only state bordering

[28]Beer prices increased "considerably," after the mandatory container law was implemented, and consumers complained "bitterly" according to S. Redfield, Maine Department of Agriculture; personal conversation, June 1, 1981.

with Maine,[29] and Maine state officials have suggested that Maine beer drinkers may have shifted some of their beer purchases to New Hampshire after the container law was implemented and beer prices increased.[30] If such cross-border purchases account for the 1,114 kiloliter per month decrease in Maine beer sales concomitant with the increase in drinking age and implementation of the container law, New Hampshire beer sales should increase by a comparable amount. Time-series modeling of New Hampshire beer sales, however, reveal no significant change at the time the Maine container law was implemented (Table 5.15). As a result, one has more confidence that observed reductions in Maine beer sales are due to the increase in drinking age, and not the mandatory container deposit law.

New Hampshire lowered the legal minimum drinking age from 21 to 18 for all alcoholic beverages in June 1973. Parameters for this legal change were included in the time-series models for beer sales in New Hampshire, and results showed a significant 7.7% increase in package beer sales after the drinking age was lowered (Table 5.15). Draft beer sales were up an estimated 10.7% (significant at $p<.05$ but not at $p<.01$, using two-tailed tests). Based on these results, it appears that lowering the drinking age in New Hampshire contributed to an increase in sales of package and draft beer.[31]

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[29]Although there might be beer purchases across Maine's northern border with Canada, the great majority of Maine's population resides in the southern region of the state.

[30]S. Redfield, Maine Department of Agriculture, personal conversation June 1, 1981, and F. Robie, Maine Liquor Control Board, personal conversation, June 1, 1981.

[31]Effects of New Hampshire's increase in drinking age from 18 to 20 in May 1979 could not be evaluated because beer sales data were only available through 1979, providing only seven post-change observations.

TABLE 5.15
Time-series Model Estimates of Changes in Average Monthly Beverage Alcohol Sales in State of New Hampshire

Type of Beverage	Intervention	
	June 1973: New Hampshire Lowered Drinking Age	January 1978: Maine Mandatory Deposit Law
Draft Beer		
Estimate	67.8	11.3
T-ratio	2.5	0.8
Percent	10.7	1.5
Package Beer		
Estimate	539.7	258.6
T-ratio	2.8[1]	1.5
Percent	7.7	3.1

[1]P<0.01, two-tailed test.

Beer sales in the entire United States from 1970 through 1980 were analyzed for comparison with the results for Maine, Michigan, and New Hampshire (Table 5.16).[32] Results showed no significant changes in nationwide draft beer sales after January 1972, when Michigan lowered the drinking age and experienced a temporary increase in draft beer sales. Second, there were no changes in nationwide draft or package beer sales after November 1977, when Maine raised the drinking age and

[32]The time-series models included parameters for January 1972 (Michigan lowered drinking age), November 1977 (Maine raised drinking age), and January 1979 (Michigan raised drinking age). Parameters for Maine and New Hampshire's drinking age reductions were not included because they occurred within a relatively short time. Inclusion of parameters for all of the drinking age reductions would have resulted in multicollinearity problems when estimating the parameters of the full time-series model (see Pindyck and Rubinfeld, 1976:66-68 for an introduction to the multicollinearity issue). In any event, the raw time-series plot with a simple 12-month moving average shown in Appendix J, Figures 2 and 3 can be examined for the exact nature of beer sales trends in the early 1970s.

experienced a 12.9% reduction in beer sales. Third, nationwide package beer sales did not change significantly after January 1979, when Michigan raised the drinking age and experienced a significant 11.5% package beer sales reduction. In each of these cases, nationwide beer sales showed no measurable change at a time when sales in a state that has changed the minimum drinking age changed significantly.

TABLE 5.16
Time-series Model Estimates of Changes in Average Monthly Beverage Alcohol Sales in the United States

Type of Beverage	Intervention		
	January 1972: Michigan Lowered Drinking Age	November 1977: Maine Raised Drinking Age	January 1979: Michigan Raised Drinking Age
Draft Beer			
Estimate	1045.8	-2765.2	11515.2
T-ratio	0.5	1.4	5.8[1]
Percent	0.6	-1.5	5.9
Package Beer			
Estimate	30431.0	17099.6	-13407.8
T-ratio	2.0	1.0	0.9
Percent	2.8	1.2	-0.9

[1]P<0.01, two-tailed test.

Total draft beer sales in the United States increased significantly beginning January 1979, when Michigan implemented the higher drinking age and also experienced a significant increase in draft beer sales. The pattern of sales of U.S. total draft beer in recent years was similar to that found in Michigan. That is, draft beer sales increased significantly in 1979 over expected sales given previous trends, with an additional significant increase in 1980 over the already higher than expected 1979 figures. However, nationwide draft beer sales in 1979 was only 5.9% higher than expected (Table 5.16), while Michigan draft beer sales increased 19.8% (Table 5.13). It is clear that part of the increased Michigan draft beer sales in recent years is a reflection of a nationwide trend. Significant increases in draft beer sales nationwide may be a result of such factors as the very successful introduction and marketing of low-calorie ("light") beers. The substantial increases in Michigan draft beer sales over the nationwide increases are likely due to factors unique to Michigan, such as the increase in drinking age, mandatory container deposit law, and unusually severe economic slowdown.[33]

5.2.4 <u>Discussion of Sales Findings</u>. Controlling for the effects of long-term trends and regular seasonal patterns, the present study found significant changes in aggregate sales of alcoholic beverages concomitant with modifications in the legal minimum drinking age. In all states examined, beer, the beverage of choice among young drinkers, was the beverage category most affected by changes in drinking age. In Michigan and New Hampshire, reductions in drinking age from 21 to 18 were associated with significant increases in beer sales. In Maine and Michigan, increases in drinking age from 18 to 20 and from 18 to 21, respectively, were associated with significant decreases in total beer sales. Results of analyses of nationwide beer sales for comparison with the state-specific analyses strengthen the argument that observed

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[33]Subtracting the 5.9% reduction in U.S. total draft beer sales from the 19.8% reduction observed in Michigan leaves a 13.9% reduction in Michigan that cannot be directly attributed to the factors causing the nationwide increase in draft beer sales.

relationships between drinking age and beer sales reflect a causal effect of the drinking age and not some other factors.

However, the results on beverage sales are not as unambiguous as the results of analyses of crash data. Simultaneous implementation of a higher drinking age and a mandatory beverage container deposit law in both Maine and Michigan complicates interpretation of the results. In addition, poor general economic conditions in the late 1970s and early 1980s in states such as Michigan may be influencing the beverage alcohol market in ways that are not yet fully understood. These complications illustrate limitations of analyses of aggregate sales data. Without age-specific consumption data, the differential effects of drinking age changes and other policy changes, such as the mandatory deposit law, cannot be unambiguously determined. Furthermore, detailed information on the drinking practices of various subpopulations, identified by stratification variables such as income level and employment status, is needed to assess the influence of economic conditions and beverage-specific price changes on individual drinking patterns.

5.3 Beverage Control Law Enforcement

In addition to detailed analyses of crash involvement and alcoholic beverage sales, the frequency of enforcement citations for violation of beverage control laws concerning selling or providing alcoholic beverages to underage persons in Michigan and Maine were briefly examined. The objective was simply to provide a preliminary impression of enforcement of the drinking age, focused on the providers of alcoholic beverages. Citations for underage individuals purchasing or consuming alcoholic beverages were not examined.

5.3.1 Michigan. The substantial effect of Michigan's higher drinking age in reducing alcohol-related crashes among youth in the first six months after the law was implemented was apparently not a result of strict enforcement of the law. In the early months after the increase in drinking age, enforcement was minimal, and the new law was "flagrantly" disobeyed, according to an advisory panel established by Michigan's governor (Grand Rapids Press, 1979). Increased enforcement efforts in late 1979 and 1980 were reflected in the frequency of citations issued by the Michigan Liquor Control Commission for selling, serving, or allowing minors to consume alcoholic beverages. Although the number of citations was 68% higher in 1979 than 1978, citation frequency in 1980 was 156% higher than 1978 (see Appendix F, Figure 1). These increased citation frequencies in 1979-80 were in contrast to the relatively constant 300-400 per year citation frequency in the mid-1970s. The effect of higher frequency of citations on alcohol-related crashes among youth in 1980 remains a question for further research.[34]

5.3.2 Maine. The frequency of citations brought before the Administrative Court in Maine for selling or allowing minors to consume alcoholic beverages are shown in Appendix E, Figure 1. Although the pattern of increase in citation frequency the first two years after the higher drinking age was implemented was similar to the Michigan experience, the magnitude of the increases were substantially smaller.

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[34] In spite of the increase in citations in 1980, underage youth were still able to acquire alcoholic beverages from licensed outlets. For example, of 41 underage youth arrested between April and September 1980 by an Oakland County (Michigan) special enforcement team for driving while intoxicated or driving under the influence of liquor, 24% reported they had been at a bar prior to arrest (Wolfe, 1981).

Citations for providing alcoholic beverages to underage persons in Maine increased 17% from 1977 to 1978, and 68% from 1977 to 1979. Based on these data, it appears that Maine also may have had minimal enforcement the first year after the new law was implemented, with increased enforcement efforts in the second year with the higher drinking age. One might also speculate that smaller increases in citation frequency in Maine compared to Michigan after the raised drinking age went into effect indicates less rigorous enforcement of the law in Maine. The lower enforcement efforts may account for the lack of a clear effect of the higher drinking age on injury crashes in Maine, in contrast to the significant effect of the increased drinking age on injury crashes in Michigan.

5.3.3 Discussion of Enforcement Findings. This very brief examination of enforcement of the legal minimum drinking age was based only on enforcement focused on the providers of alcoholic beverages, primarily off-premise retail outlets, bars and taverns, and restaurants. Enforcement of the drinking age focused on the individual underage drinker, and enforcement of laws against drinking-driving all would be expected to influence the frequency of alcohol-related crash involvement, the main dependent variable of the present study. The frequency of citations is also only a gross indicator of the level of enforcement, since information was not available on the number of citations in relation to the total number of citable violations, or the perceived risk of experiencing sanctions for providing alcohol to minors. The role of enforcement of drinking age laws is complex and deserves the attention of a separate study.

6.0 SUMMARY, DISCUSSION, AND RECOMMENDATIONS

6.1 Summary

The core issue of this investigation was whether raising the legal minimum age for purchase of alcoholic beverages has a significant effect in reducing alcohol-related motor vehicle crash involvement among young drivers, the leading cause of death for this age group. The findings are unambiguous; analyses of extended crash time series, comparing (1) alcohol-related with non-alcohol-related crashes, (2) young drivers with older drivers, and (3) states that raised the legal age with those that have not, demonstrate that significant reductions in alcohol-related crash involvement among young drivers result from increases in the minimum drinking age. Taking into account the results from analyses of multiple states, age groups, and indicators of alcohol involvement, the best estimates of the effects of the raised drinking age in Michigan and Maine are as follows. First, Michigan drivers age 18-20 experienced a net reduction of approximately 20% in the frequency of involvement in alcohol-related injury-producing crashes due to the higher drinking age. The 20% reduction means that about 1100 fewer young Michigan drivers were injured in the first 12 months with the higher drinking age than would have been expected had the legal age not been raised. Second, young Michigan drivers were involved in 17% fewer alcohol-related property damage crashes after the drinking age change, representing a reduction of about 1500 crash-involved drivers per year. Third, 18-19-year-old Maine drivers were involved in approximately 20% fewer alcohol-related property damage crashes after the drinking age was raised; that is, 75 fewer young drivers were involved in property damage crashes than one would have expected had the law not been changed. These crash reductions are causally attributable to the higher drinking ages because substantial decreases in crash involvement were limited to alcohol-related crashes among young drivers in states that raised the drinking age, with no comparable reductions in non-alcohol-related crashes among youth, crash involvement of older drivers within the same state, or crash involvement of young drivers in comparison states with unchanged drinking ages.

Although the public health benefits and reduced social costs resulting from injury and property damage reductions identified in this research are large, note that the benefits of higher drinking ages are understated, because reductions in injuries to passengers of young crash involved drivers have not been taken into account.

The conclusion that the legal minimum drinking age affects youth crash involvement is further strengthened by comparing results of this research on the raised drinking age with results of earlier research on effects of lowered drinking age. Douglass and Freedman (1977) analyzed a subset of Michigan jurisdictions with complete accident reporting over the 1968 through 1975 period, using a time-series design. Results revealed a 17% ($p<.06$) increase in total (i.e., property damage and injury producing) single-vehicle nighttime male crash involvement among drivers age 18-20 associated with the lowered drinking age in 1972. Police-reported drinking driver crash involvement increased 35% ($p<.01$) after the drinking age was reduced. Similar analyses for the State of Maine revealed a 29% ($p<.02$) decrease in reported alcohol-related crashes, and a 16% ($p<.10$) decrease in single-vehicle nighttime male crash involvement associated with Maine's reduction in drinking age from 20 to 18 in 1972 (Douglass et al., 1974). Comparisons between these earlier findings and results of the present investigation reveal that raising the drinking age reverses the effect of prior reductions in drinking age. Estimates of the increase in alcohol-related crash involvement among young drivers associated with Michigan and Maine's lowered drinking ages ranged from 16 to 35%, remarkably similar to the 11 to 34% range of estimates obtained in the present study of decreased alcohol-related crash involvement associated with raising the drinking age in these two states.

6.2 Discussion

Although the effect of the raised drinking age in reducing youthful auto crashes is now clearly documented, some caution is warranted before a blanket statement is made that any state raising the drinking age can count on a 20% decrease in youth crash involvement. The effect of higher drinking ages is not necessarily uniform across states. In this research, the effect in Michigan was larger and more obvious that the effect in Maine, particularly for the more serious, injury-producing crashes. As noted in section 3.2.2, two studies of fatal crash involvement in Massachusetts found no significant reductions due to an increase in drinking age from 18 to 20 (Hingson et al., 1981; Williams et al., 1981).

One possible reason for the lack of an effect in Massachusetts is that four of the five state bordering Massachusetts had minimum drinking aged of 18 for all alcoholic beverages after Massachusetts' higher drinking age was implemented.[35] The availability of beverage alcohol to

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[35]Vermont, New York, Connecticut, and Rhode Island permitted 18-year-olds to purchase all types of alcoholic beverages during the period for which the Massachusetts law was evaluated. New Hampshire increased

Massachusetts youth was not reduced as much as in other states that raised the drinking age, since Massachusetts youth had a legal supply of alcohol in contiguous states. Hingson et al.'s (1981) survey results provide some support for this line of reasoning, since underage Massachusetts youth reported little difficulty obtaining alcohol after the drinking age was raised. Evidence that contiguous states with differential minimum drinking ages create problems with cross-border purchases of alcohol by youth was provided by Lillis et al. (1981), who found that 18-20-year-old Pennsylvania residents were over-represented in alcohol-related traffic crashes occurring in New York counties contiguous with Pennsylvania.[36] Taking such cross-border problems into consideration, one might suggest the development of a nationwide consensus for a drinking age at 20 or 21, with uniform effective enforcement of the law across states. In any event, potential cross-border purchase of alcohol must be considered when evaluating effects of state-specific drinking age laws.

Another potential explanation of the lack of an observed effect of Massachusetts' higher drinking age is related to the data analyzed. In both studies where no effect of higher drinking ages was found (Hingson et al., 1981; Williams et al., 1981), the dependent variable, fatal crash involvement, had low frequencies. The number of alcohol-related crash fatalities among a limited age group within one state is relatively small for analysis purposes, and, as a result, the large random variation in the number of fatalities from month to month, or

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its drinking age from 18 to 20 in May 1979, just one month after the Massachusetts increase was implemented.

[36]The minimum drinking age is 21 in Pennsylvania and 18 in New York.

even year to year, makes it difficult to identify a significant effect of a policy change such as the drinking age. Even in Michigan, where substantial reductions in both injury-producing and property damage crash involvement due to the raised drinking age were clearly found, no significant effect of the raised drinking age was discernable when fatal crashes alone were analyzed (Wagenaar, 1980). The problems with low crash counts for analysis might also emerge for non-fatal crashes in less populous states like Maine, making it more difficult to detect any effect of policy changes. As a result, while evidence to date clearly demonstrates an effect of raising the drinking age, reductions in crashes and injuries may not always be clearly evident in less populous jurisdictions.

One implication of these findings for future evaluations of the drinking age or other public policy changes is that analyses should not be limited to fatalities only, but should also include the much larger numbers of injury and property damage crashes. Although the effort and costs associated with analyzing non-fatal crashes is substantially higher, such analyses may avoid incorrect conclusions that a policy change had no effect on the outcome of interest.[37]

In spite of the substantial effect of the raised drinking age in reducing alcohol-related crash involvement among young drivers, it is important to keep in mind that the drinking age does not eliminate this

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[37]Increased cost and effort required for analyses of non-fatal crash involvement is readily apparent when the number of fatally injured drivers is compared with the total number of crash involved drivers. For example, in 1979 about 2,500 Michigan drivers were fatally injured in crashes, while about 625,000 drivers were involved in reported crashes. Analyses of all crash-involved drivers over a multi-year period in several states, as was done in the present investigation, requires the processing of millions of crash records.

very serious public health problem. If a raised drinking age reduces the magnitude of the problem by 20%, by implication 80% of the alcohol-related crashes are continuing to occur, and require continuing prevention efforts. If a large number of alcohol-related crashes continue to occur among underage persons, it is clear that some young people continue to drink alcoholic beverages after an increase in drinking age, and therefore must still have alcohol available to them. Raising the legal minimum drinking age does not eliminate the availability of alcohol to young people, but rather is one public policy that reduces alcohol availability and public health problems associated with alcohol use.

Minimum purchasing ages have never prevented underage youth from drinking any alcoholic beverages. Recall the literature reviewed in Section 2.1, which indicates that a majority of high school youth are not abstainers. It is not reasonable to expect a raised legal drinking age to eliminate all youthful alcohol consumption. The observation that youth continue to drink after implementation of higher drinking ages has been cited as evidence that the laws have no effect. However, evaluation of any prevention policy or program is based on marginal effects in reducing public health problems. No prevention effort is realistically expected to prevent all of the incidence of a major public health problem. The legal minimum drinking age substantially reduces alcohol-related crash involvement among young drivers; that it does not eliminate this serious problem is no reason not to consider minimum drinking age as one component of a broader prevention effort.

The minimum drinking age is one of many public policies affecting the availability of alcoholic beverages. The drinking age is a particularly good test of effects of alcohol control laws and alcohol availability for several reasons. First, changes in alcohol availability are focused on a specific age-group, permitting other age-groups to serve as comparisons. Abundant high quality data over an extended period of time are readily available for motor vehicle crashes, the leading alcohol-related health problem among the focal age group.[38] The outcome variable is an acute (not chronic) alcohol-related health problem, the incidence of which can be expected to respond immediately to a major change in drinking patterns. Finally, the drinking age is one indicator of alcohol availability that has changed in both directions in the past decade, providing the opportunity to evaluate effects of reduced as well as expanded availability. For these reasons, the legal minimum drinking age has provided an ideal opportunity for the scientific evaluation of propositions based on availability theory.

In addition to the primary focus on motor vehicle crashes, this investigation also analyzed the effect of the drinking age on aggregate alcoholic beverage sales. Implementation of mandatory beverage container deposit laws in both Michigan and Maine at the same time the drinking age was raised complicated interpretation of the findings. Mandatory container deposit laws also affect alcohol availability not only by increasing the inconvenience of purchasing package beer (and

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[38]Although data on traffic crashes are far from perfect, their quality is high compared to data on the incidence of other alcohol-related social and health problems such as non-motor-vehicle accidents, homicide, assault, child or spouse abuse, divorce, unemployment, and chronic diseases resulting from or exacerbated by heavy alcohol consumption. Furthermore, although data on police-reported alcohol-involvement in traffic crashes is often disparaged, such data are often very useful, particularly for states (such as Michigan) with separate dichotomous alcohol involvement items on statewide standard crash reporting forms.

returning empty containers), but also by causing a significant increase in retail price of package beer. Although the independent effects of the drinking age and container laws could not be determined, major changes in sales of beer were associated with the legal changes of the late 1970s. These results provide further evidence of the importance of evaluating public policies for their effects on alcoholic beverage sales/consumption and associated public health problems.

6.3 Recommendations

Followup studies should be conducted, assessing whether the effects observed in this research increase or decrease over time. This research was limited to an examination of the first year or two after higher drinking ages were implemented. One might hypothesize that the long-term effect will be larger than the short-term effect identified here, since the 18-20-year-old cohort the first few years after a legal change includes individuals who had had the right to drink prior to implementation of the higher drinking age. One might suppose that those who were drinking legally prior to the new laws would be less likely to give up their drinking habits than later cohorts who never had the right to drink. Thus, one would hypothesize that the reduction in alcohol-related crash involvement during the transitional age cohort are smaller than the long-term effect of raising the drinking age.

The pre-driving drinking environment and drinking practices of youth should be investigated. The present research established a link between legal drinking age and crash involvement. As was discussed in Section 3.3, a variety of intervening factors mediate this relationship. One main intervening factor is the drinking practices of youth, including both quantity-frequency of consumption and social situations in which pre-driving drinking occurs. Further research on drinking practices of youth should focus on behavioral patterns which precede driving after drinking.

Another intervening variable between a change in legal drinking age and crash outcomes is enforcement of the drinking age. Levels of enforcement activity, as perceived by both law enforcement officials and young people the focus of the enforcement efforts, deserves more attention.

Analyses of specific subpopulations of crash-involved drivers should be conducted. This research assessed the effect of drinking age on the aggregate of all reported 18-20-year-old crash-involved youth in Michigan. Analyses of single-year age categories would aid in the determination of an optimal legal drinking age. For example, if the beneficial effect of a higher drinking age is largely due to reduced alcohol-related crash involvement among 18 and 19-year-olds, with little effect on 20-year-olds, a minimum drinking age at 20 may provide most of the benefits of the higher legal age at a lower cost in terms of restricting the freedom of young people. A second main demographic characteristic of crash-involved drivers that should be taken into account is sex. As discussed in Chapter 2.0, the alcohol-related crash problem is largely a problem of male drivers. However, there is some evidence that the differential drinking (and perhaps driving after drinking) patterns between males and females is decreasing (National Institute on Alcohol Abuse and Alcoholism, 1980). Very little research to date has focused on the young female alcohol-related crash-involved driver.

Other major changes in alcohol availability should be evaluated for public health effects. Since substantial changes in the availability of alcohol to young drinkers, as reflected in the legal drinking age, have been found to have a clear impact on a major alcohol-related health problem, other changes in alcohol availability should be examined for public health effects. Governmental actions, either through administrative policy, regulatory changes, or legislation, frequently have direct implications for alcohol availability. For example, deregulation or other changes in alcoholic beverage prices, changes in alcohol tax formulae, and zoning and other local ordinance modifications should be adequately evaluated regarding their consequences for alcohol-related morbidity and mortality. Some of these policies, which may appear to have no direct connection with alcohol policy, such as mandatory container deposit laws, were found in this research to be associated with major changes in aggregate alcoholic beverage sales. The effects of new legislation and regulations should be regularly measured, and the results should be used to guide the formulation of public policies designed to prevent alcohol abuse and other alcohol-related problems.

Alcohol control policies historically have been used to accomplish many purposes. In addition to protecting the public health, these laws have been used to reflect social and moral standards, to ensure a stable market for beverage alcohol, and to create mechanisms for governmental revenues. Although other considerations enter into a determination of the minimum age at which alcoholic beverages can be legally purchased, the recommendation below is based solely on the public health and social cost implications of research findings concerning effects of the drinking age on alcohol-related motor vehicle crash involvement.

A legal drinking age at 20 or 21 should be encouraged. Rarely in the field of public health is it possible to identify a law, public policy, or programmatic effort that has a demonstrable effect on a major cause of morbidity due to individual behavioral patterns. Few traffic safety prevention programs have been found to have prevented significant numbers of alcohol-related traffic accidents among young drivers. Recent changes in legal drinking age in Michigan and Maine produced significant reductions in injuries and social costs associated with traffic accidents. The higher drinking age can be considered a successful public health countermeasure against a leading cause of morbidity and mortality among youth. If the basis for a determination of the minimum age of purchase for alcoholic beverages is the public health consequences of alternative drinking ages, one must conclude that higher drinking ages should be encouraged.[39]

The view that demonstrable effects of the drinking age lead to the conclusion that the drinking age should be high is not universally held. It has been argued (Bowen and Kagay, 1973, Cucchiaro et al., 1974) that the higher frequency of alcohol-related collisions among young drivers when the drinking age is low should not be interpreted as support for a higher drinking age, because the lower legal age simply results in young drivers experiencing the high rates of alcohol-related collisions characteristic of drivers in their early 20s. Since the proportion of all collisions that are alcohol-related is approximately the same for

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[39]The "protection of life and limb" was found by the courts to be the rational basis for the 1978 change in Michigan's legal drinking age (Guy, 1978:51).

18-20-year-olds under a lower legal drinking age as the proportion that are alcohol-related among drivers in the early 20s, the increased frequency of alcohol-related crashes among 18-20-year-olds resulting from a lowered drinking age provides insufficient justification for a higher minimum drinking age, according to these authors.

However, it must be recognized that the lower drinking age expands the age group with a particularly high risk of alcohol-related crash involvement by three years. There is no evidence that a lower drinking age causes a shift in the high risk age group from those in their early 20s to those in their late teens. When the drinking age is reduced to 18, drivers age 21-24 remain at high risk of alcohol-related collision involvement, while those age 18-20 are added to the high risk age group.

The prevention of alcohol-related crash involvement is inevitably an ethical, value, or political issue. The prevention of health problems that are a result of individual behavioral patterns is based on the exercise of power by those who want to change individual behavior to minimize health problems, against those who are viewed as contributors to the problems. With regard to the legal drinking age, there is a compromise between the pleasures/liberties of young drinkers and other positive functions alcohol may provide for society (e.g., enhancing the stability of the socio-political system), and dysfunctional consequences of youthful alcohol use, of which traffic crash involvement is one example. The classic issue for public health prevention is, how much interference in the lives of individuals is acceptable in pursuit of improved health? Do we only intervene when the individual's actions affect others? Almost everything a person does affects others to some extent in our increasingly complex social system. A balance between competing values such as individual freedom and the public's health and safety must be obtained through the political system, where, hopefully, a compromise is achieved that is acceptable to most of the members of the social system.[40]

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[40]It is important to note, however, that those with an economic interest in increased use of alcoholic beverages are likely to have a disproportionate influence in the political process.

APPENDICES

Introduction to Appendices

Appendices A through H depict a time-series plot including actual values and trend line, and the final estimated model for each variable analyzed.[41] The trend line shown is a simple front-ended moving average calculated as follows:

$$x_t = \frac{y_t + y_{t-1} + y_{t-2} + y_{t-3} + \dots y_{t-11}}{12}$$

If no model accompanies a plot, no model was estimated, either because the reliability and validity of the variable was low, the time series had insufficient cases for analysis, or the variable was not included in the design, and is presented for informational purposes only. The t-ratio associated with each parameter is shown immediately below the corresponding point estimate. Adequacy of the model in explaining the dependent variable is indicated with an R-square statistic. The R-square statistics shown were adjusted (i.e. corrected) for the number of degrees of freedom used by the model's parameters; as a result, they are smaller than values obtained using the conventional R-square formula (Pindyck and Rubinfeld, 1976).

The independent variables shown in the models are identified as follows:

S_t -- step function beginning November 1977

S_{2t} -- step function beginning January 1979

S_{3t} -- step function beginning July 1977

S_{4t} -- step function beginning January 1974

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[41]The least significant digit of the y-axis label values may be inaccurate due to rounding errors in the computer plot generation routine.

S_{5t} -- step function beginning January 1978

S_{6t} -- step function beginning June 1972

S_{7t} -- step function beginning October 1970

S_{8t} -- step function beginning January 1972

S_{9t} -- step function beginning January 1980

S_{10t} -- step function beginning June 1973

P_t -- pulse function at January 1972

P_{2t} -- pulse function at February 1978

Appendix A

Crash Frequency Plots and Time-series Models, State of Maine

$$Y_t = \frac{(1 + .23B^2 + .30B^3)(1 - .83B^{12})u_t + .85}{1 - B^{12}} + 2.67\, S_t$$

t-ratio 2.26 2.92 20.76 2.52 1.64

$R^2 = .59$

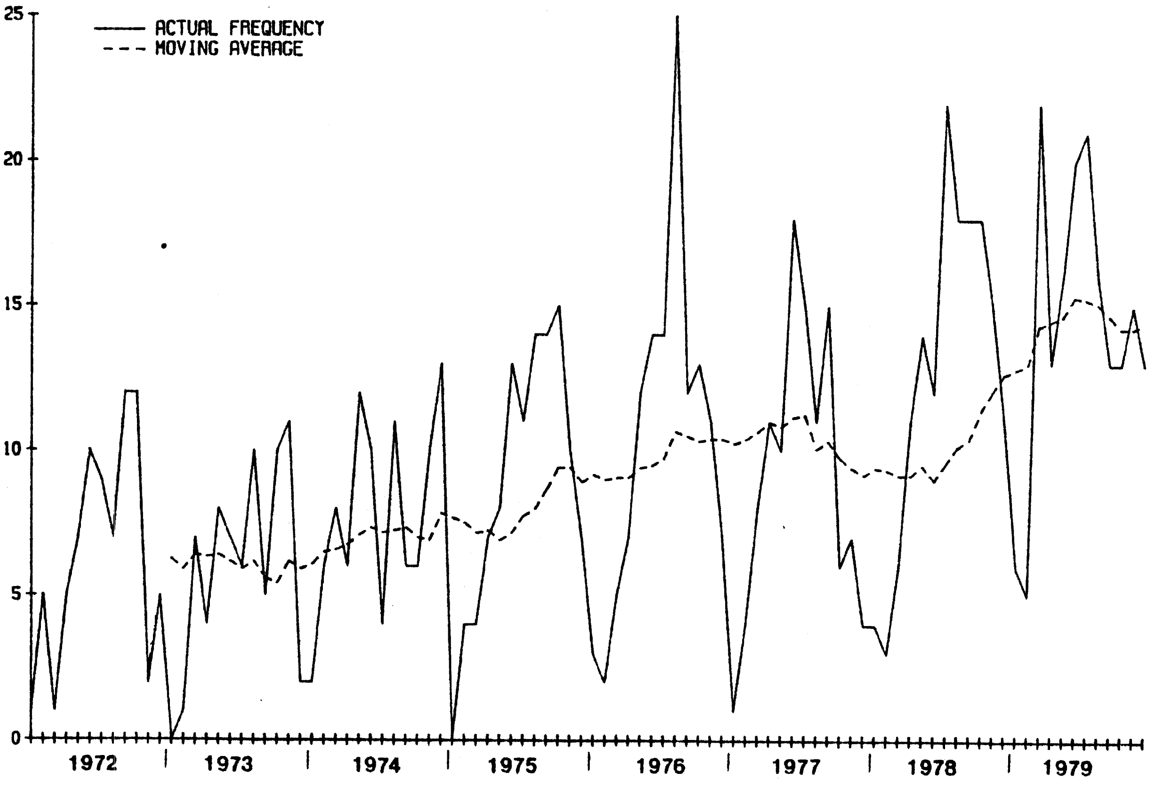


Figure A.1 Police-reported Had Been Drinking Drivers Age 16-17 Involved in Crashes Including at Least One Injury or Fatality, State of Maine

$$\log Y_t = \frac{(1 + .18B + .14B^2 + .21B^3)(1 - .86B^{12})u_t + .17}{1 - B^{12}} - .28\,S_t$$

t-ratio 1.66 1.33 2.05 21.51 3.94 1.35

$R^2 = .42$

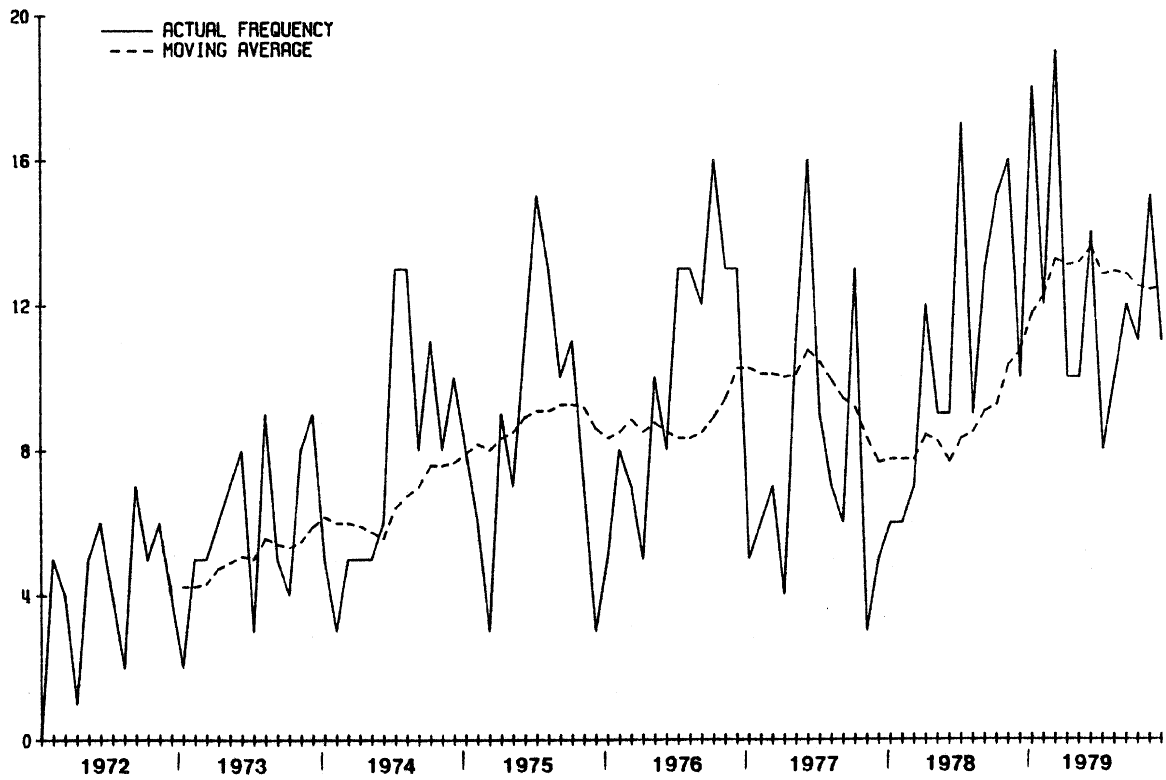


Figure A.2 Police-reported Had Been Drinking Drivers Age 16-17 Involved in Property Damage Only Crashes, State of Maine

$$Y_t = \frac{(1 - .80B^{12})u_t + .68}{1 - B^{12}} + .36\ S_t$$

t-ratio 18.33 2.38 .27

$R^2 = .51$

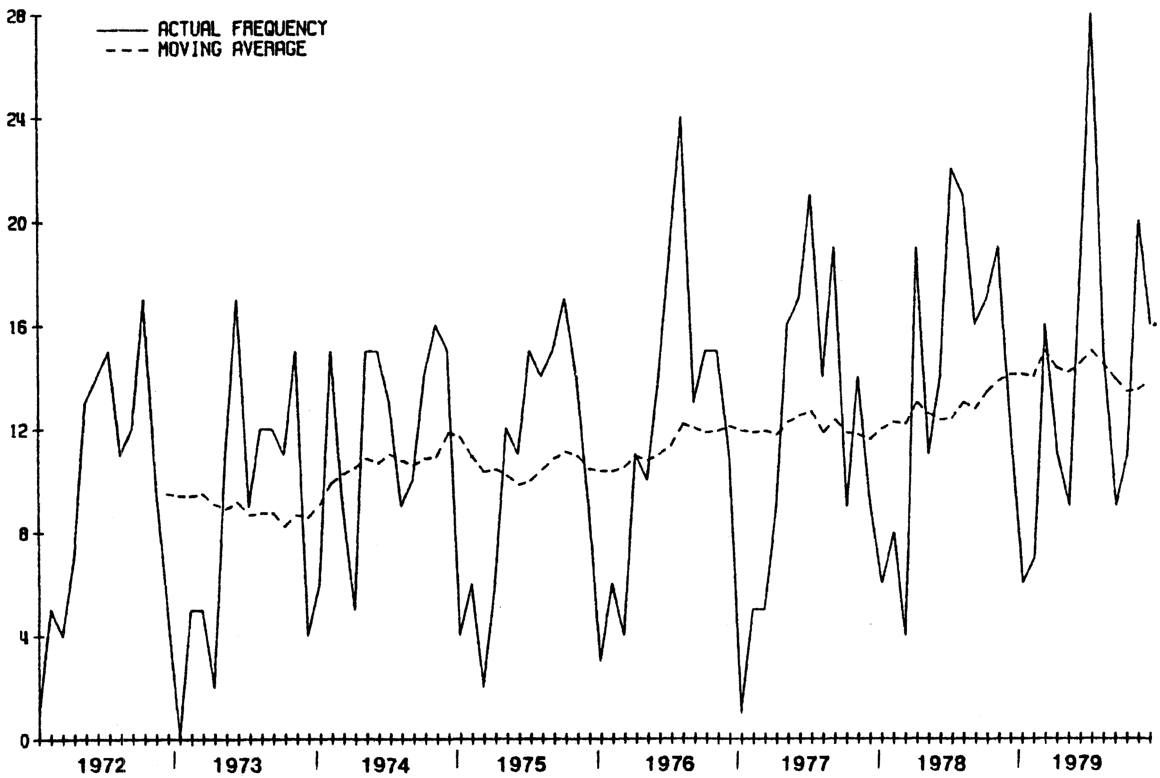


Figure A.3 Male Drivers Age 16-17 Involved in Late-night, Single-vehicle Crashes Including at Least One Injury or Fatality, State of Maine

$$Y_t = \frac{(1 - .86B^{12})u_t + 1.51}{1 - B^{12}} - 2.75\ S_t$$

t-ratio 22.12 5.62 2.15

$R^2 = .45$

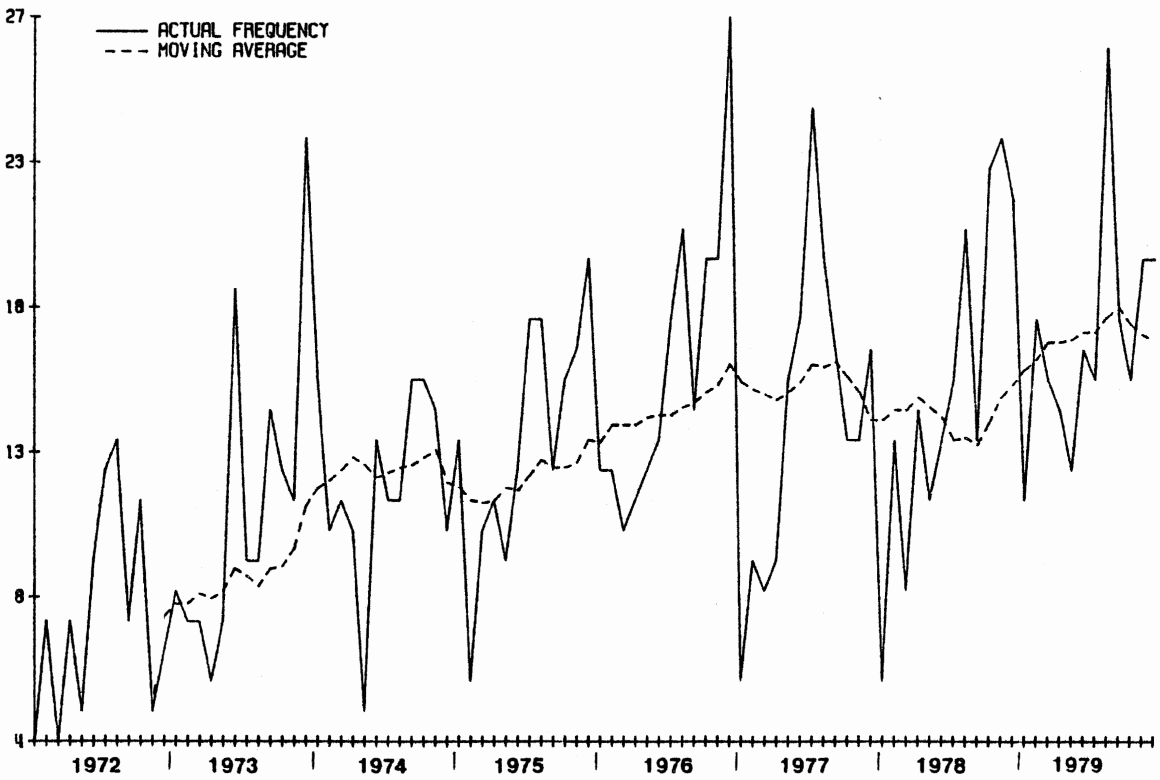


Figure A.4 Male Drivers Age 16-17 Involved in Late-night, Single-vehicle, Property Damage Only Crashes, State of Maine

$$Y_t = \frac{(1 + .19B)(1 - .85B^{12})u_t + 2.43}{1 - B^{12}} + .83\ S_t$$

t-ratio 1.78 19.58 2.67 .19

$R^2 = .68$

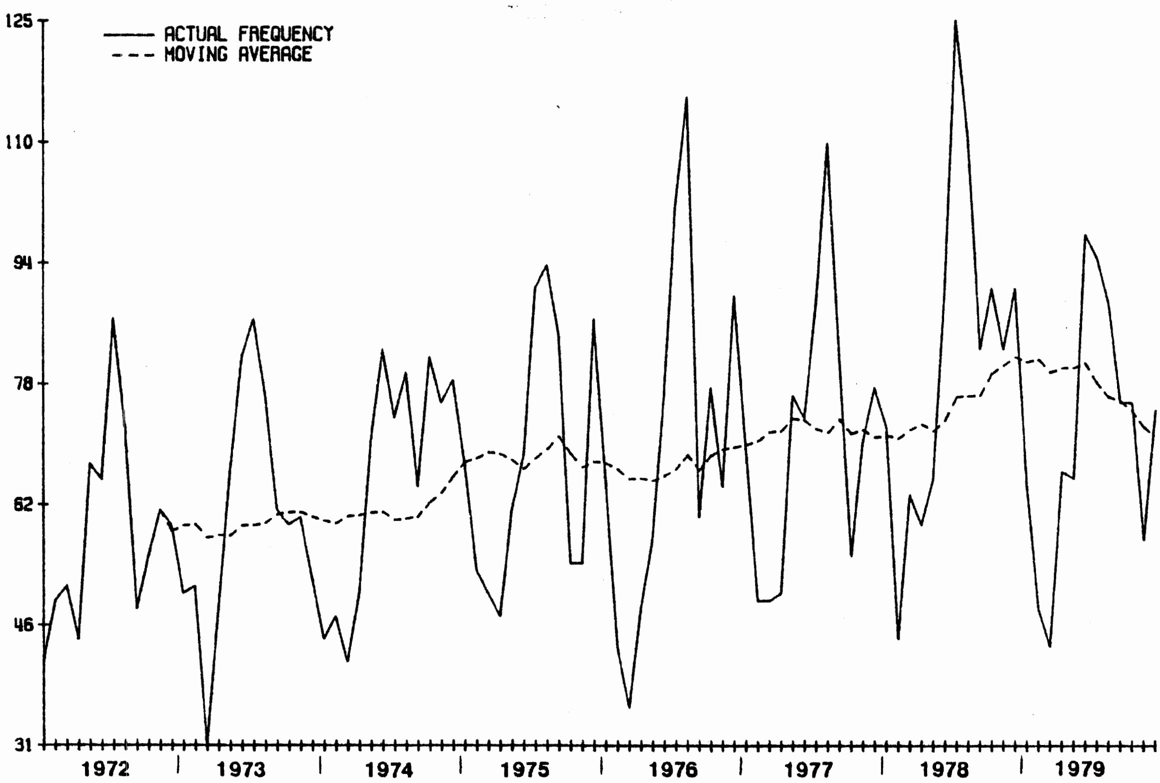


Figure A.5 Police-reported Had Not Been Drinking Drivers Age 16-17 Involved in Crashes Including at Least One Injury or Fatality, State of Maine

$$Y_t = \frac{(1 + .31B + .28B^2)(1 - 1.46B^{12} + .60B^{24})u_t + 12.46}{1 - B^{12}} + 5.77\ S_t - 52.40\ S_{2t}$$

t-ratio	2.92	2.58	27.85	11.97	6.37	.48	3.71

$R^2 = .81$

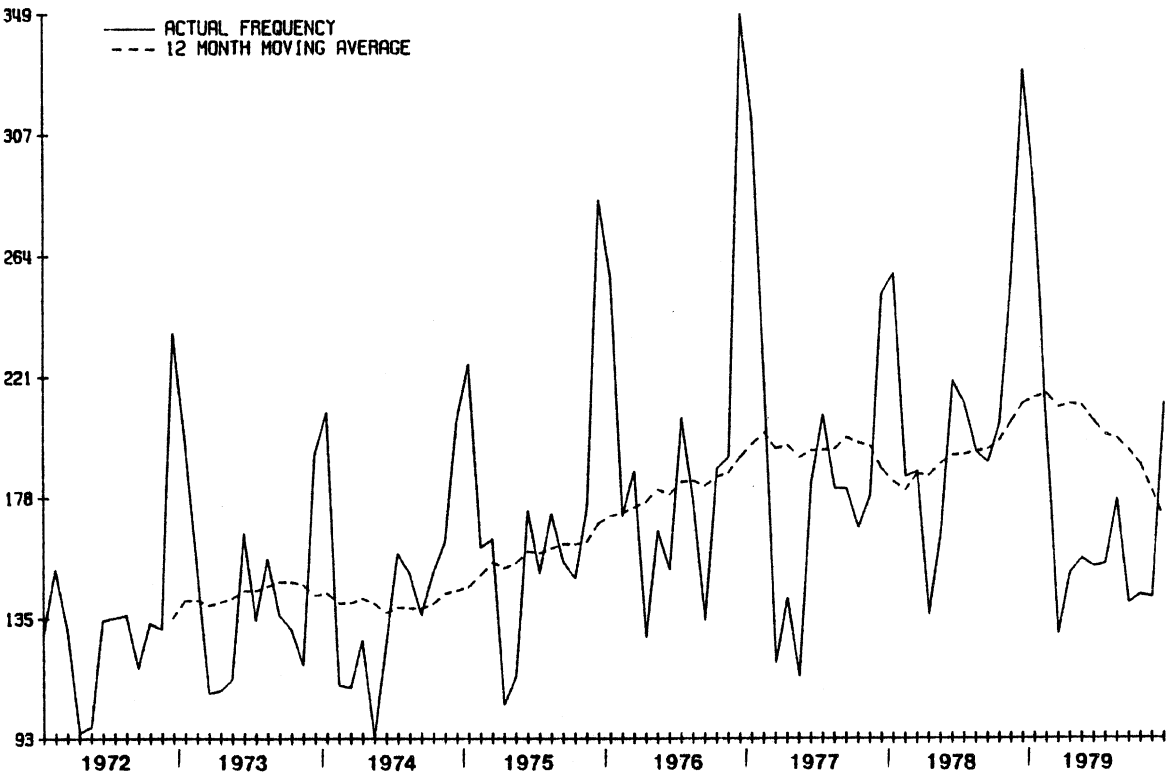


Figure A.6 Police-reported Had Not Been Drinking Drivers Age 16-17 Involved in Property Damage Only Crashes, State of Maine

$$Y_t = \frac{(1 + .20B)(1 - .84B^{12})u_t + 1.91}{1 - B^{12}} + 2.05\ S_t$$

t-ratio 1.84 20.42 2.33 .53

$R^2 = .63$

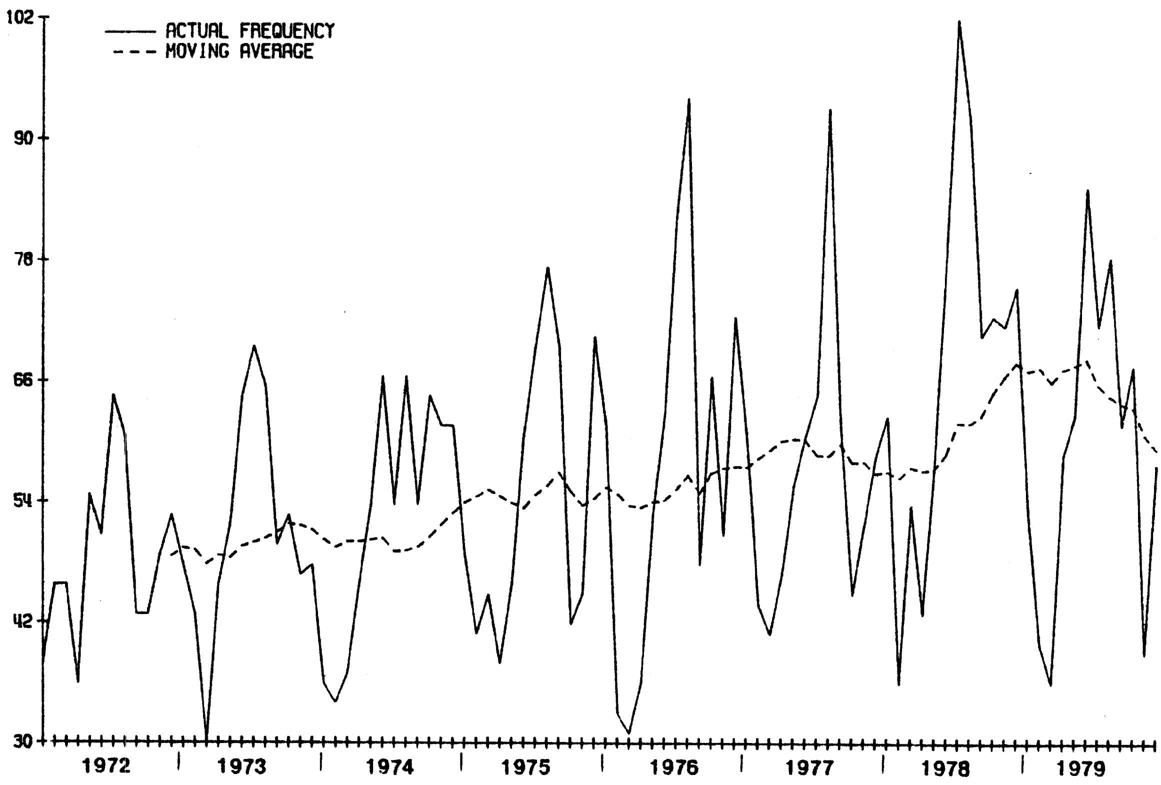


Figure A.7 Drivers Age 16-17 Involved in Daytime Crashes Including at Least One Injury or Fatality, State of Maine

$$Y_t = \frac{(1 + .29B + .21B^2)(1 - .83B^{12})u_t + 9.93}{1 - B^{12}} + 3.48\ S_t - 43.93\ S_{2t}$$

t-ratio 2.57 1.81 19.44 3.99 .30 3.80

$R^2 = .73$

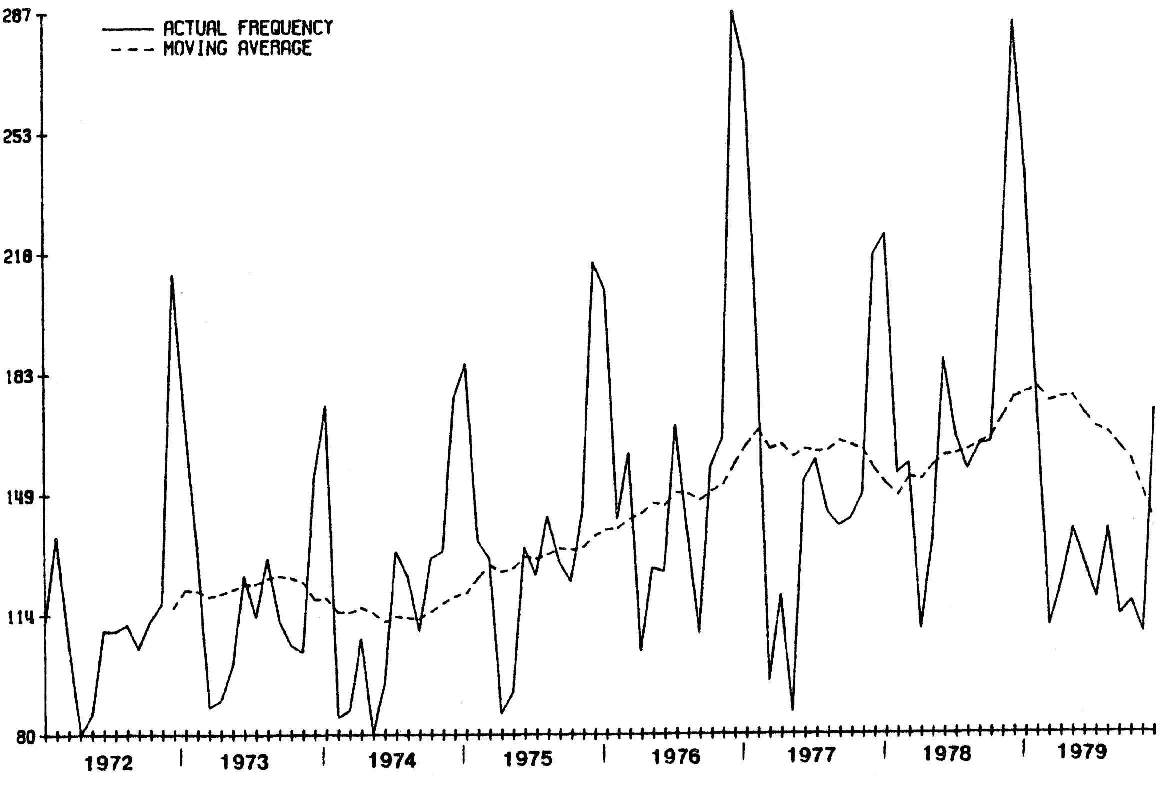


Figure A.8 Drivers Age 16-17 Involved in Daytime Property Damage Only Crashes, State of Maine

$$Y_t = \frac{(1 - .85B^{12})u_t + 1.21}{1 - B^{12}} + 1.92\ S_t$$

t-ratio 20.01 2.64 .84

$R^2 = .52$

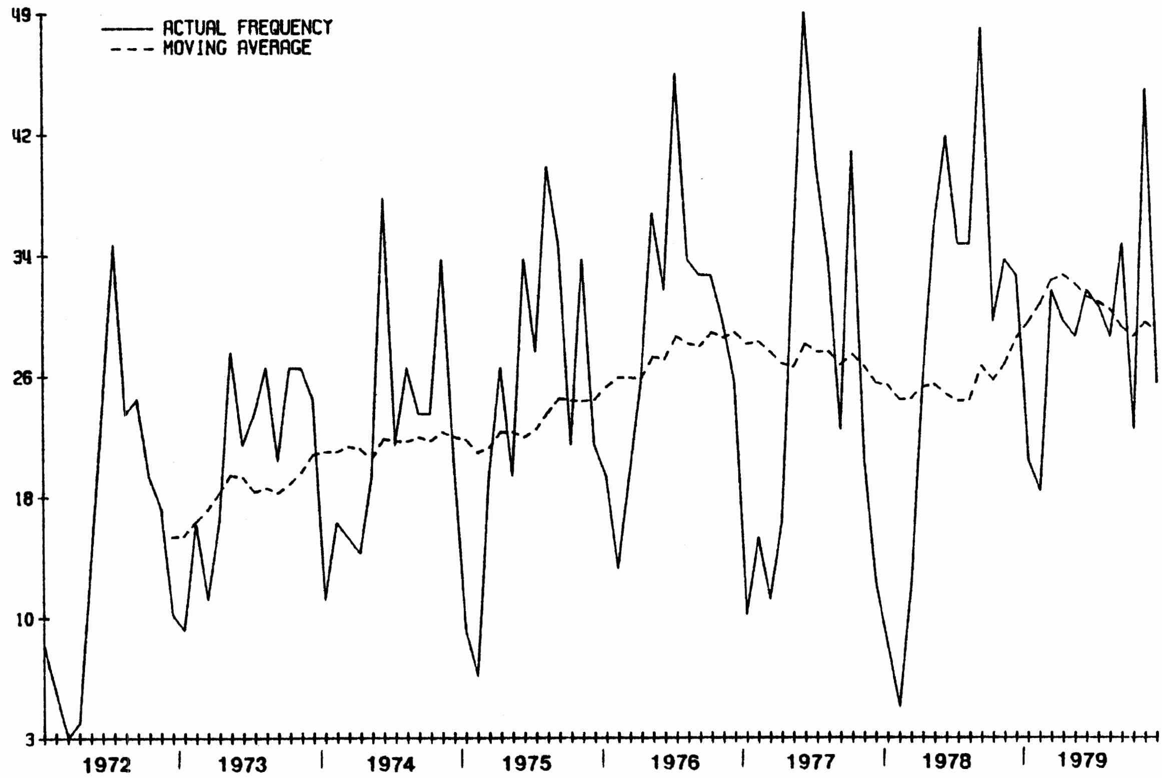


Figure A.9 Police-reported Had Been Drinking Drivers Age 18-19 Involved in Crashes Including at Least One Injury or Fatality, State of Maine

$$Y_t = \frac{(1 - .34B^3)(1 - .86B^{12})u_t + 2.15}{1 - B^{12}} - 5.11\ S_t$$

t-ratio	3.33	20.10	7.42	3.70

$R^2 = .41$

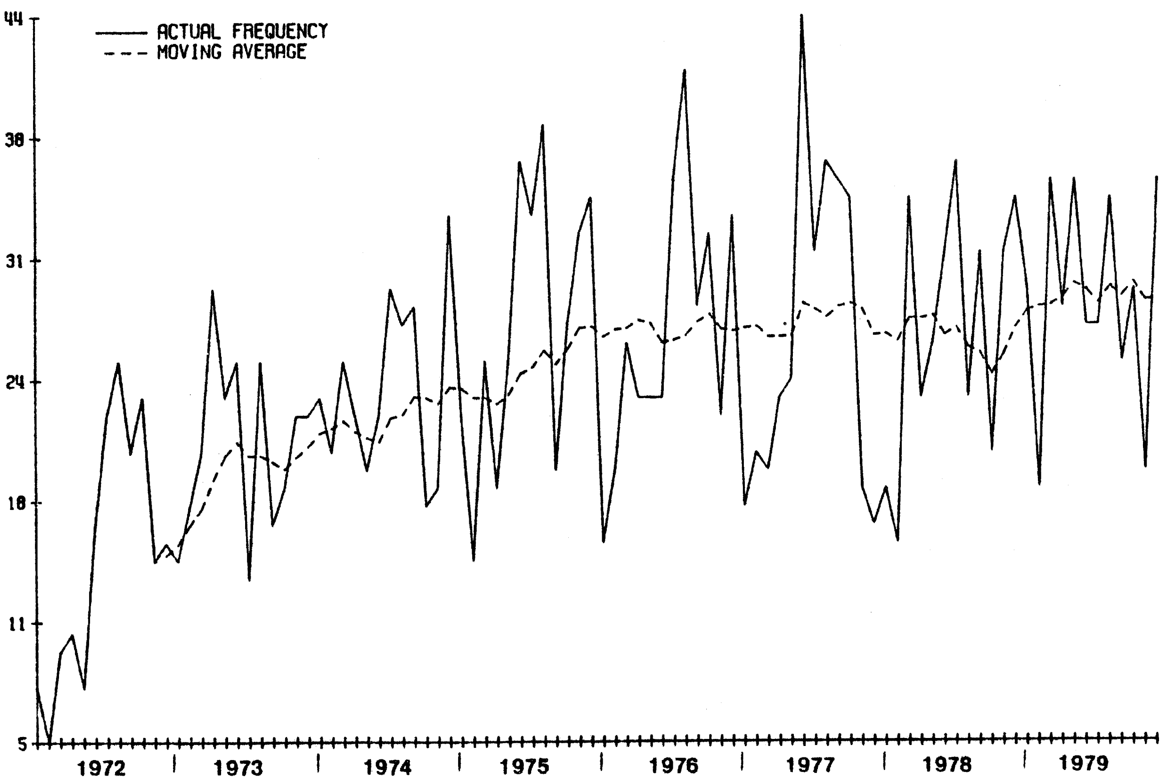


Figure A.10 Police-reported Had Been Drinking Drivers Age 18-19 Involved in Property Damage Only Crashes, State of Maine

$$Y_t = \frac{(1 + .20B)(1 - .84B^{12})u_t + 1.09}{1 - B^{12}} - 3.23\, S_t$$

t-ratio 1.95 21.81 2.23 1.41

$R^2 = .64$

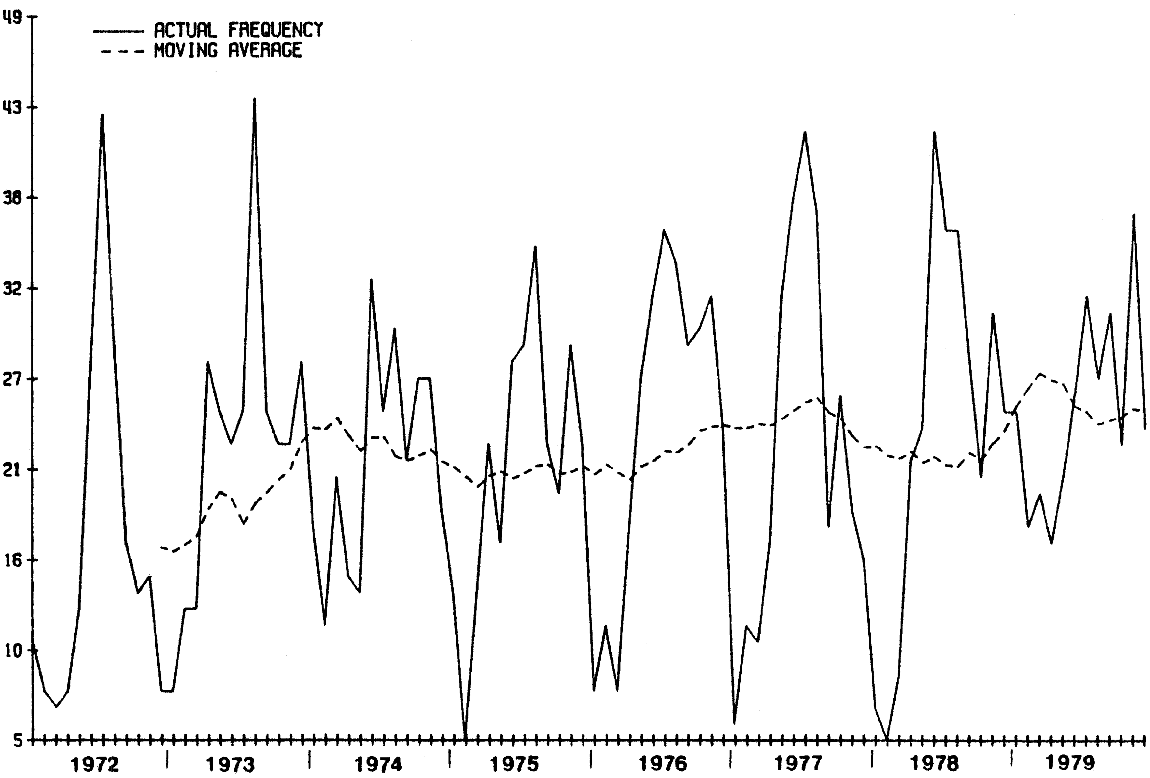


Figure A.11 Male Drivers Age 18-19 Involved in Late-night, Single-vehicle Crashes Including at Least One Injury or Fatality, State of Maine

$$Y_t = \frac{(1 - .82B^{12})u_t + 2.41}{1 - B^{12}} - 7.47\ S_t$$

t-ratio 19.42 5.35 3.53

$R^2 = .45$

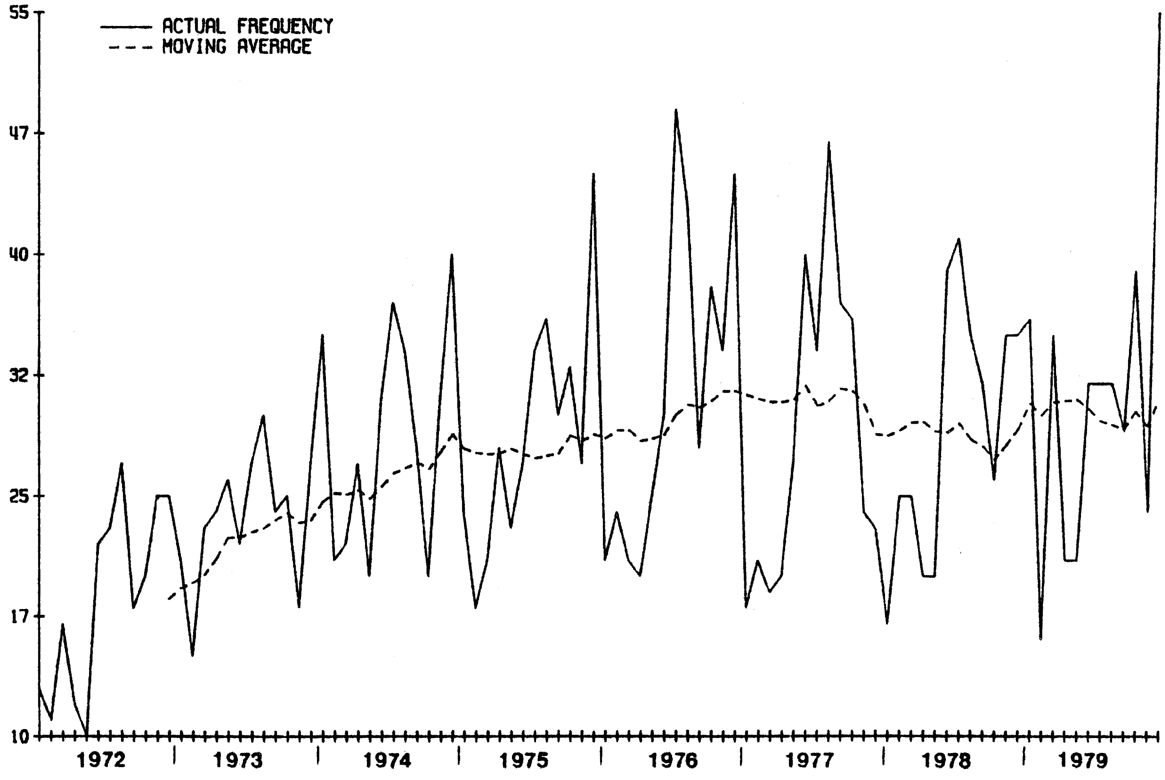


Figure A.12 Male Drivers Age 18-19 Involved in Late-night, Single-vehicle, Property Damage Only Crashes, State of Maine

$$Y_t = \frac{(1 + .29B + .25B^2)(1 - .84B^{12})u_t + 2.69}{1 - B^{12}} - 1.80\ S_t$$

t-ratio 2.77 2.44 21.21 1.67 .24

$R^2 = .70$

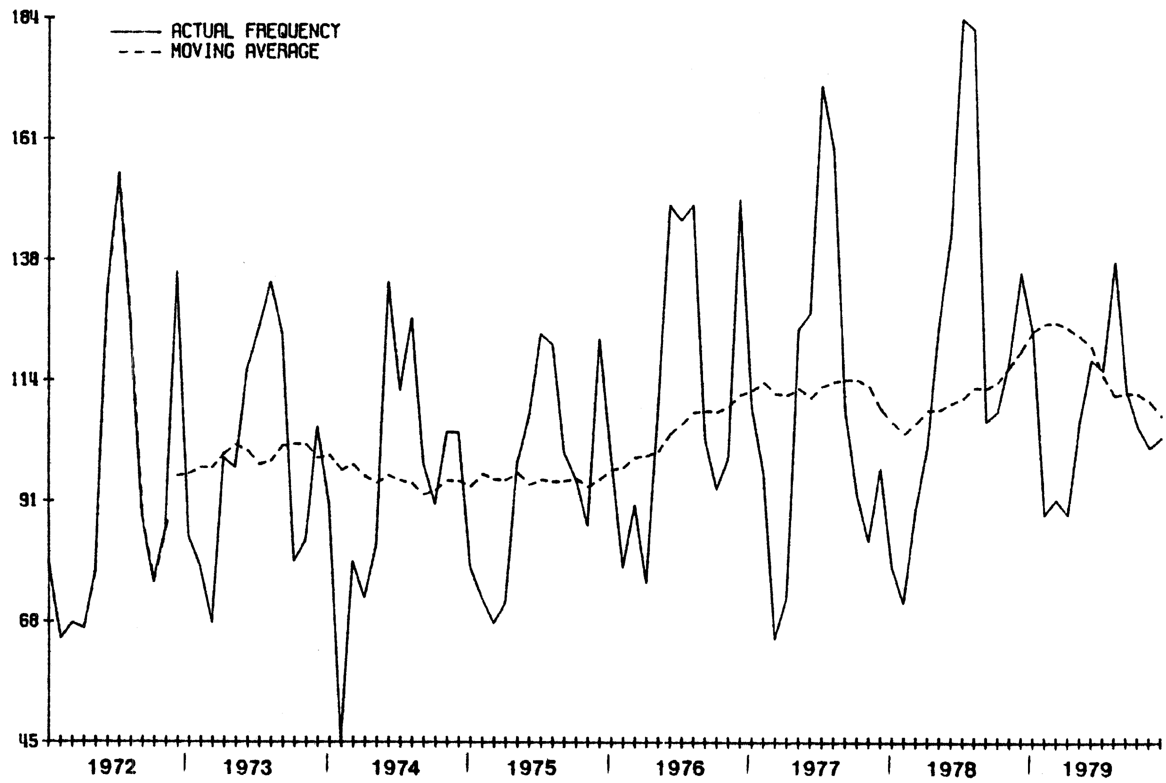


Figure A.13 Police-reported Had Not Been Drinking Drivers Age 18-19 Involved in Crashes Including at Least One Injury or Fatality, State of Maine

$$Y_t = \frac{(1 + .20B)(1 - .79B^{12})u_t + 18.27}{1 - B^{12}} - 19.76\ S_t - 61.00\ S_{2_t}$$

t-ratio 1.76 18.32 5.37 1.23 3.83

$R^2 = .77$

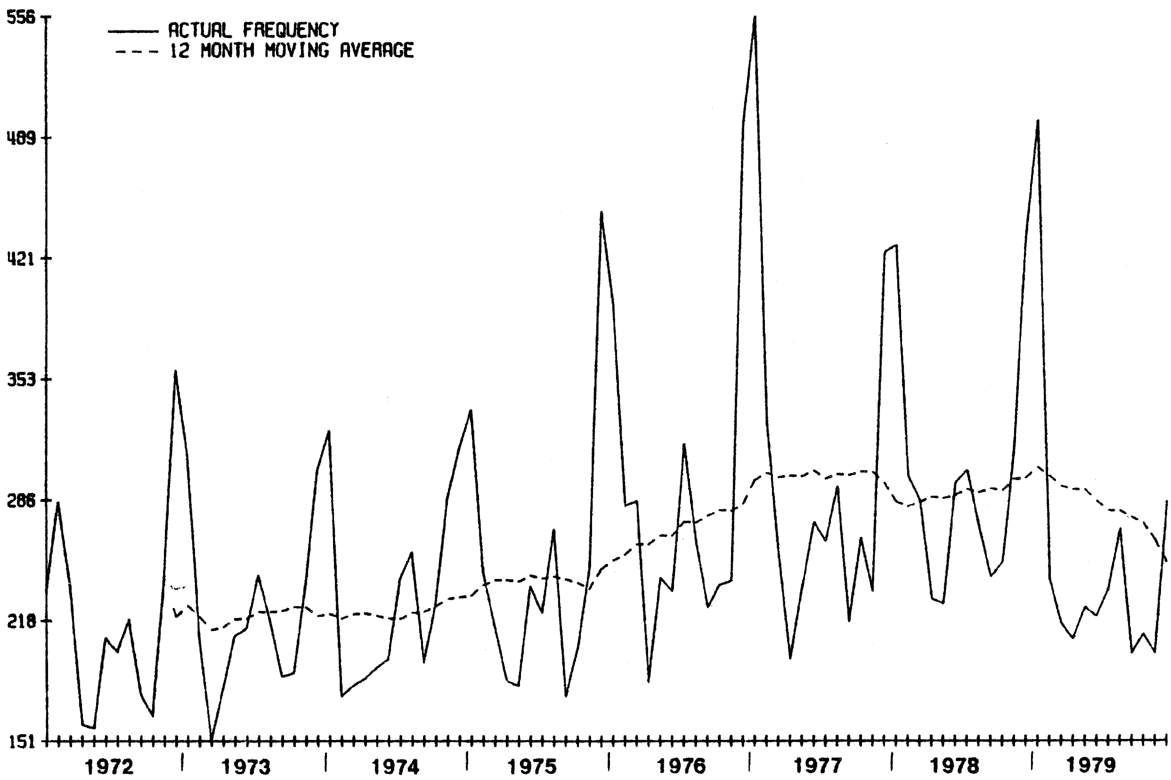


Figure A.14 Police-reported Had Not Been Drinking Drivers Age 18-19 Involved in Property Damage Only Crashes, State of Maine

$$Y_t = \frac{(1 + .14B + .39B^2)(1 - .87B^{12})u_t}{1 - B^{12}} + 19.02\ S_t - 21.34\ S_{2t}$$

t-ratio 1.41 3.95 22.32 4.42 3.56

$R^2 = .73$

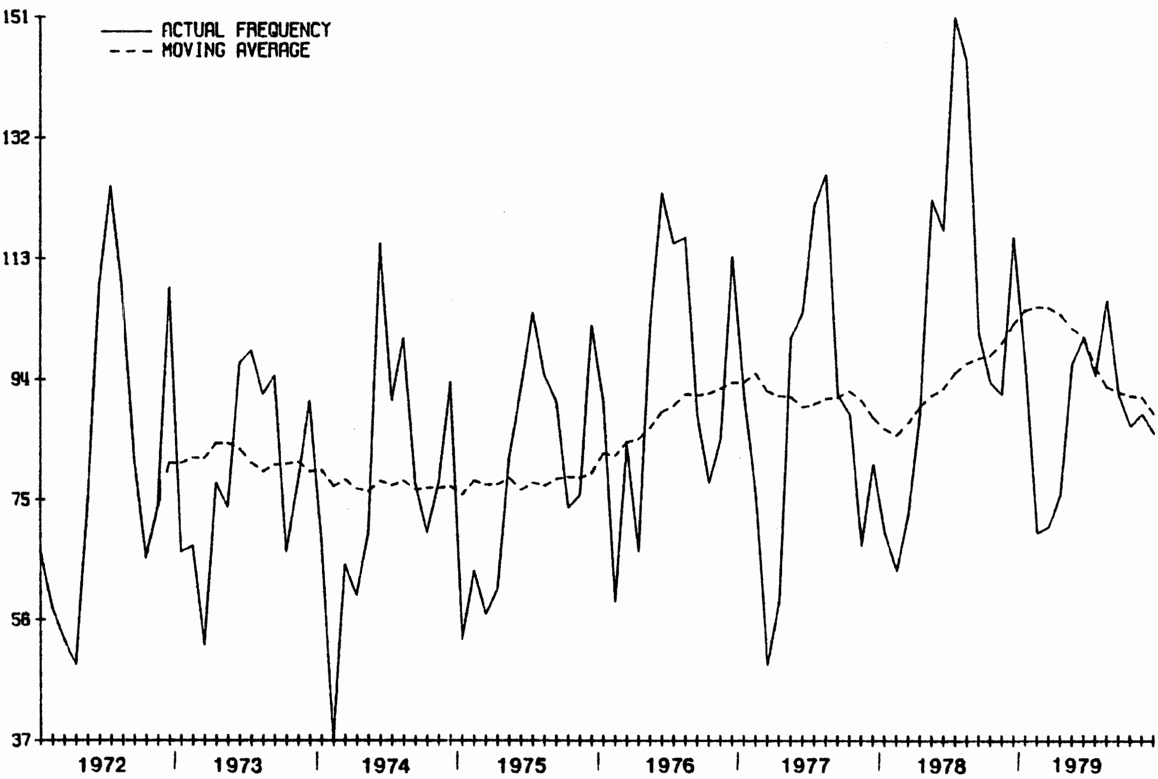


Figure A.15 Drivers Age 18-19 Involved in Daytime Crashes Including at Least One Injury or Fatality, State of Maine

$$Y_t = \frac{(1 + .33B)(1 - .79B^{12})u_t + 13.92}{1 - B^{12}} - 10.83\ S_t - 51.06\ S_{2t}$$

t-ratio	3.09	18.51	4.16	.69	3.28

$R^2 = .76$

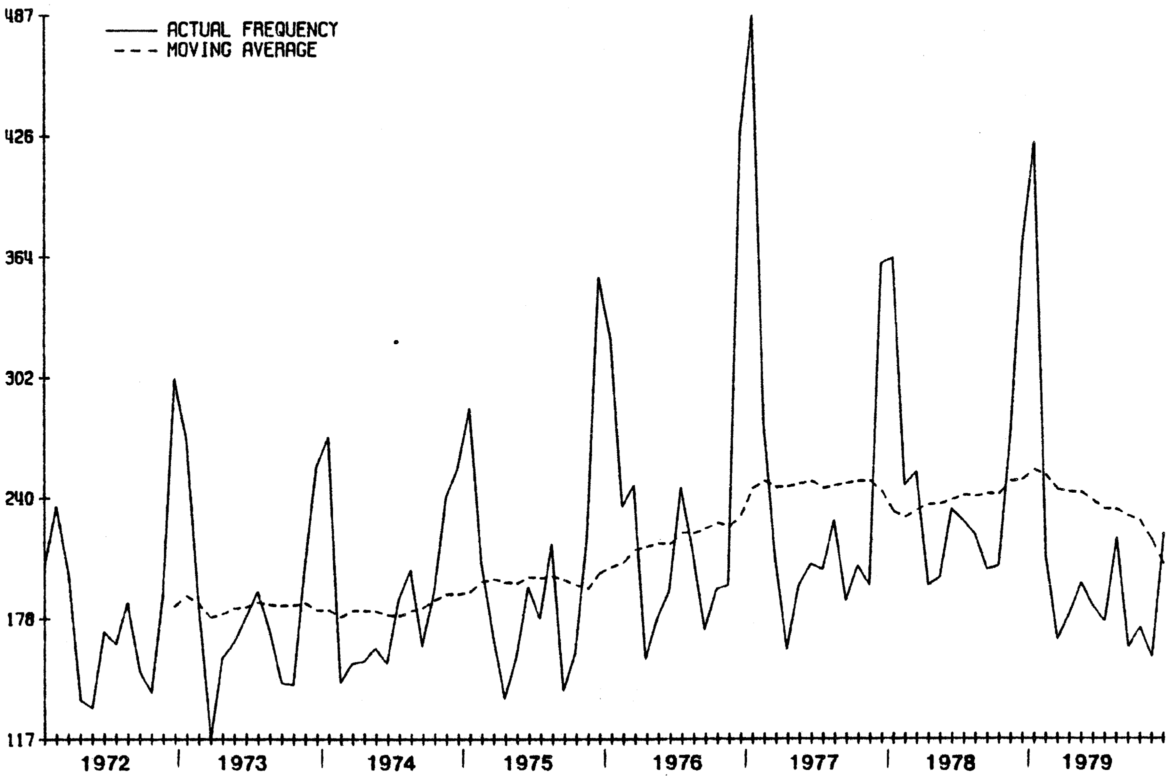


Figure A.16 Drivers Age 18-19 Involved in Daytime Property Damage Only Crashes, State of Maine

$$Y_t = \frac{(1 - .86B^{12})u_t + .75}{1 - B^{12}} + 4.90\ S_t$$

t-ratio 22.57 2.09 2.75

$$R^2 = .66$$

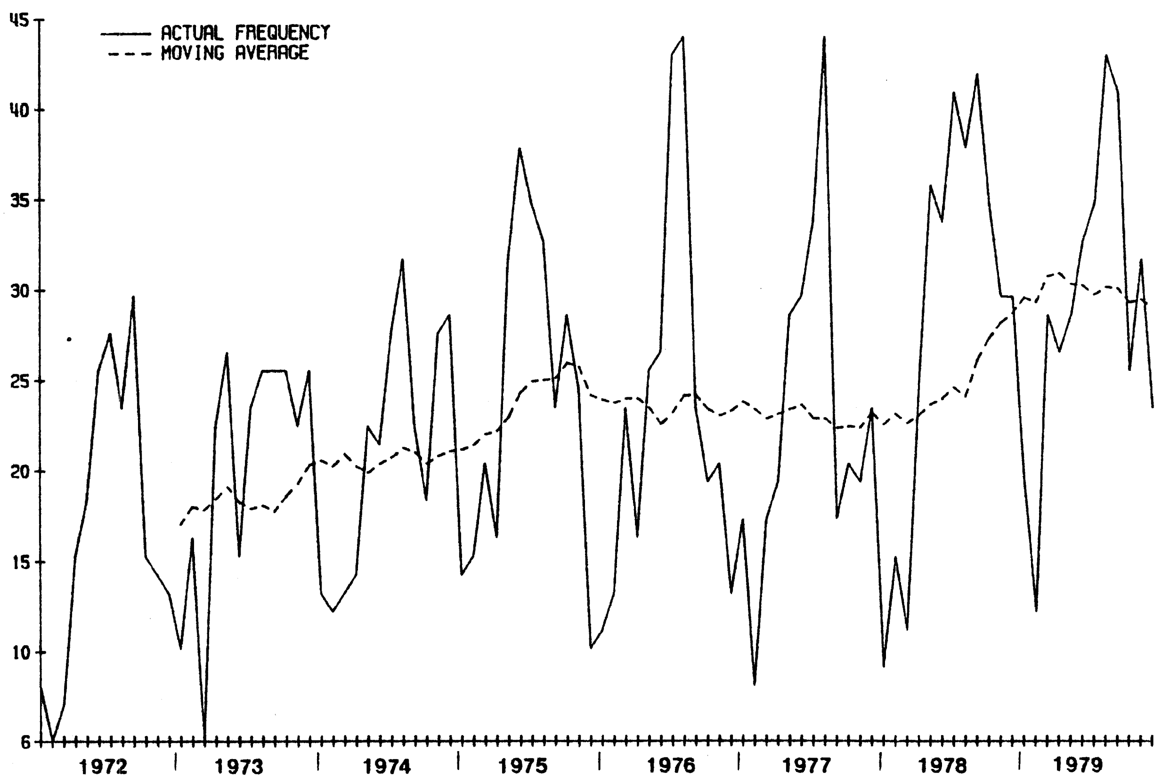


Figure A.17 Police-reported Had Been Drinking Drivers Age 20-21 Involved in Crashes Including at Least One Injury or Fatality, State of Maine

$$Y_t = \frac{(1 + .15B)(1 - .85B^{12})u_t + 2.26}{1 - B^{12}} - 3.03\, S_t$$

t-ratio 1.36 20.14 5.10 1.45

$R^2 = .45$

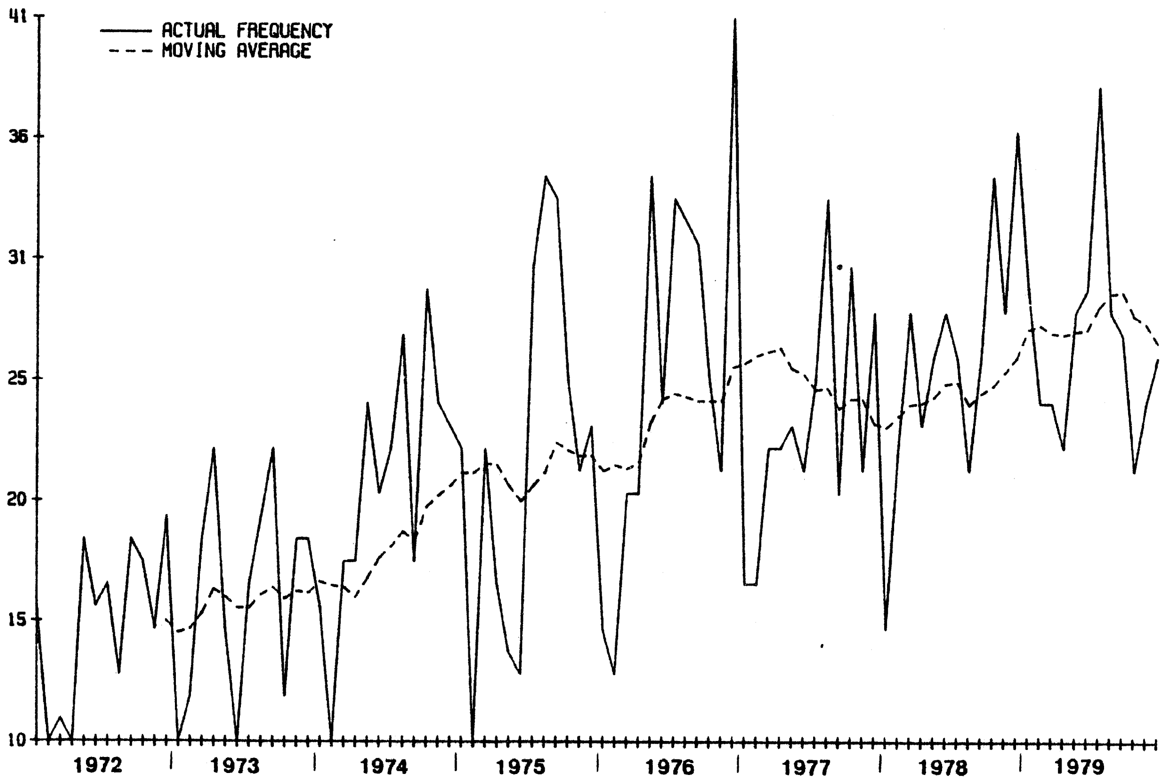


Figure A.18 Police-reported Had Been Drinking Drivers Age 20-21 Involved in Property Damage Only Crashes, State of Maine

$$Y_t = \frac{(1 - .86B^{12})u_t}{1 - B^{12}} + 2.41\ S_t$$

t-ratio 20.15 2.73

$R^2 = .65$

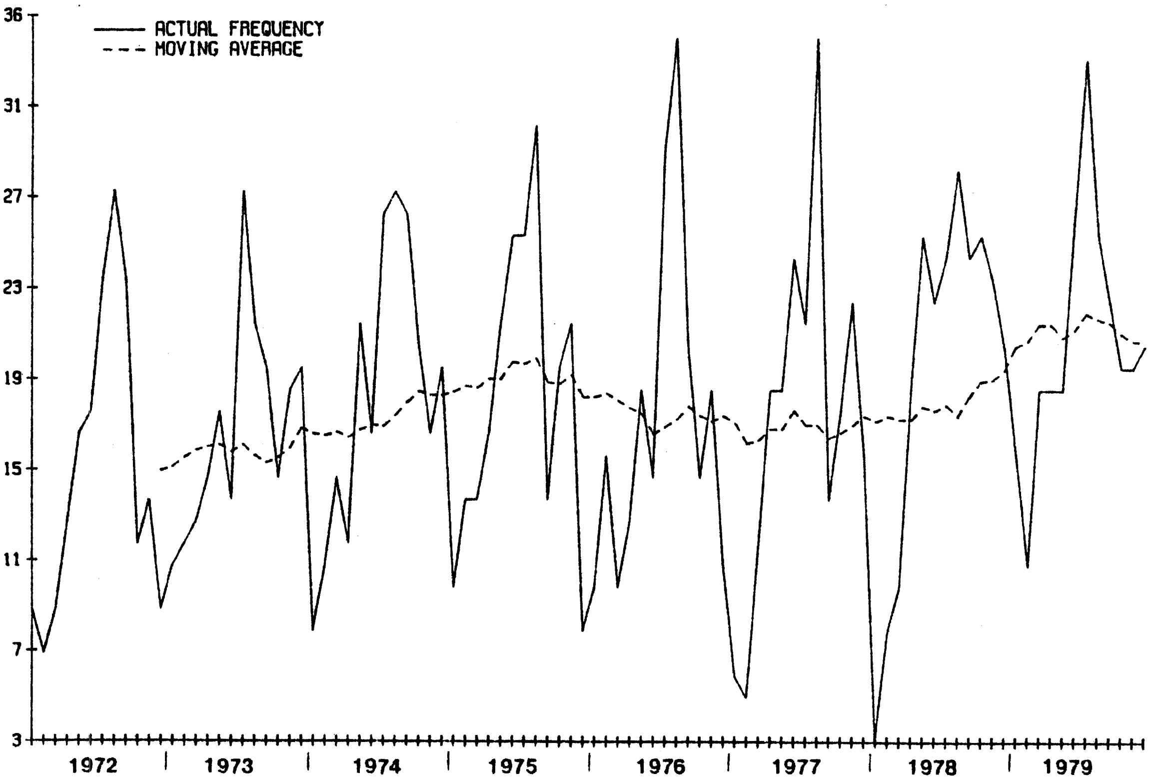


Figure A.19 Male Drivers Age 20-21 Involved in Late-night, Single-vehicle Crashes Including at Least One Injury or Fatality, State of Maine

$$Y_t = \frac{(1 - .85B^{12})u_t + 1.53}{1 - B^{12}} - .87\ S_t$$

t-ratio 19.52 4.17 .50

$R^2 = .37$

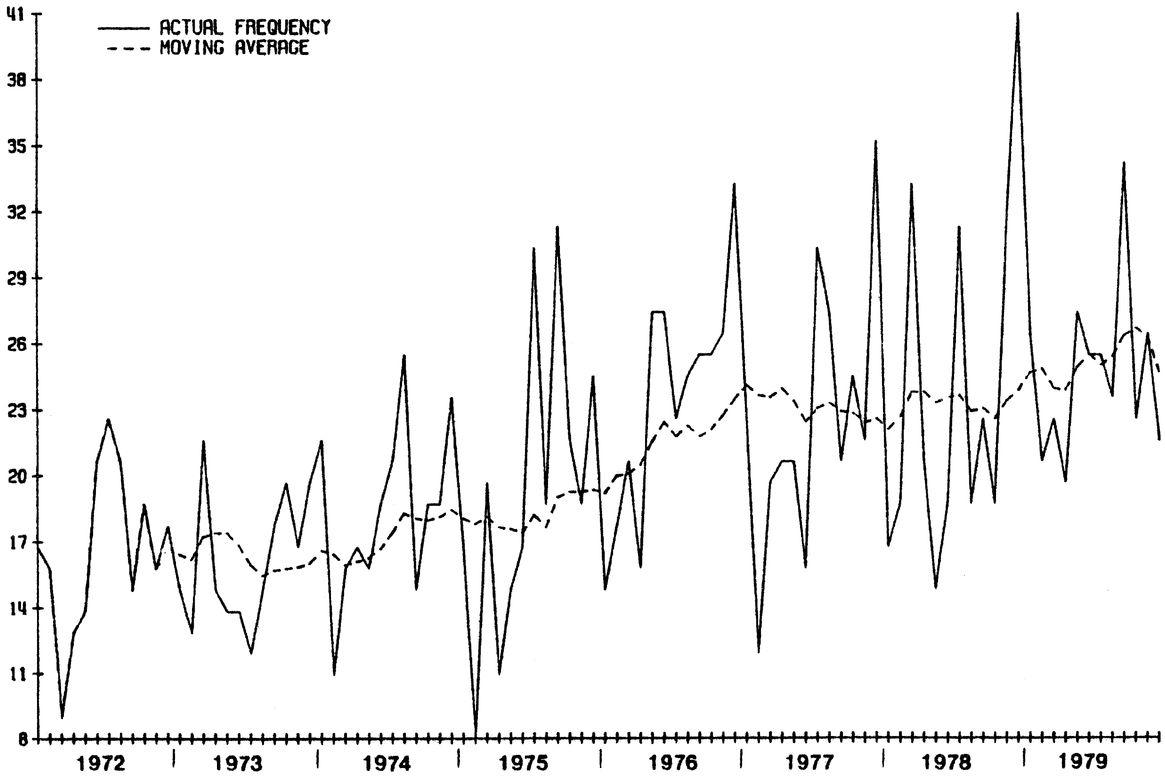


Figure A.20 Male Drivers Age 20-21 Involved in Late-night, Single-vehicle, Property Damage Only Crashes, State of Maine

$$Y_t = \frac{(1 + .25B^3)(1 - .83B^{12})u_t + 2.75}{1 - B^{12}} - 1.38\ S_t$$

t-ratio 2.35 20.20 2.17 .23

$R^2 = .43$

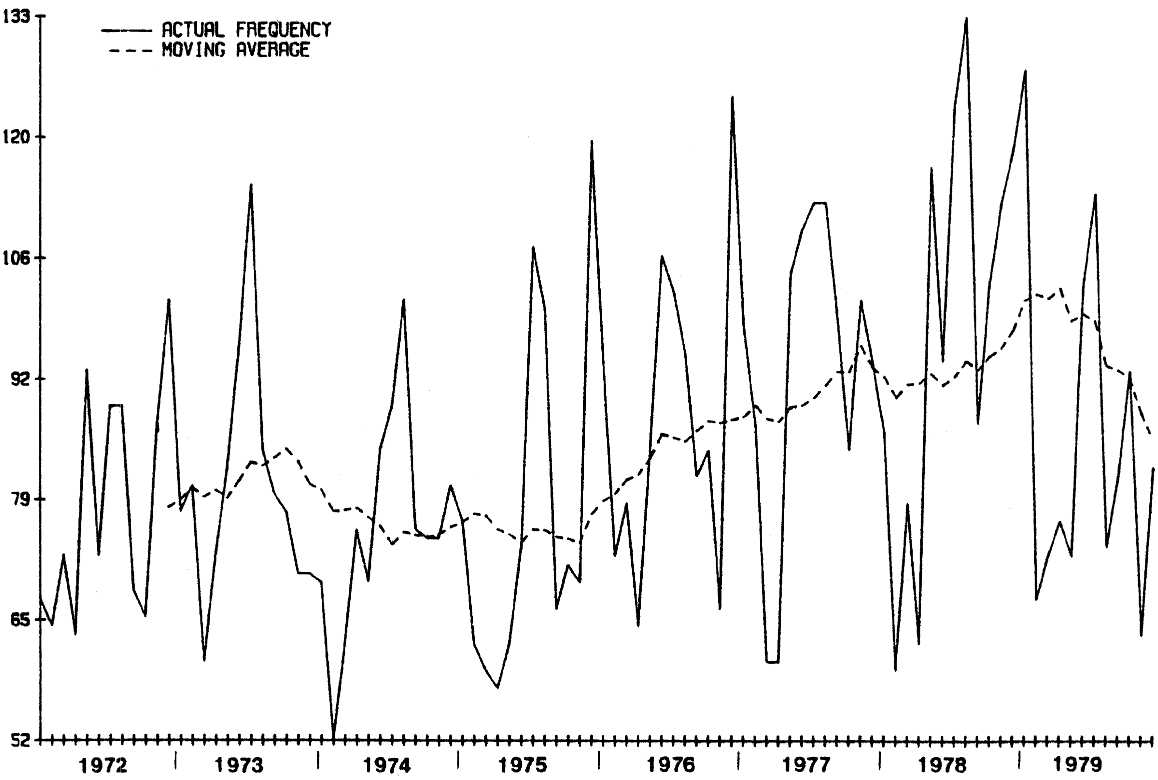


Figure A.21 Police-reported Had Not Been Drinking Drivers Age 20-21 Involved in Crashes Including at Least One Injury or Fatality, State of Maine

$$Y_t = \frac{(1 + .33B)(1 - .78B^{12})u_t + 15.05}{1 - B^{12}} - 12.47\ S_t - 52.05\ S_{2t}$$

t-ratio 2.87 17.42 3.54 .63 2.64

$R^2 = .69$

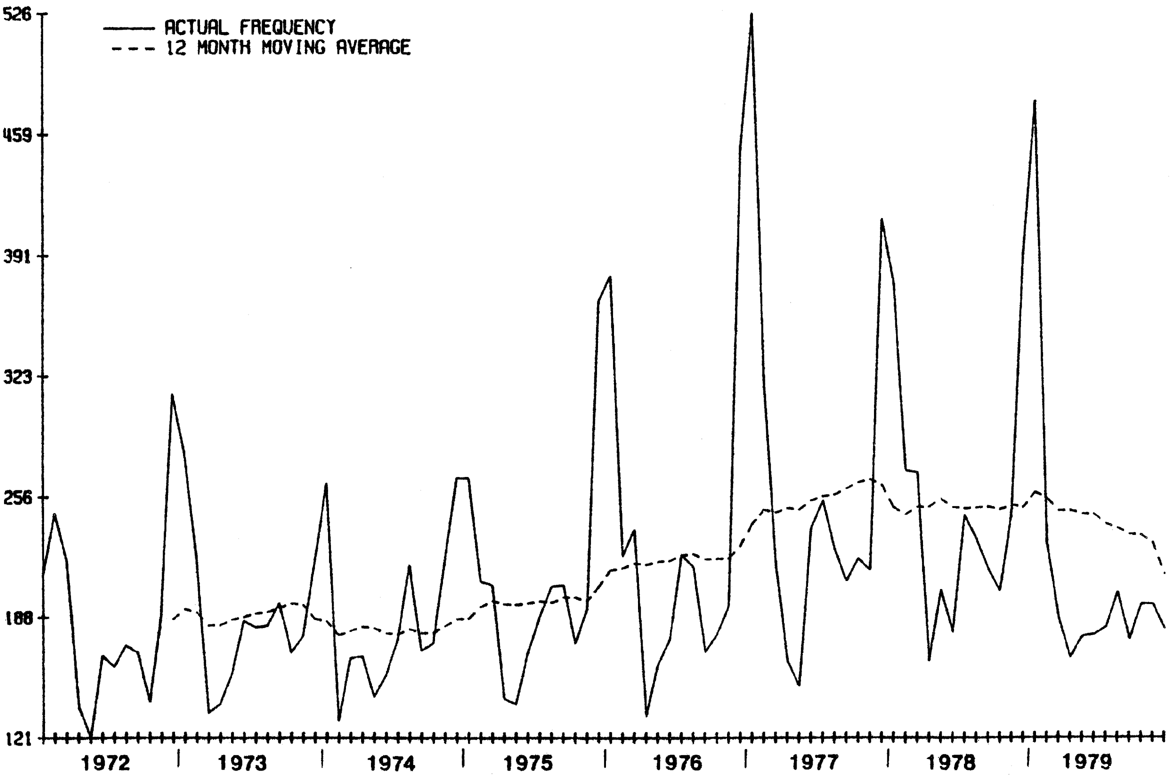


Figure A.22 Police-reported Had Not Been Drinking Drivers Age 20-21 Involved in Property Damage Only Crashes, State of Maine

$$Y_t = \frac{(1 + .21B^3)(1 - .84B^{12})u_t + 2.50}{1 - B^{12}} + 5.69\ S_t - 19.48\ S_{2t}$$

t-ratio 1.91 21.51 2.49 1.13 3.32

$R^2 = .49$

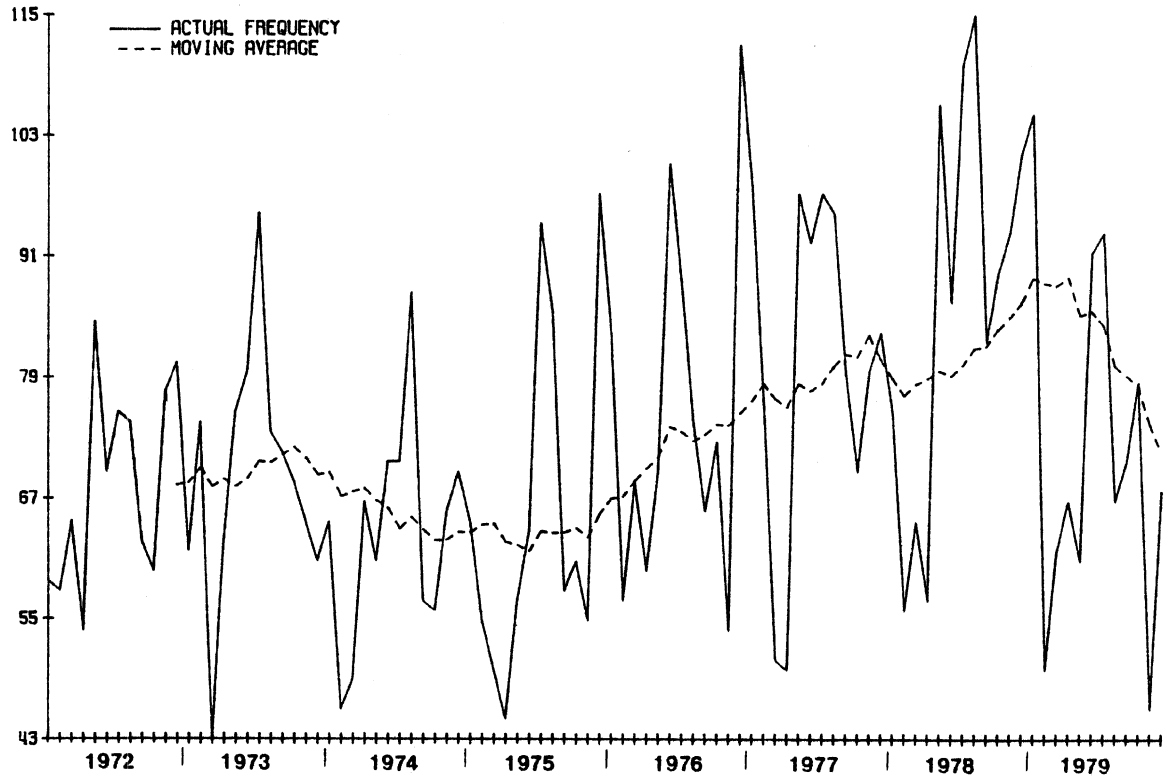


Figure A.23 Drivers Age 20-21 Involved in Daytime Crashes Including at Least One Injury or Fatality, State of Maine

$$Y_t = \frac{(1 + .37B)(1 - .78B^{12})u_t + 12.82}{1 - B^{12}} - 8.04\ S_t - 46.82\ S_{2t}$$

t-ratio 3.25 17.64 3.49 .47 2.75

$R^2 = .71$

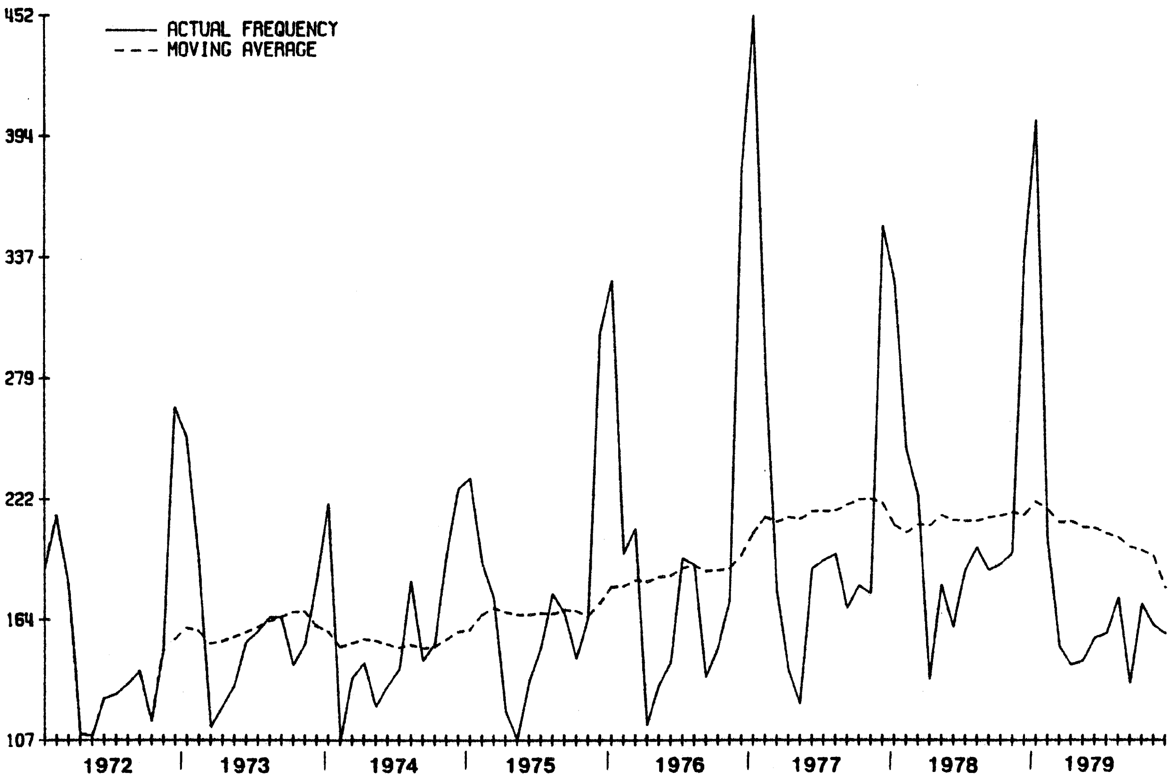


Figure A.24 Drivers Age 20-21 Involved in Daytime Property Damage Only Crashes, State of Maine

$$Y_t = \frac{(1 - .85B^{12})u_t + 4.03}{1 - B^{12}} + 3.16\ S_t$$

t-ratio 23.88 5.33 .84

$R^2 = .71$

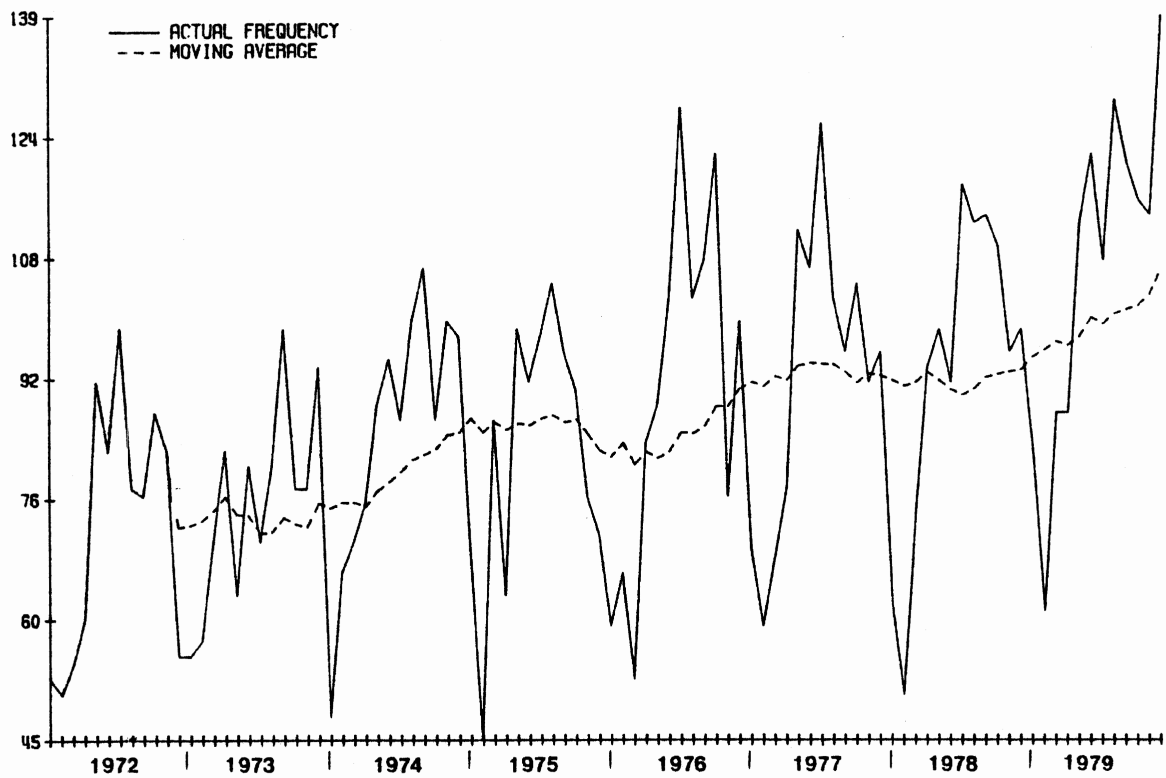


Figure A.25 Police-reported Had Been Drinking Drivers Age 22-45 Involved in Crashes Including at Least One Injury or Fatality, State of Maine

$$Y_t = \frac{(1 - .82B^{12})u_t + 4.67}{1 - B^{12}} - 7.02\ S_t$$

t-ratio 20.39 5.53 1.78

R^2 = .55

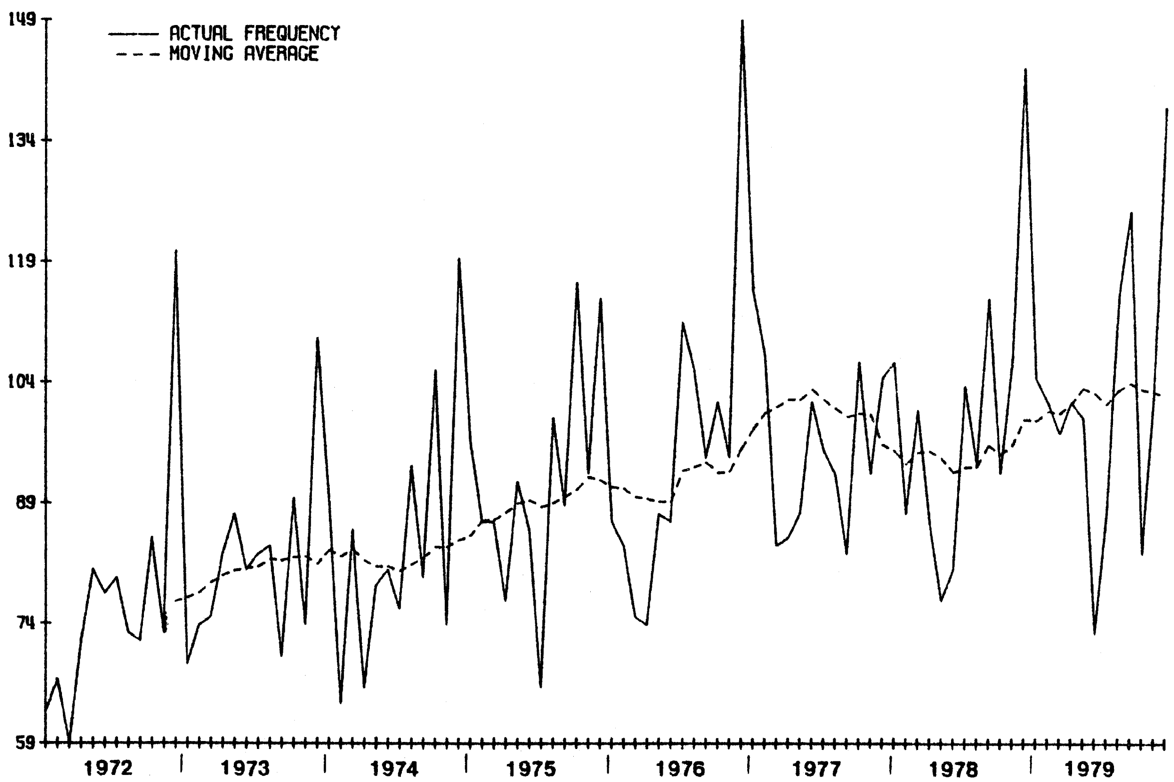


Figure A.26 Police-reported Had Been Drinking Drivers Age 22-45 Involved in Property Damage Only Crashes, State of Maine

$$Y_t = \frac{(1 - .86B^{12})u_t + 2.08}{1 - B^{12}} + 2.45\, S_t$$

t-ratio 22.82 3.50 .87

$R^2 = .69$

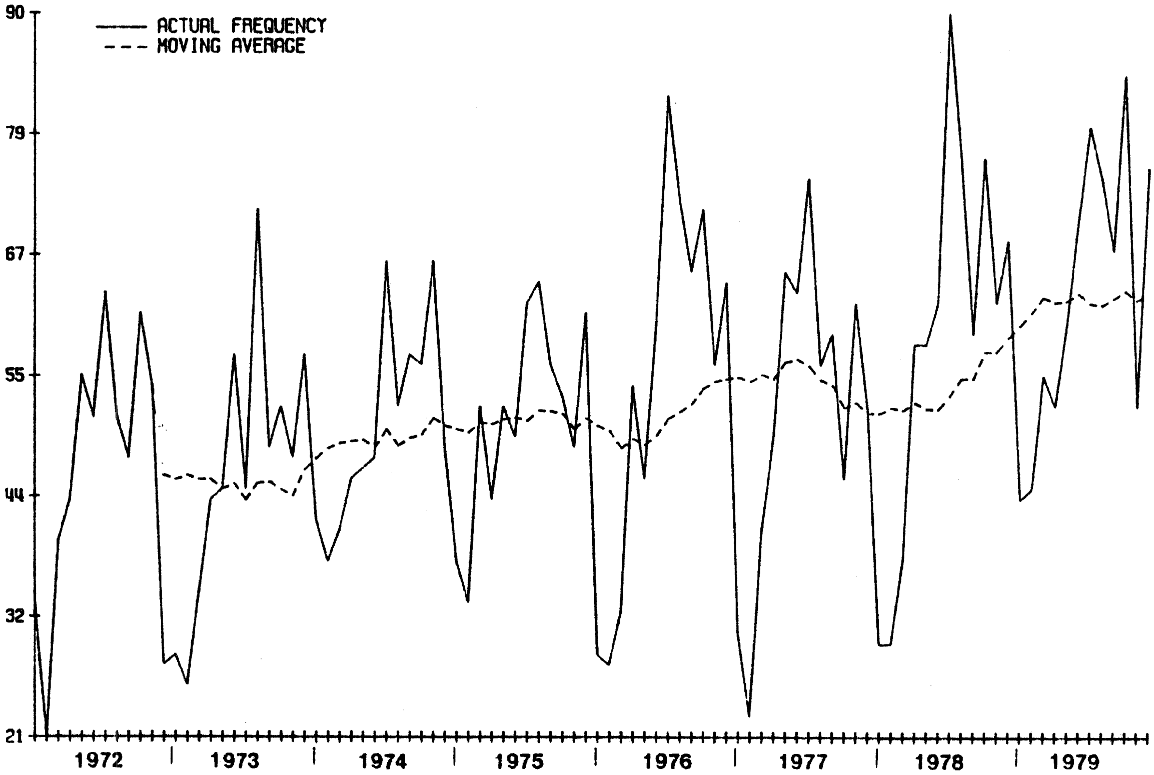


Figure A.27 Male Drivers Age 22-45 Involved in Late-night, Single-vehicle Crashes Including at Least One Injury or Fatality, State of Maine

$$Y_t = \frac{(1 - .82B^{12})u_t + 5.16}{1 - B^{12}} + 1.07\ S_t$$

t-ratio 20.38 5.46 .24

$R^2 = .56$

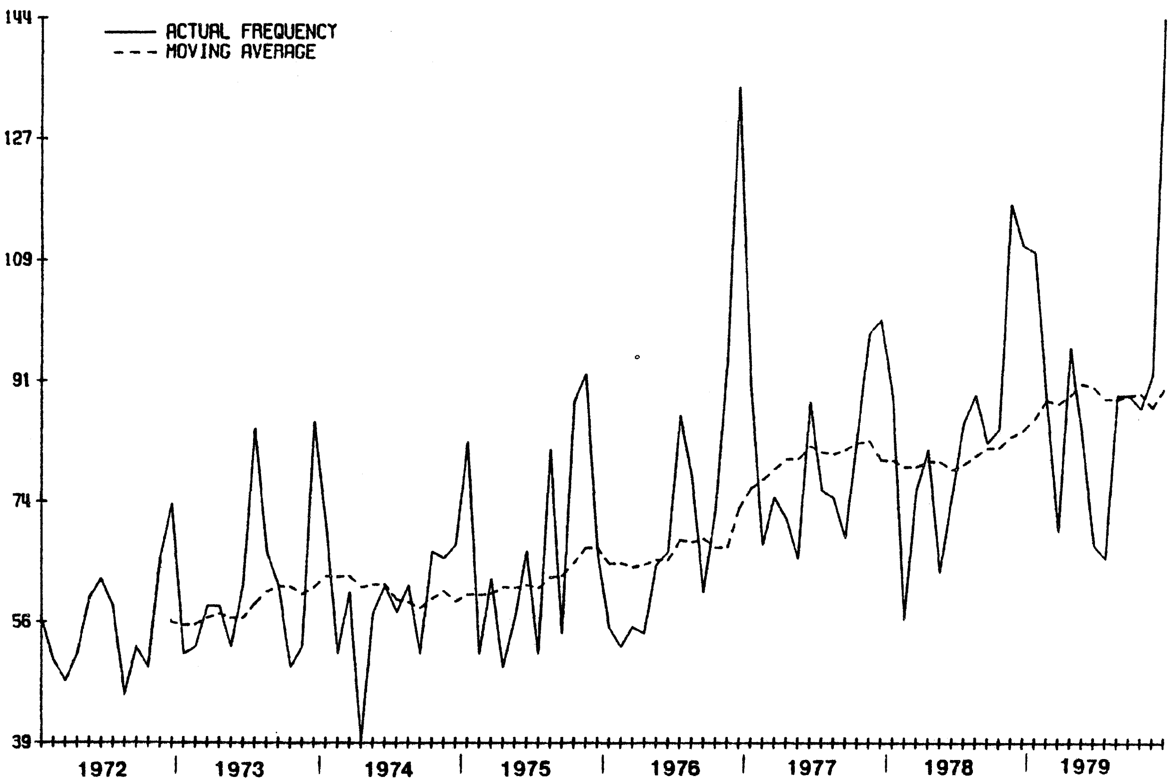


Figure A.28 Male Drivers Age 22-45 Involved in Late-night, Single-vehicle, Property Damage Only Crashes, State of Maine

$$Y_t = \frac{(1 + .24B + .33B^2)(1 - .81B^{12})u_t + 21.02}{1 - B^{12}} - 18.34\ S_t$$

t-ratio 2.28 3.05 19.63 3.45 .65

$R^2 = .69$

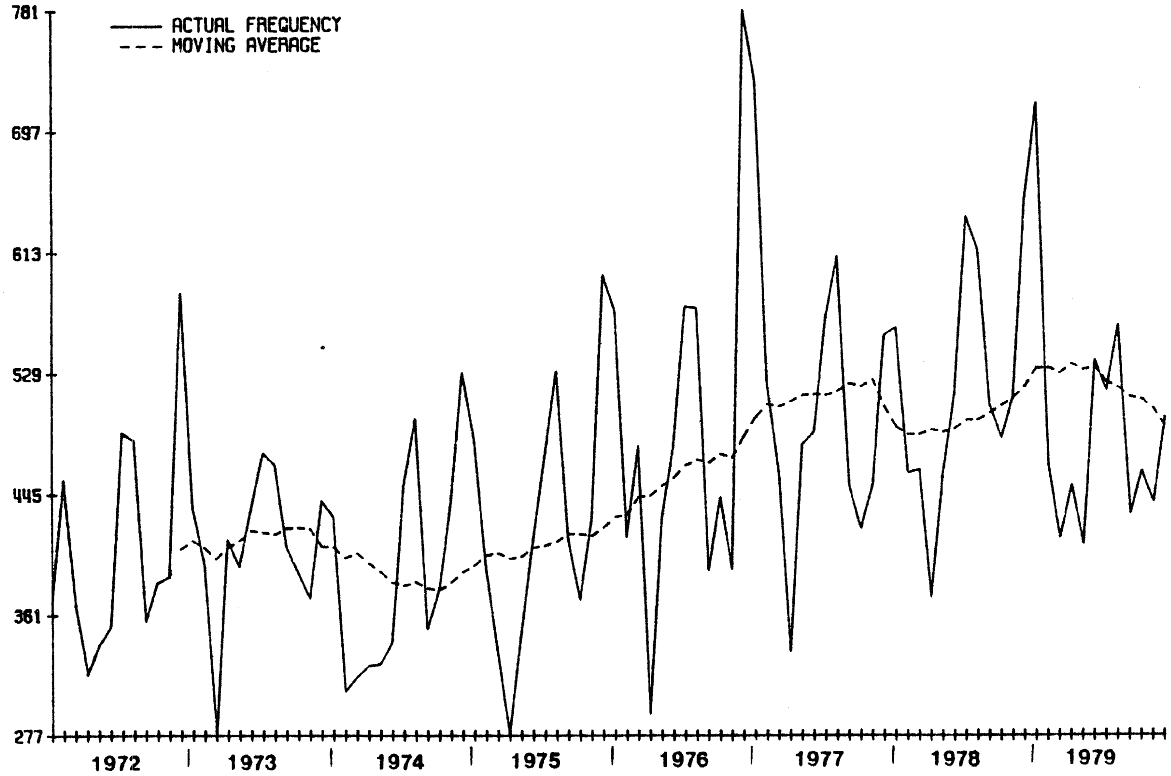


Figure A.29 Police-reported Had Not Been Drinking Drivers Age 22-45 Involved in Crashes Including at Least One Injury or Fatality, State of Maine

$$Y_t = \frac{(1 + .43B)(1 - .79B^{12})u_t + 88.80}{1 - B^{12}} - 28.83\ S_t - 255.20\ S_{2t}$$

t-ratio 4.26 18.40 3.59 .25 2.23

$R^2 = .77$

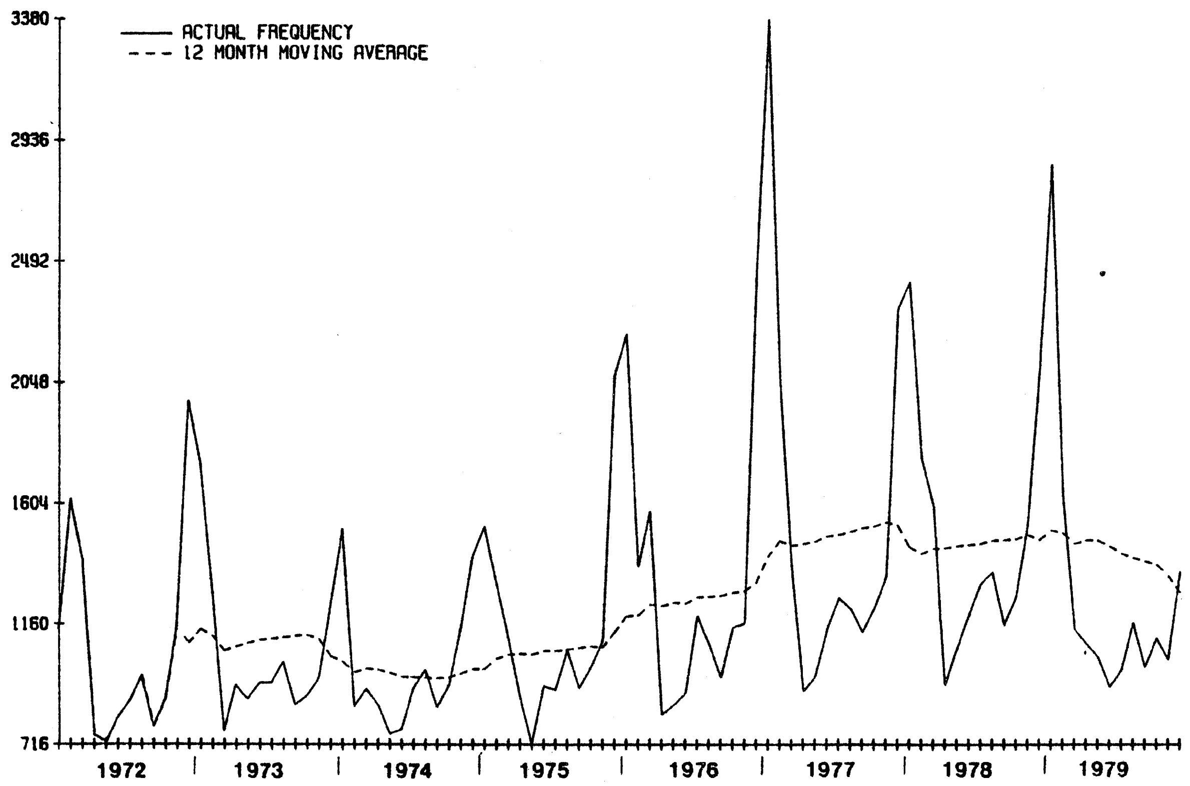


Figure A.30 Police-reported Had Not Been Drinking Drivers Age 22-45 Involved in Property Damage Only Crashes, State of Maine

$$Y_t = \frac{(1 + .28B + .44B^2)(1 - .82B^{12})u_t + 20.06}{1 - B^{12}} - 26.38\ S_t$$

t-ratio 2.87 4.51 20.45 3.75 1.02

$$R^2 = .70$$

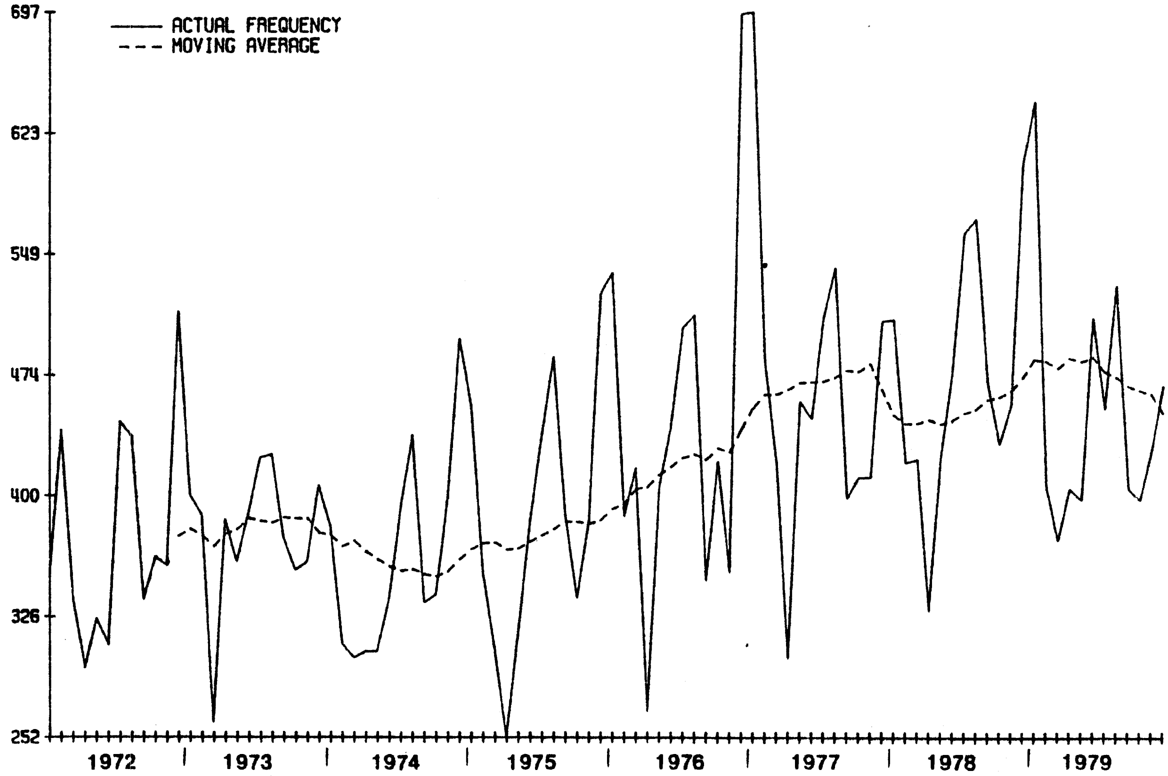


Figure A.31 Drivers Age 22-45 Involved in Daytime Crashes Including at Least One Injury or Fatality, State of Maine

$$Y_t = \frac{(1 + .45B)(1 - .80B^{12})u_t + 77.68}{1 - B^{12}} - 31.41\ S_t - 226.06\ S_{2t}$$

t-ratio 4.46 19.61 3.40 .29 2.14

$R^2 = .78$

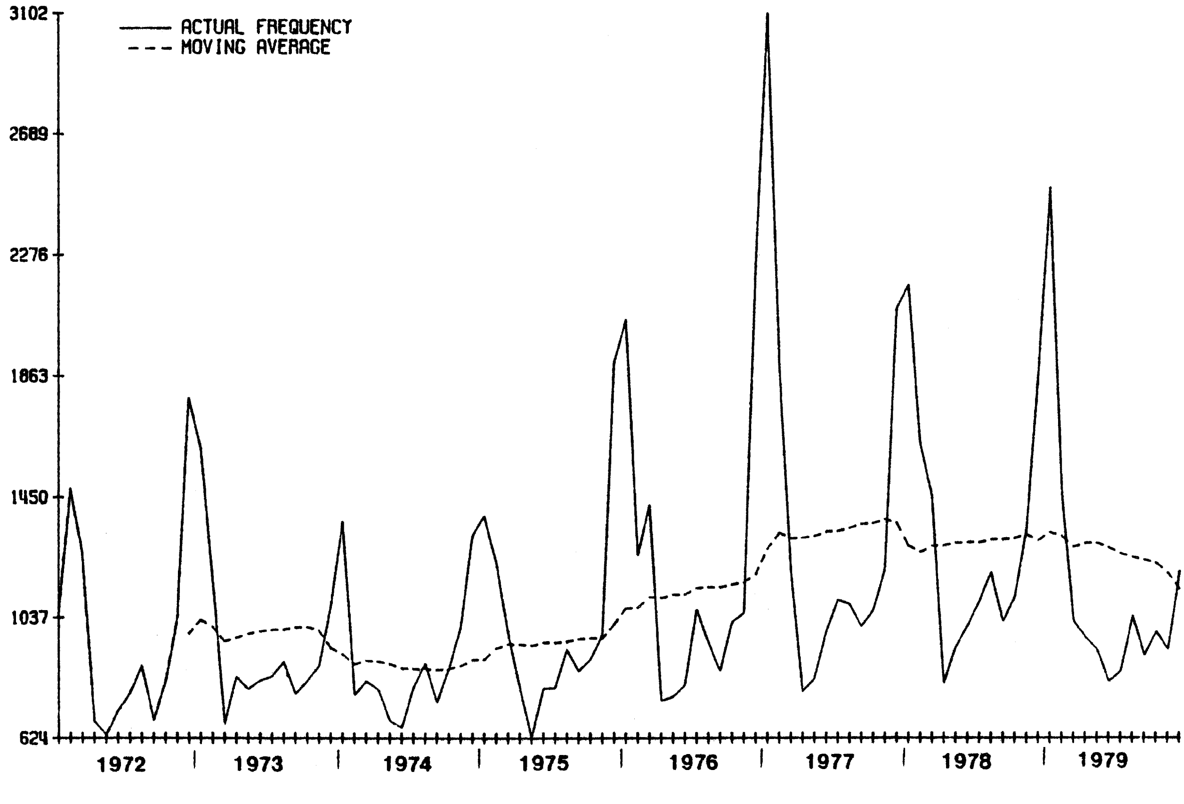


Figure A.32 Drivers Age 22-45 Involved in Daytime Property Damage Only Crashes, State of Maine

Appendix B

Crash Frequency Plots and Time-series Models, State of Michigan

$$Y_t = \frac{(1 + .21B + .22B^3)(1 - .90B^{12})u_t + 6.60}{1 - B^{12}} - 20.20\ S_{2t}$$

t-ratio 2.09 2.25 27.73 4.58 2.47

$$R^2 = .62$$

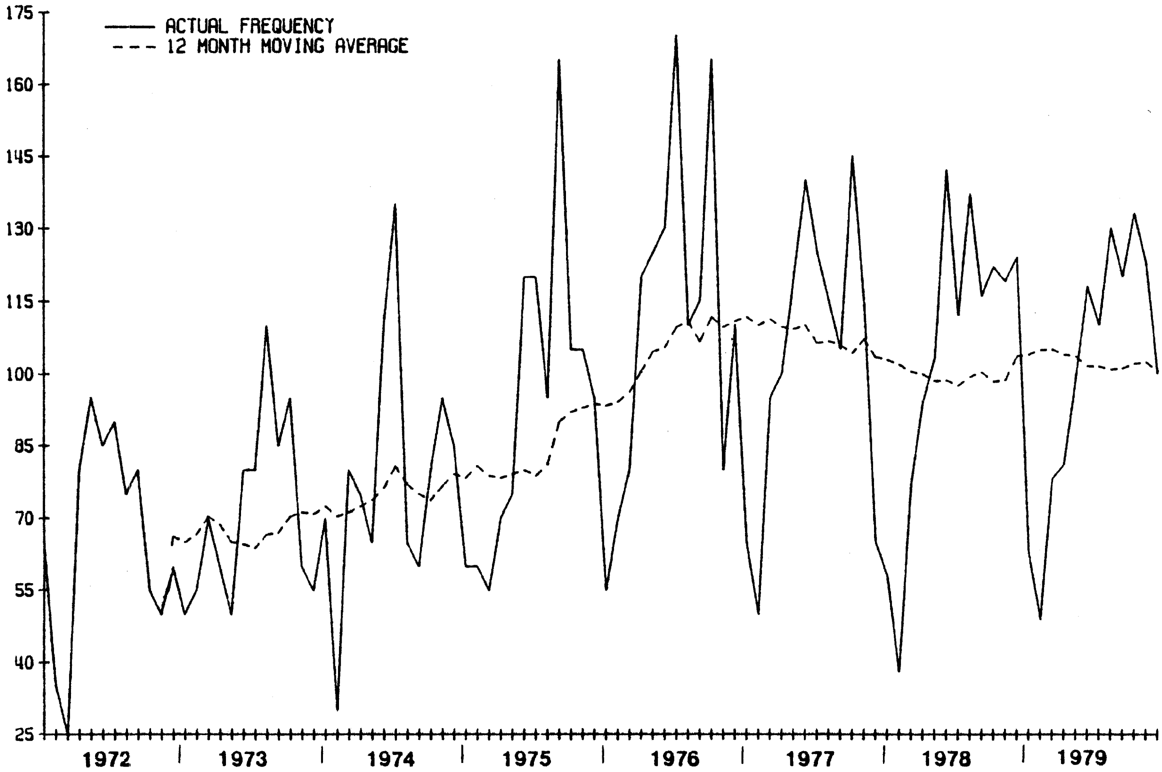


Figure B.1 Police-reported Had Been Drinking Drivers Age 16-17 Involved in Crashes Including at Least One Injury or Fatality, State of Michigan

$$Y_t = \frac{(1 - .89B^{12})u_t + 8.81}{1 - B^{12}} - 21.36\, S_{2_t}$$

t-ratio 25.65 7.29 2.98

$$R^2 = .54$$

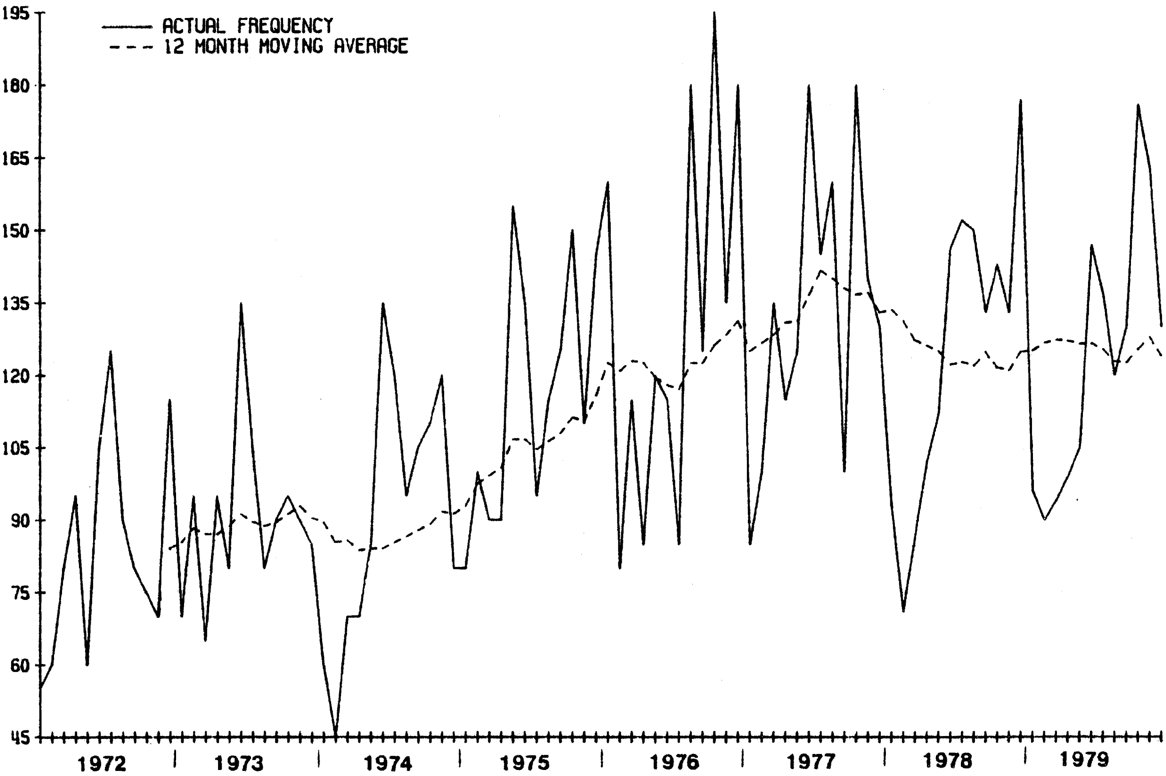


Figure B.2 Police-reported Had Been Drinking Drivers Age 16-17 Involved in Property Damage Only Crashes, State of Michigan

$$Y_t = \frac{(1 - .88B^{12})u_t}{1 - B^{12}} - 12.72\, S_{2t}$$

t-ratio 27.59 2.34

$R^2 = .57$

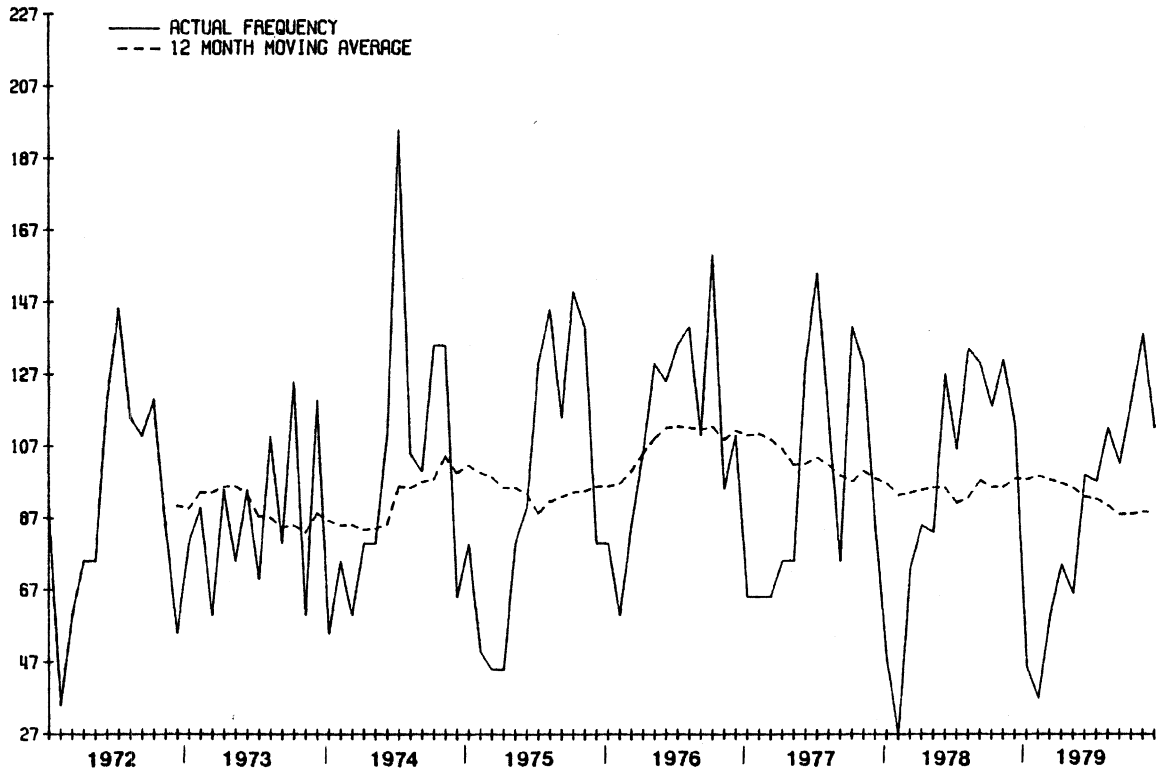


Figure B.3 Male Drivers Age 16-17 Involved in Late-night, Single-vehicle Crashes Including at Least One Injury or Fatality, State of Michigan

$$Y_t = \frac{(1 + .25B^2)(1 - .88B^{12})u_t + 4.95}{1 - B^{12}} - 34.92\ S_{2t}$$

t-ratio 2.41 25.47 2.20 2.59

$R^2 = .55$

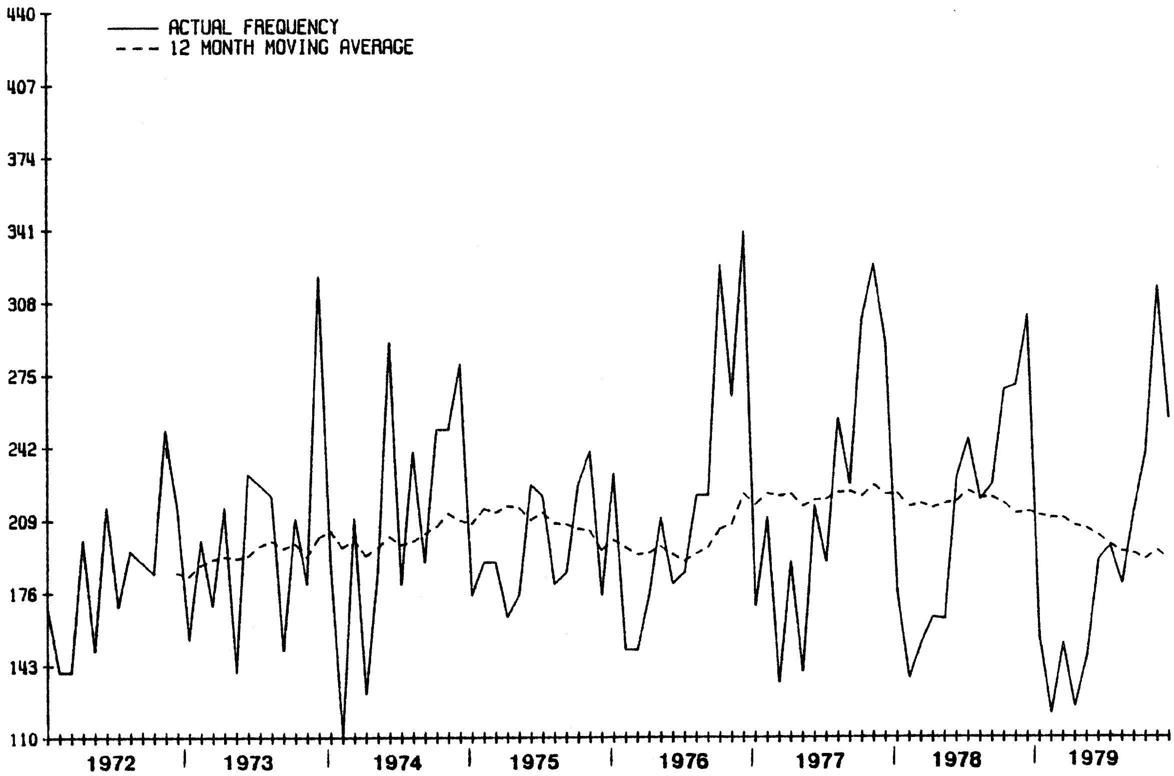


Figure B.4 Male Drivers Age 16-17 Involved in Late-night, Single-vehicle, Property Damage Only Crashes, State of Michigan

$$Y_t = \frac{(1 - .83B^{12})u_t + 41.32}{1 - B^{12}} - 217.13\ S_{4_t} - 100.83\ S_{2_t}$$

t-ratio 20.19 4.49 5.46 2.50

$$R^2 = .68$$

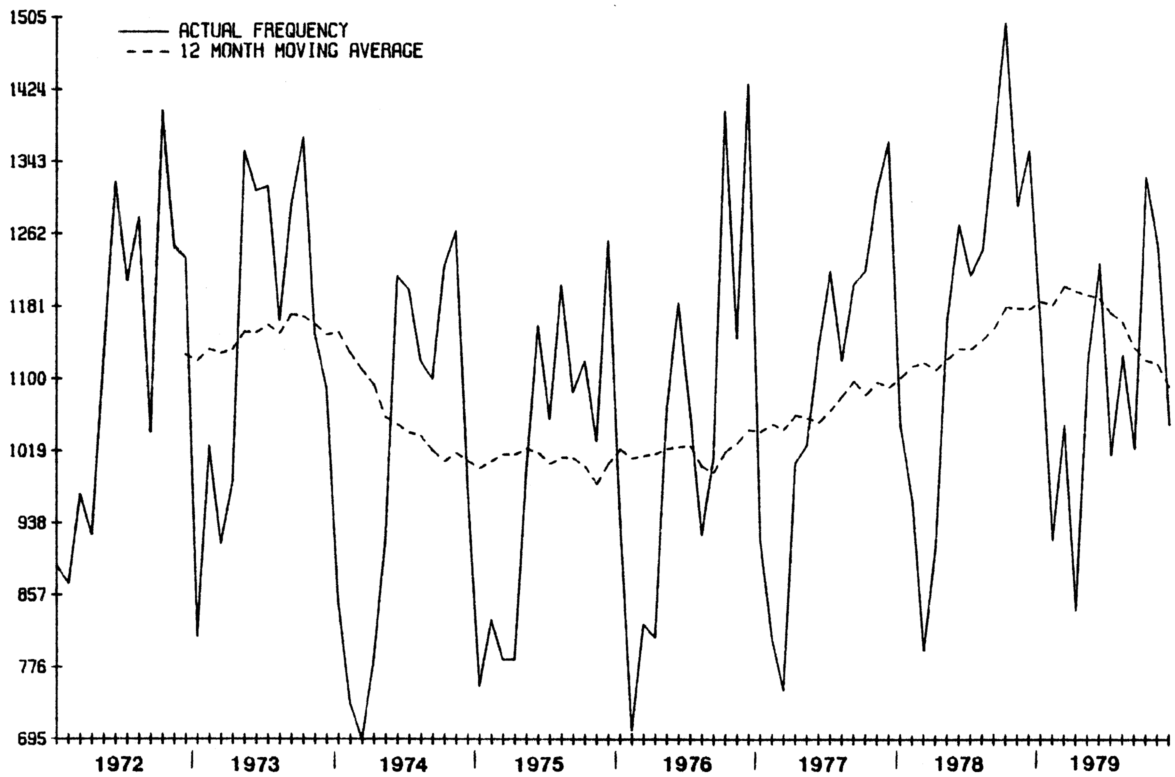


Figure B.5 Police-reported Had Not Been Drinking Drivers Age 16-17 Involved in Crashes Including at Least One Injury or Fatality, State of Michigan

$$Y_t = \frac{(1 + .53B^{12})u_t + 103.81}{1 - B^{12}} - 244.18\, S_{4_t} - 400.16\, S_{2_t}$$

t-ratio 4.35 3.57 2.29 3.69

$R^2 = .72$

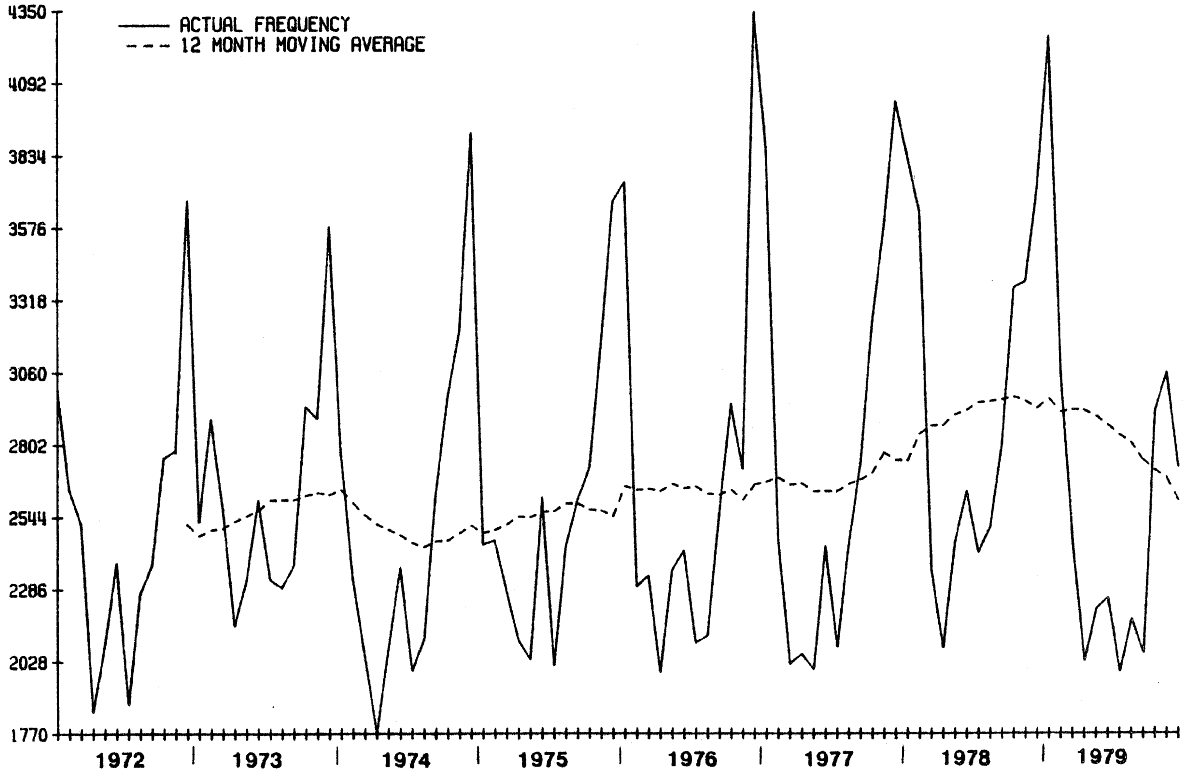


Figure B.6 Police-reported Had Not Been Drinking Drivers Age 16-17 Involved in Property Damage Only Crashes, State of Michigan

$$Y_t = \frac{(1 - .83B^{12})u_t + 32.84}{1 - B^{12}} - 186.63\ S_{4_t} - 73.22\ S_{2_t}$$

t-ratio 20.13 4.05 5.32 2.06

$R^2 = .63$

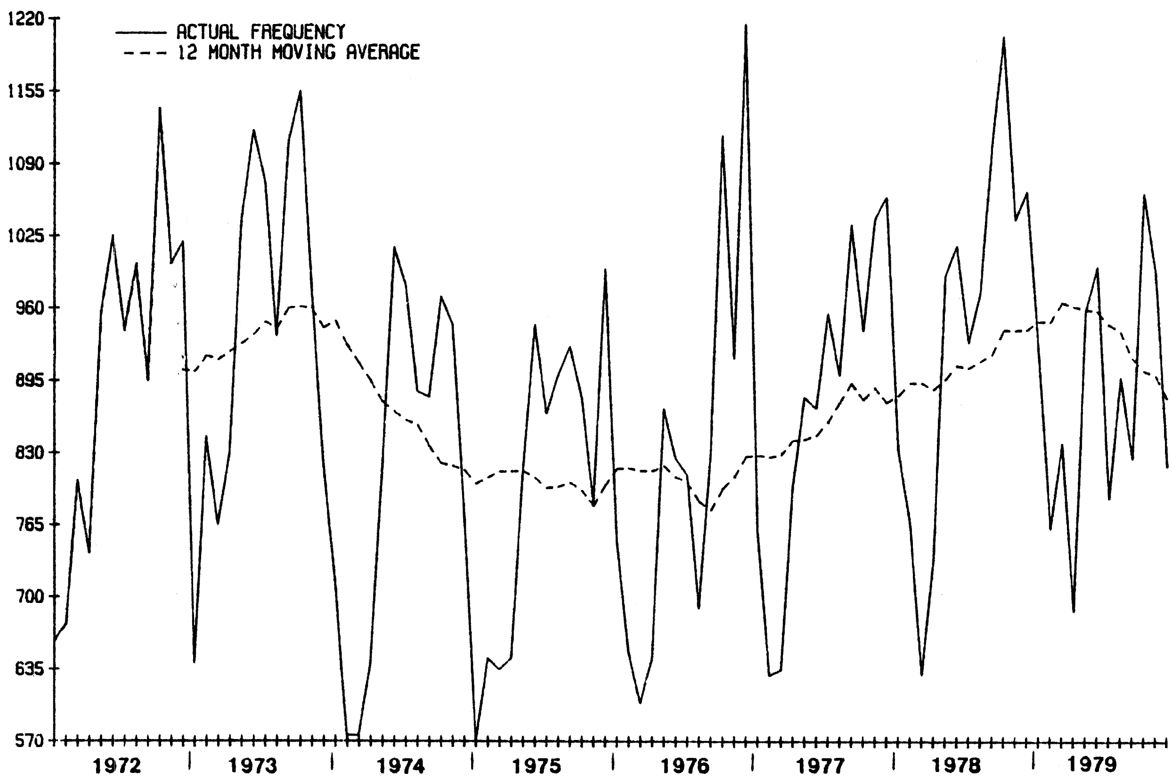


Figure B.7 Drivers Age 16-17 Involved in Daytime Crashes Including at Least One Injury or Fatality, State of Michigan

$$Y_t = \frac{(1 - .55B^{12})u_t + 91.73}{1 - B^{12}} - 253.36\, S_{4_t} - 324.20\, S_{2_t}$$

t-ratio 4.57 3.65 2.72 3.42

$R^2 = .71$

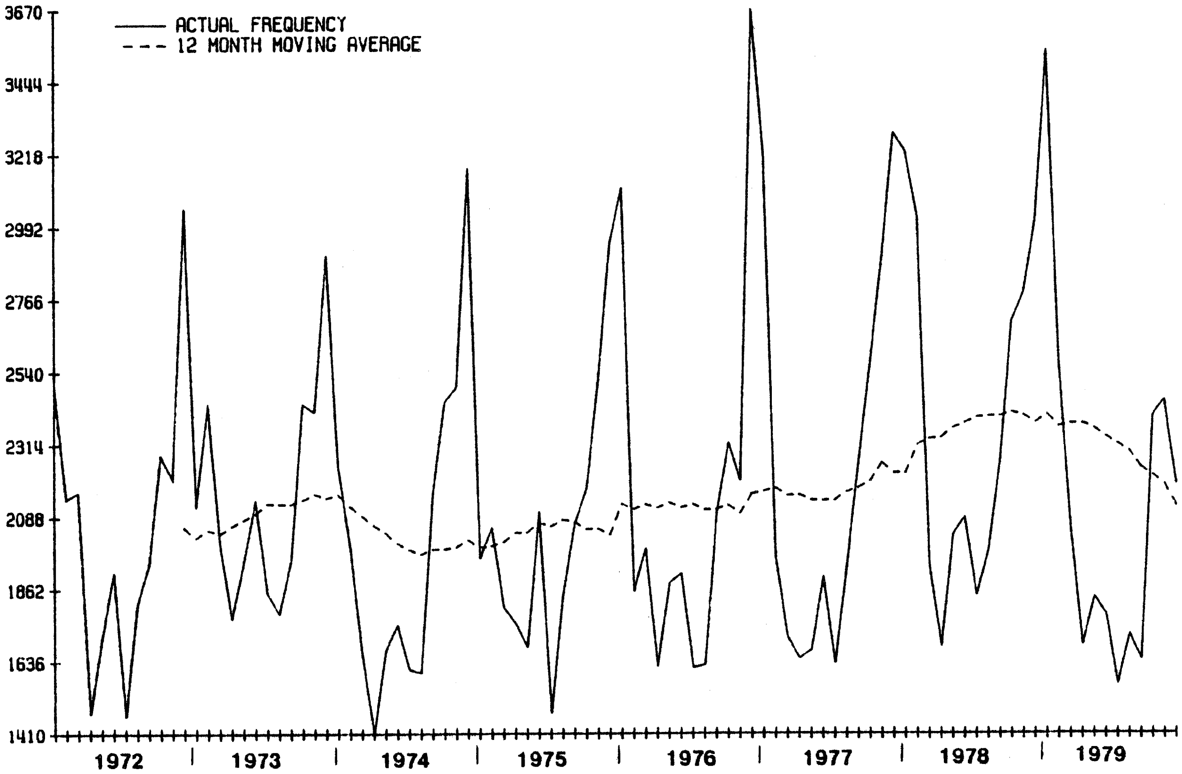


Figure B.8 Drivers Age 16-17 Involved in Daytime Property Damage Only Crashes, State of Michigan

$$Y_t = \frac{(1 + .37B + .47B^2 + .23B^3)(1 - .89B^{12})u_t + 30.84}{1 - B^{12}} - 143.78\, S_{2_t}$$

t-ratio 3.53 4.76 2.29 26.79 5.55 4.60

$$R^2 = .72$$

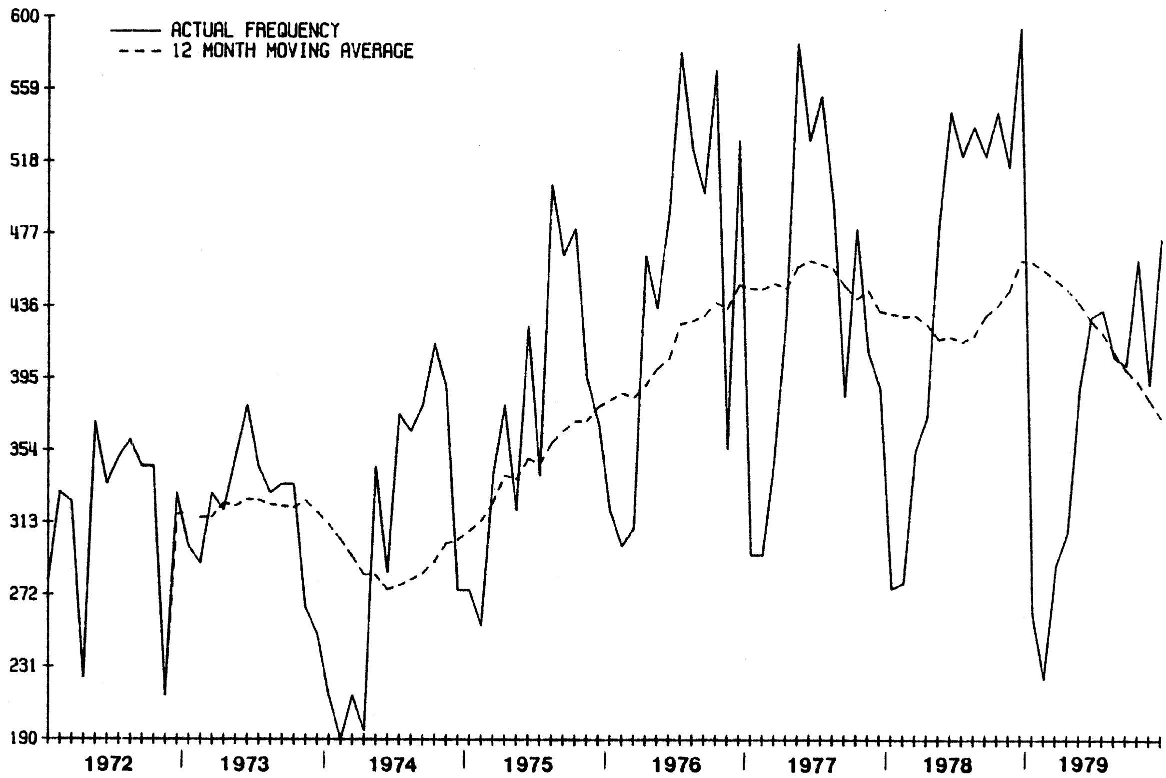


Figure B.9 Police-reported Had Been Drinking Drivers Age 18-20 Involved in Crashes Including at Least One Injury or Fatality, State of Michigan

$$Y_t = \frac{(1 + .36B + .40B^3)(1 - .88B^{12})u_t + 36.20}{1 - B^{12}} - 208.21\ S_{2_t}$$

t-ratio	4.01	4.43	21.90	7.25	7.21

$$R^2 = .74$$

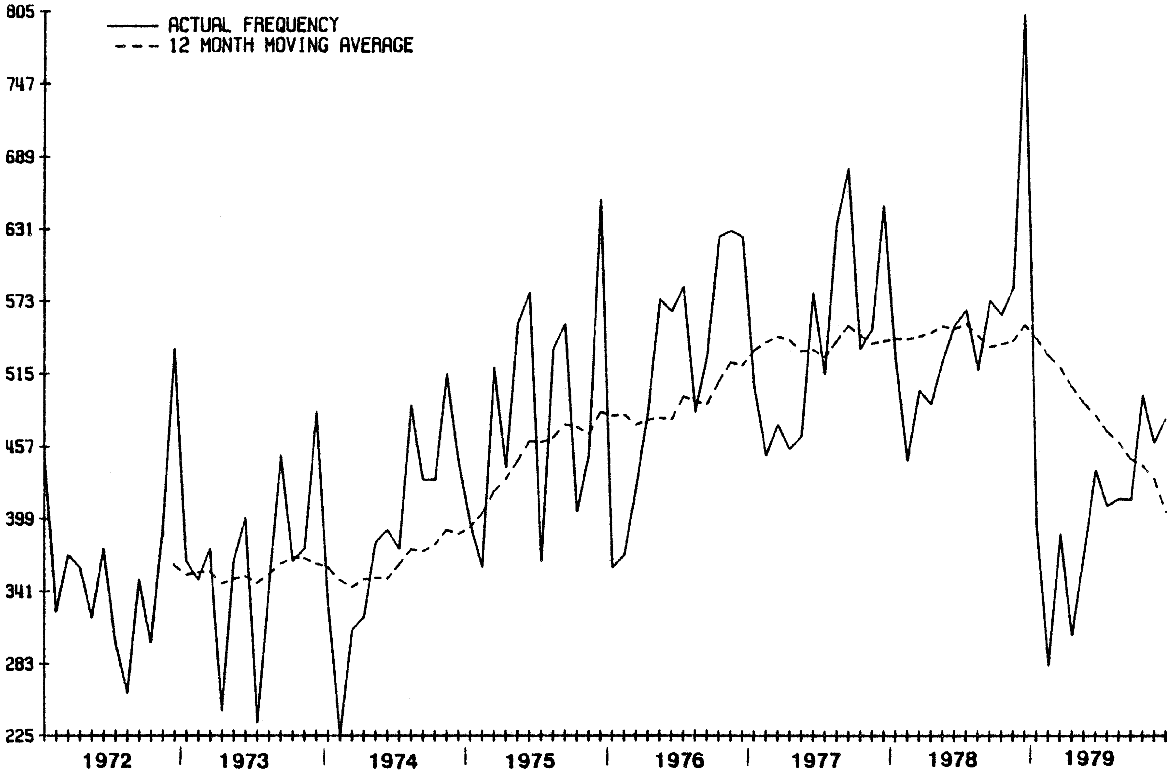


Figure B.10 Police-reported Had Been Drinking Drivers Age 18-20 Involved in Property Damage Only Crashes, State of Michigan

$$Y_t = \frac{(1 + .21B)(1 - .85B^{12})u_t + 15.04}{1 - B^{12}} - 34.34\, S_{4_t} - 32.61\, S_{5_t} - 62.96\, S_{2_t}$$

t-ratio 1.97 22.87 2.77 1.78 1.68 3.56

$R^2 = .67$

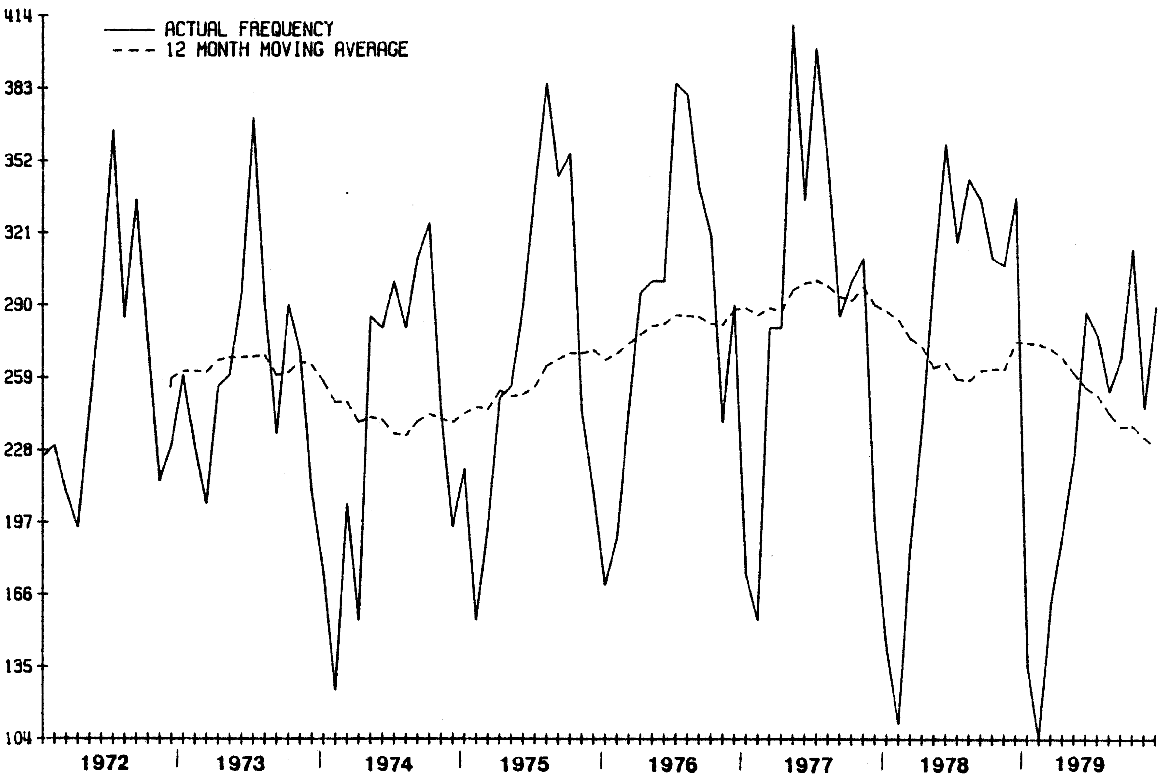


Figure B.11 Male Drivers Age 18-20 Involved in Late-night, Single-vehicle Crashes Including at Least One Injury or Fatality, State of Michigan

$$Y_t = \frac{(1 + .28B + .43B^2)(1 - .89B^{12})u_t + 19.10}{1 - B^{12}} - 129.35\ S_{2_t}$$

t-ratio 3.06 4.72 26.10 4.38 5.13

$R^2 = .74$

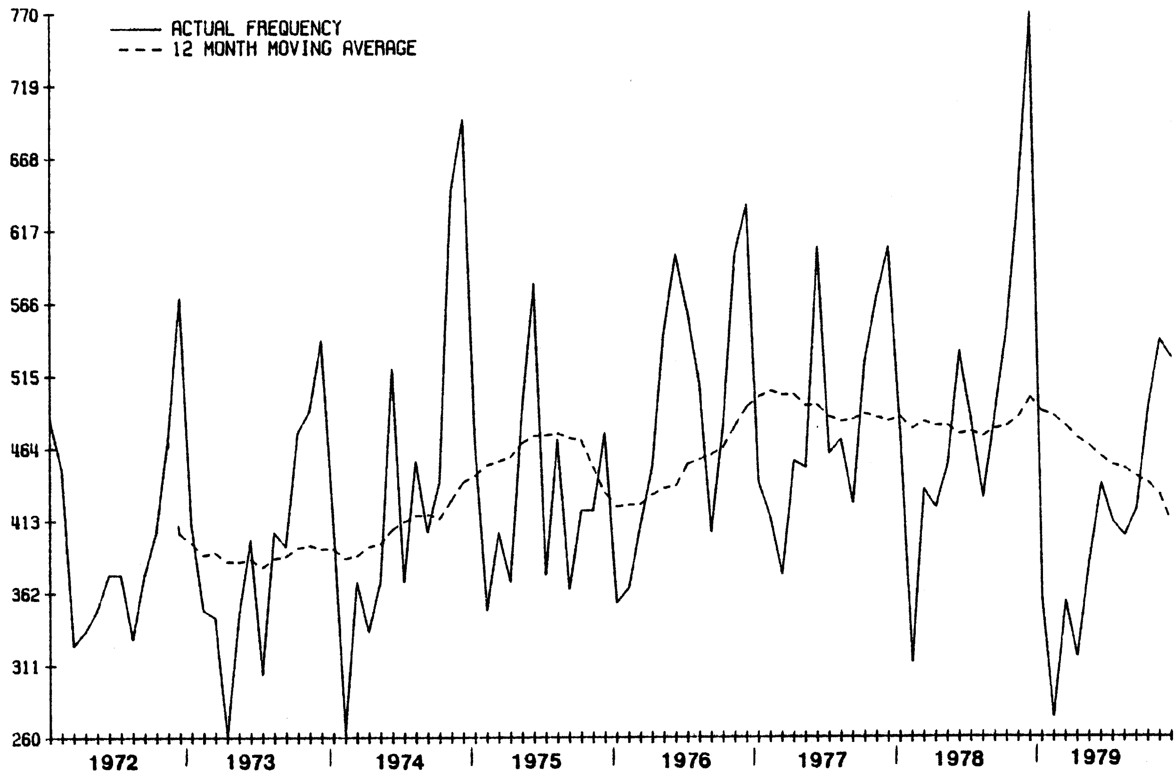


Figure B.12 Male Drivers Age 18-20 Involved in Late-night, Single-vehicle, Property Damage Only Crashes, State of Michigan

$$Y_t = \frac{(1 + .21B)(1 - .82B^{12})u_t + 53.54}{1 - B^{12}} - 475.17\ S_{4_t} - 160.41\ S_{2_t}$$

t-ratio 1.97 21.06 2.66 5.49 1.83

$R^2 = .61$

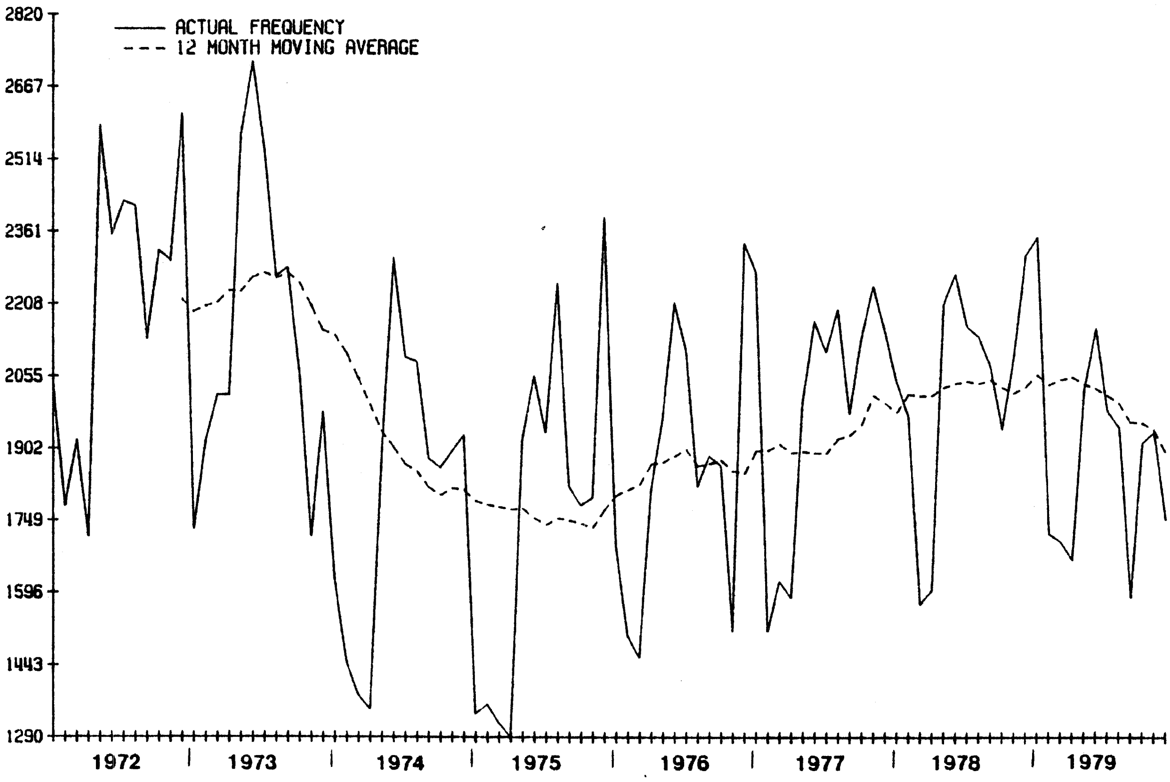


Figure B.13 Police-reported Had Not Been Drinking Drivers Age 18-20 Involved in Crashes Including at Least One Injury or Fatality, State of Michigan

$$\log Y_t = \frac{(1 + .24B)(1 - .57B^{12})u_t + .04}{1 - B^{12}} - .13\, S_{4t} - .13\, S_{2t}$$

t-ratio 2.06 5.03 3.42 2.87 2.96

$R^2 = .72$

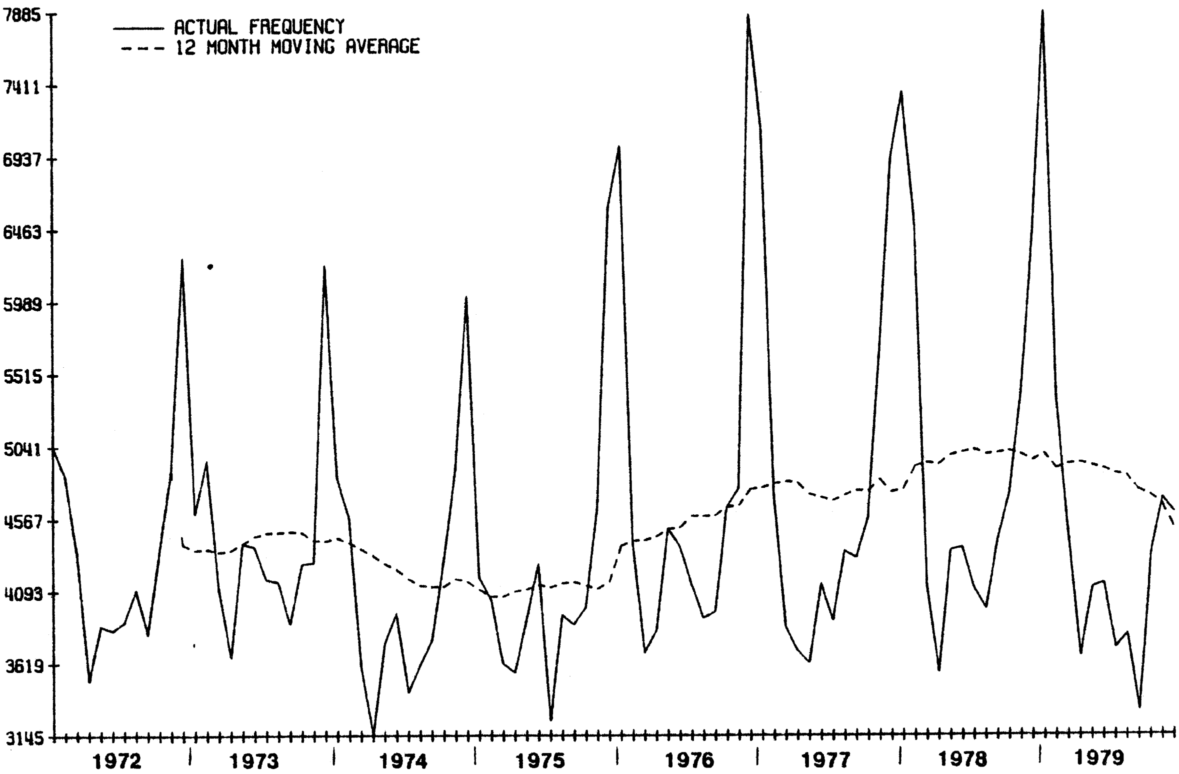


Figure B.14 Police-reported Had Not Been Drinking Drivers Age 18-20 Involved in Property Damage Only Crashes, State of Michigan

$$Y_t = \frac{(1 - .84B^{12})u_t + 61.49}{1 - B^{12}} - 435.61\ S_{4t} - 187.65\ S_{2t}$$

t-ratio 22.68 4.29 7.01 2.99

$R^2 = .55$

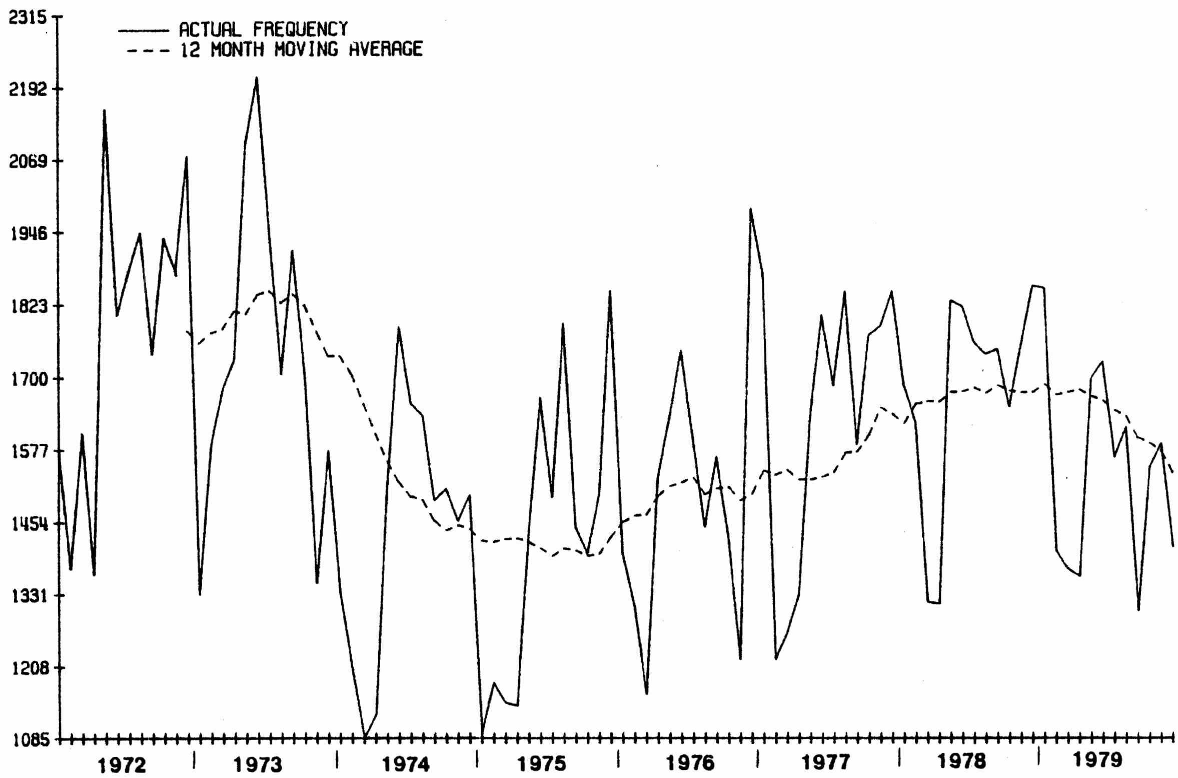


Figure B.15 Drivers Age 18-20 Involved in Daytime Crashes Including at Least One Injury or Fatality, State of Michigan

$$Y_t = \frac{(1 + .16B)(1 - .41B^{12})u_t + 164.10}{1 - B^{12}} - 518.66\ S_{4_t} - 539.88\ S_{2_t}$$

t-ratio 1.33 3.34 2.94 2.77 2.90

$R^2 = .59$

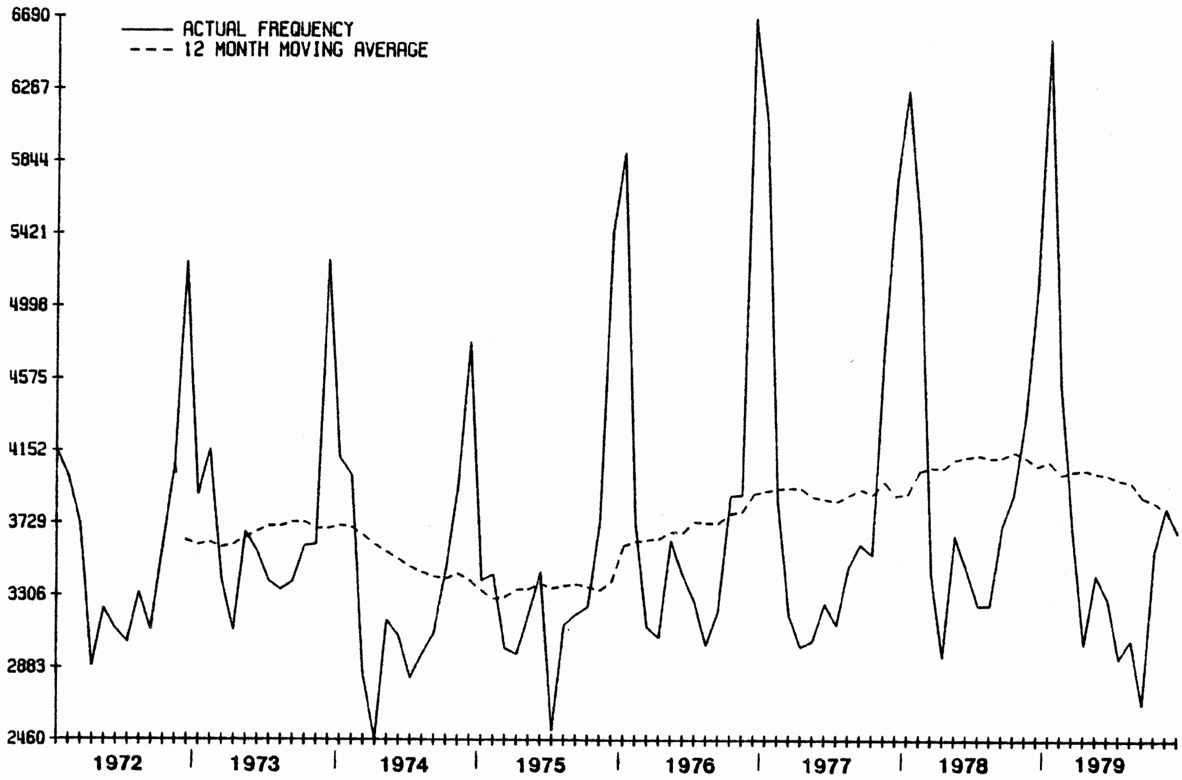


Figure B.16 Drivers Age 18-20 Involved in Daytime Property Damage Only Crashes, State of Michigan

$$Y_t = \frac{(1 - .87B^{12})u_t + 23.40}{1 - B^{12}} - 28.19\ S_{4_t} + 9.56\ S_{2_t}$$

t-ratio 24.89 6.48 1.79 .62

$R^2 = .67$

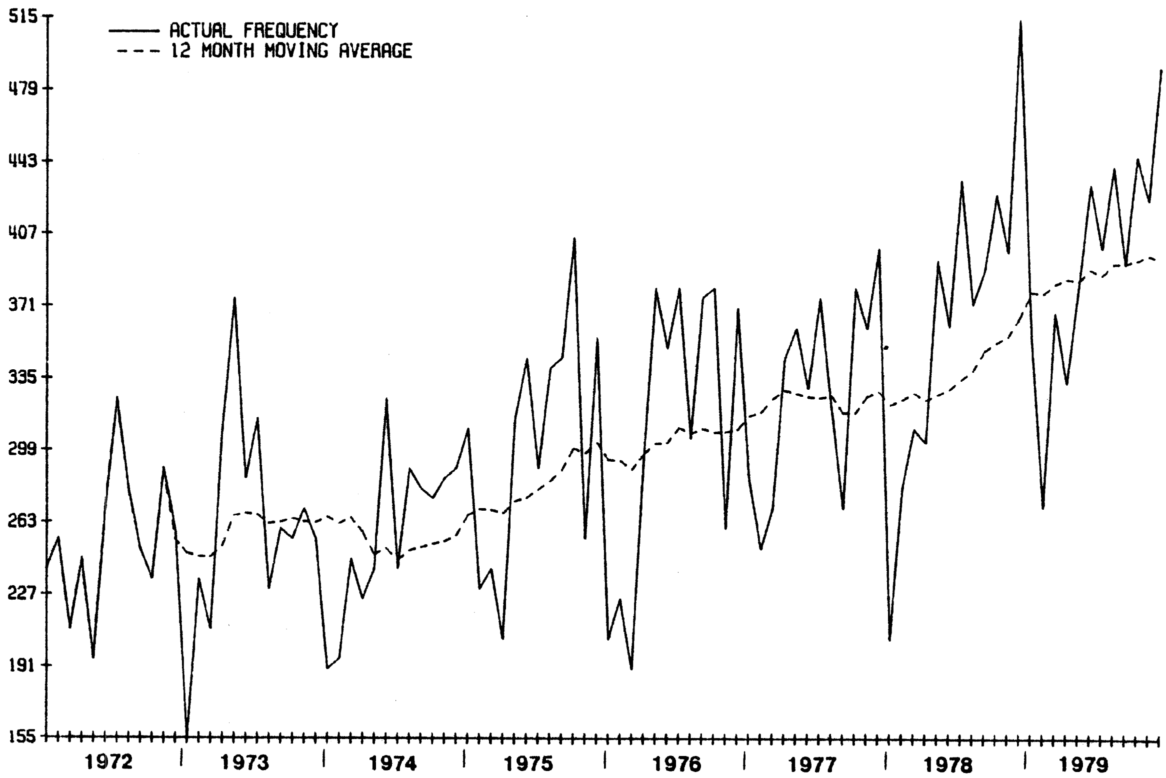


Figure B.17 Police-reported Had Been Drinking Drivers Age 21-23 Involved in Crashes Including at Least One Injury or Fatality, State of Michigan

$$Y_t = \frac{(1 - .87B^{12})u_t + 22.27}{1 - B^{12}} - 7.61\ S_{2t}$$

t-ratio 23.12 9.57 .54

$R^2 = .72$

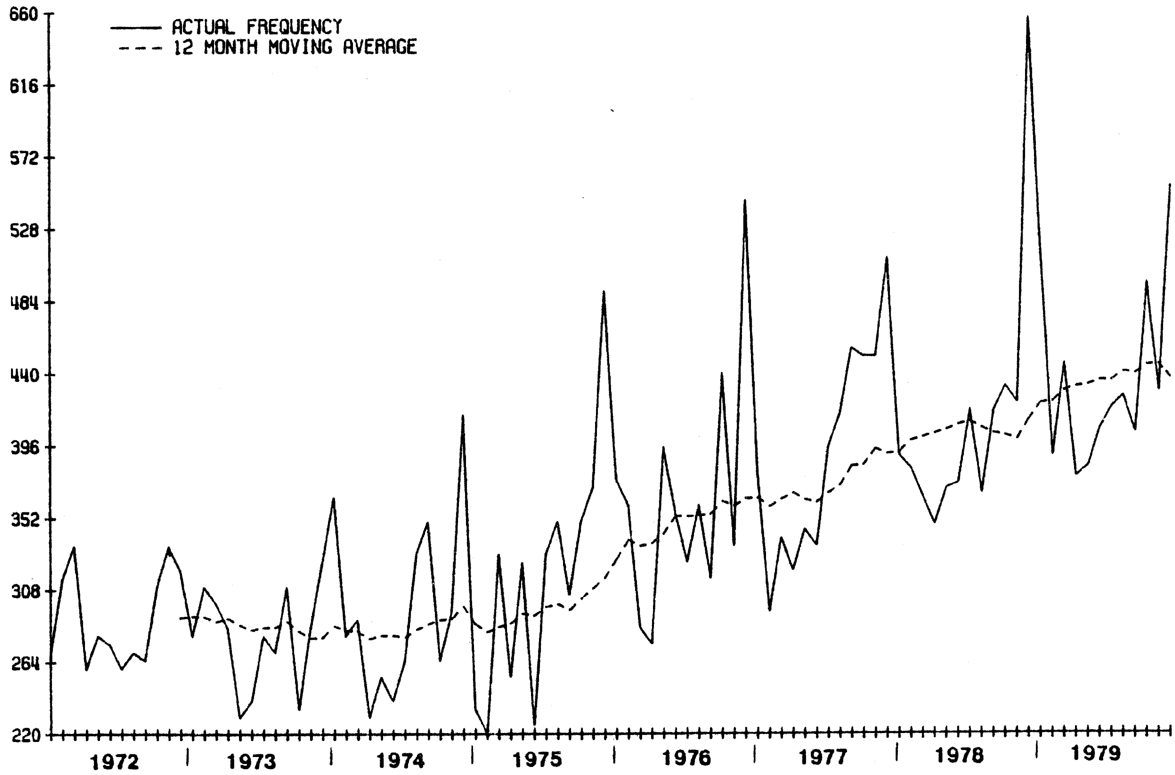


Figure B.18 Police-reported Had Been Drinking Drivers Age 21-23 Involved in Property Damage Only Crashes, State of Michigan

$$Y_t = \frac{(1 - .91B^{12})u_t}{1 - B^{12}} + 9.26\ S_{2t}$$

t-ratio 28.35 1.33

$R^2 = .51$

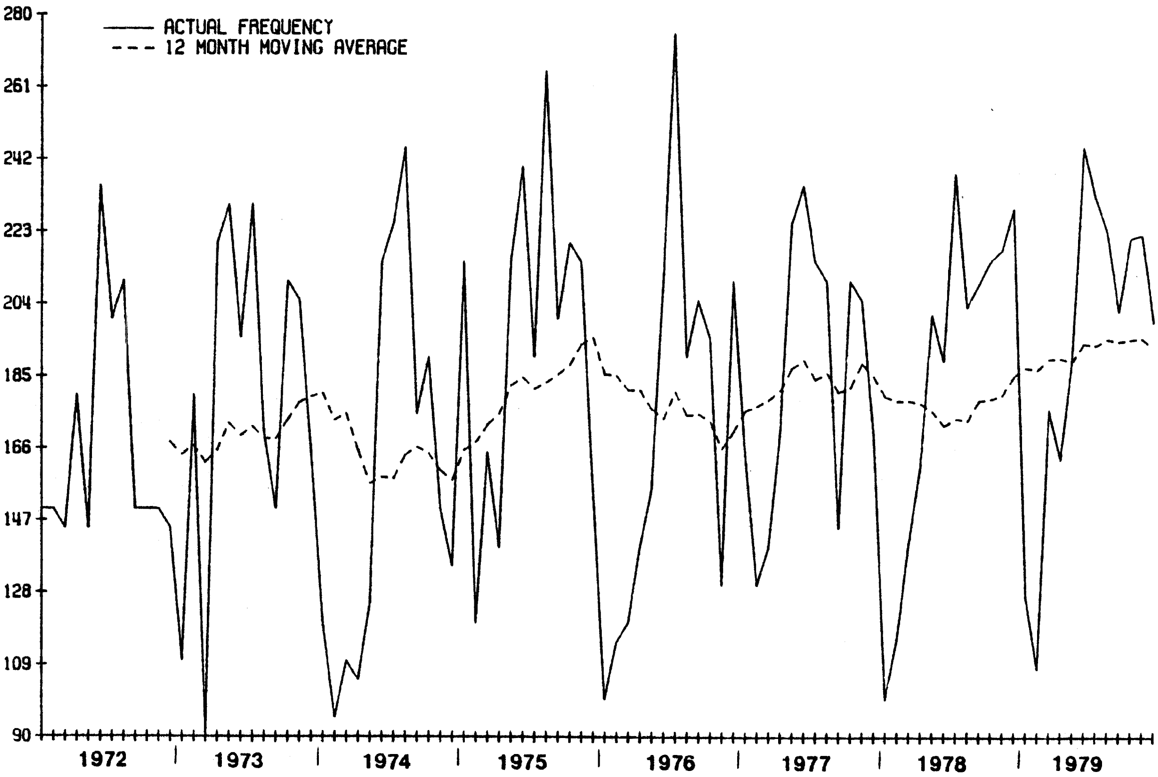


Figure B.19 Male Drivers Age 21-23 Involved in Late-night, Single-vehicle Crashes Including at Least One Injury or Fatality, State of Michigan

$$Y_t = \frac{(1 - .90B^{12})u_t + 20.19}{1 - B^{12}} - 25.50\, S_{4t} - 31.19\, S_{2t}$$

t-ratio 26.64 6.09 1.75 2.30

$R^2 = .68$

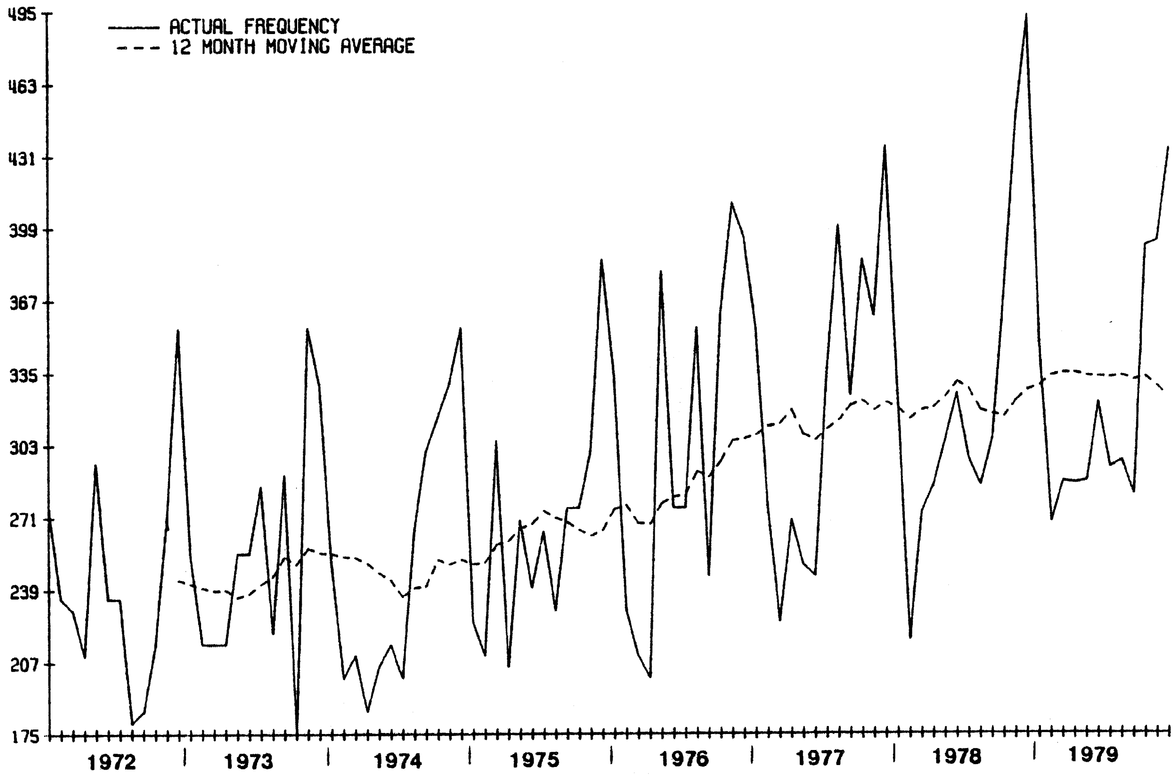


Figure B.20 Male Drivers Age 21-23 Involved in Late-night, Single-vehicle, Property Damage Only Crashes, State of Michigan

$$Y_t = \frac{(1 + .41B)(1 - .79B^{12})u_t + 47.95}{1 - B^{12}} - 361.05\, S_{4t} - 60.32\, S_{2t}$$

t-ratio 4.06 17.76 2.65 4.72 .77

$R^2 = .59$

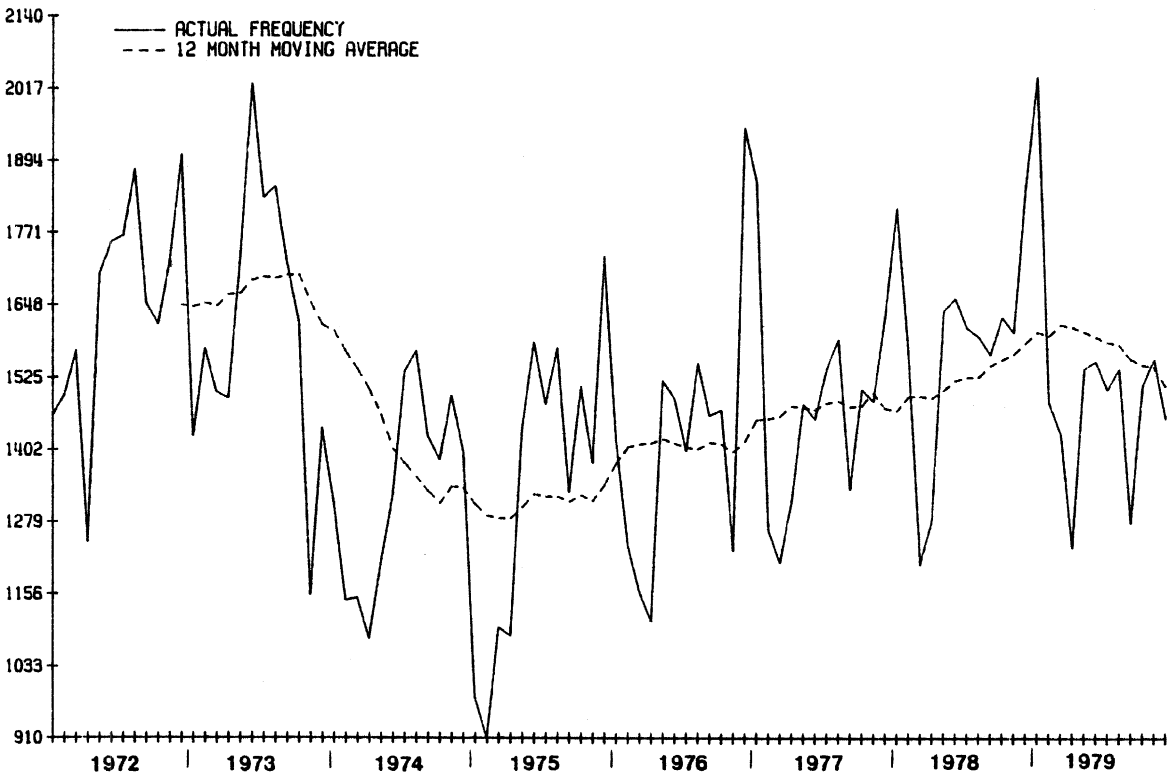


Figure B.21 Police-reported Had Not Been Drinking Drivers Age 21-23 Involved in Crashes Including at Least One Injury or Fatality, State of Michigan

$$\log Y_t = \frac{(1 + .14B)(1 - .66B^{12})u_t + .05}{1 - B^{12}} - .19\, S_{4t} - .11\, S_{2t}$$

t-ratio 1.25 7.12 4.65 4.06 2.38

$R^2 = .72$

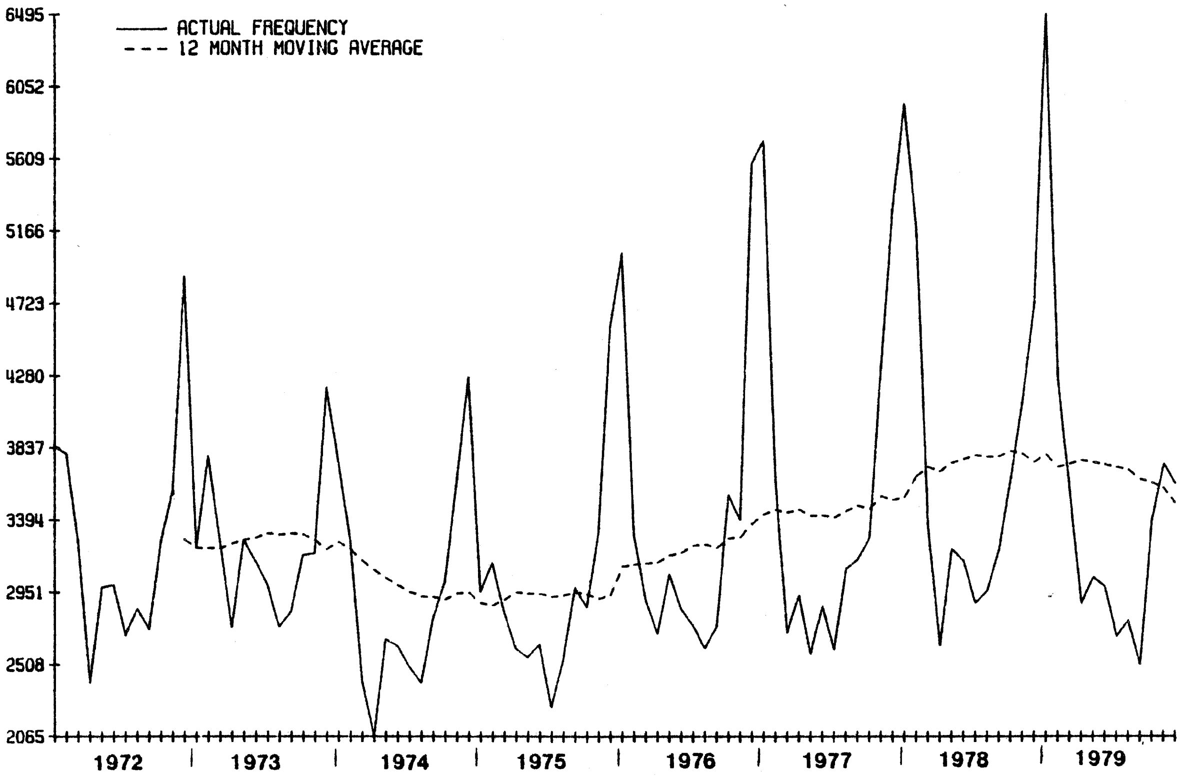


Figure B.22 Police-reported Had Not Been Drinking Drivers Age 21-23 Involved in Property Damage Only Crashes, State of Michigan

$$Y_t = \frac{(1 + .33B)(1 - .80B^{12})u_t + 47.20}{1 - B^{12}} - 308.63\ S_{4t} - 53.00\ S_{2t}$$

t-ratio 3.10 18.53 3.03 4.65 .78

$$R^2 = .44$$

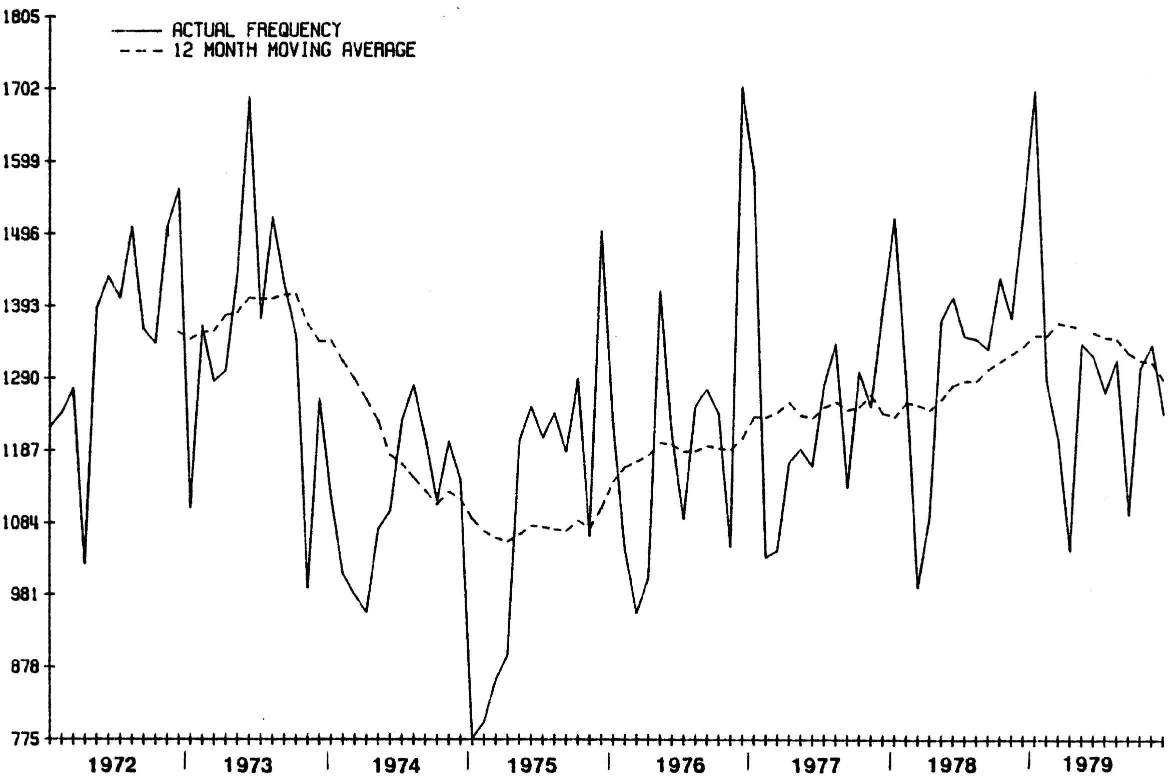


Figure B.23 Drivers Age 21-23 Involved in Daytime Crashes Including at Least One Injury or Fatality, State of Michigan

$$Y_t = \frac{(1 + .14B)(1 - .41B^{12})u_t + 142.59}{1 - B^{12}} - 436.58\ S_{4_t} - 315.54\ S_{2_t}$$

t-ratio 1.26 3.44 3.01 2.72 1.99

$R^2 = .69$

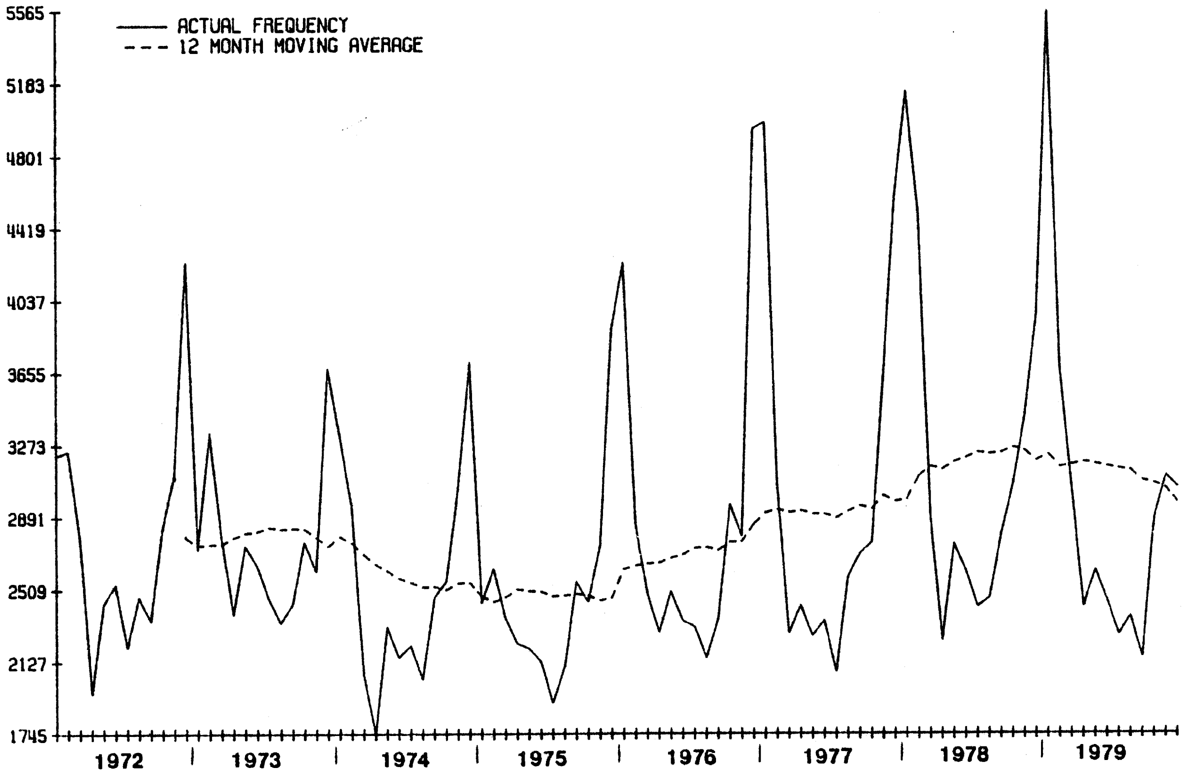


Figure B.24 Drivers Age 21-23 Involved in Daytime Property Damage Only Crashes, State of Michigan

$$Y_t = \frac{(1 + .20B)(1 - .90B^{12})u_t + 38.74}{1 - B^{12}} - 120.07\ S_{4_t} + 88.24\ S_{2_t}$$

t-ratio	1.96	25.59	4.20	2.98	2.34

$R^2 = .67$

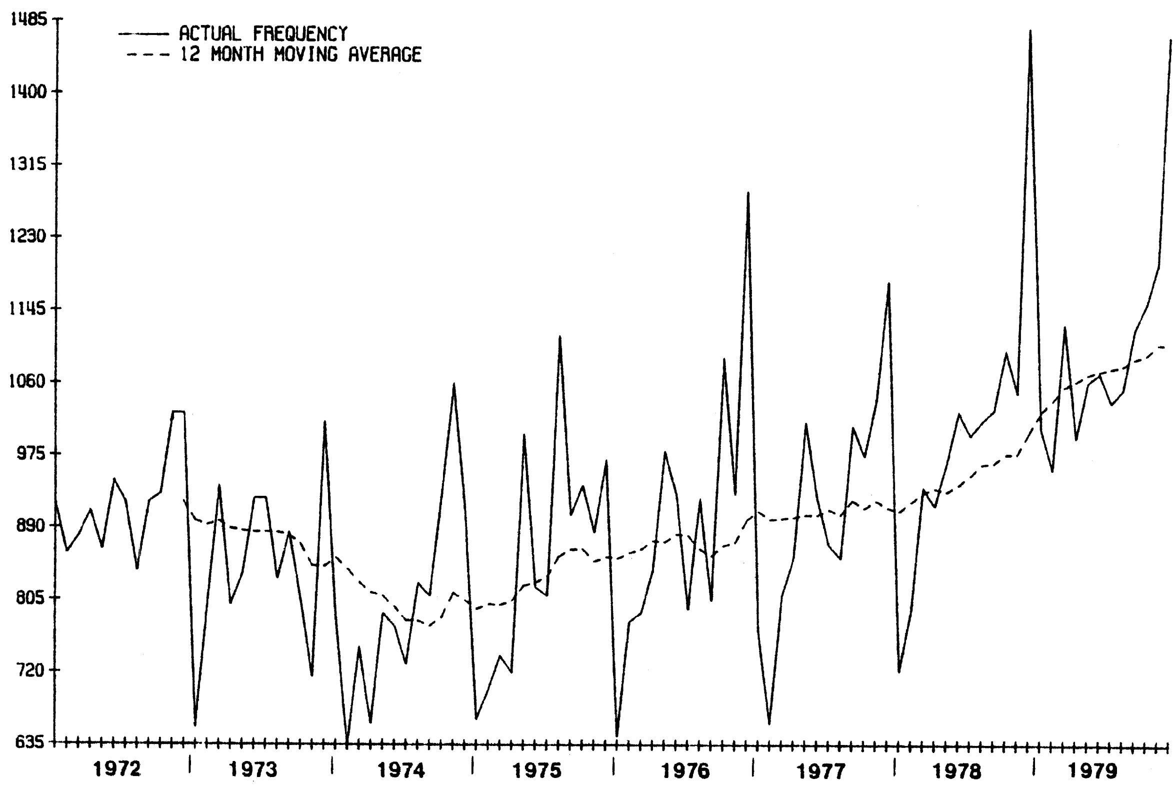


Figure B.25 Police-reported Had Been Drinking Drivers Age 24-45 Involved in Crashes Including at Least One Injury or Fatality, State of Michigan

$$Y_t = \frac{(1 - .86B^{12})u_t + 27.75}{1 - B^{12}} - 110.29\ S_{4_t} + 44.91\ S_{2_t}$$

t-ratio	24.26	3.10	2.83	1.17

$R^2 = .73$

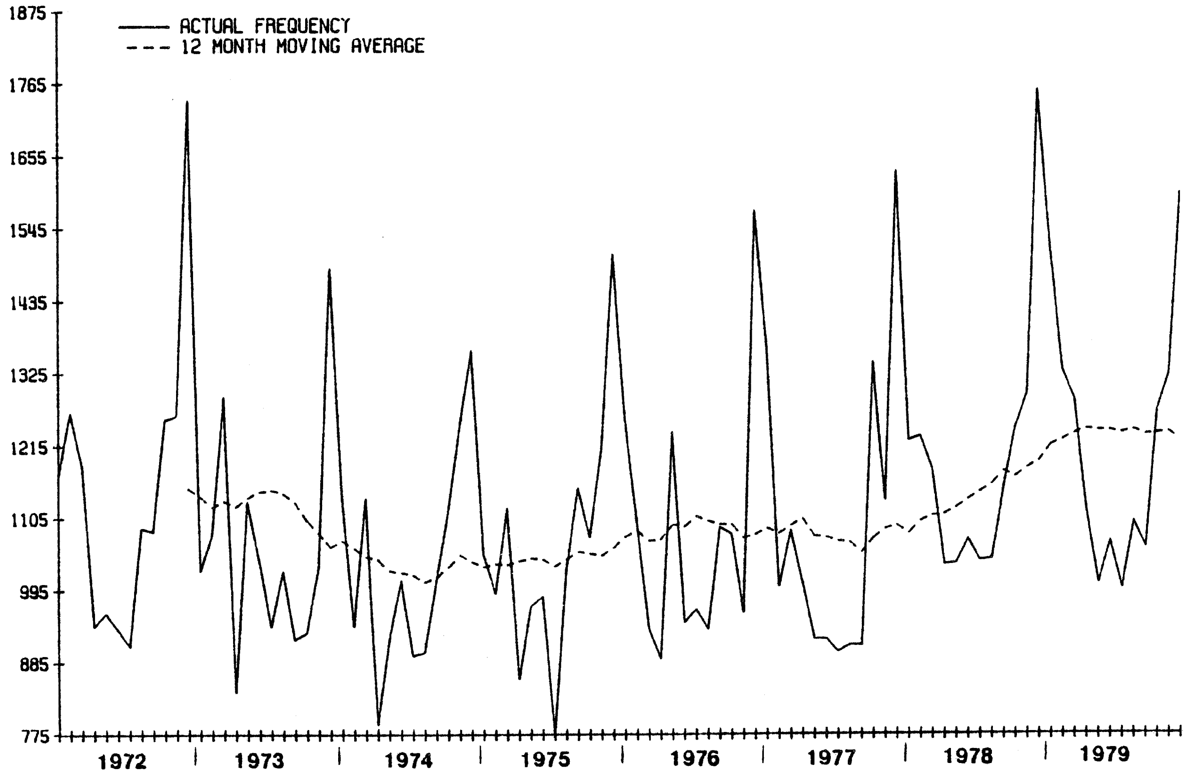


Figure B.26 Police-reported Had Been Drinking Drivers Age 24-45 Involved in Property Damage Only Crashes, State of Michigan

$$Y_t = \frac{(1 + .21B^2)(1 - .87B^{12})u_t}{1 - B^{12}} + 38.63\ S_{2t}$$

t-ratio 2.05 22.70 2.43

$R^2 = .53$

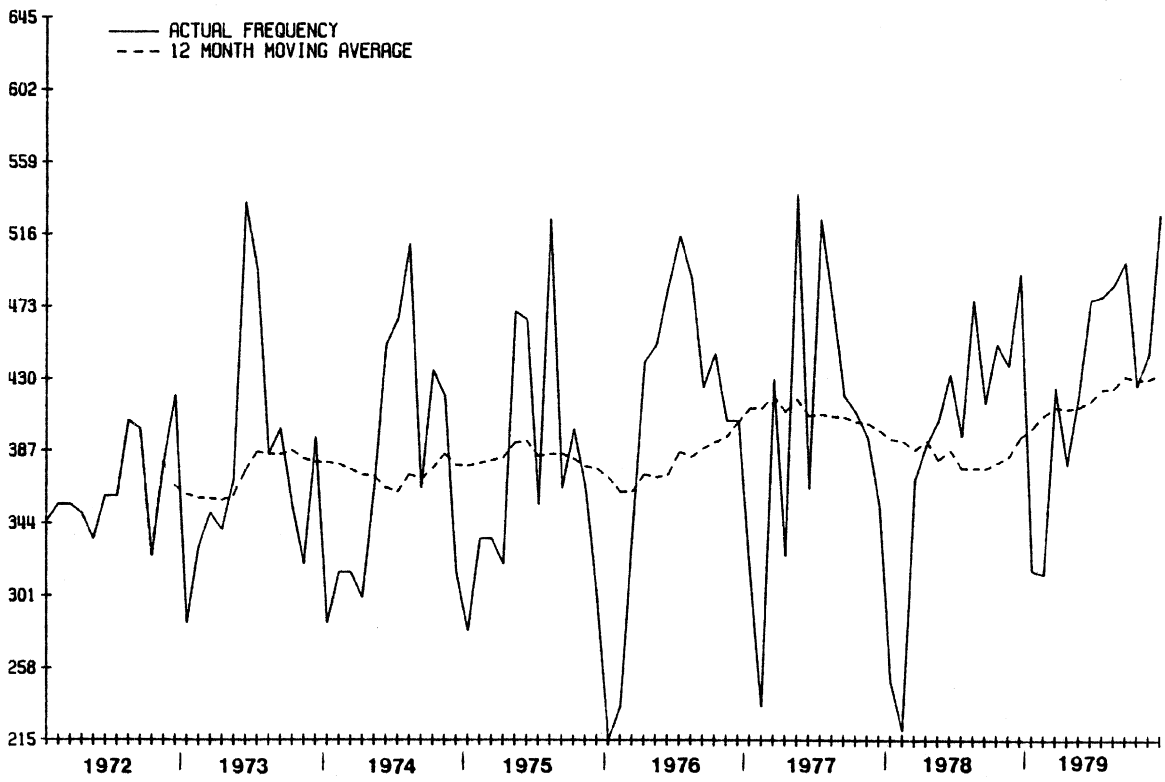


Figure B.27 Male Drivers Age 24-45 Involved in Late-night, Single-vehicle Crashes Including at Least One Injury or Fatality, State of Michigan

$$Y_t = \frac{(1 + .25B + .29B^2)(1 - .91B^{12})u_t + 29.29}{1 - B^{12}} - 55.00\ S_{4_t} - 20.70\ S_{2_t}$$

t-ratio 2.51 2.91 27.66 2.94 1.27 .52

$R^2 = .77$

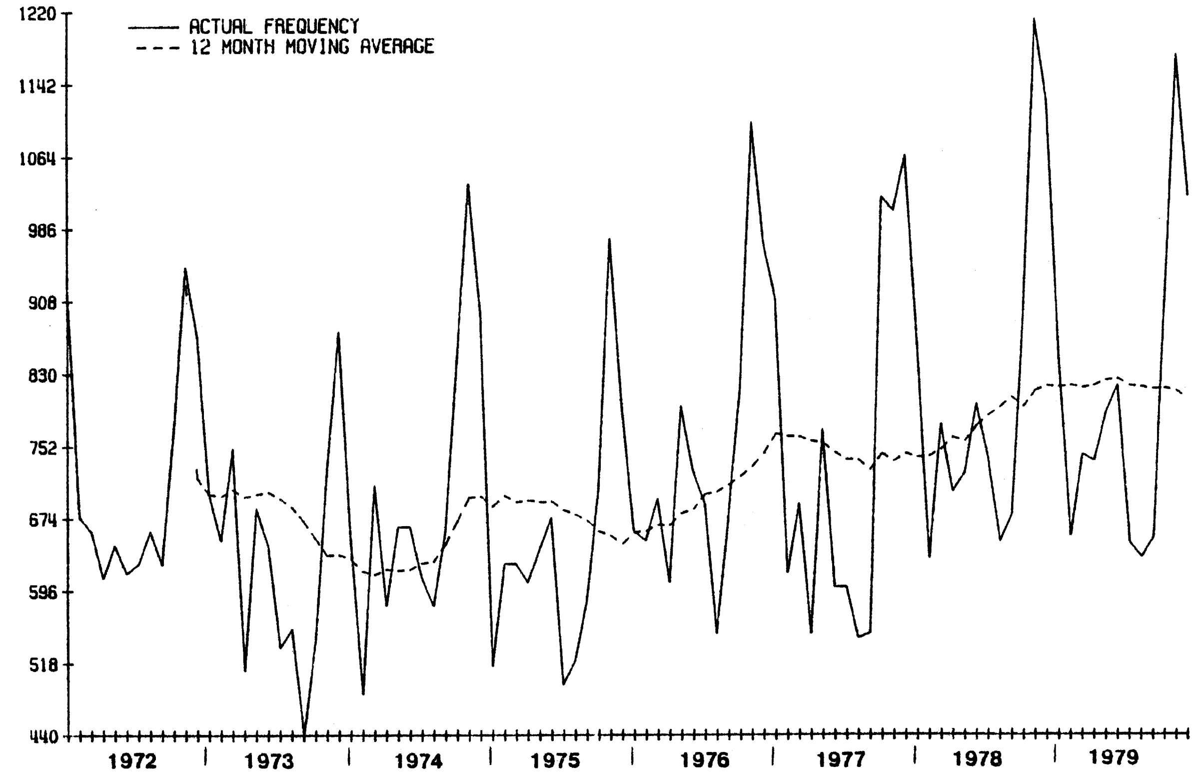


Figure B.28 Male Drivers Age 24-45 Involved In Late-night, Single-vehicle, Property Damage Only Crashes, State of Michigan

$$Y_t = \frac{(1 + .39B)(1 - .80B^{12})u_t + 196.49}{1 - B^{12}} - 1190.21\ S_{4_t} - 262.99\ S_{2_t}$$

t-ratio 3.85 19.32 3.37 4.80 1.04

$R^2 = .53$

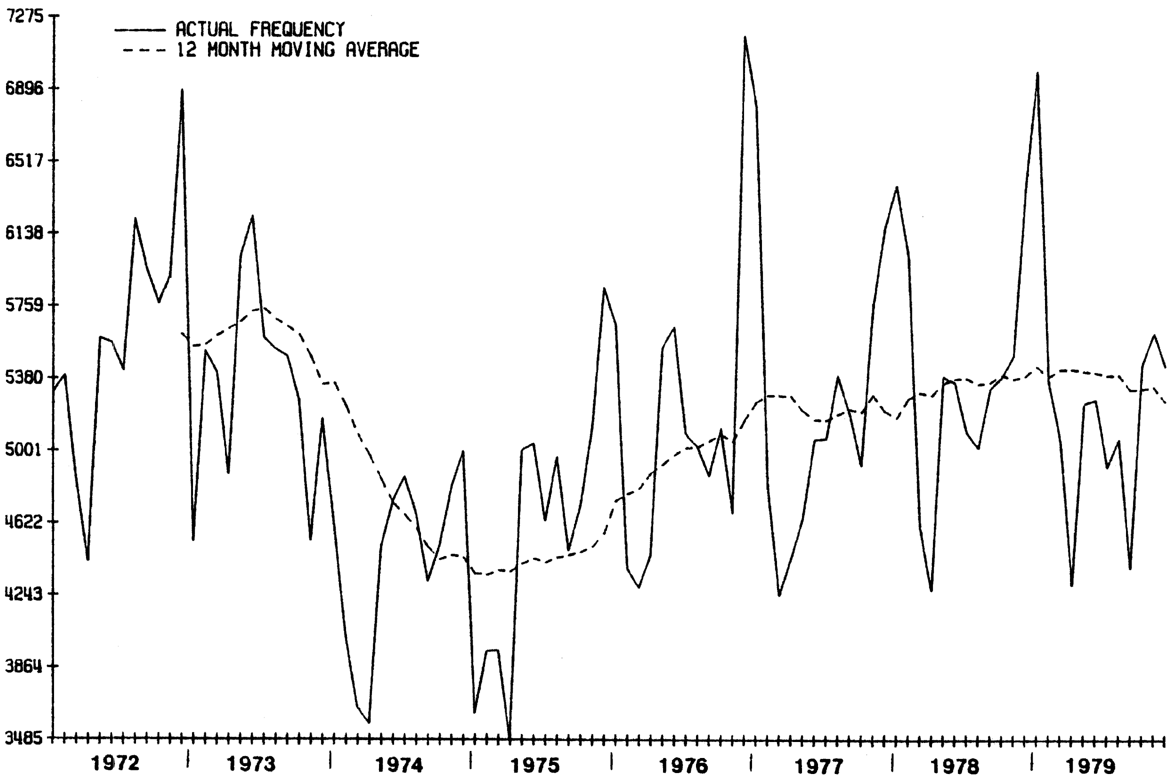


Figure B.29 Police-reported Had Not Been Drinking Drivers Age 24-45 Involved in Crashes Including at Least One Injury or Fatality, State of Michigan

$$\log Y_t = \frac{(1 + .18B)(1 - .57B^{12})u_t + .05}{1 - B^{12}} - .16\, S_{4_t} - .10\, S_{2_t}$$

t-ratio 1.65 5.29 4.12 3.49 2.28

$R^2 = .77$

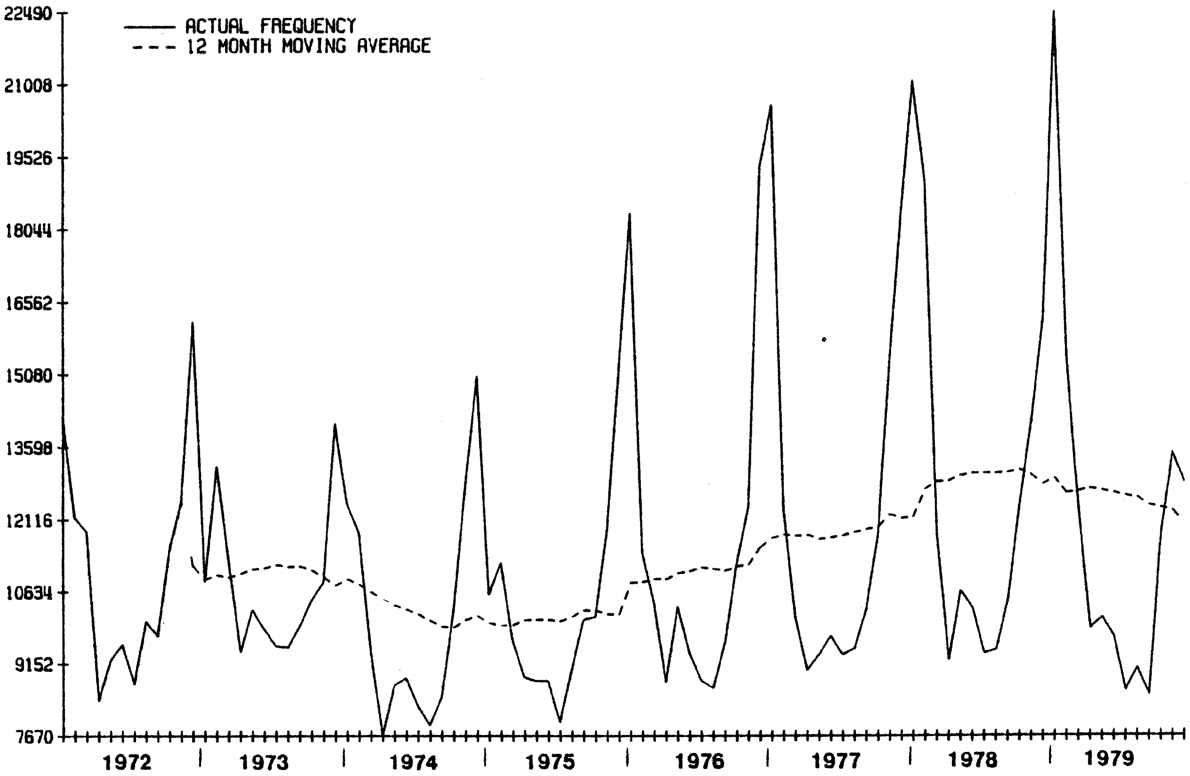


Figure B.30 Police-reported Had Not Been Drinking Drivers Age 24-45 Involved in Property Damage Only Crashes, State of Michigan

$$Y_t = \frac{(1 + .40B)(1 - .82B^{12})u_t + 183.84}{1 - B^{12}} - 1107.34\ S_{4_t} - 219.89\ S_{2_t}$$

t-ratio	3.98	20.93	3.45	4.85	.95

$R^2 = .54$

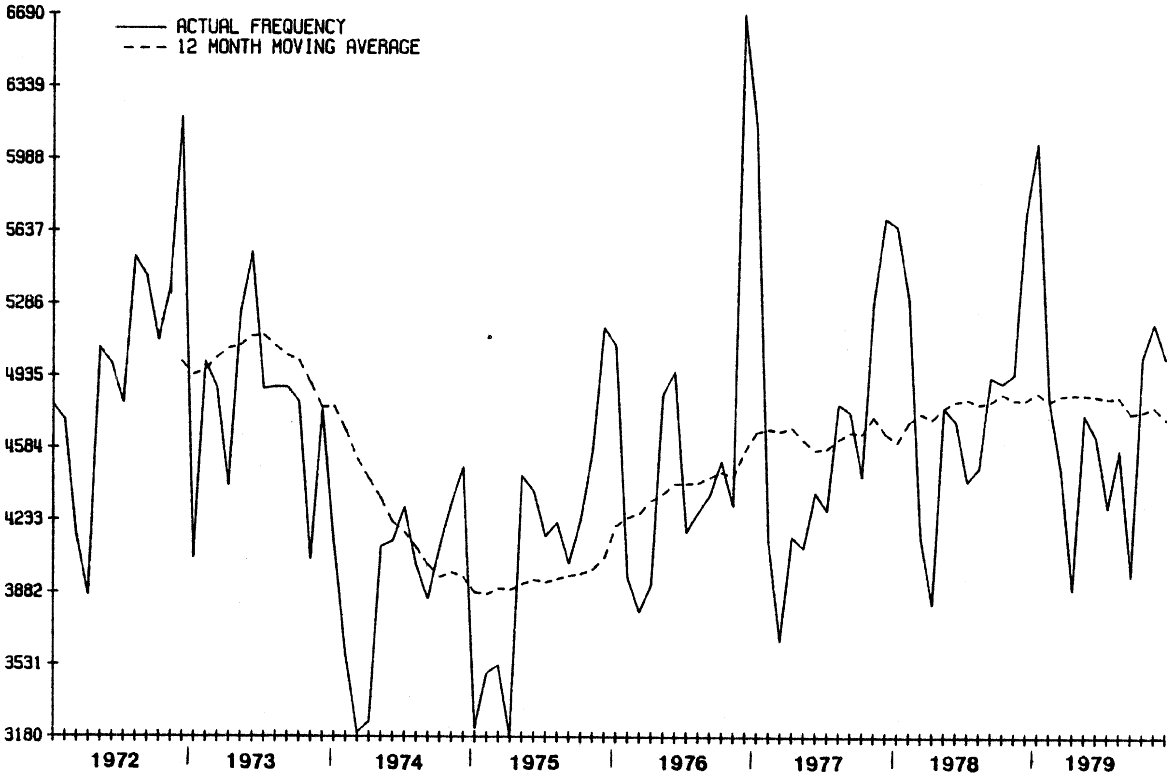


Figure B.31 Drivers Age 24-45 Involved in Daytime Crashes Including at Least One Injury or Fatality, State of Michigan

$$Y_t = \frac{(1 - .35B^{12})u_t + 522.02}{1 - B^{12}} - 1519.03\ S_{4_t} - 1186.66\ S_{2_t}$$

t-ratio 3.10 3.43 3.04 2.44

$R^2 = .73$

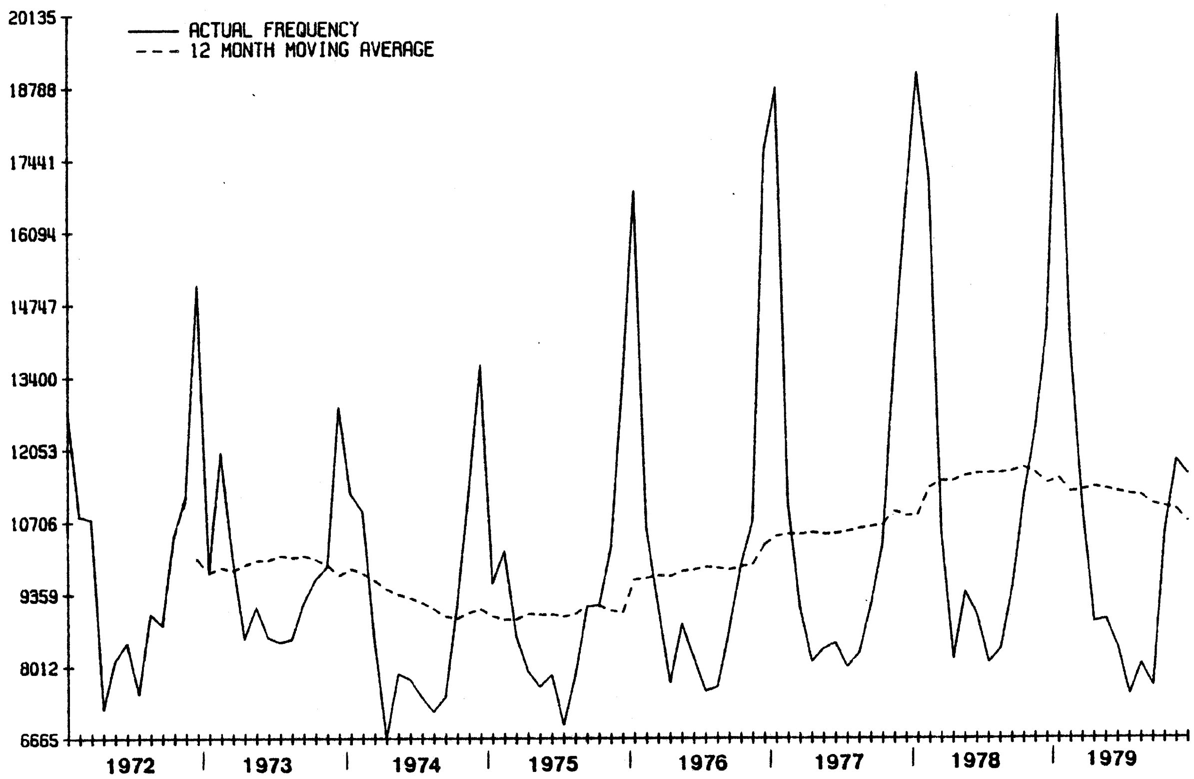


Figure B.32 Drivers Age 24-45 Involved in Daytime Property Damage Only Crashes, State of Michigan

Appendix C

Crash Frequency Plots and Time-series Models,
State of New York, Including New York City

$$Y_t = \frac{(1 - .51B^5)(1 - .81B^{12})u_t}{1 - B^{12}} + 7.53\ S_t + 11.43\ S_{2t}$$

t-ratio	4.10	13.68	4.09	5.24

$R^2 = .70$

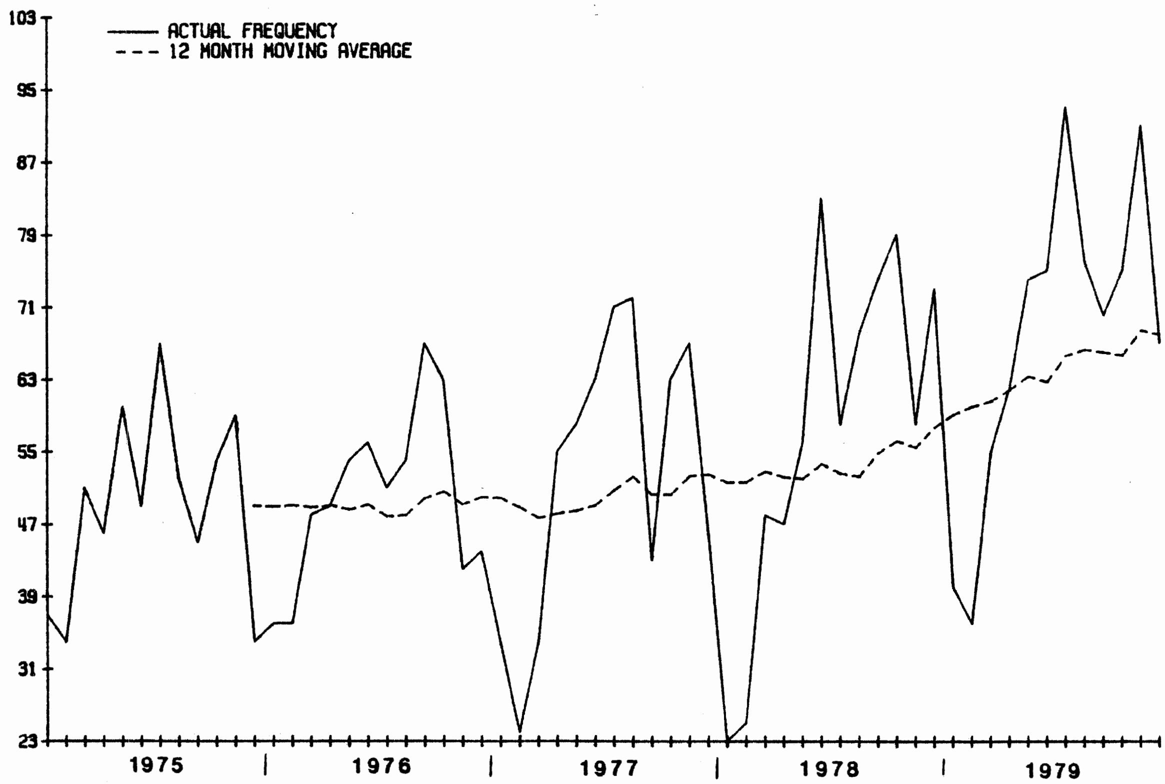


Figure C.1 Police-reported Had Been Drinking Drivers Age 16-17 Involved in Crashes Including at Least One Injury or Fatality, State of New York

$$Y_t = u_t + 9.65 + .43\ S_t + 1.26\ S_{2t}$$

t-ratio 16.77 .40 .96

$$R^2 = .00$$

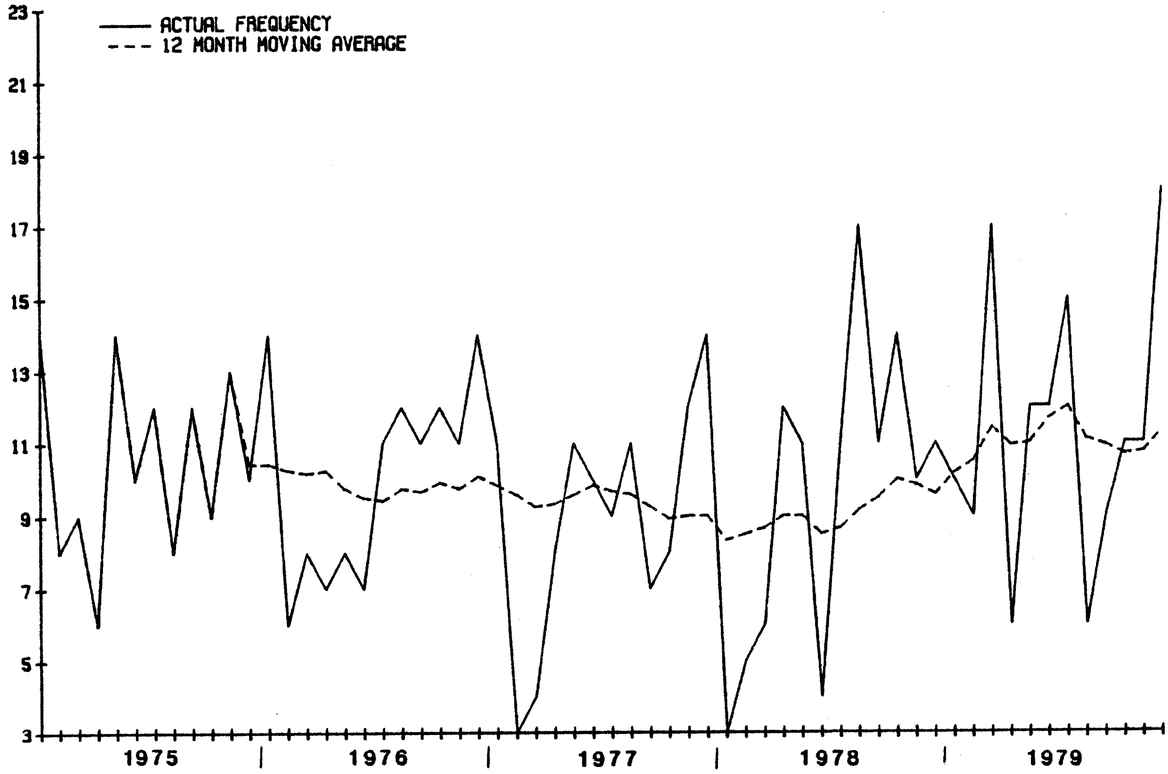


Figure C.2 Police-reported Had Been Drinking Drivers Age 16-17 Involved in Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 - .79B^{12})u_t - 3.91}{1 - B^{12}} + 16.09\ S_t - 24.97\ P_{2_t} + 8.22\ S_{2_t}$$

t-ratio	14.23	1.82	2.99	2.12	1.80

$R^2 = .74$

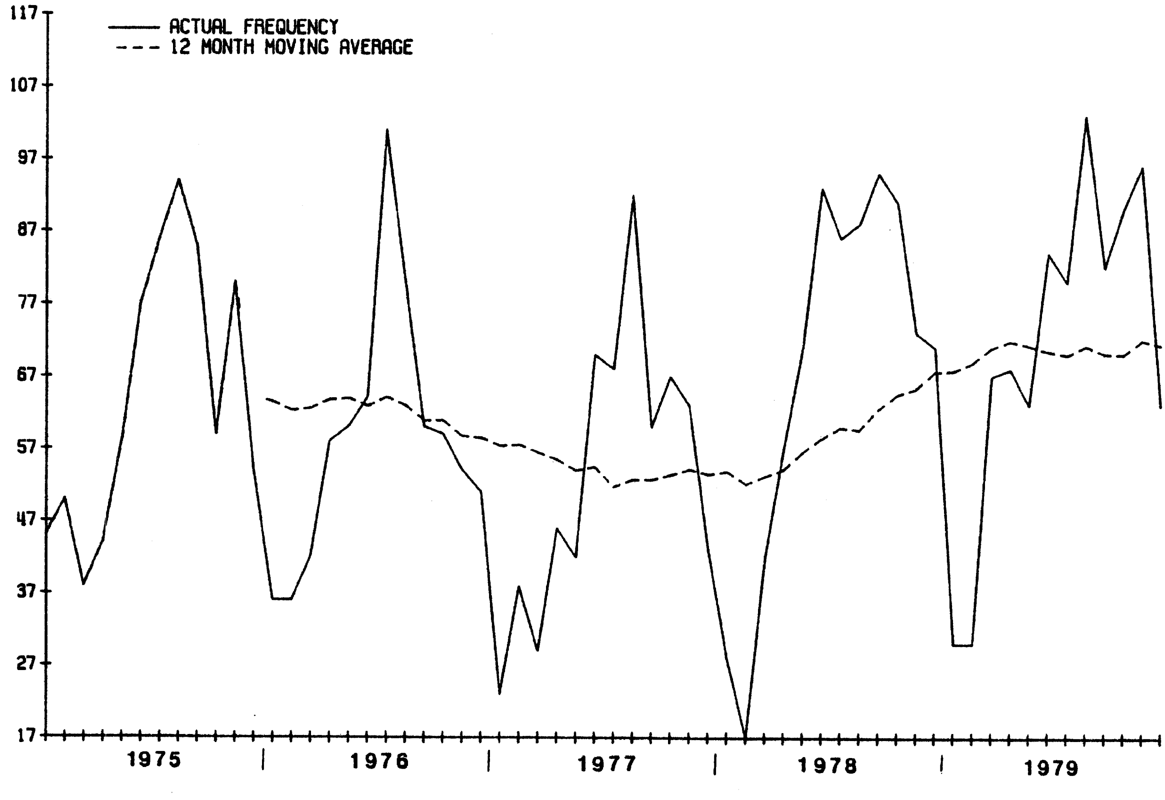


Figure C.3 Male Drivers Age 16-17 Involved in Late-night, Single-vehicle Crashes Including at Least One Injury or Fatality, State of New York

$$Y_t = (1 + .22B + .59B^2)u_t + 16.28 - 3.39\ S_t - 1.49\ S_{2t}$$

t-ratio	2.02	5.30	10.88	1.33	.48

$$R^2 = .26$$

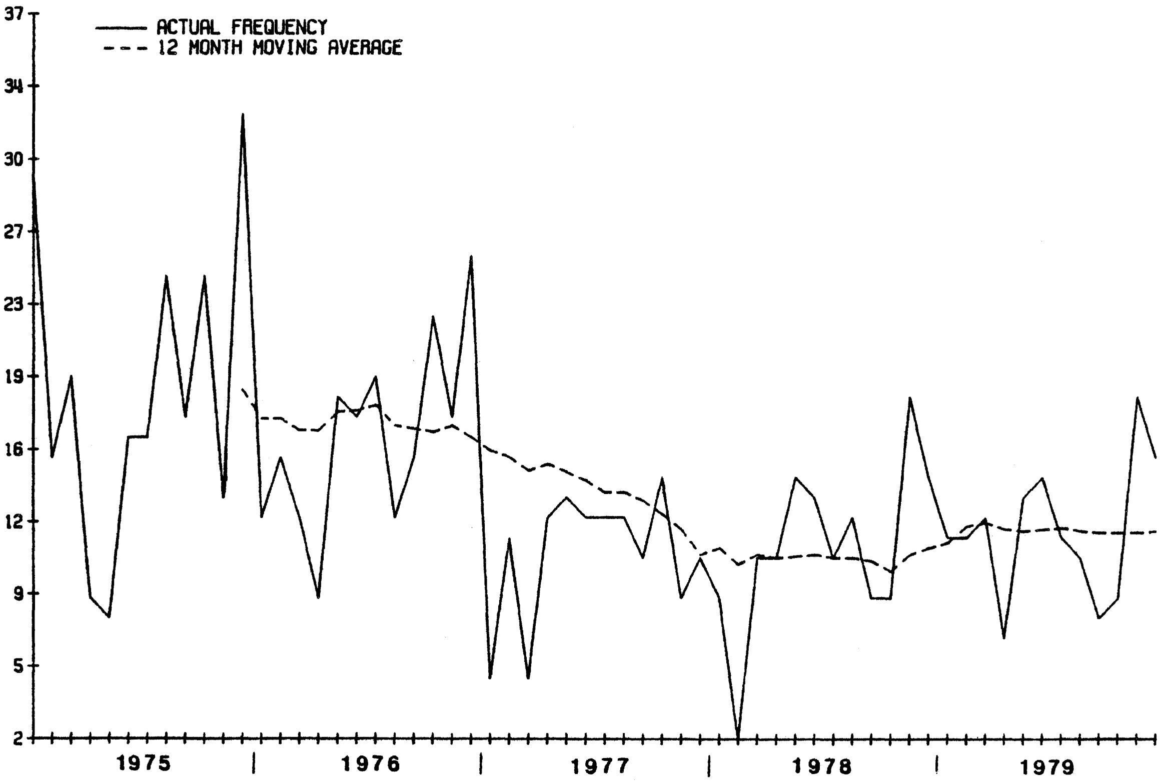


Figure C.4 Male Drivers Age 16-17 Involved in Late-night, Single-vehicle, Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 + .58B^3)(1 - .84B^{12})u_t}{1 - B^{12}} + .55\ S_t - 20.17\ P_{2t} + 1.98\ S_{2t}$$

t-ratio 6.09 15.17 .11 1.94 .36

$$R^2 = .79$$

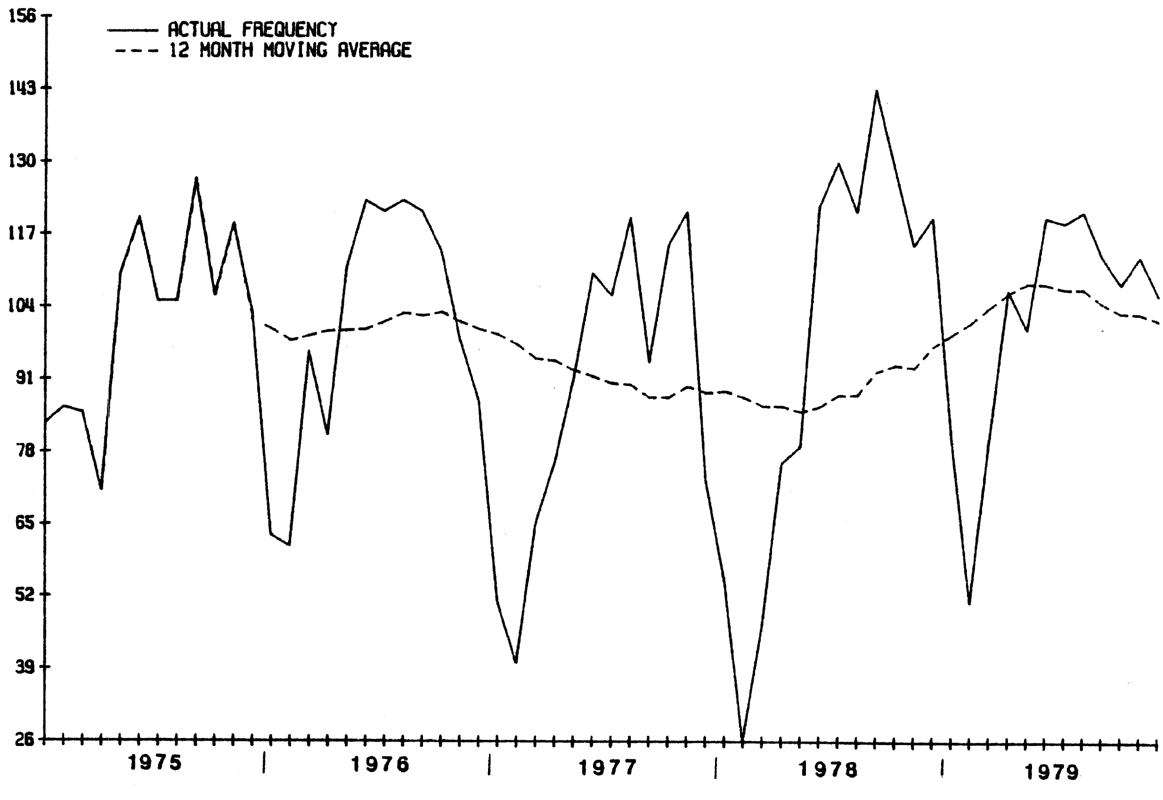


Figure C.5 Male Drivers Age 16-17 Involved in Daytime, Single-vehicle Crashes Including at Least One Injury or Fatality, State of New York

$$Y_t = \frac{(1 - .82B^{12})u_t - 7.64}{1 - B^{12}} + 1.91\ S_t + 5.01\ S_{2t}$$

t-ratio 18.98 6.23 .63 1.99

$R^2 = .76$

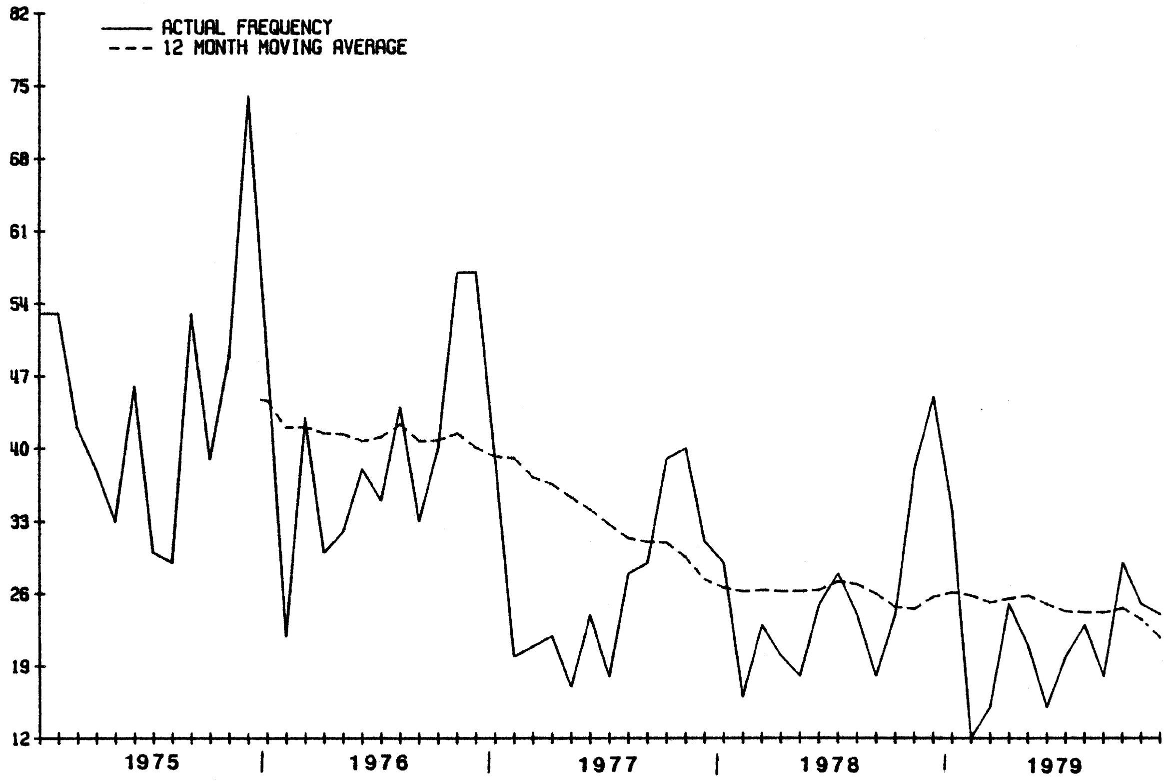


Figure C.6 Male Drivers Age 16-17 Involved in Daytime, Single-vehicle, Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 + .23B)(1 - .80B^{12})u_t}{1 - B^{12}} + 39.96\ S_t + 40.61\ S_{2t}$$

t-ratio 1.71 14.09 3.89 3.45

$R^2 = .79$

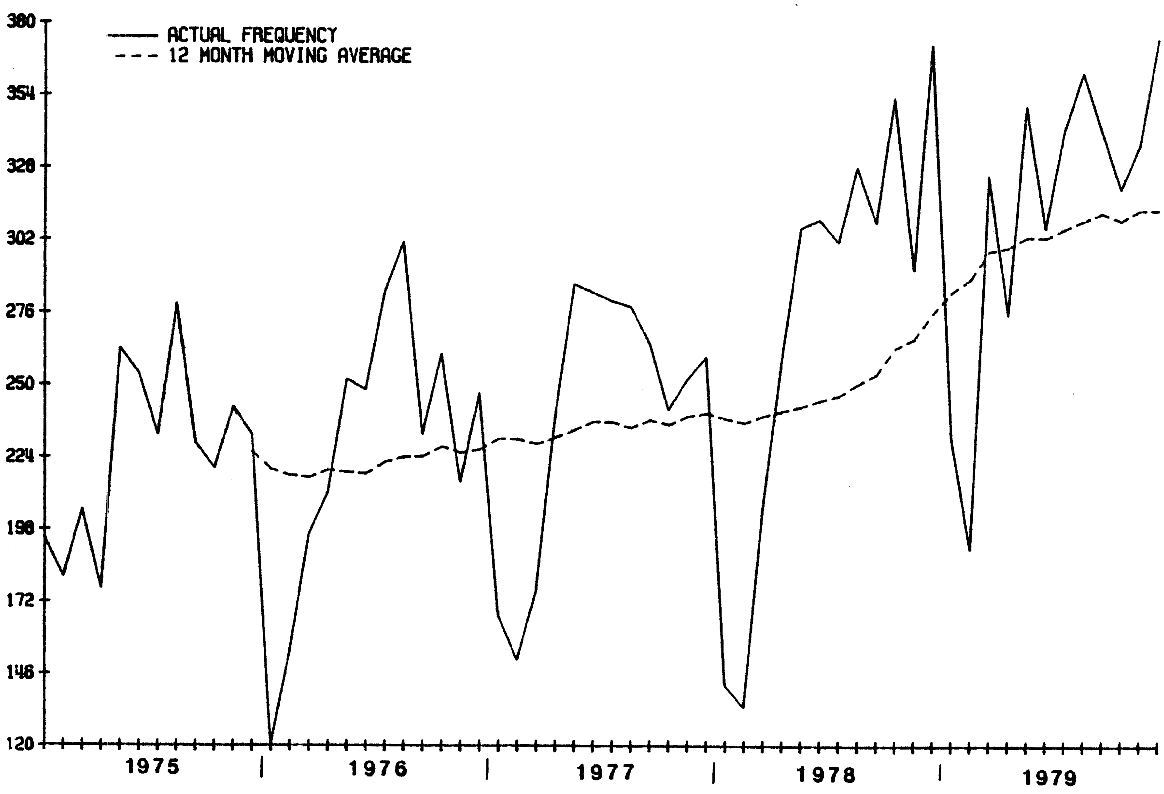


Figure C.7 Police-reported Had Been Drinking Drivers Age 18-20 Involved in Crashes Including at Least One Injury or Fatality, State of New York

$$Y_t = \frac{(1 - .80B^{12})u_t - 2.72}{1 - B^{12}} + 8.78\ S_t + .96\ S_{2t}$$

t-ratio 15.62 2.23 2.90 .38

$$R^2 = .37$$

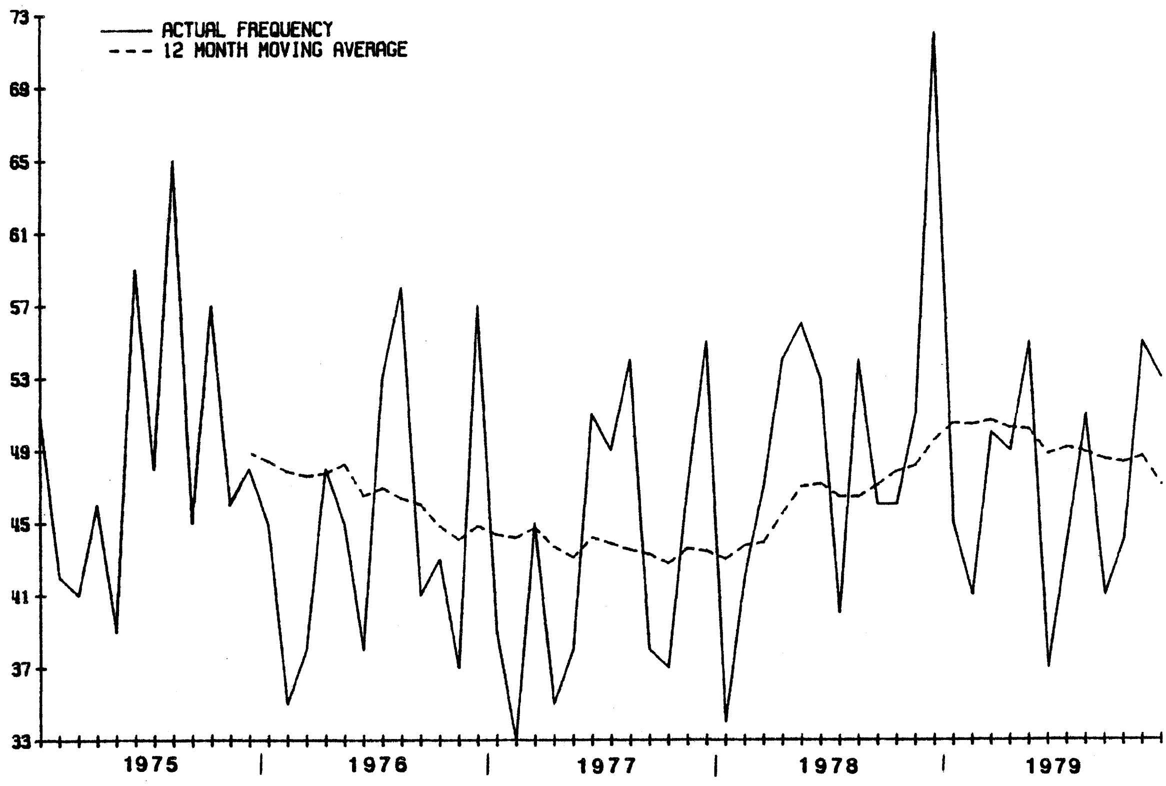


Figure C.8 Police-reported Had Been Drinking Drivers Age 18-20 Involved in Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 + .14B)(1 - .90B^{12})u_t}{1 - B^{12}} + 4.76\, S_t - 66.83\, P_{2t} + 36.59\, S_{2t}$$

t-ratio	1.20	18.22	.48	2.30	3.68

$R^2 = .86$

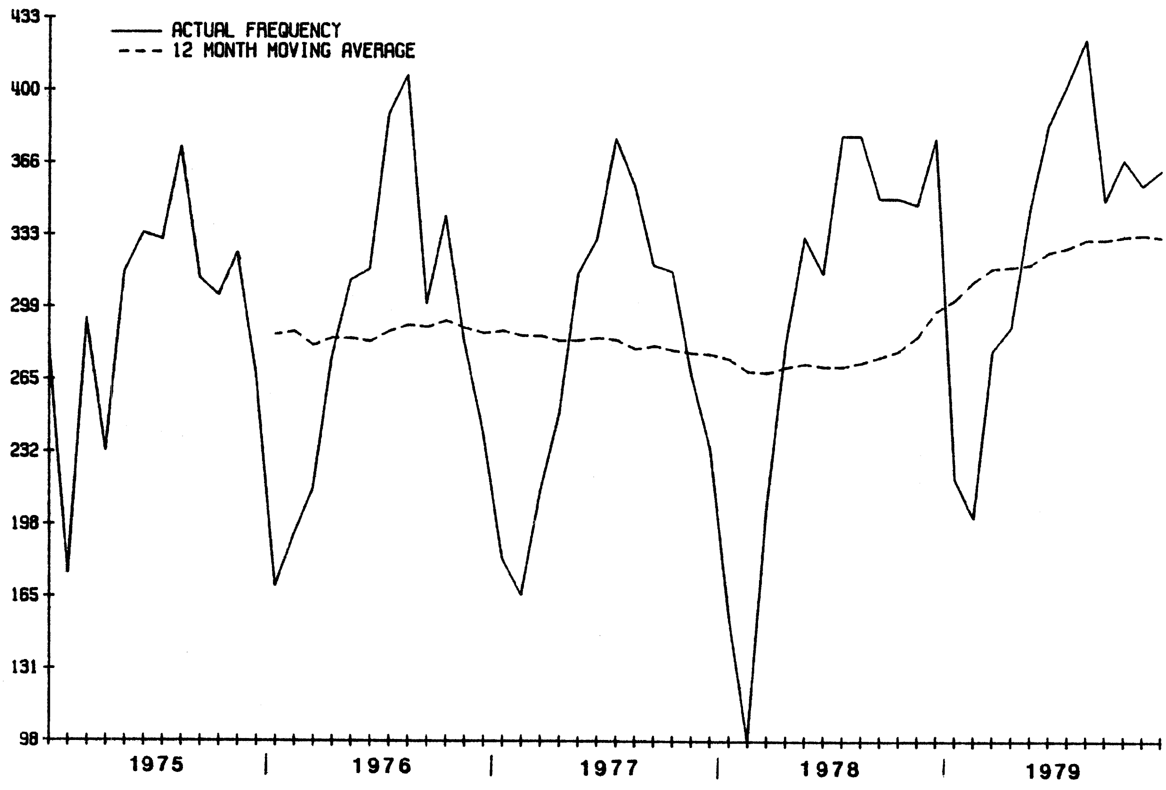


Figure C.9 Male Drivers Age 18-20 Involved in Late-night, Single vehicle Crashes Including at Least One Injury or Fatality, State of New York

$$Y_t = \frac{(1 - .63B)(1 - .82B^{12})u_t}{(1 - B)(1 - B^{12})} - 6.88\ S_t + 12.61\ S_{2t}$$

t-ratio 6.33 16.30 .80 1.55

$$R^2 = .78$$

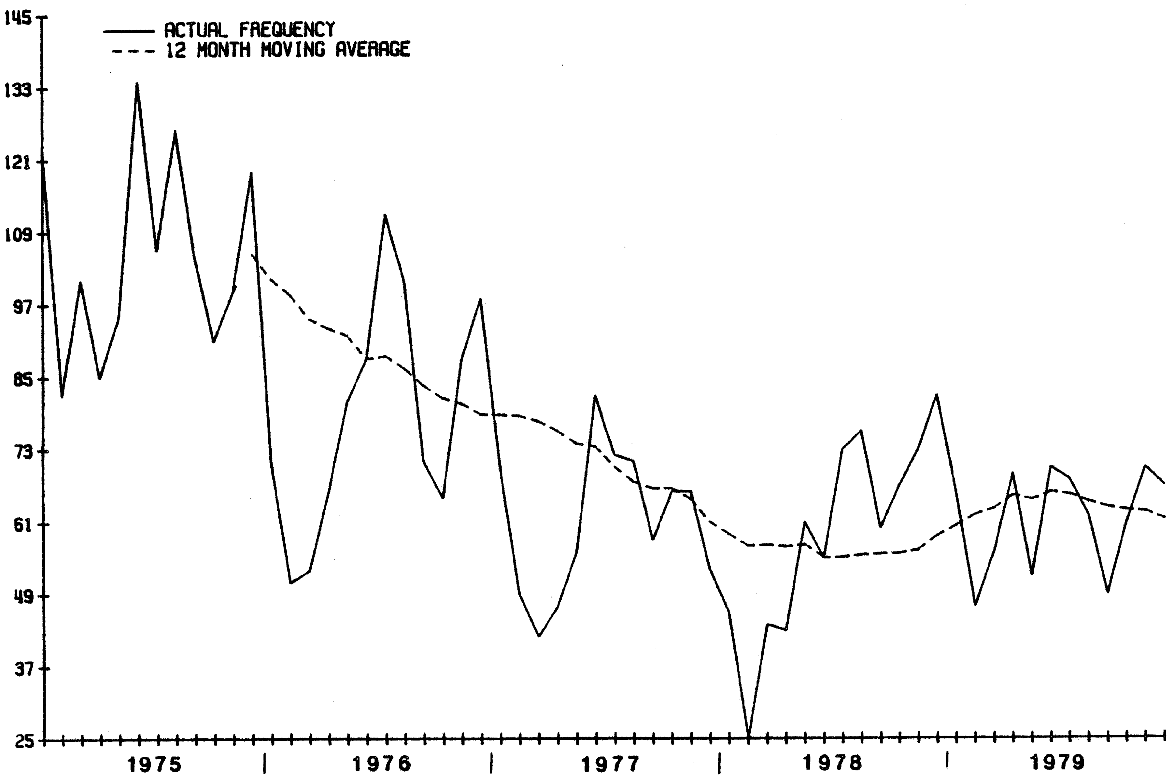


Figure C.10 Male Drivers Age 18-20 Involved in Late-night, Single-vehicle, Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 - .83B^{12})u_t - 9.56}{1 - B^{12}} + 13.52\ S_t - 57.91\ P_{2_t} + 7.35\ S_{2_t}$$

t-ratio 13.94 2.67 1.50 2.98 .98

$R^2 = .85$

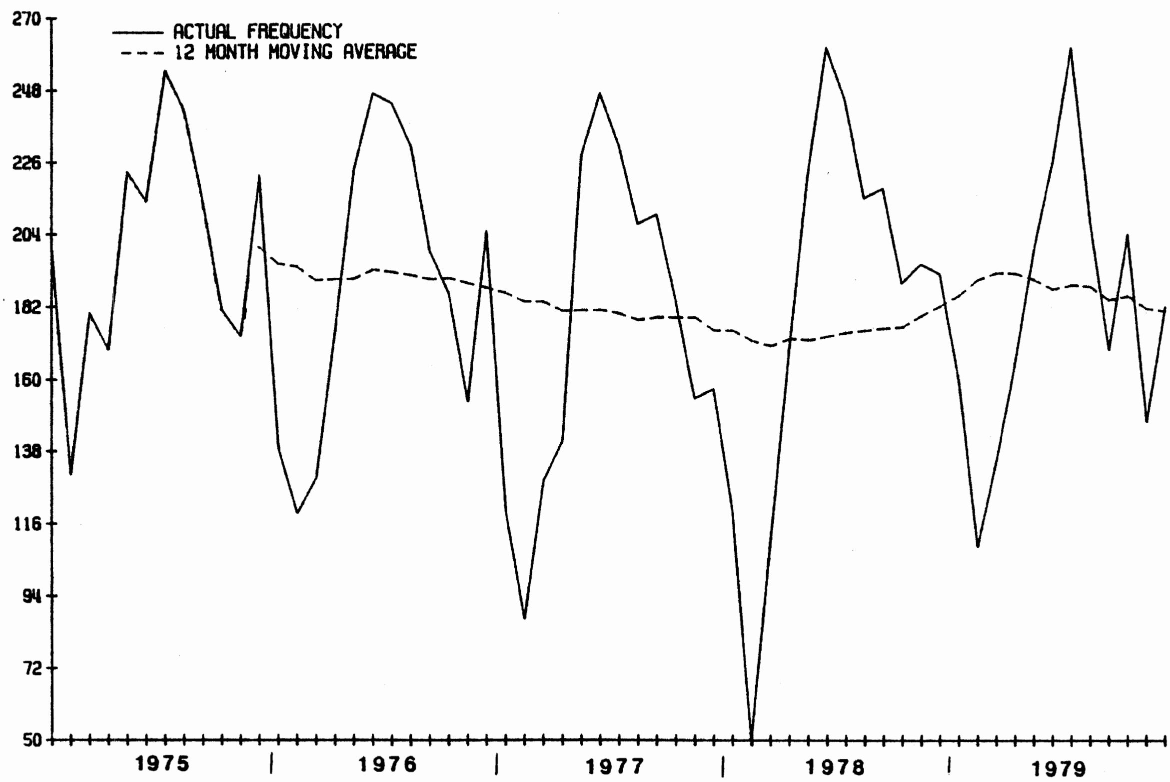


Figure C.11 Male Drivers Age 18-20 Involved in Daytime, Single-vehicle Crashes Including at Least One Injury or Fatality, State of New York

$$Y_t = \frac{(1 + .19B)(1 - .84B^{12})u_t - 19.19}{1 - B^{12}} + 9.34\ S_t + 24.85\ S_{2t}$$

t-ratio 1.47 15.77 8.54 1.69 5.42

$$R^2 = .85$$

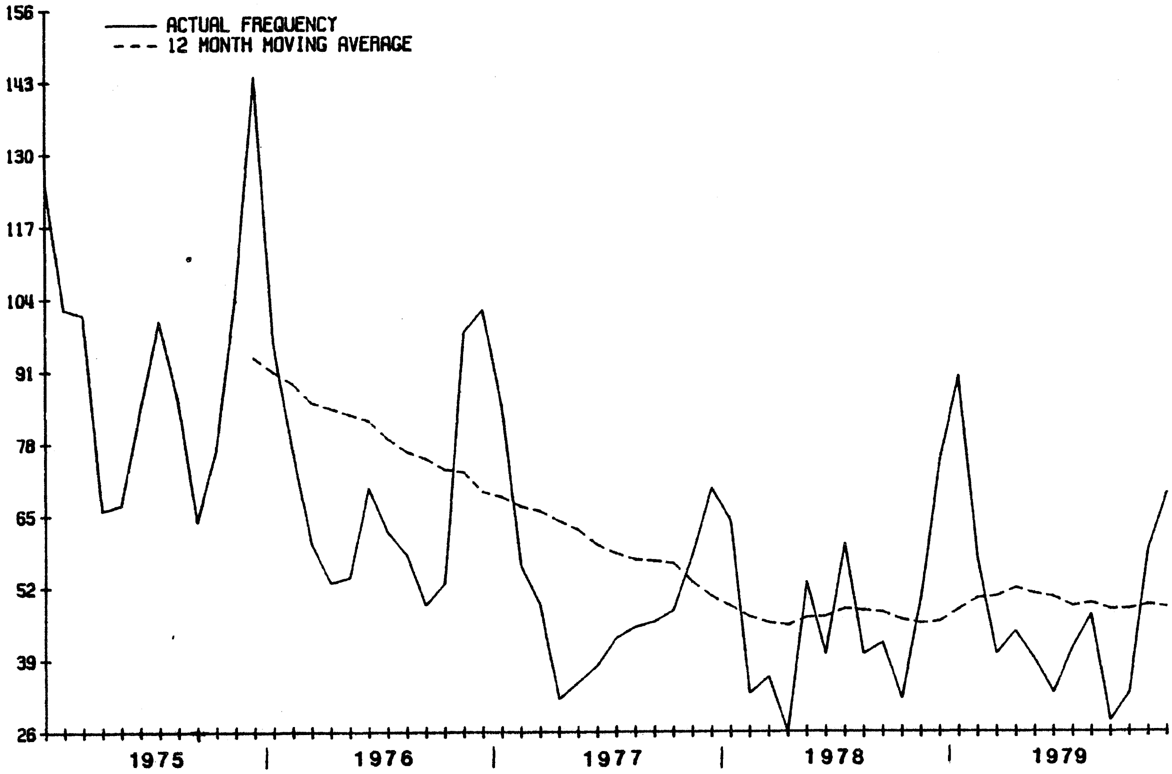


Figure C.12 Male Drivers Age 18-20 Involved in Daytime, Single-vehicle Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 - .85B^{12})u_t}{1 - B^{12}} + 29.89\ S_t - 40.99\ P_{2_t} + 35.66\ S_{2_t}$$

t-ratio	17.29	5.47	2.18	6.00

$$R^2 = .86$$

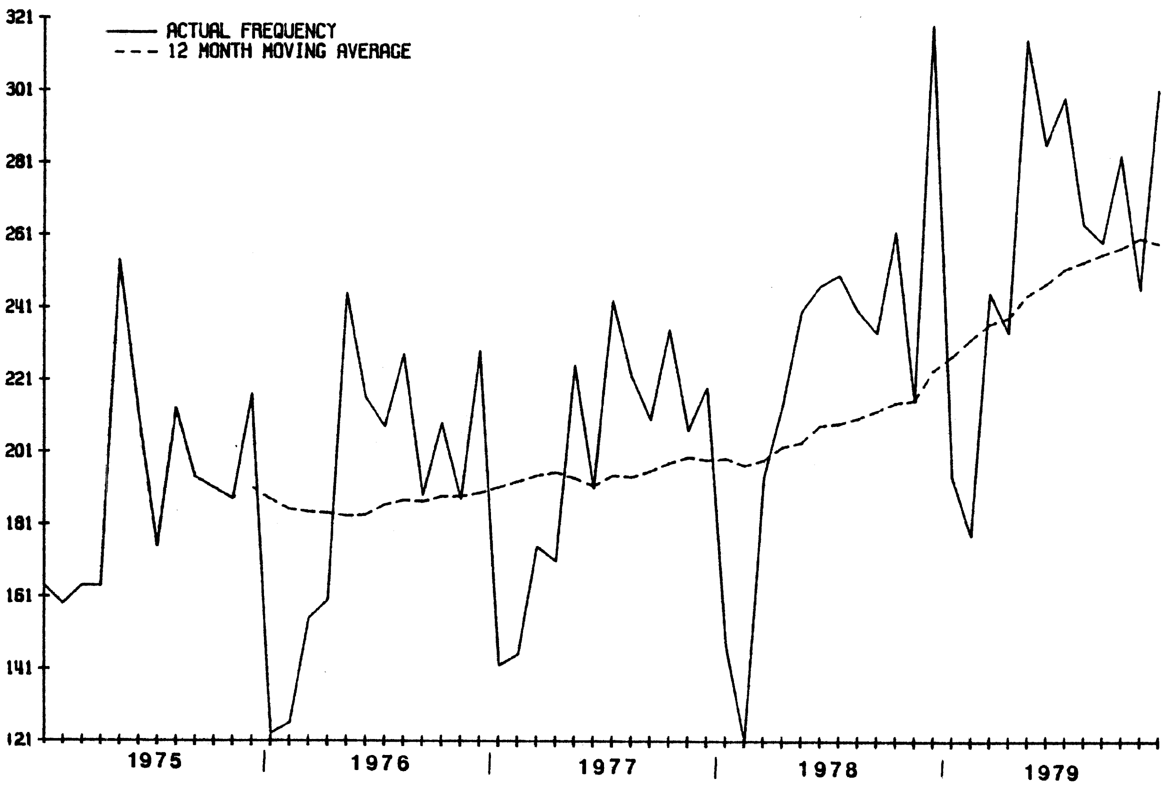


Figure C.13 Police-reported Had Been Drinking Drivers Age 21-23 Involved in Crashes Including at Least One Injury or Fatality, State of New York

$$Y_t = u_t + 35.65 + 3.78\,S_t + 2.65\,S_{2t}$$

t-ratio	30.94	1.77	1.00

$$R^2 = .11$$

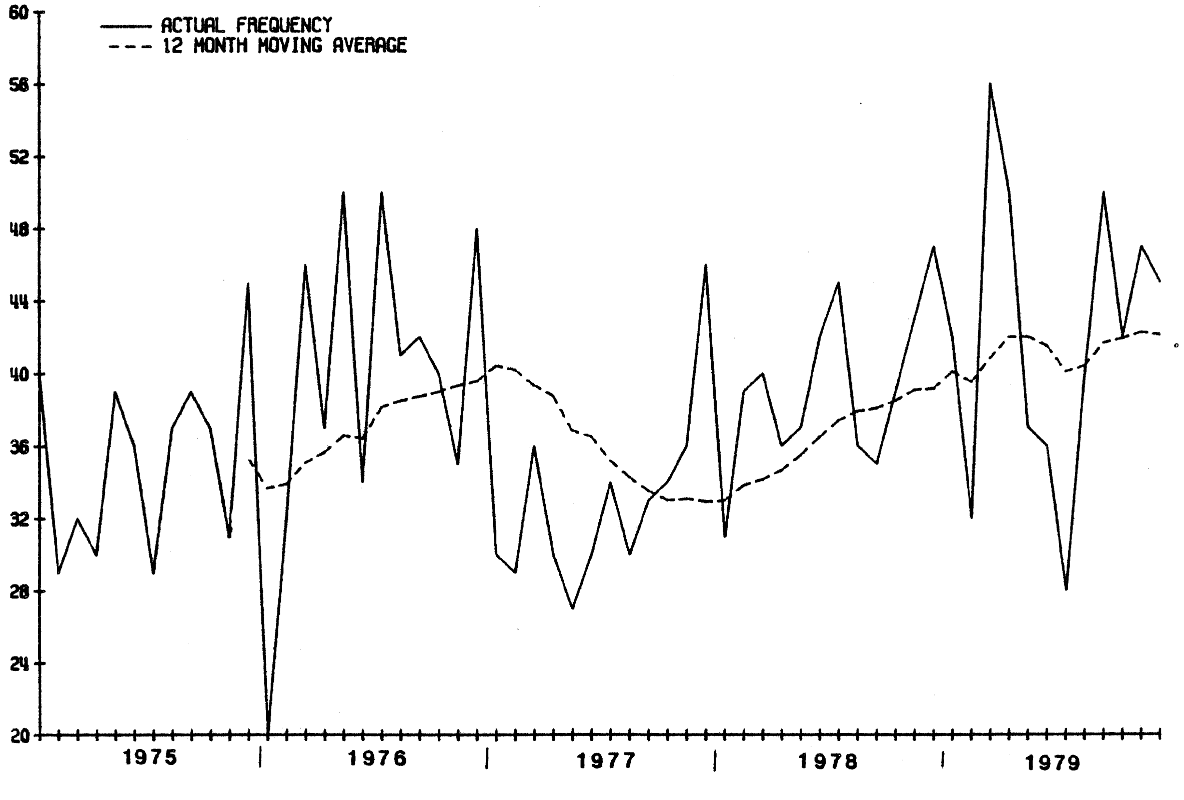


Figure C.14 Police-reported Had Been Drinking Drivers Age 21-23 Involved in Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 + .41\ B^2)u_t}{1 - B^{12}} + 1.26\ S_t - 32.64\ P_{2_t} + 20.59\ S_{2_t}$$

t-ratio 3.10 .13 1.84 2.02

$$R^2 = .68$$

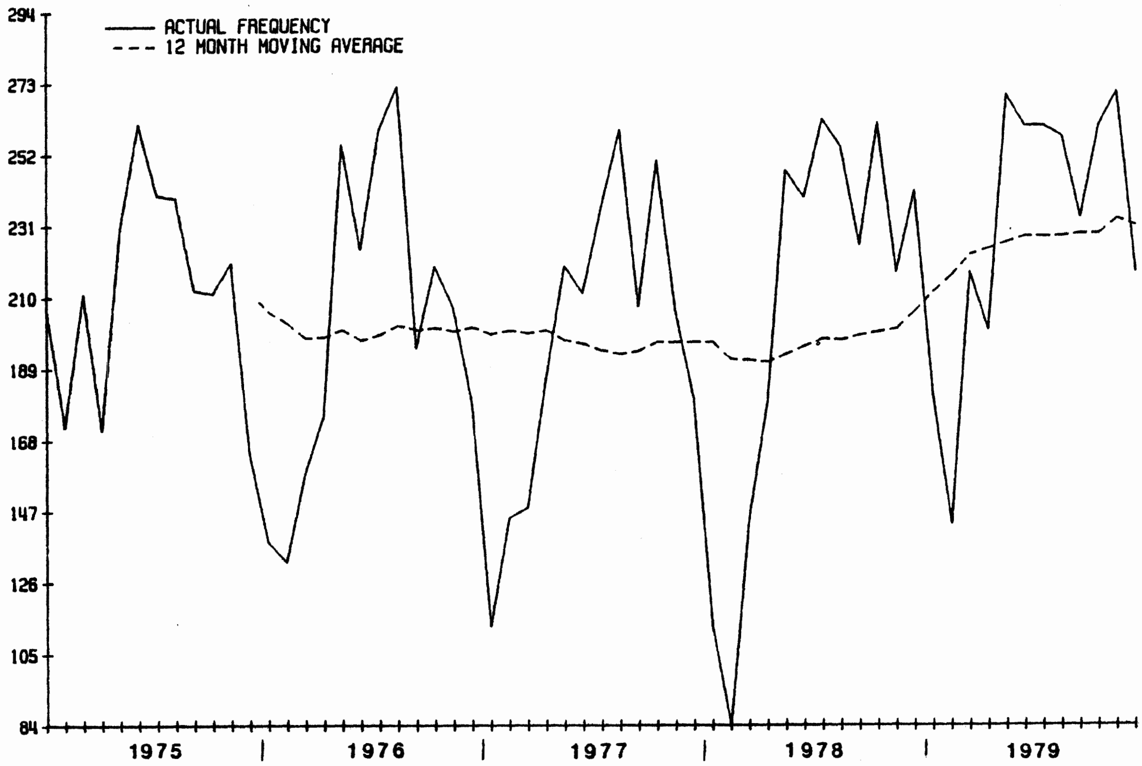


Figure C.15 Male Drivers Age 21-23 Involved in Late-night, Single-vehicle Crashes Including at Least One Injury or Fatality, State of New York

$$Y_t = \frac{(1 - .86B)(1 - .77B^{12})u_t}{(1 - B^1)(1 - B^{12})} + 8.32\ S_t - 20.24\ P_{2_t} + 19.46\ S_{2_t}$$

t-ratio	12.77	13.81	1.56	2.17	4.13

$$R^2 = .72$$

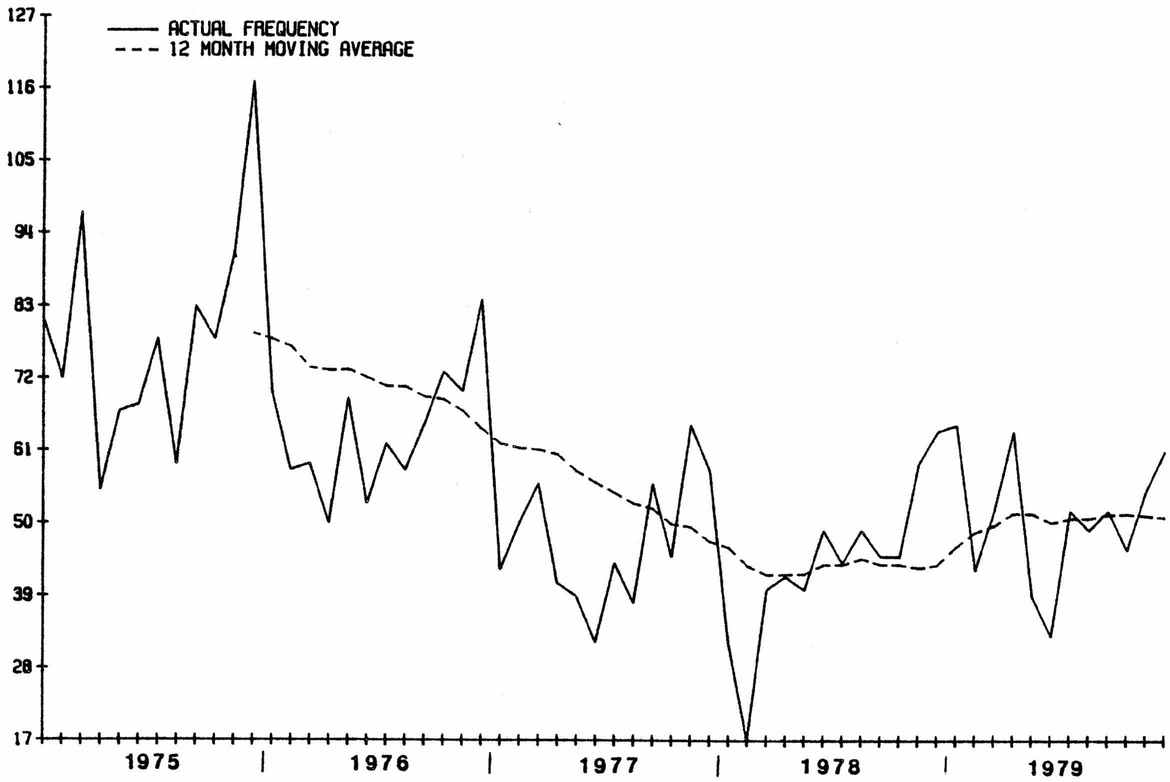


Figure C.16 Male Drivers Age 21-23 Involved in Late-night, Single-vehicle Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 - .43B^3)(1 - .89B^{12})u_t - 5.64}{1 - B^{12}} + 8.45\ S_t - 45.89\ P_{2_t} + 4.99\ S_{2_t}$$

t-ratio 3.43 14.32 3.37 1.90 3.80 1.60

$$R^2 = .88$$

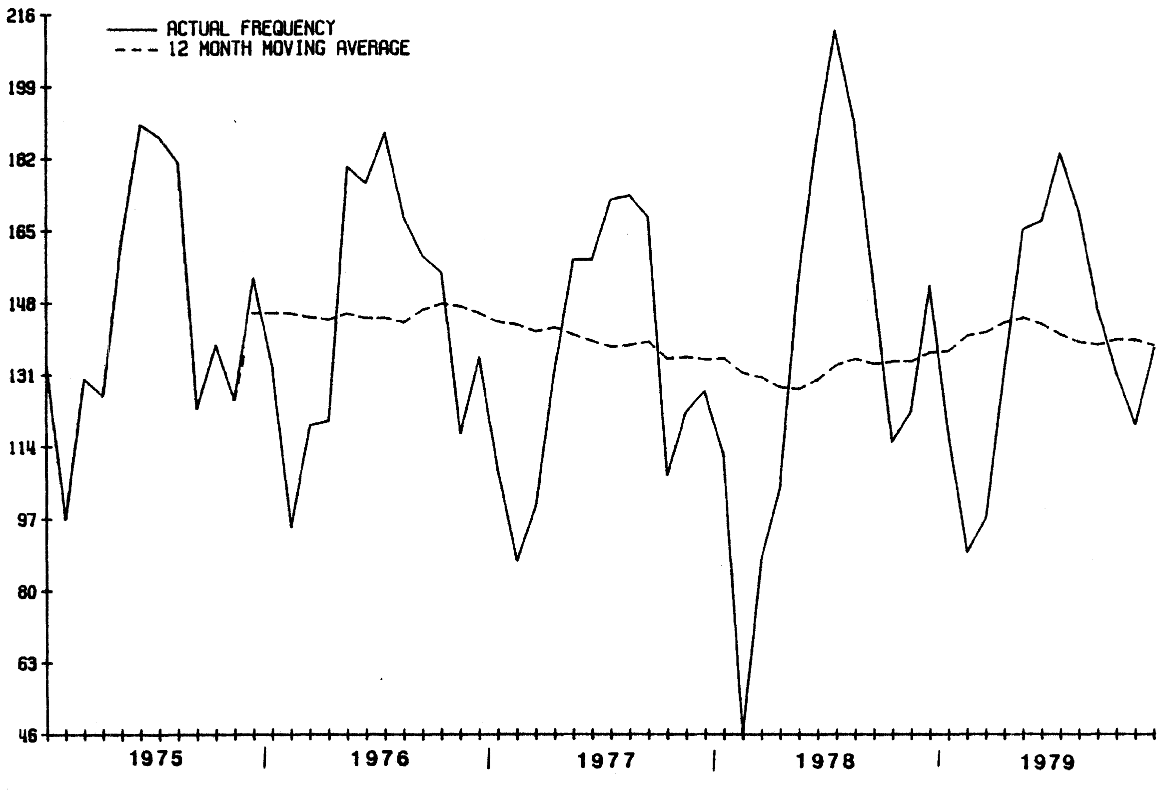


Figure C.17 Male Drivers Age 21-23 Involved in Daytime, Single-vehicle Crashes Including at Least One Injury or Fatality, State of New York

$$Y_t = \frac{(1 - .81B^{12})u_t - 13.37}{1 - B^{12}} + 5.64\ S_t + 12.51\ S_{2t}$$

t-ratio 18.99 7.49 1.28 3.40

$$R^2 = .84$$

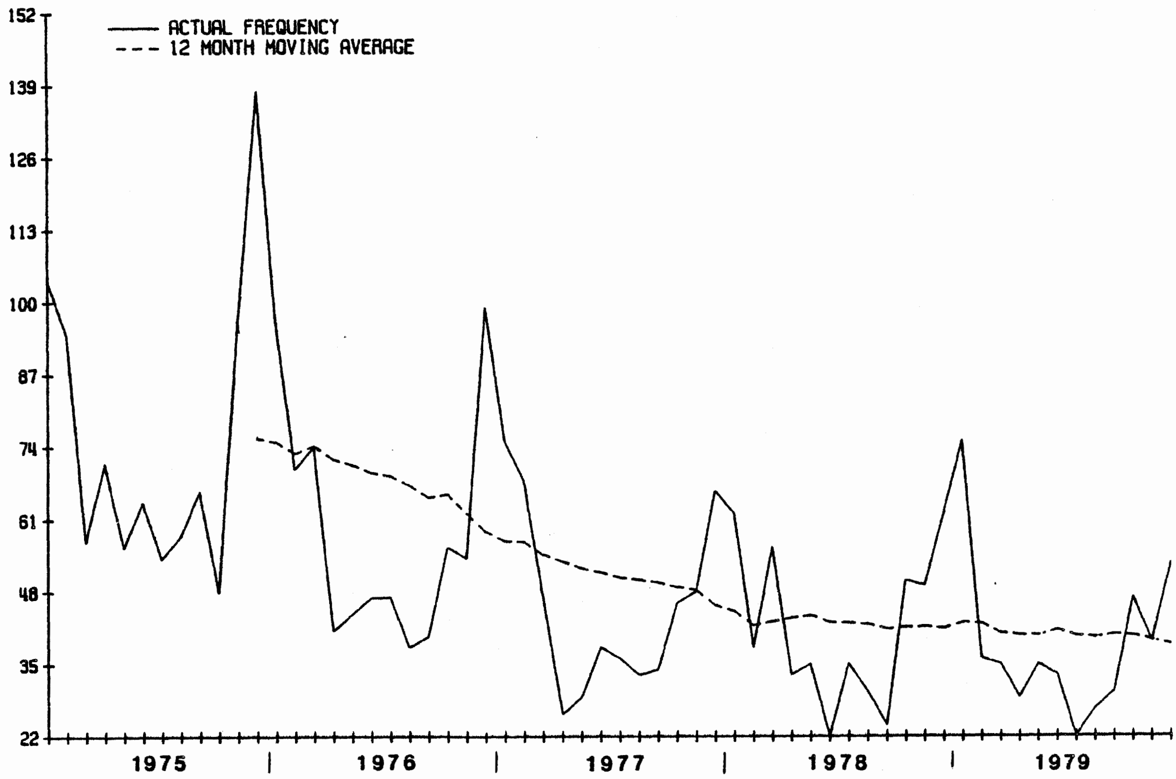


Figure C.18 Male Drivers Age 21-23 Involved in Daytime, Single-vehicle Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 - .78B^{12})u_t}{1 - B^{12}} + 55.39\ S_t + 74.30\ S_{2t}$$

t-ratio 13.92 3.37 3.90

$$R^2 = .77$$

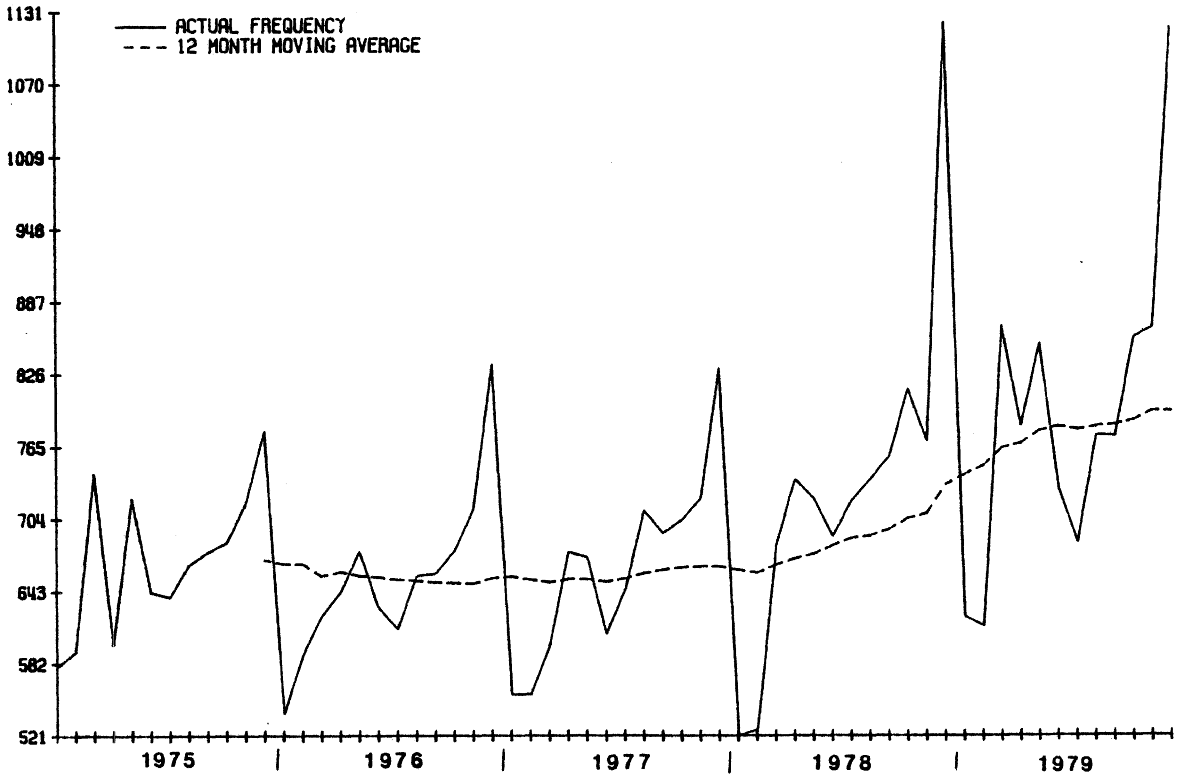


Figure C.19 Police-reported Had Been Drinking Drivers Age 24-45 Involved in Crashes Including at Least One Injury or Fatality, State of New York

$$Y_t = \frac{(1 - .83B^{12})u_t - 6.78}{1 - B^{12}} + 11.32\ S_t - .25\ S_{2t}$$

t-ratio 15.50 2.38 1.60 .04

$$R^2 = .54$$

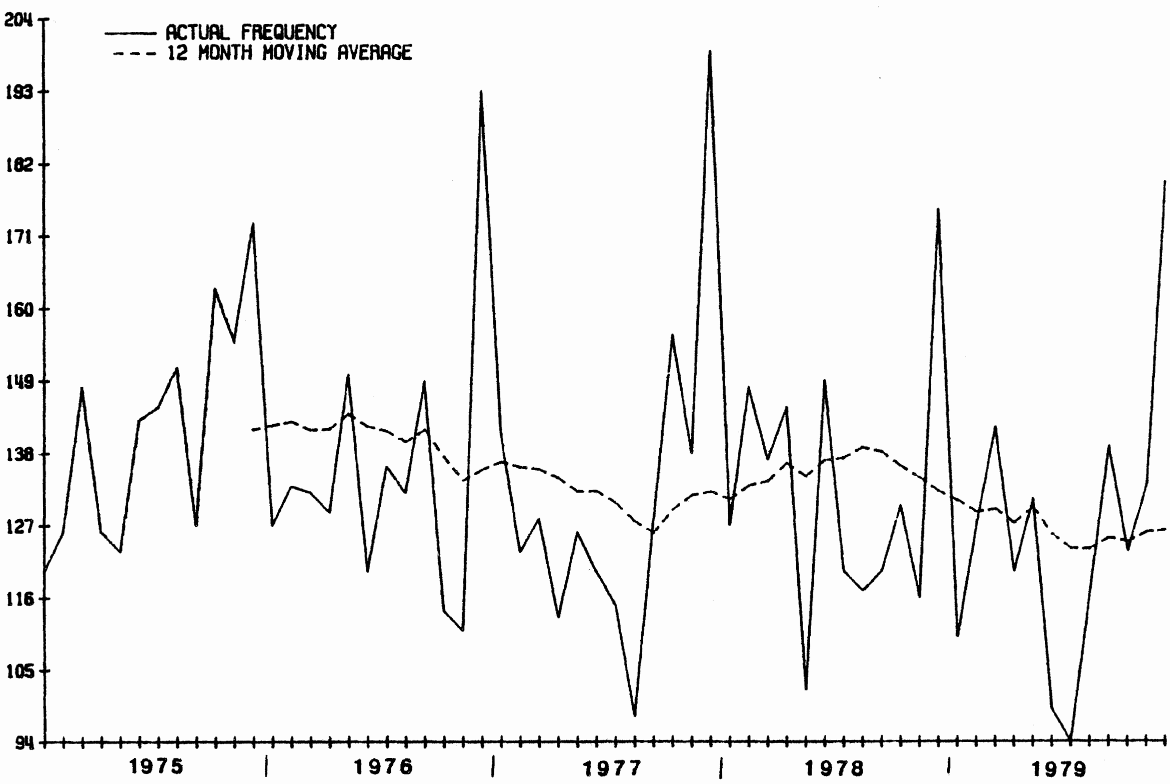


Figure C.20 Police-reported Had Been Drinking Drivers Age 24-45 Involved in Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 - .88B^{12})u_t - 21.68}{1 - B^{12}} + 35.88\, S_t - 113.92\, P_{2t} + 64.67\, S_{2t}$$

t-ratio 12.59 3.00 1.96 2.90 4.51

$R^2 = .69$

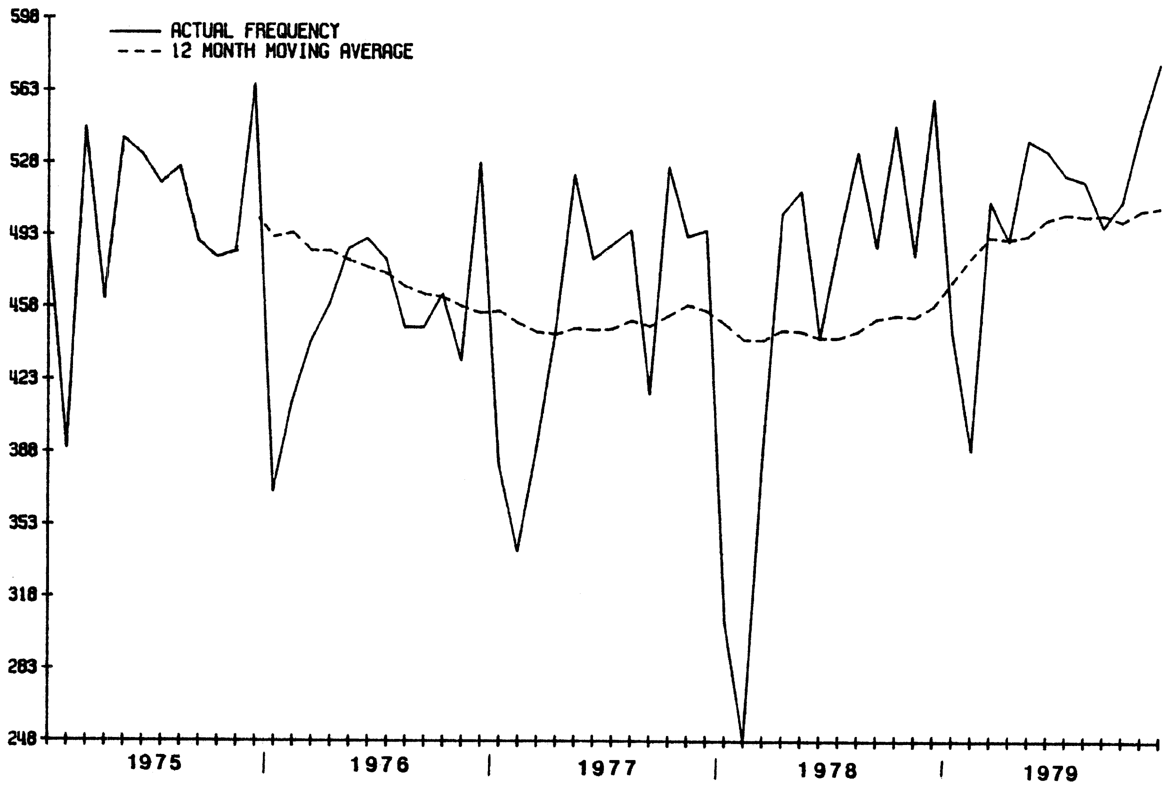


Figure C.21 Male Drivers Age 24-45 Involved in Late-night, Single-vehicle Crashes Including at Least One Injury or Fatality, State of New York

$$Y_t = \frac{(1 + .17B)(1 - .80B^{12})u_t - 19.65}{1 - B^{12}} - 7.85\ S_t + 26.31\ S_{2t}$$

t-ratio 1.24 14.63 4.34 .70 2.78

$$R^2 = .75$$

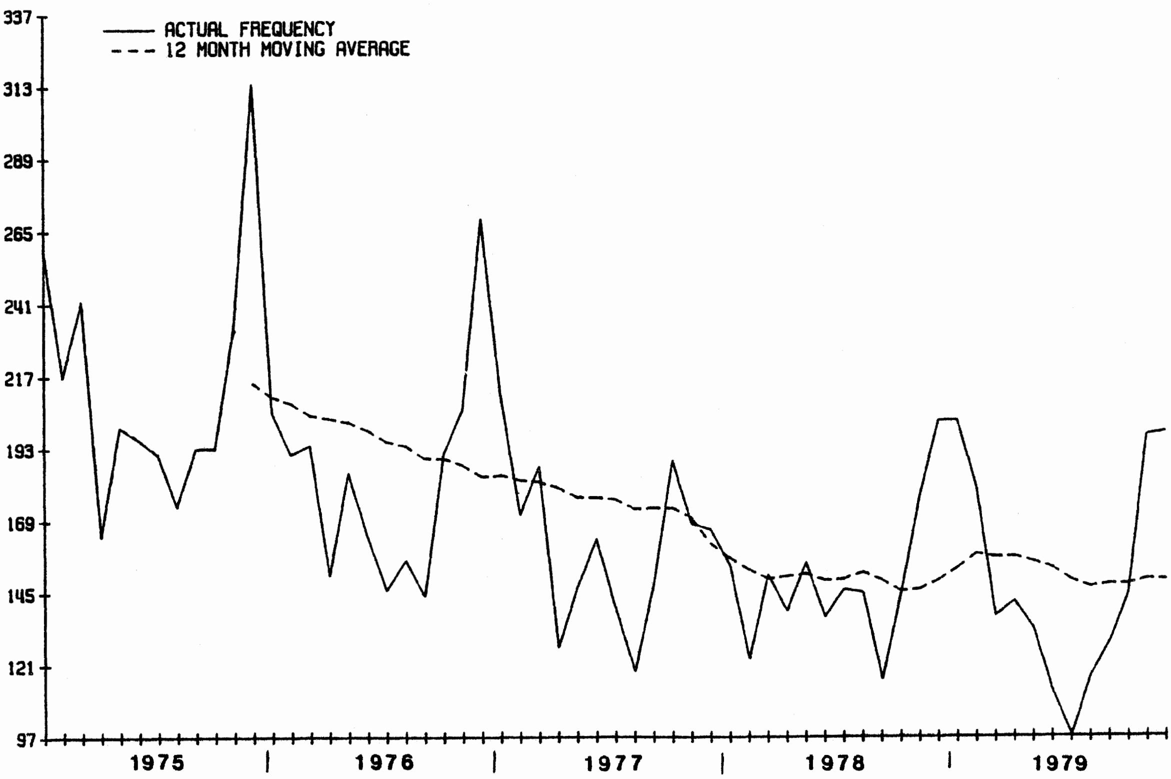


Figure C.22 Male Drivers Age 24-45 Involved in Late-night, Single-vehicle Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 - .26B)(1 - .82B^{12})u_t - 9.31}{1 - B^{12}} + 1.42\ S_t - 136.82\ P_{2_t} + 6.73\ S_{2_t}$$

t-ratio 1.90 15.11 2.25 .13 4.56 .78

$$R^2 = .81$$

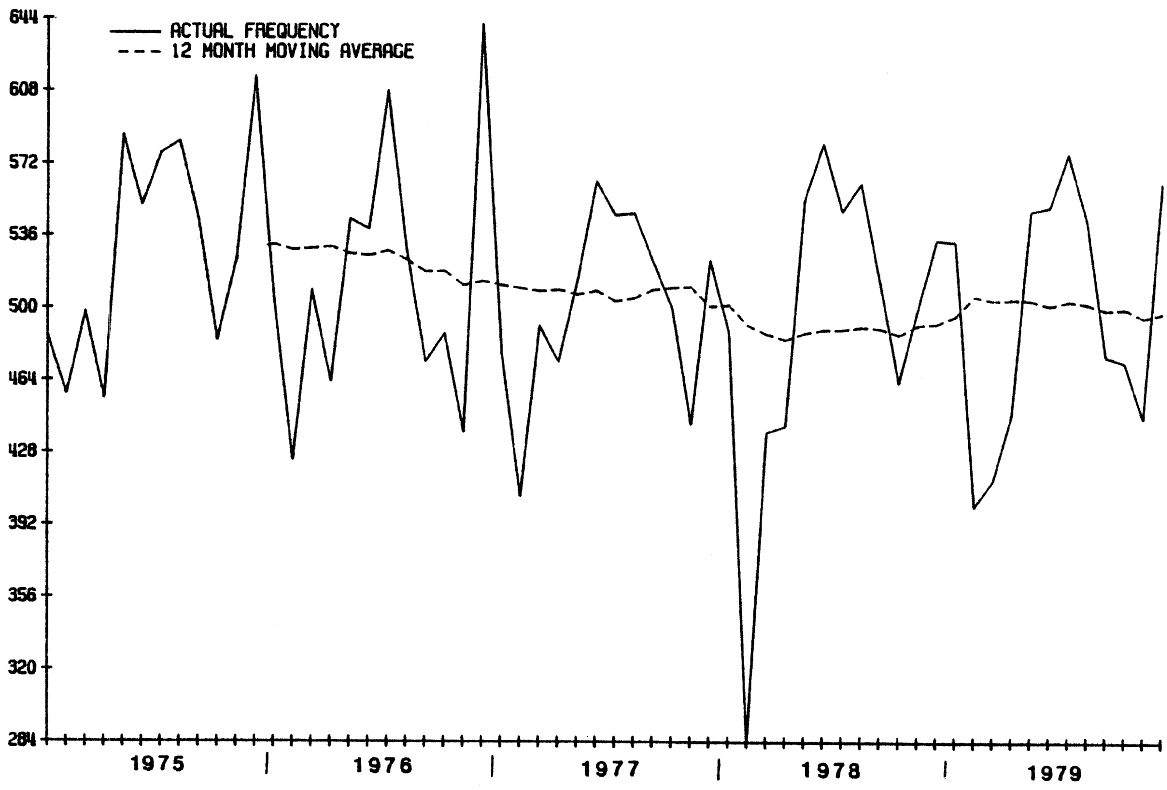


Figure C.23 Male Drivers Age 24-45 Involved in Daytime, Single-vehicle Crashes Including at Least One Injury or Fatality, State of New York

$$Y_t = \frac{(1 - .79B^{12})u_t - 30.67}{1 - B^{12}} - 4.36\ S_t + 29.64\ S_{2t}$$

t-ratio	17.34	5.11	.29	2.38

$$R^2 = .90$$

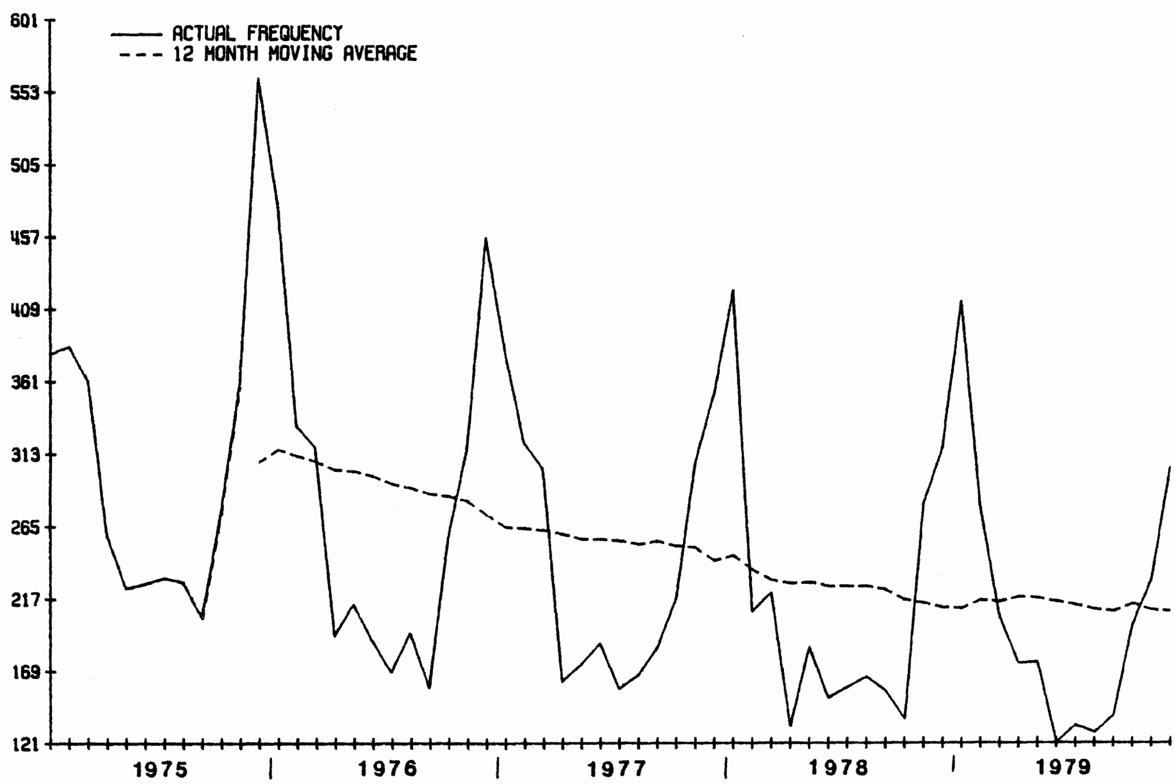
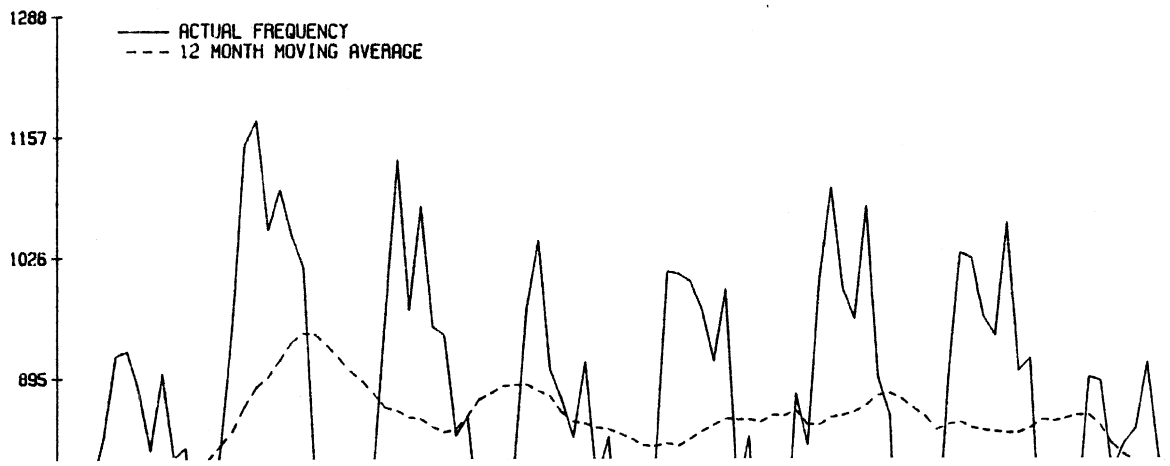


Figure C.24 Male Drivers Age 24-45 Involved in Daytime, Single-vehicle Property Damage Only Crashes, State of New York

Appendix D

Crash Frequency Plots and Time-series Models, State of Pennsylvania


1288
1157
1026
895
ACTUAL FREQUENCY
12 MONTH MOVING AVERAGE

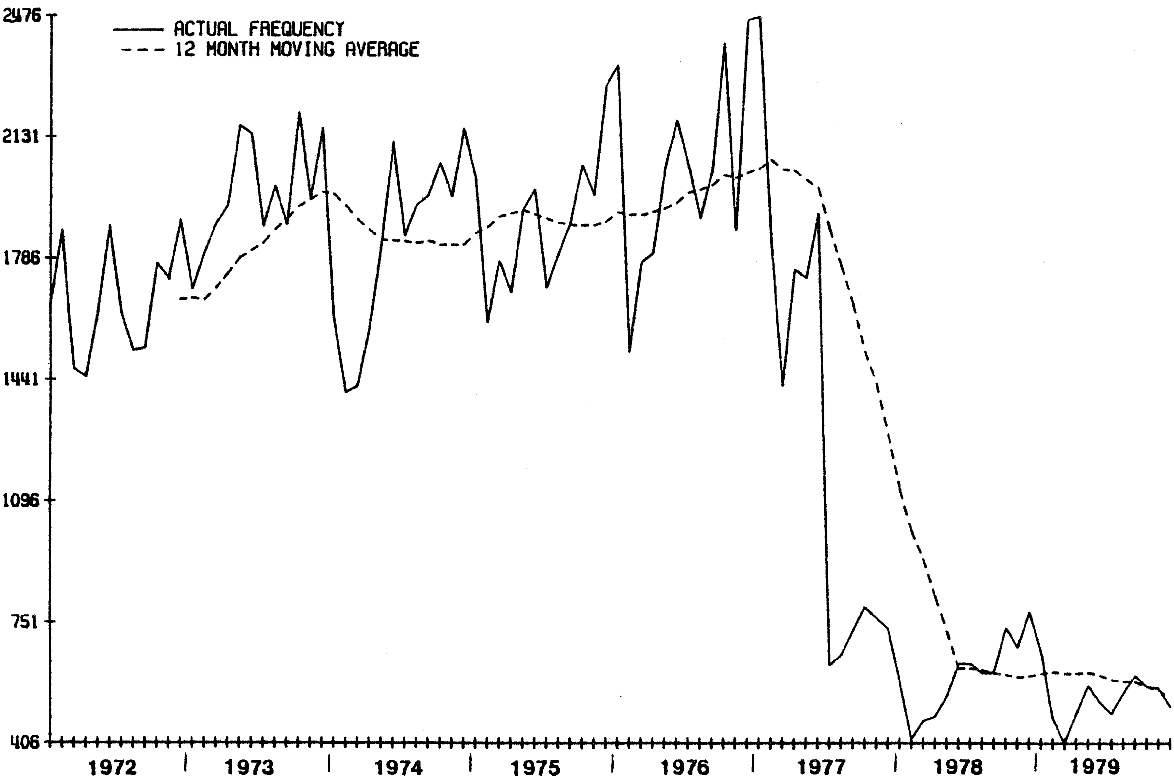


Figure D.6 Police-reported Had Not Been Drinking Drivers Age 16-17 Involved in Property Damage Only Crashes, State of Pennsylvania

$$Y_t = \frac{(1 - .29B)(1 - .86B^{12})u_t - .938}{(1 - B)(1 - B^{12})} + 90.90\ S_{3t} + 20.78\ S_t - 52.63\ S_{2t}$$

t-ratio 2.80 23.77 .61 1.96 .45 1.24

$R^2 = .85$

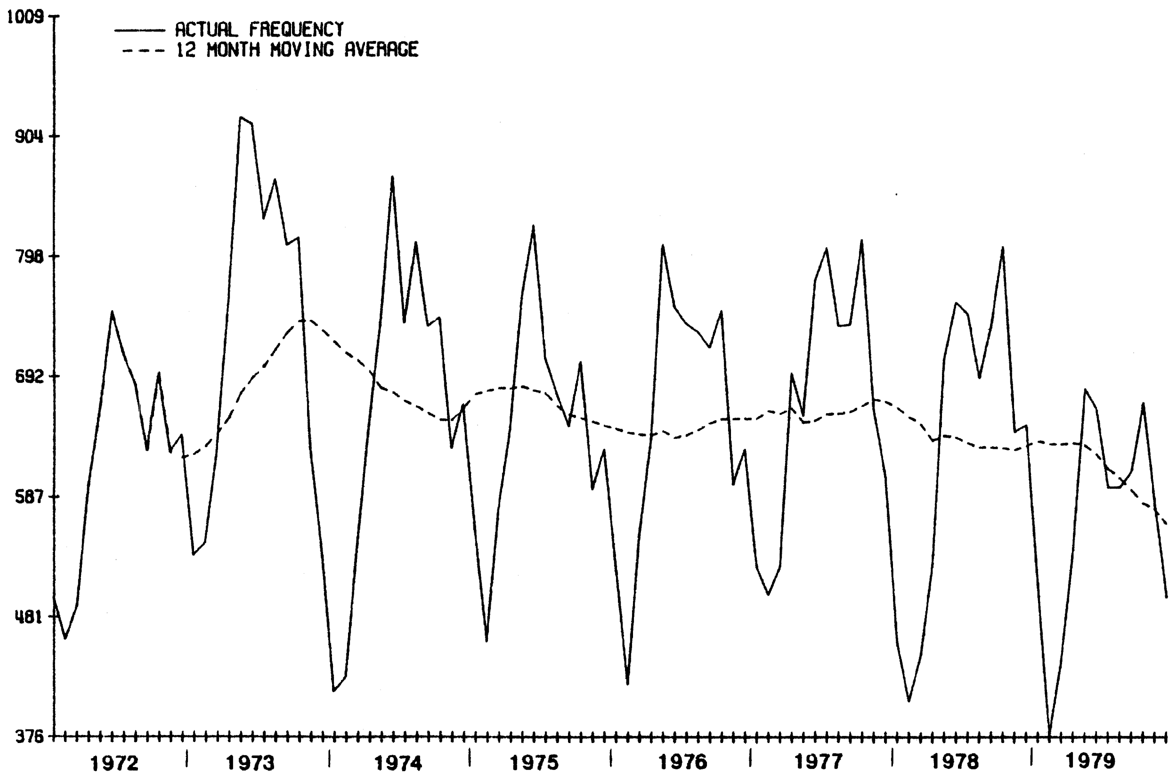


Figure D.7 Drivers Age 16-17 Involved in Daytime Crashes Including at Least One Injury or Fatality, State of Pennsylvania

$$\log Y_t = \frac{(1 + .32B)(1 - .81B^{12})u_t + .023}{1 - B^{12}} - 1.19\, S_{3_t} - .130\, S_t - .182\, S_{2_t}$$

t-ratio	3.06	19.08	2.56	17.57	1.89	3.79

$R^2 = .97$

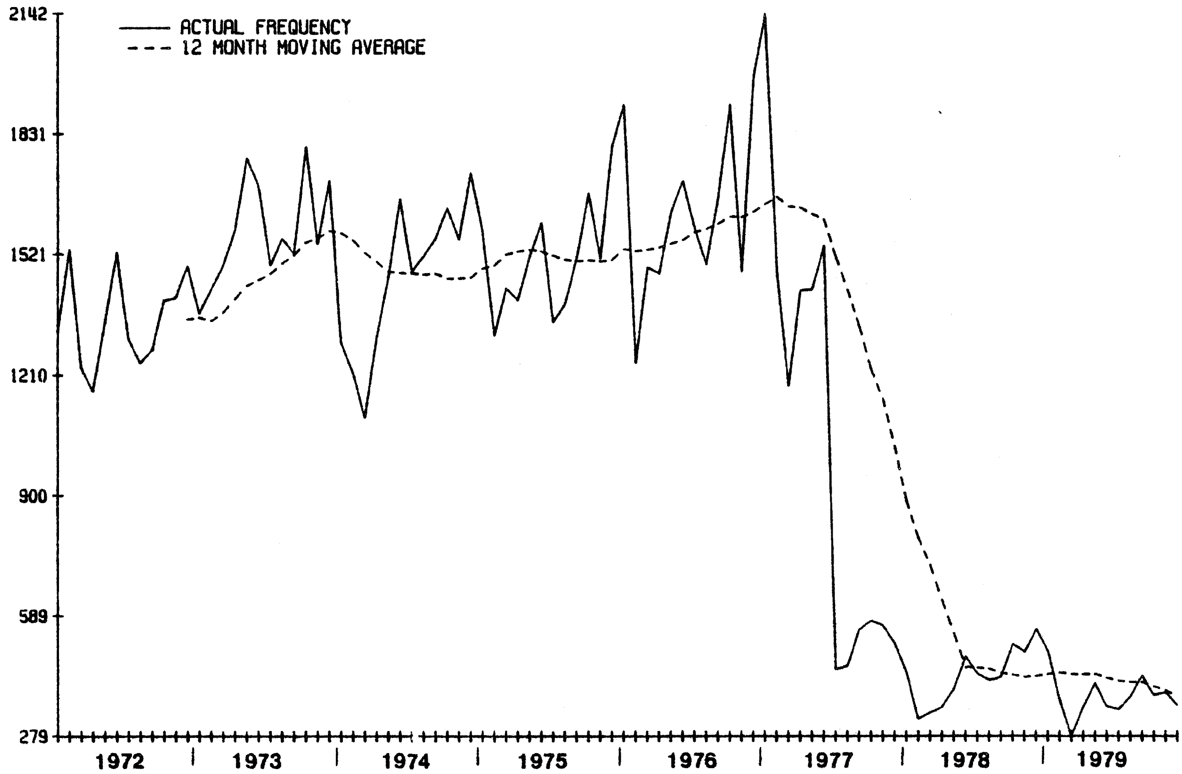


Figure D.8 Drivers Age 16-17 Involved in Daytime Property Damage Only Crashes, State of Pennsylvania

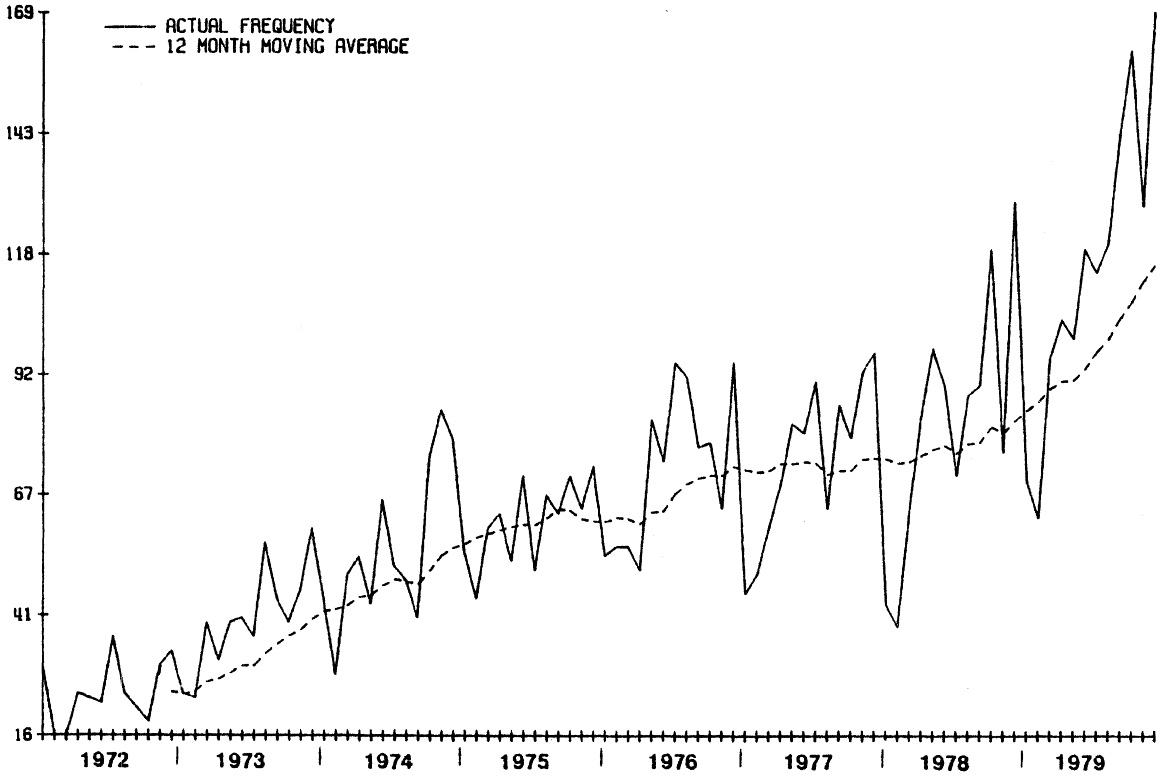


Figure D.9 Police-reported Had Been Drinking Drivers Age 18-19 Involved in Crashes Including at Least One Injury or Fatality, State of Pennsylvania

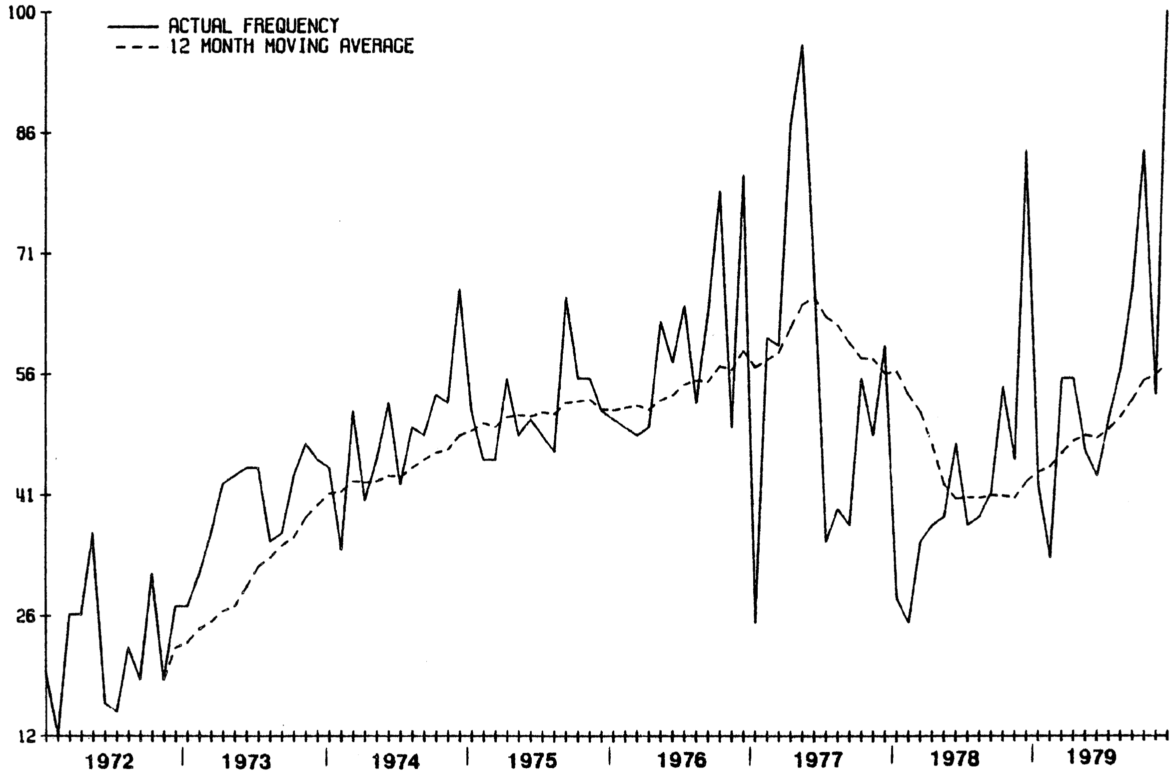


Figure D.10 Police-reported Had Been Drinking Drivers Age 18-19 Involved in Property Damage Only Crashes, State of Pennsylvania

$$\log Y_t = \frac{(1 + .20B + .33B^2)(1 - .84B^{12})u_t + .039}{1 - B^{12}} + .088\ S_{3t} - .006\ S_t + .05\ S_{2t}$$

t-ratio 1.93 3.16 19.63 2.47 .82 .06 .68

$R^2 = .74$

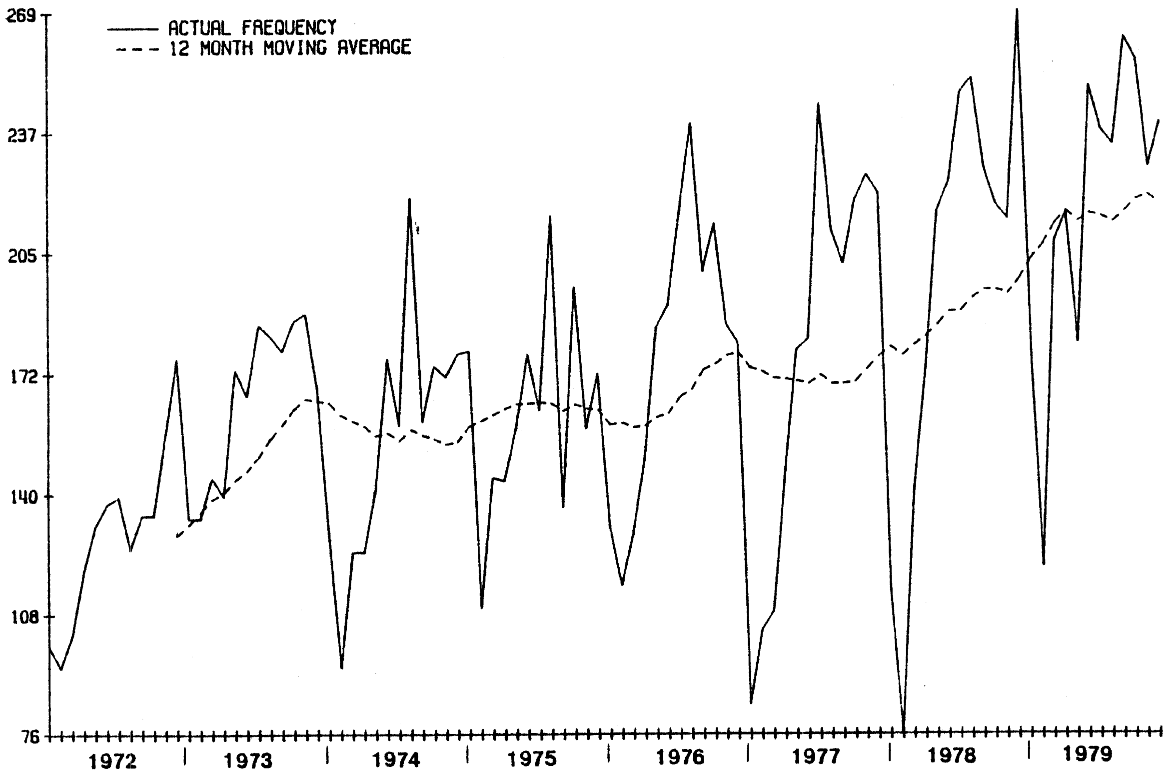


Figure D.11 Male Drivers Age 18-19 Involved in Late-night, Single-vehicle Crashes Including at Least One Injury or Fatality, State of Pennsylvania

$$Y_t = \frac{(1 - .69B + .16B^2)(1 - .85B^{12})u_t - .413}{(1 - B)(1 - B^{12})} - 68.91\ S_{3_t} - 17.18\ S_t - 20.74\ S_{2_t}$$

t-ratio 6.12 1.45 20.26 .73 3.37 .84 1.00

$R^2 = .70$

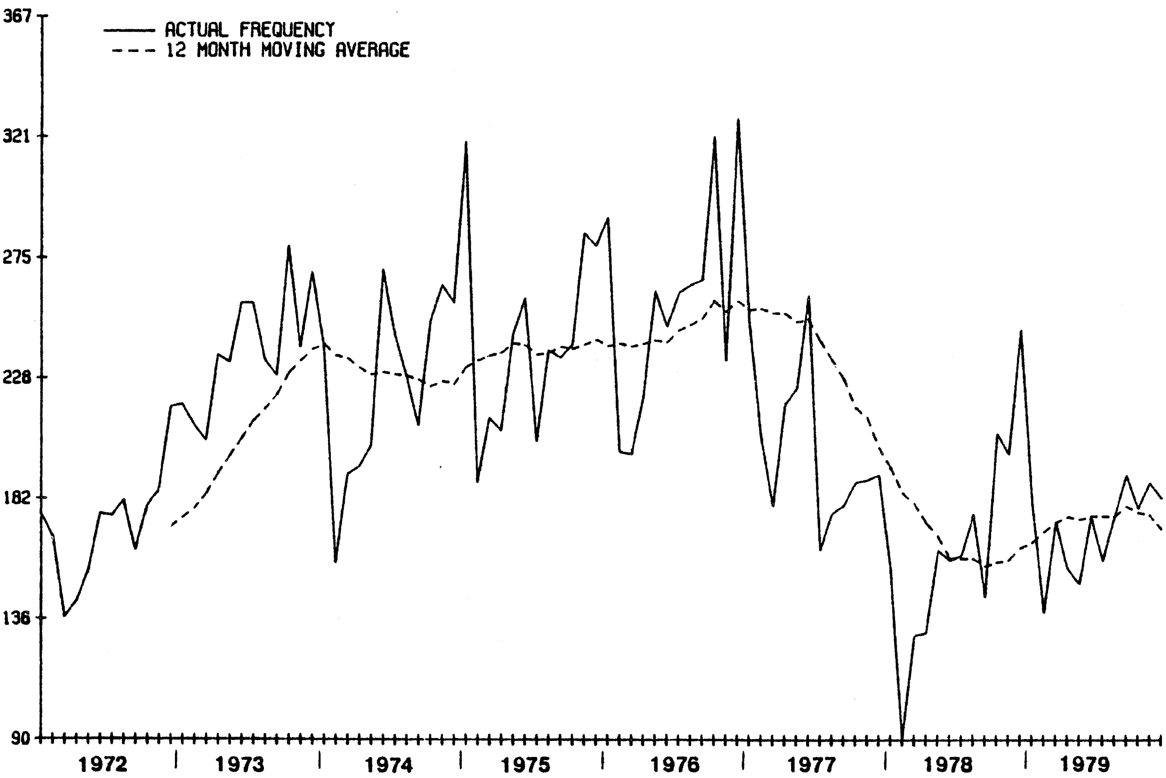


Figure D.12 Male Drivers Age 18-19 Involved in Late-night, Single-vehicle, Property Damage Only Crashes, State of Pennsylvania

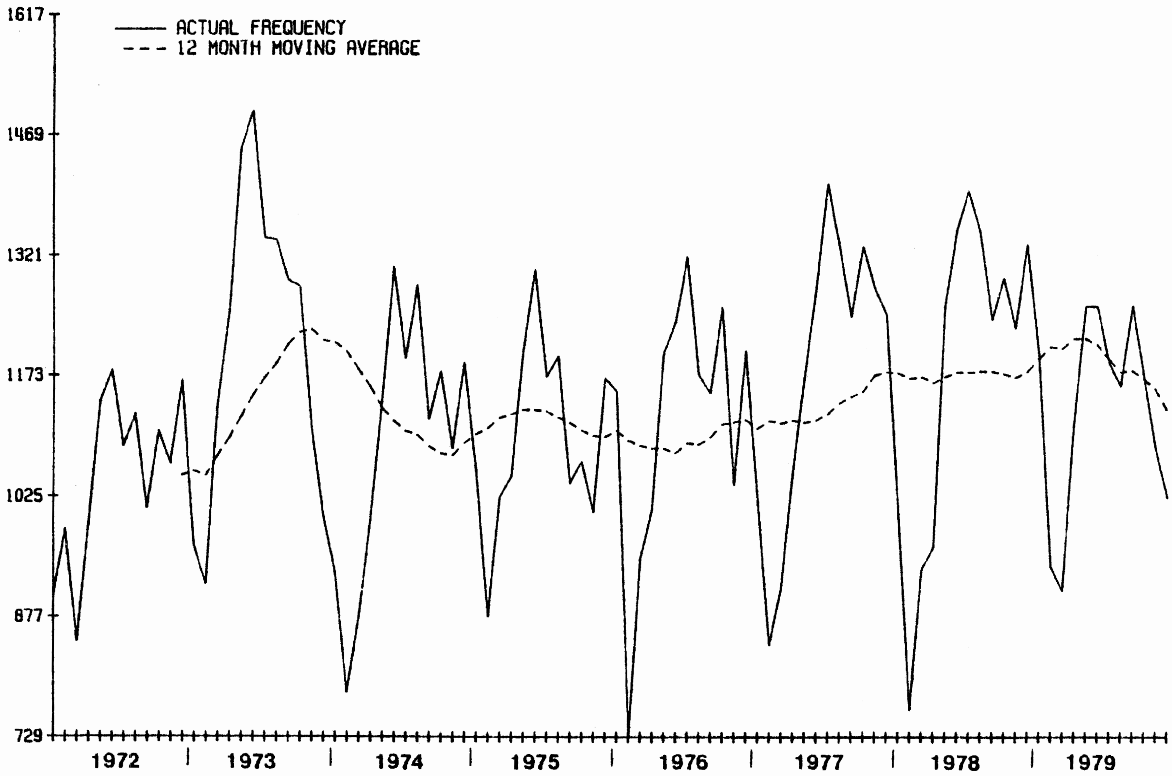


Figure D.13 Police-reported Had Not Been Drinking Drivers Age 18-19 Involved in Crashes Including at Least One Injury or Fatality, State of Pennsylvania

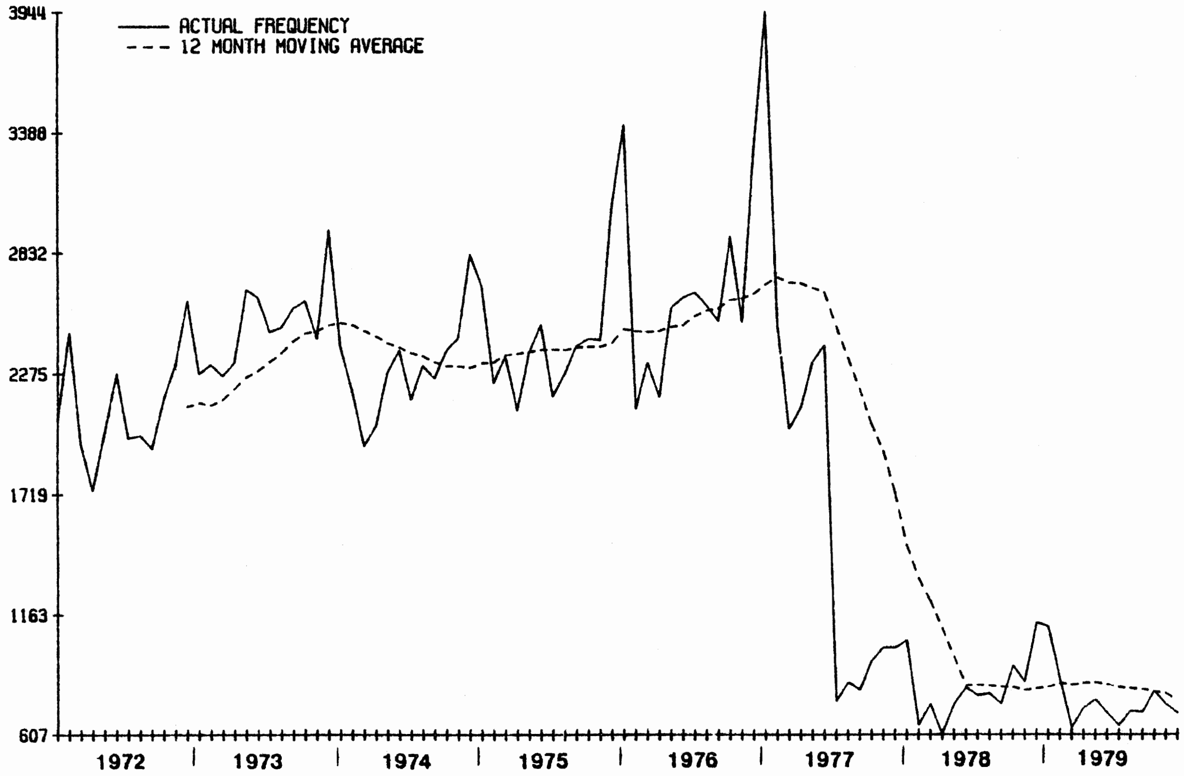


Figure D.14 Police-reported Had Not Been Drinking Drivers Age 18-19 Involved in Property Damage Only Crashes, State of Pennsylvania

$$Y_t = \frac{(1-.49B)(1-.84B^{12})u_t - 1.34}{(1-B)(1-B^{12})} + 76.73\ S_{3_t} + 31.66\ S_t - 20.29\ S_{2_t}$$

t-ratio 5.23 20.03 .80 1.29 .53 .34

$R^2 = .59$

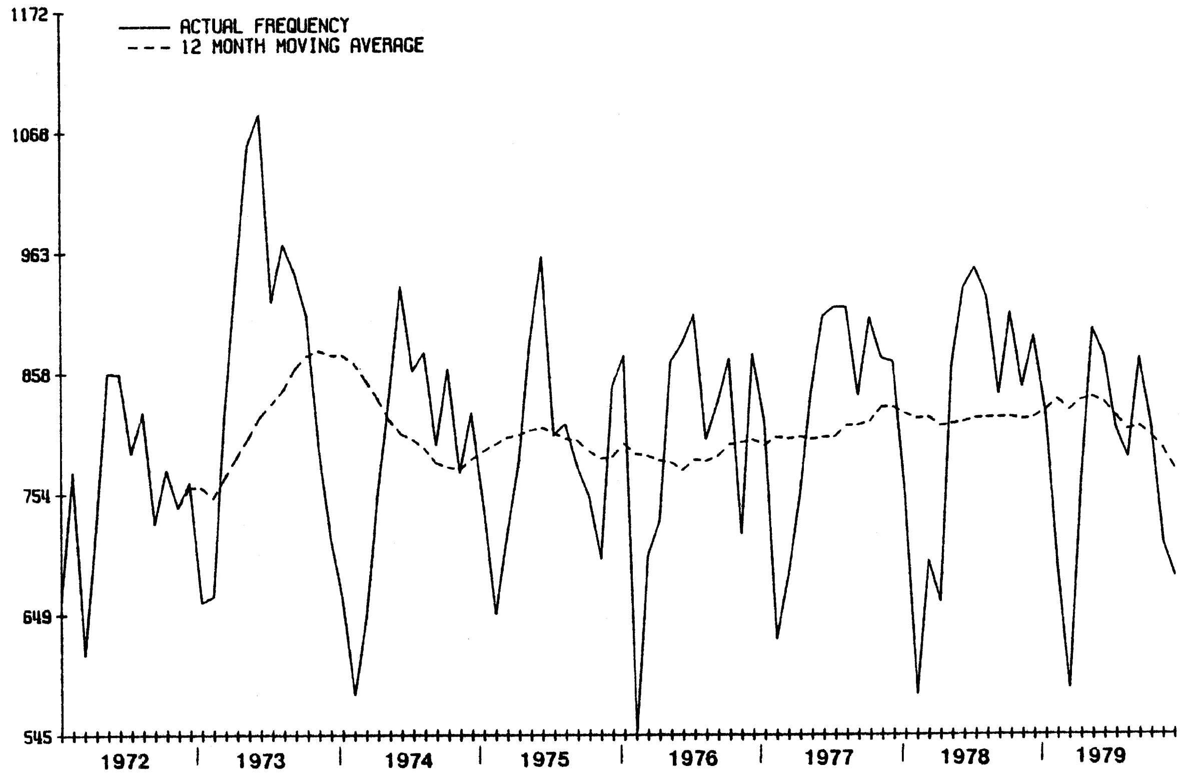


Figure D.15 Drivers Age 18-19 Involved in Daytime Crashes Including at Least One Injury or Fatality, State of Pennsylvania

$$\log Y_t = \frac{(1 + .24B)(1 - .76B^{12})u_t + .032}{1 - B^{12}} - 1.27\,S_{3_t} - .035\,S_t - .155\,S_{2_t}$$

t-ratio 2.25 13.97 3.04 18.08 .50 3.12

$$R^2 = .96$$

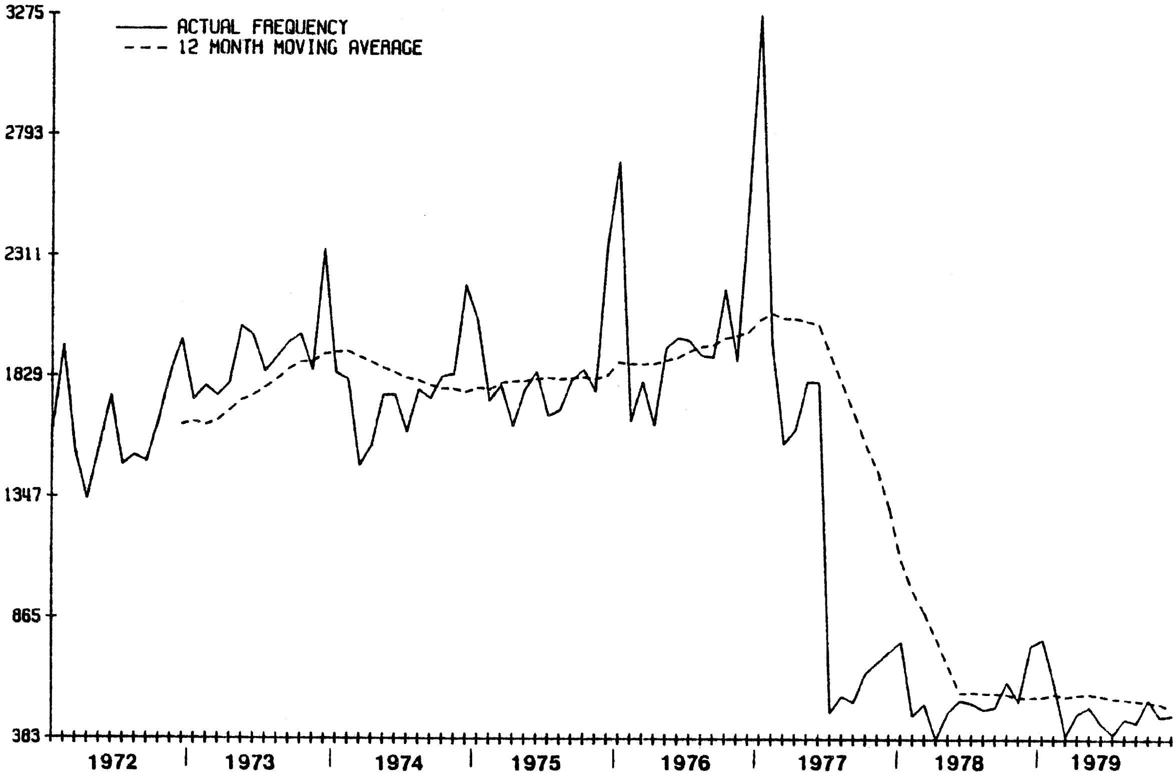


Figure D.16 Drivers Age 18-19 Involved in Daytime Property Damage Only Crashes, State of Pennsylvania

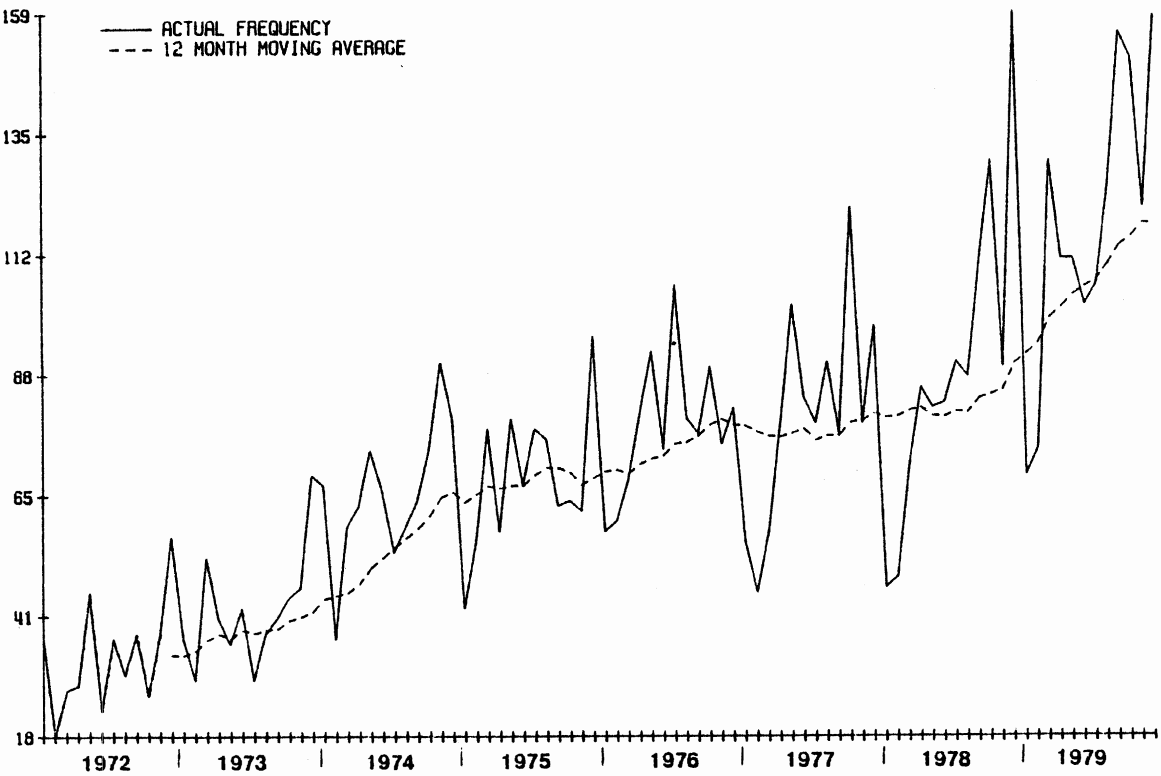


Figure D.17 Police-reported Had Been Drinking Drivers Age 20-21 Involved in Crashes Including at Least One Injury or Fatality, State of Pennsylvania

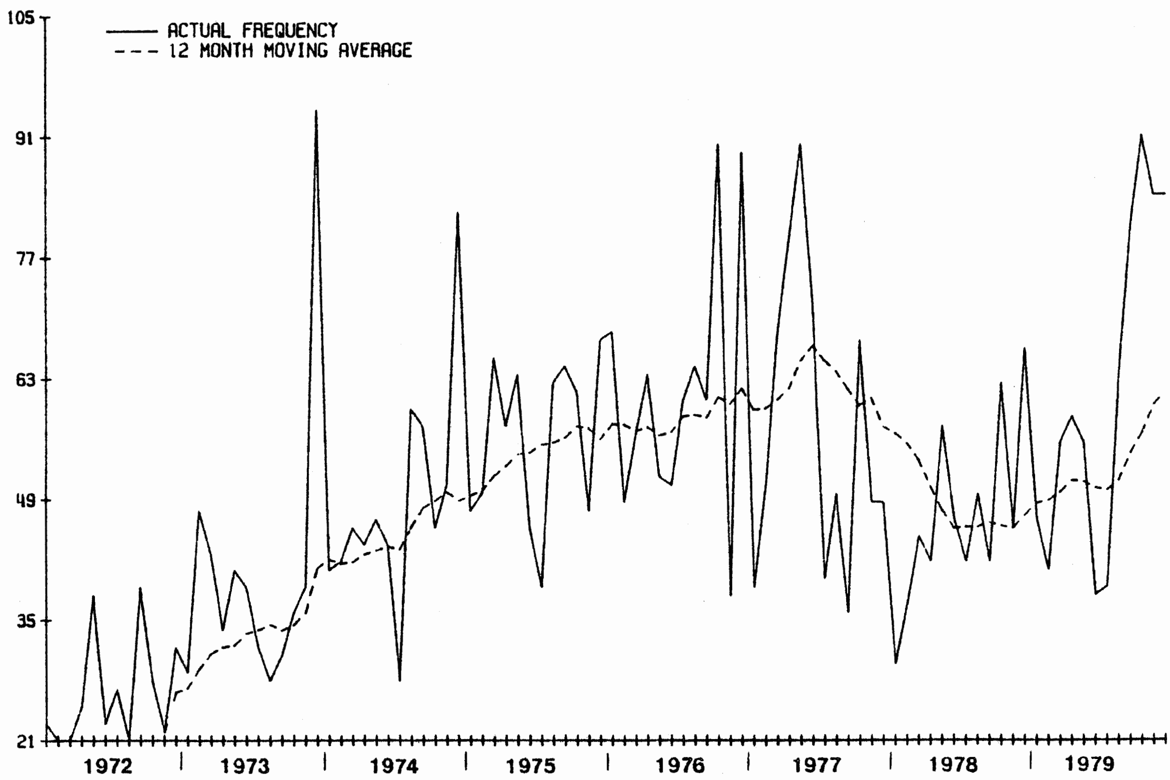


Figure D.18 Police-reported Had Been Drinking Drivers Age 20-21 Involved in Property Damage Only Crashes, State of Pennsylvania

$$\log Y_t = \frac{(1 - .87B^{12})u_t + .049}{1 - B^{12}} + .267\ S_{3_t} - .160\ S_t + .045\ S_{2_t}$$

t-ratio 22.35 5.45 3.55 2.11 1.05

$R^2 = .78$

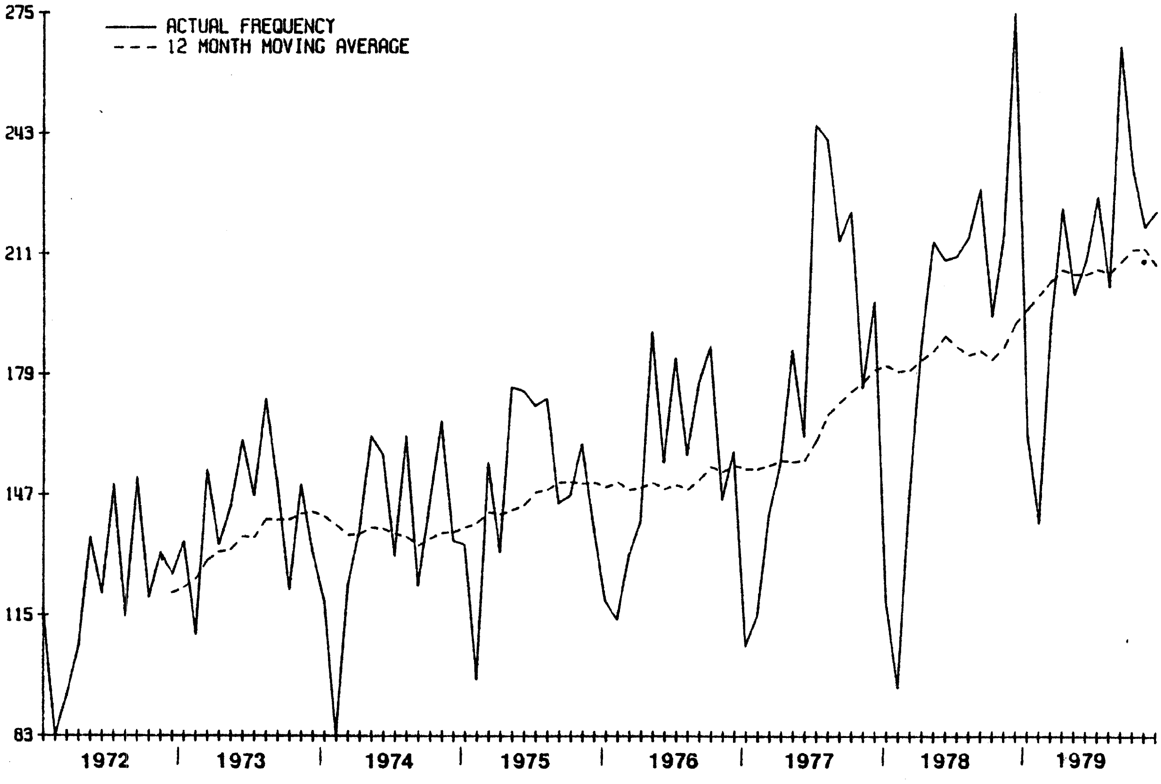


Figure D.19 Male Drivers Age 20-21 Involved in Late-night, Single-vehicle Crashes Including at Least One Injury or Fatality, State of Pennsylvania

$$Y_t = \frac{(1 - .73B)(1 - .85B^{12})u_t - .274}{(1 - B)(1 - B^{12})} - 53.10\, S_{3_t} - 12.65\, S_t + 12.72\, S_{2_t}$$

t-ratio 9.99 23.89 .88 3.41 .81 .82

$R^2 = .61$

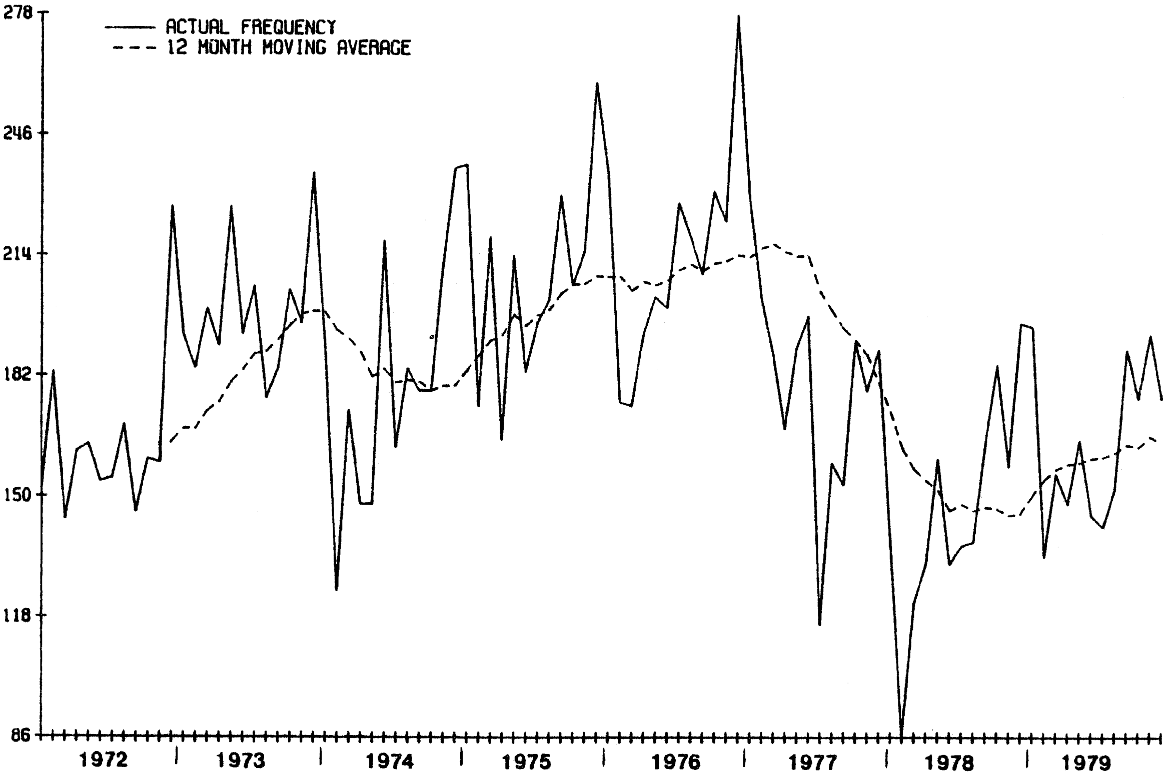


Figure D.20 Male Drivers Age 20-21 Involved in Late-night, Single-vehicle, Property Damage Only Crashes, State of Pennsylvania

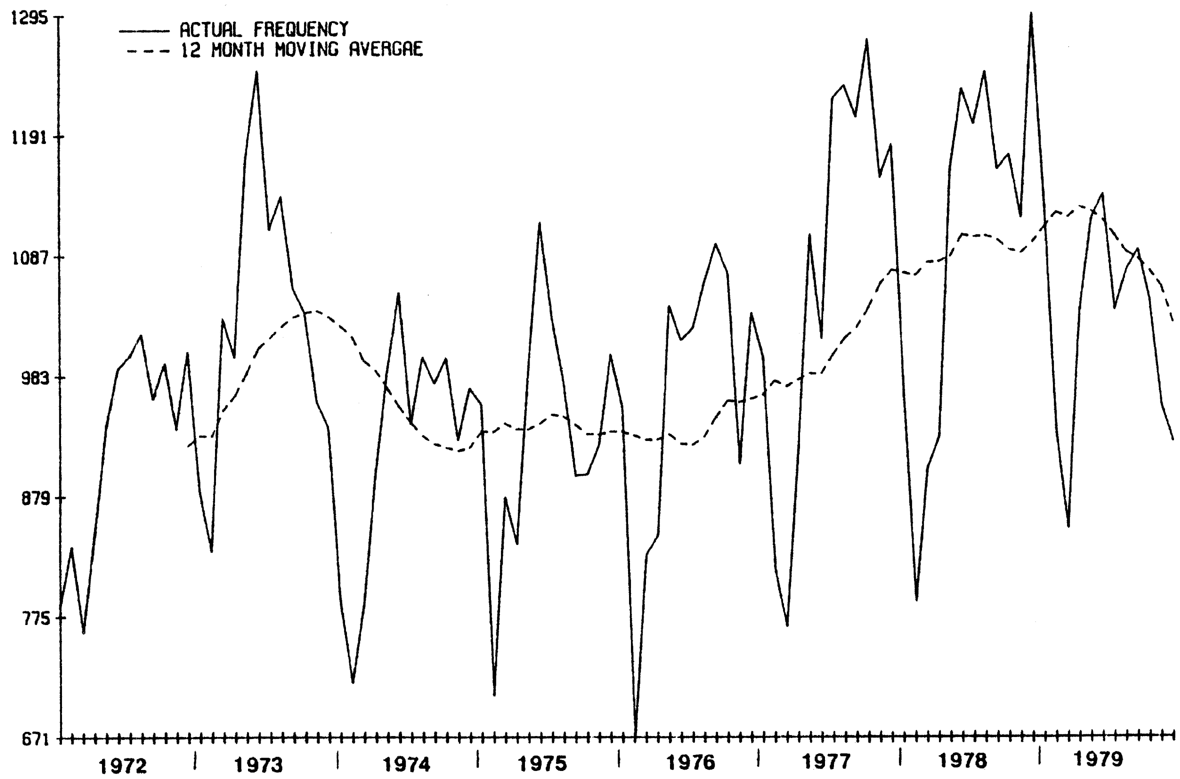


Figure D.21 Police-reported Had Not Been Drinking Drivers Age 20-21 Involved in Crashes Including at Least One Injury or Fatality, State of Pennsylvania

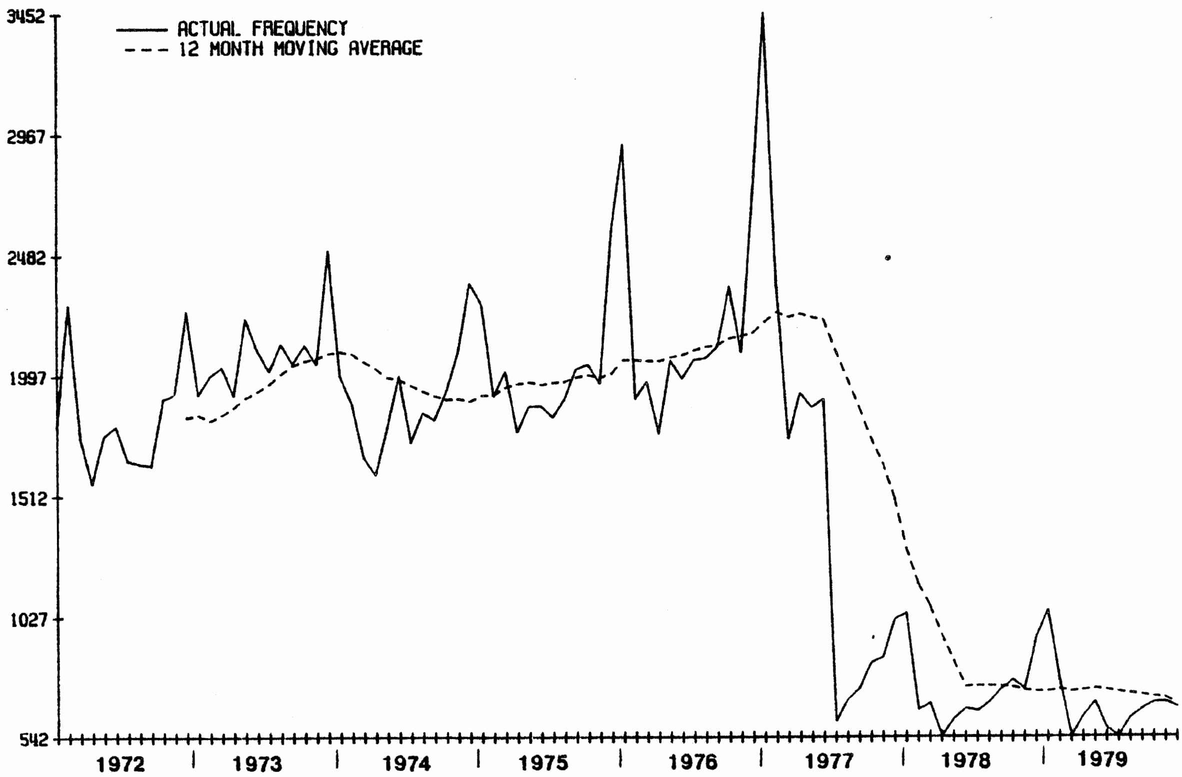


Figure D.22 Police-reported Had Not Been Drinking Drivers Age 20-21 Involved in Property Damage Only Crashes, State of Pennsylvania

$$Y_t = \frac{(1 - .57B)(1 - .83B^{12})u_t - 1.66}{(1 - B)(1 - B^{12})} + 93.76\ S_{3_t} - 6.02\ S_t - 8.33\ S_{2_t}$$

t-ratio 6.18 19.62 1.42 2.09 .13 .18

$R^2 = .60$

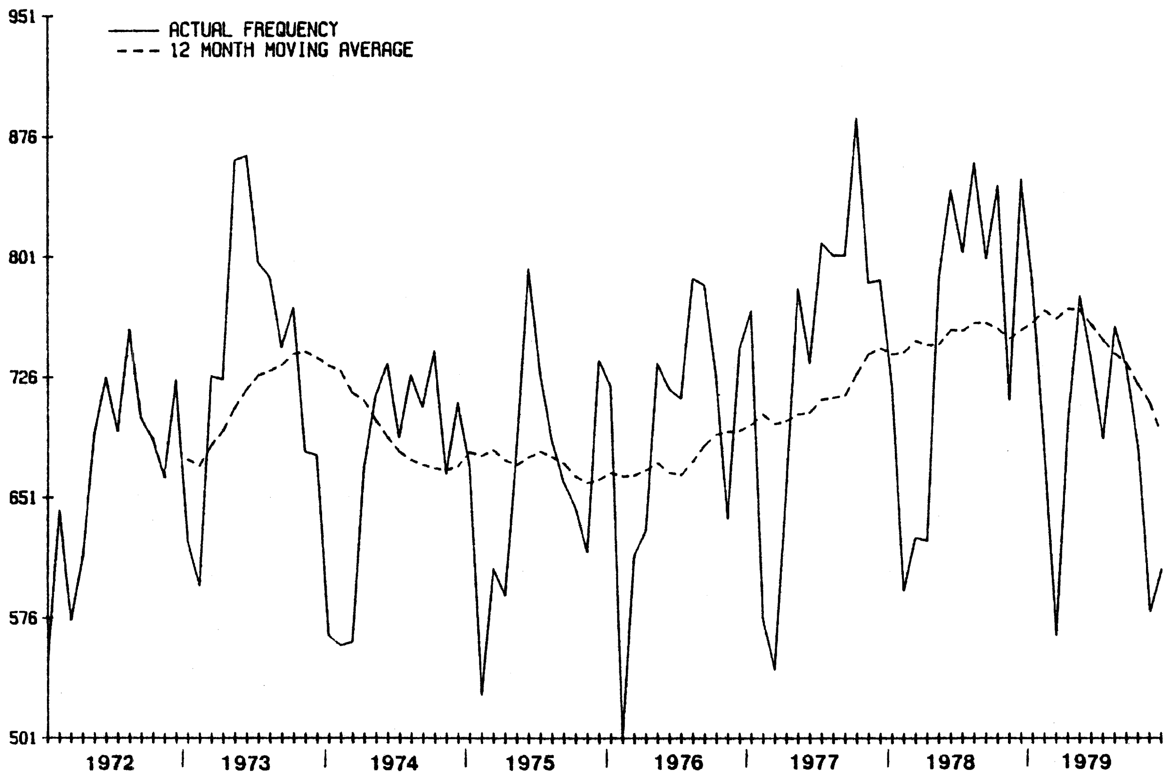


Figure D.23 Drivers Age 20-21 Involved in Daytime Crashes Including at Least One Injury or Fatality, State of Pennsylvania

$$\log Y_t = \frac{(1 + .24B)(1 - .56B^{12})u_t + .028}{1 - B^{12}} - 1.19\, S_{3_t} - .049\, S_t - .180\, S_{2_t}$$

t-ratio 2.20 6.08 2.32 17.63 .72 3.34

$R^2 = .96$

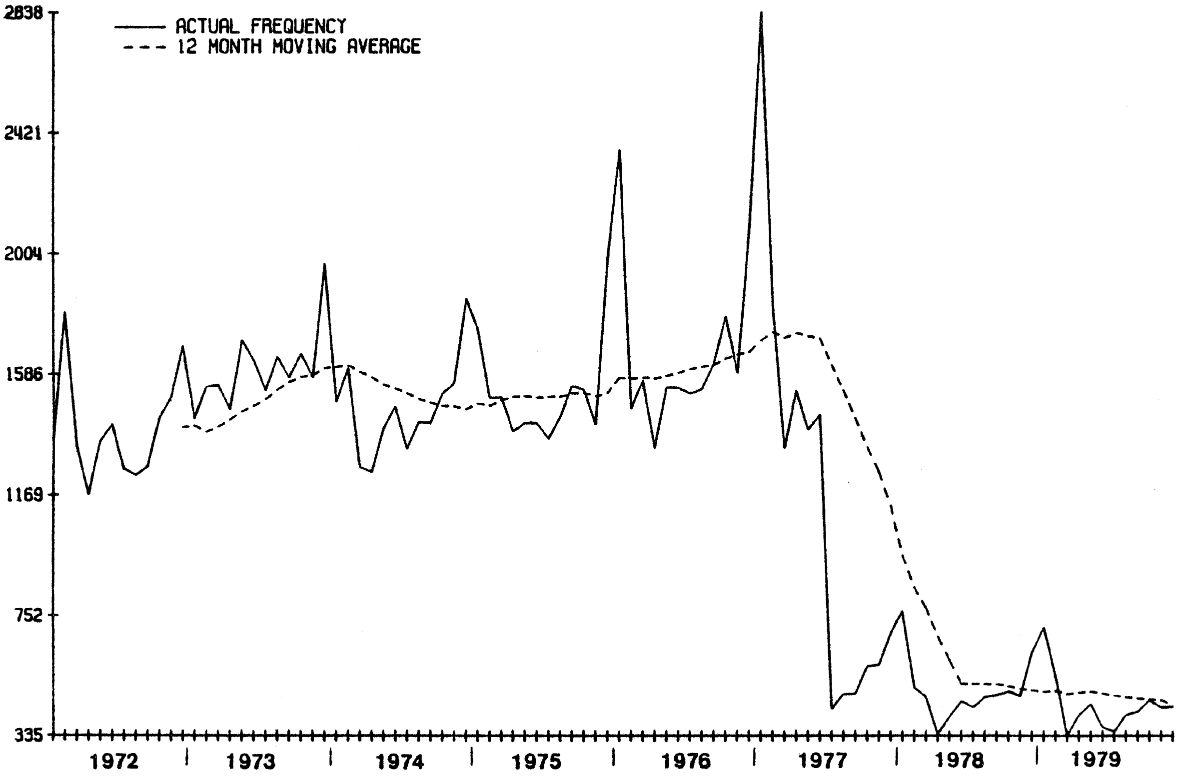


Figure D.24 Drivers Age 20-21 Involved in Daytime Property Damage Only Crashes, State of Pennsylvania

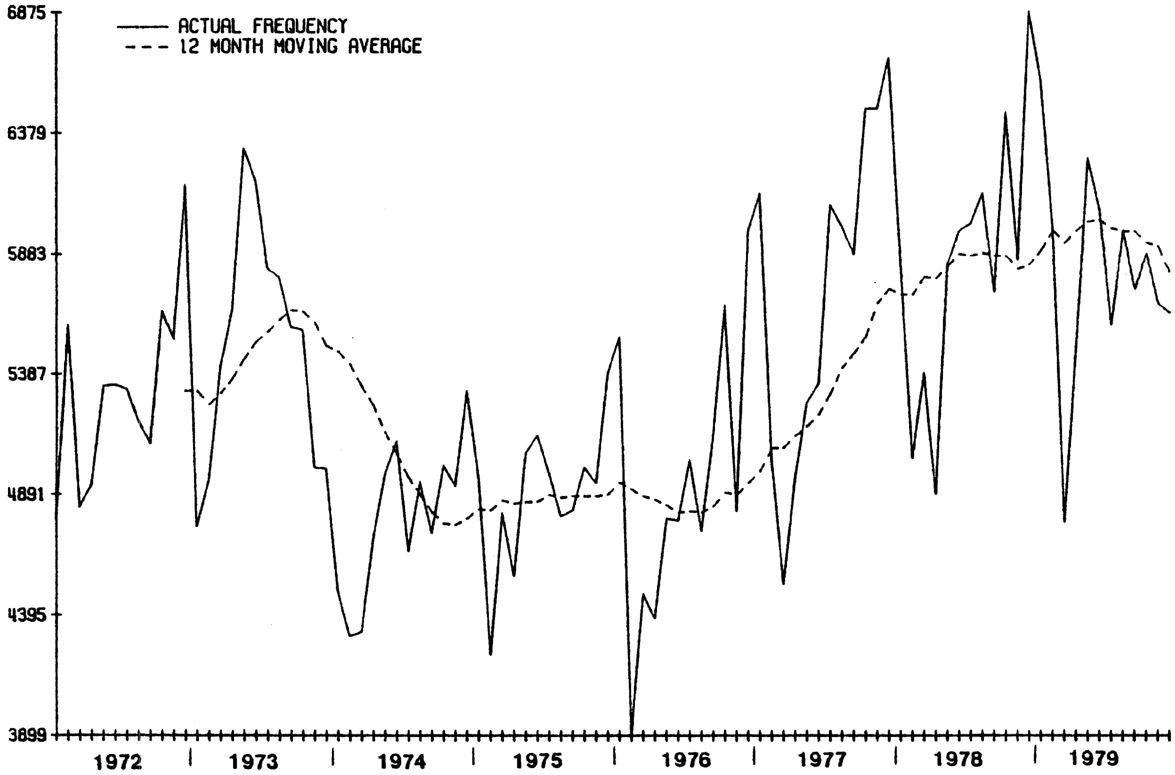


Figure D.25 Police-reported Had Been Drinking Drivers Age 22-45 Involved in Crashes Including at Least One Injury or Fatality, State of Pennsylvania

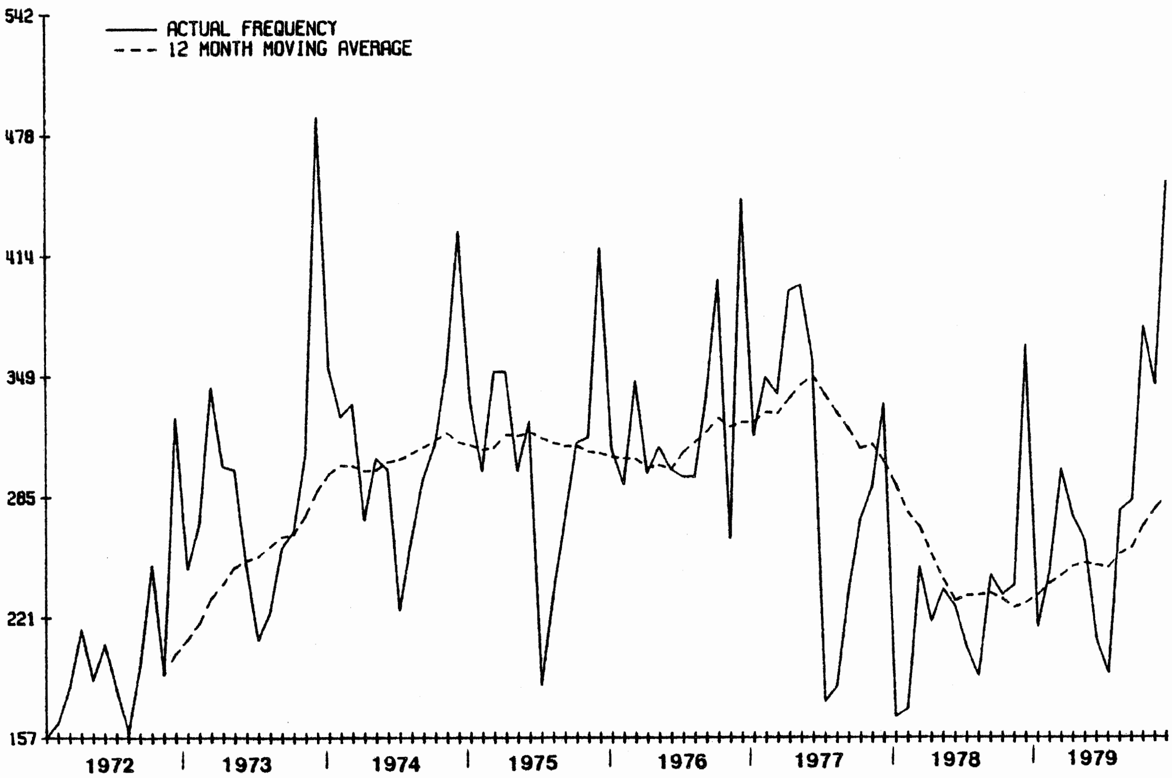


Figure D.26 Police-reported Had Been Drinking Drivers Age 22-45 Involved in Property Damage Only Crashes, State of Pennsylvania

$$\log Y_t = \frac{(1 + .31B + .27B^2)(1 - .91B^{12})u_t + .012}{1 - B^{12}} + .271\ S_{3t} - .035\ S_t + .086\ S_{2t}$$

t-ratio 3.08 2.68 27.20 1.11 3.61 .46 1.89

$R^2 = .79$

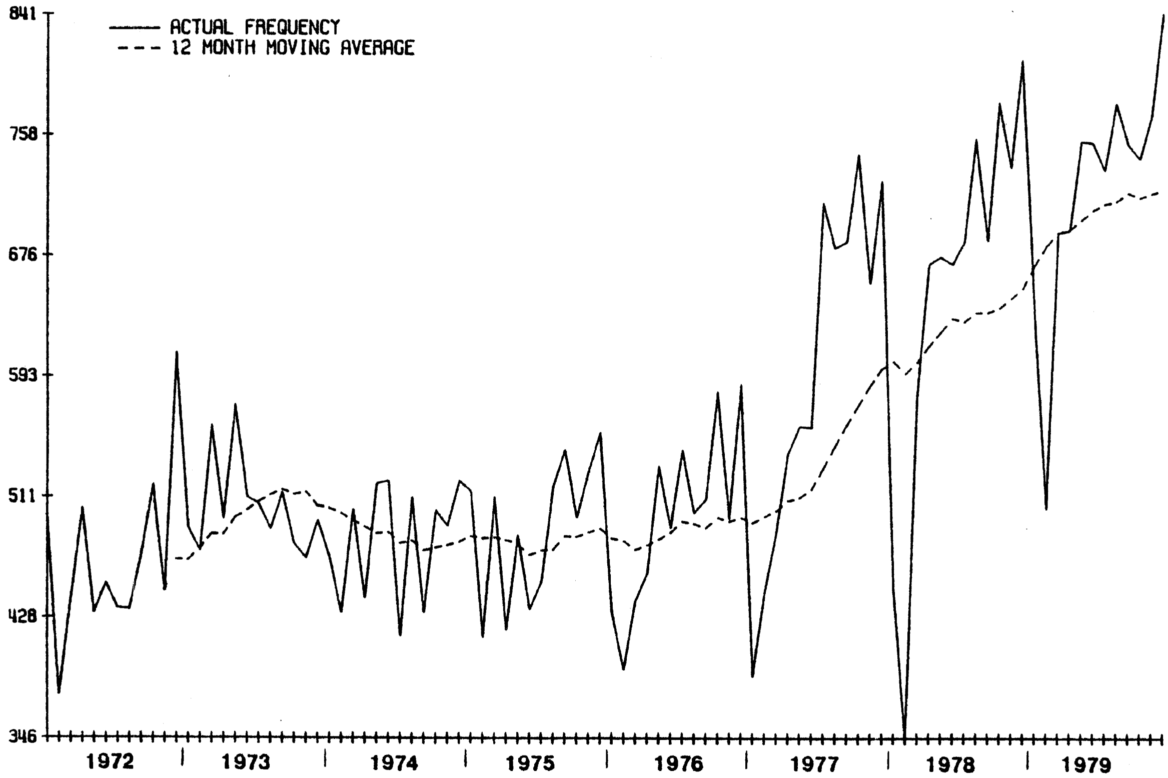


Figure D.27 Male Drivers Age 22-45 Involved in Late-night, Single-vehicle Crashes Including at Least One Injury or Fatality, State of Pennsylvania

$$Y_t = \frac{(1 - .61B)(1 - .85B^{12})u_t - .351}{(1 - B)(1 - B^{12})} - 230.46\, S_{3t} - 77.06\, S_t + 42.40\, S_{2t}$$

t-ratio 7.23 22.70 .30 4.68 1.55 .86

$R^2 = .80$

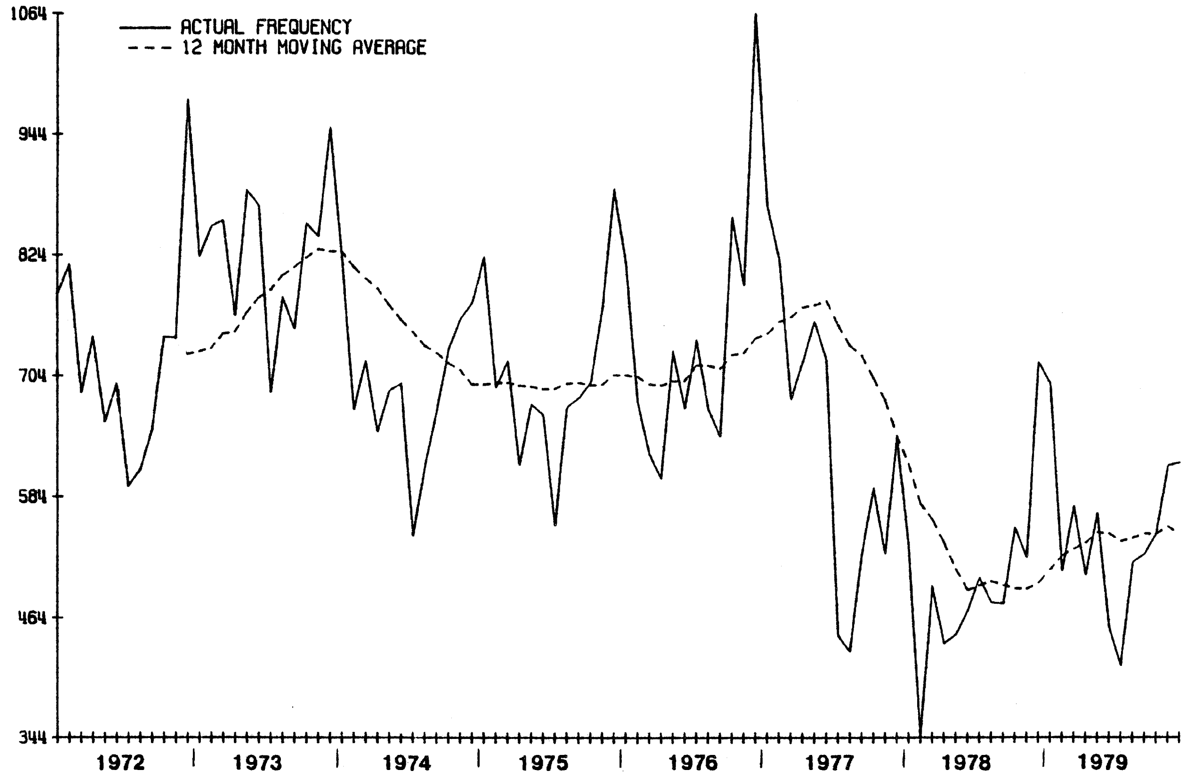


Figure D.28 Male Drivers Age 22-45 Involved in Late-night, Single-vehicle, Property Damage Only Crashes, State of Pennsylvania

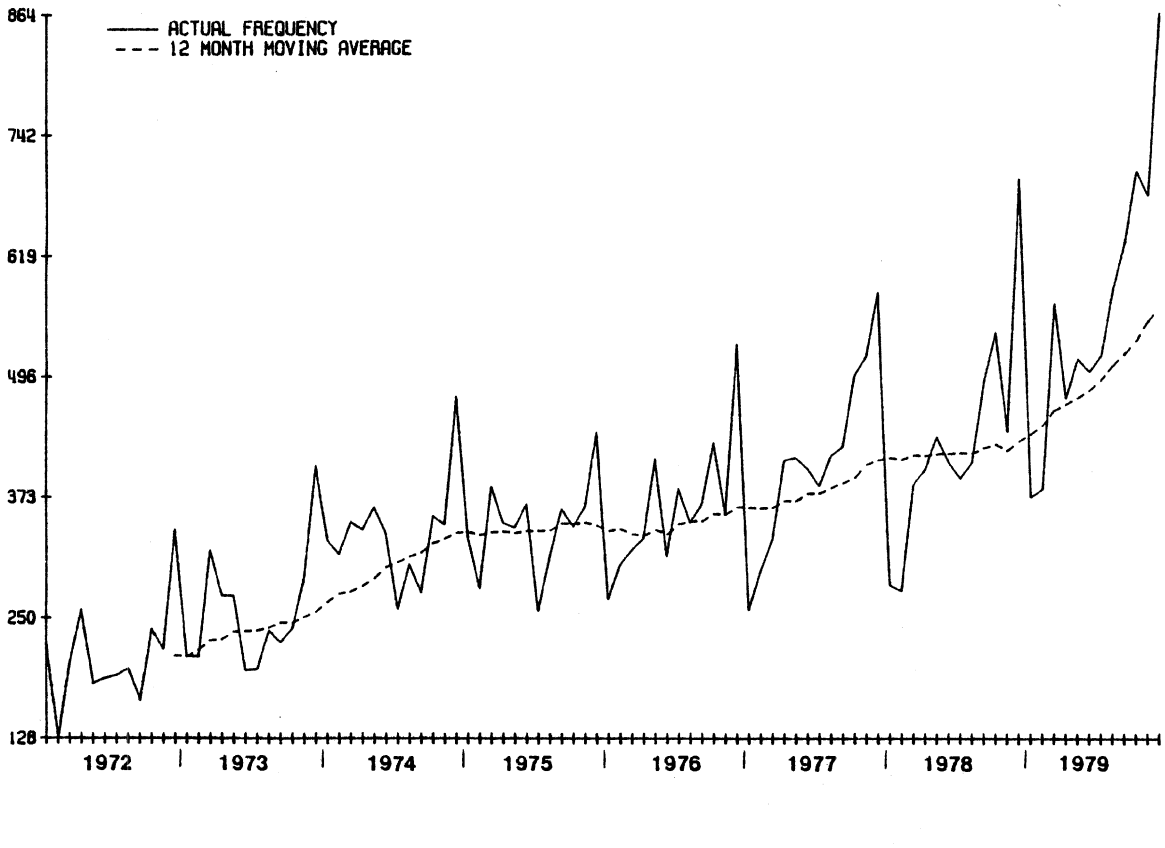


Figure D.29 Police-reported Had Not Been Drinking Drivers Age 22-45 Involved in Crashes Including at Least One Injury or Fatality, State of Pennsylvania

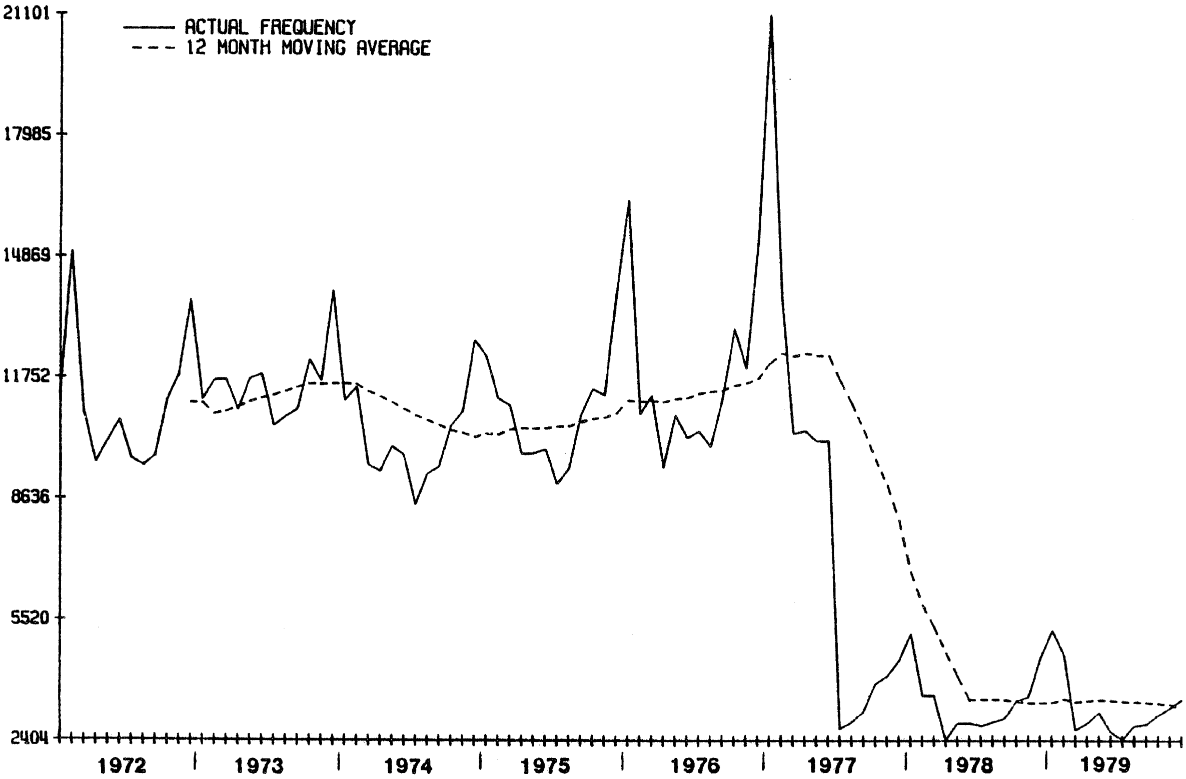


Figure D.30 Police-reported Had Not Been Drinking Drivers Age 22-45 Involved in Property Damage Only Crashes, State of Pennsylvania

$$Y_t = \frac{(1 - .60B)(1 - .78B^{12})u_t - 4.20}{(1 - B)(1 - B^{12})} + 500.60\, S_{3t} + 133.72\, S_t + 64.12\, S_{2t}$$

t-ratio 6.84 14.67 .59 1.86 .49 .22

$R^2 = .45$

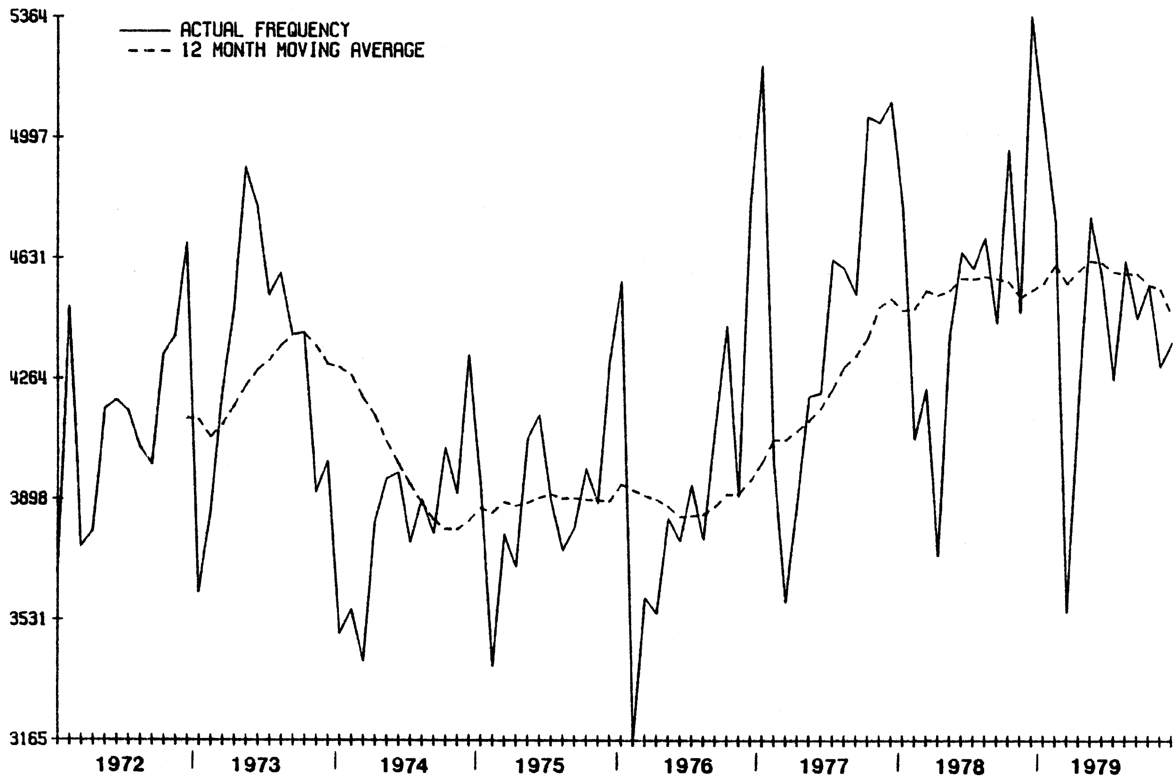


Figure D.31 Drivers Age 22-45 Involved in Daytime Crashes Including at Least One Injury or Fatality, State of Pennsylvania

$$\log Y_t = \frac{(1 + .15B)(1 - .50B^{12})u_t + .015}{1 - B^{12}} - 1.32\ S_{3t} - .021\ S_t - .095\ S_{2t}$$

t-ratio	1.33	4.84	1.18	20.20	.32	2.08

$R^2 = .96$

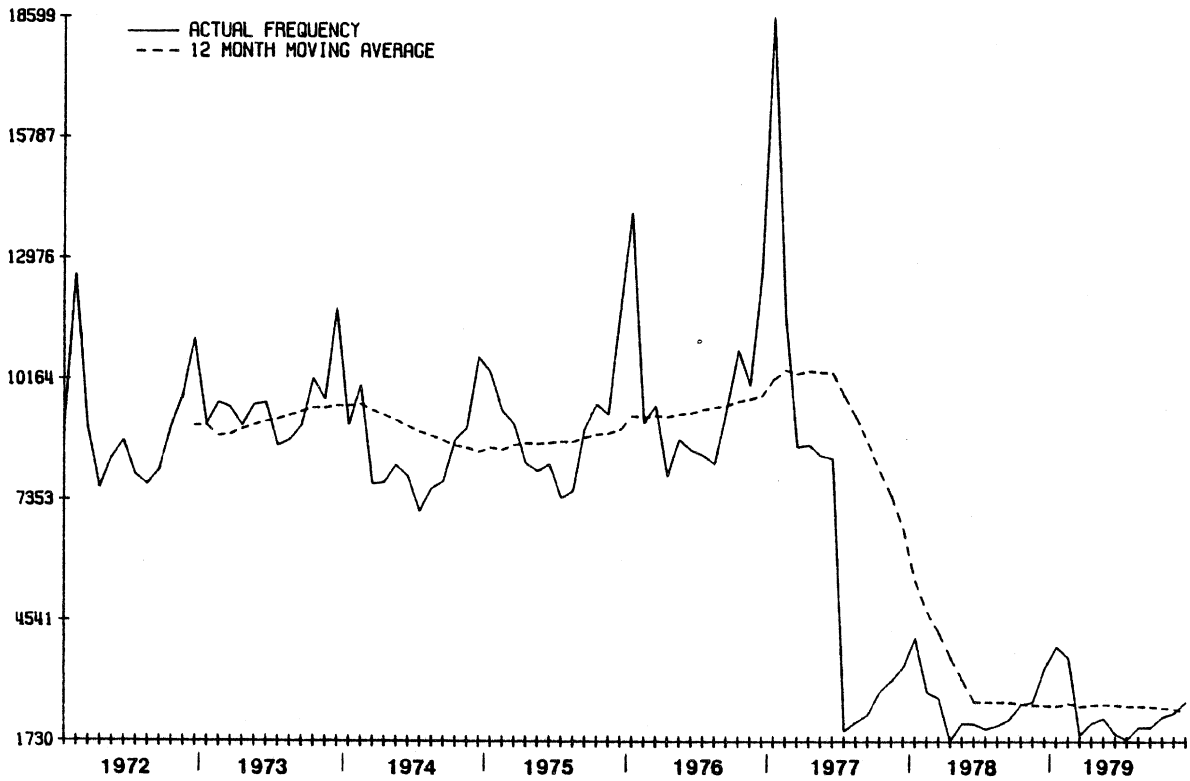


Figure D.32 Drivers Age 22-45 Involved in Daytime Property Damage Only Crashes, State of Pennsylvania

$$Y_t = \frac{(1 - .28B)(1 - .85B^{12})u_t - .657}{(1 - B)(1 - B^{12})} + 155.12\ S_{3t} - 34.48\ S_t - 104.04\ S_{2t}$$

t-ratio 2.68 21.66 .29 2.33 .52 1.62

$R^2 = .82$

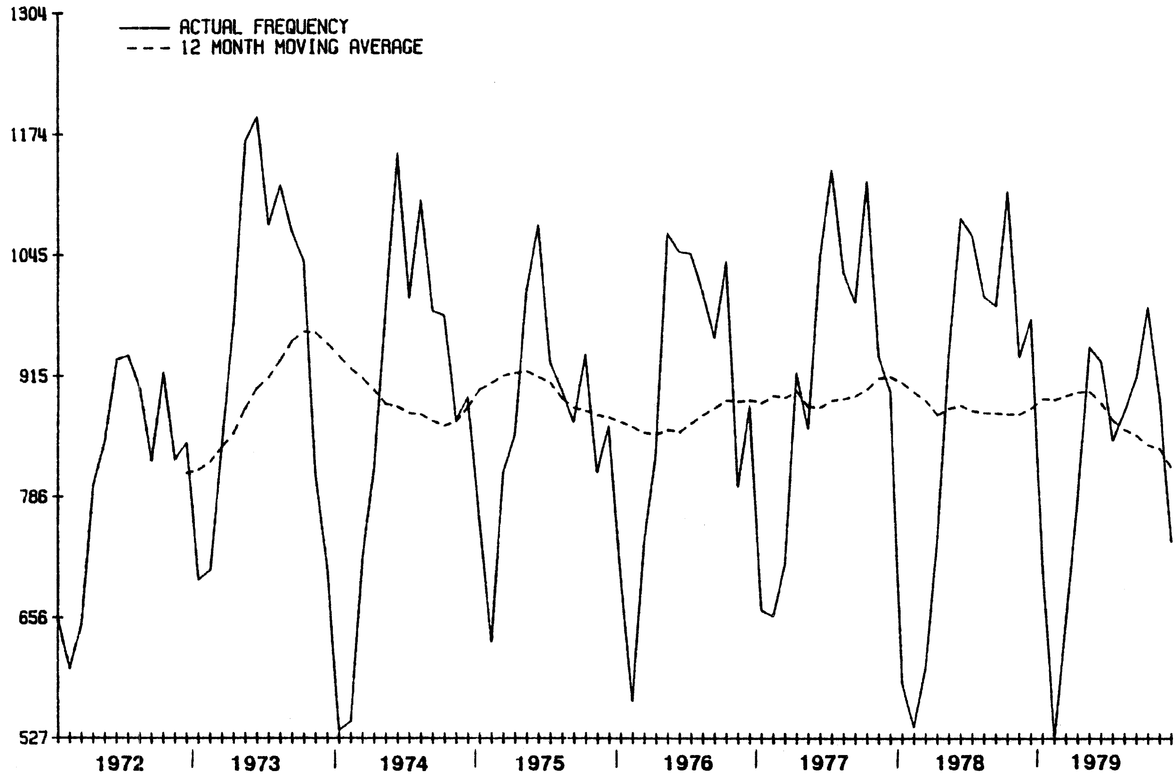


Figure D.33 All Drivers Age 16-17 Involved in Crashes Including at Least One Injury or Fatality, State of Pennsylvania

$$\log Y_t = \frac{(1 + .36B)(1 - .82B^{12})u_t + .029}{1 - B^{12}} - 1.10\, S_{3_t} - .112\, S_t - .150\, S_{2_t}$$

t-ratio	3.60	20.31	2.99	16.96	1.71	3.25

$R^2 = .97$

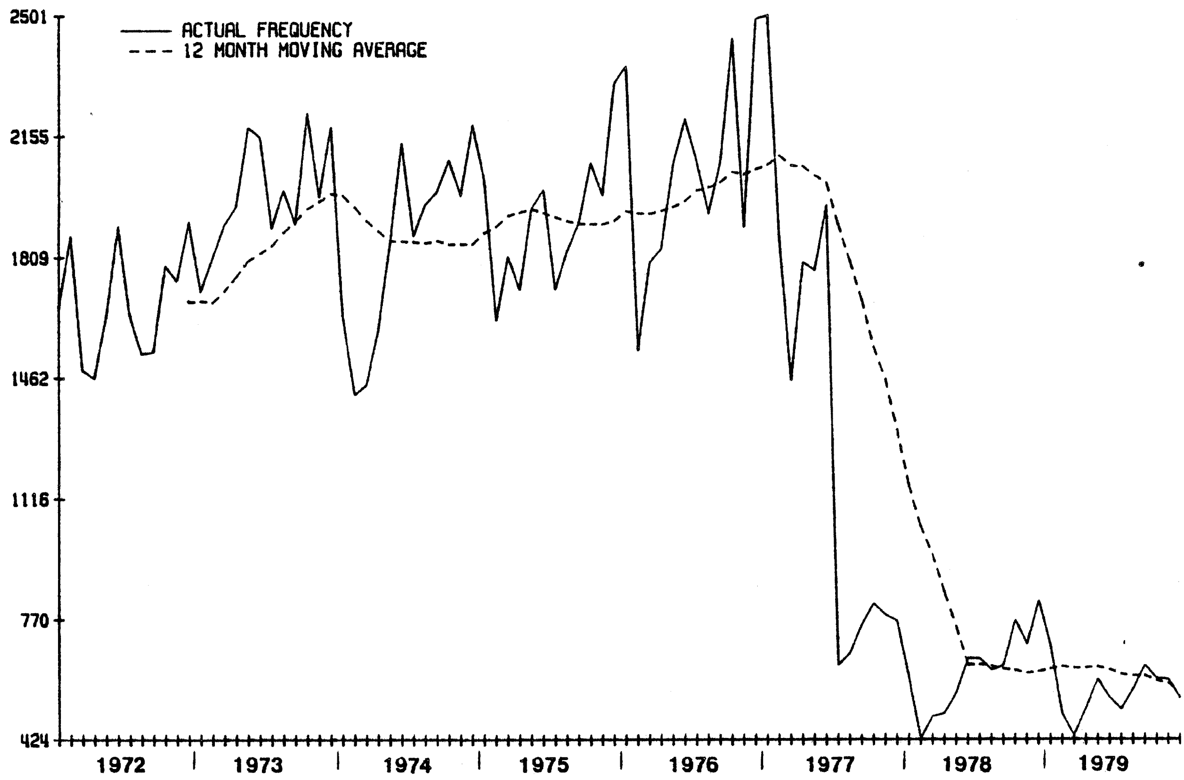


Figure D.34 All Drivers Age 16-17 Involved in Property Damage Only Crashes, State of Pennsylvania

$$Y_t = \frac{(1 - .40B)(1 - .84B^{12})u_t - 1.66}{(1 - B)(1 - B^{12})} + 175.91\ S_{3_t} + 25.05\ S_t - 27.66\ S_{2_t}$$

t-ratio 4.12 21.52 .68 2.21 .31 .35

$R^2 = .75$

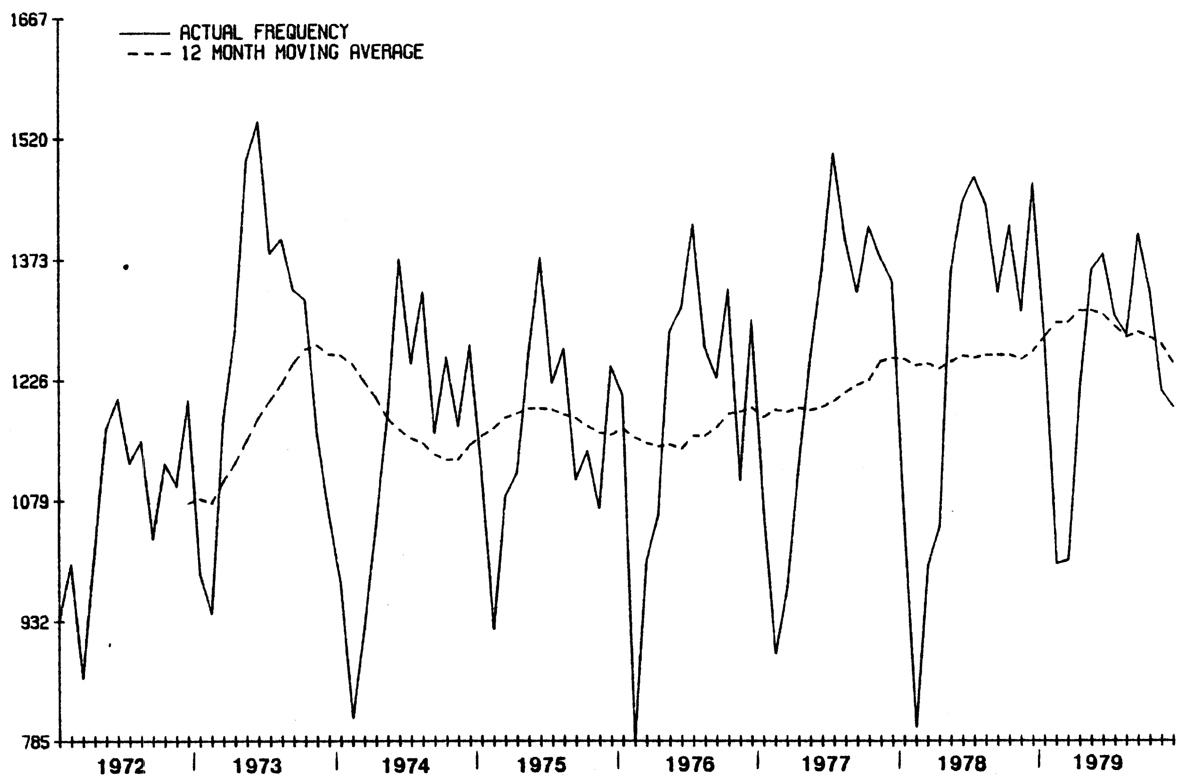


Figure D.35 All Drivers Age 18-19 Involved in Crashes Including at Least One Injury or Fatality, State of Pennsylvania

$$\log Y_t = \frac{(1 + .27B)(1 - .80B^{12})u_t + .038}{1 - B^{12}} - 1.12\ S_{3_t} - .051\ S_t - .113\ S_{2_t}$$

t-ratio 2.65 17.94 4.15 18.01 .81 2.58

$$R^2 = .96$$

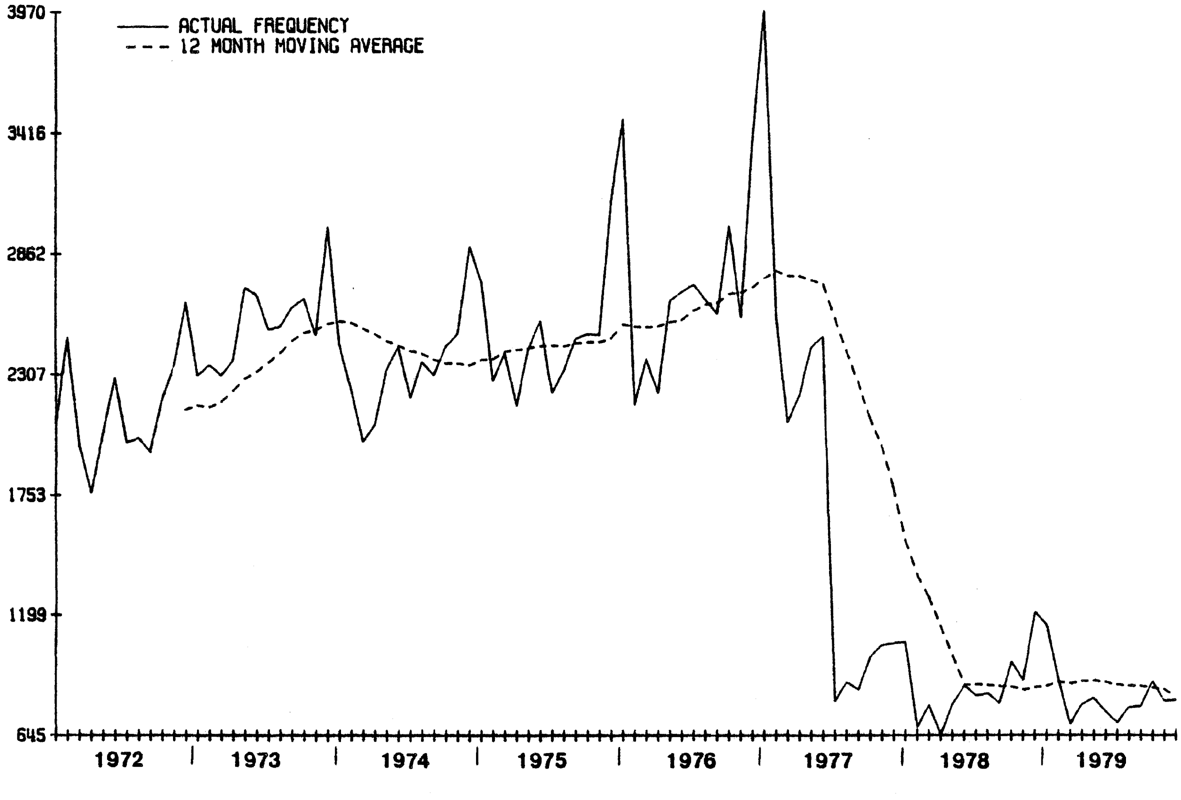


Figure D.36 All Drivers Age 18-19 Involved in Property Damage Only Crashes, State of Pennsylvania

$$Y_t = \frac{(1 - .47B)(1 - .84B^{12})u_t - 1.34}{(1 - B)(1 - B^{12})} + 215.82\ S_{3t} - 76.45\ S_t - 91.33\ S_{2t}$$

t-ratio 4.63 20.38 .72 3.29 1.15 1.38

$R^2 = .76$

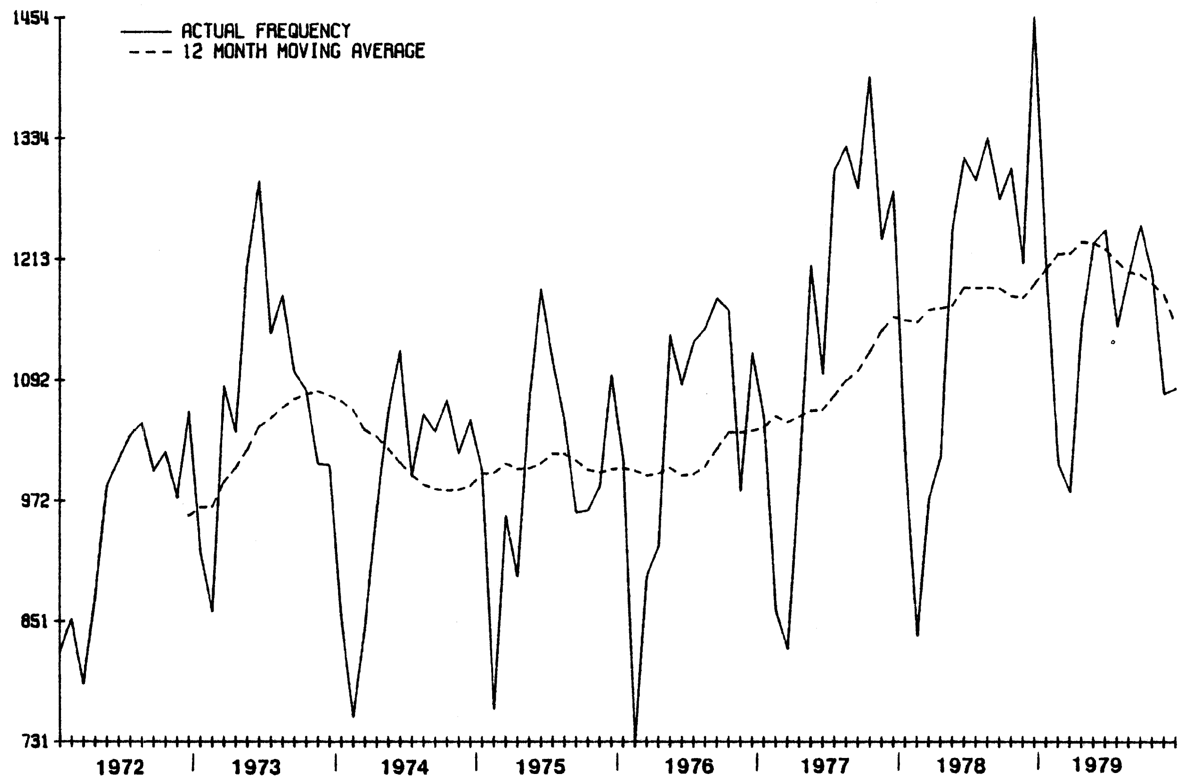


Figure D.37 All Drivers Age 20-21 Involved in Crashes Including at Least One Injury or Fatality, State of Pennsylvania

$$\log Y_t = \frac{(1 + .27B)(1 - .62B^{12})u_t + .033}{1 - B^{12}} - 1.06\ S_{3t} - .029\ S_t - .107\ S_{2t}$$

t-ratio	2.53	7.73	3.28	17.62	.48	2.50

$R^2 = .96$

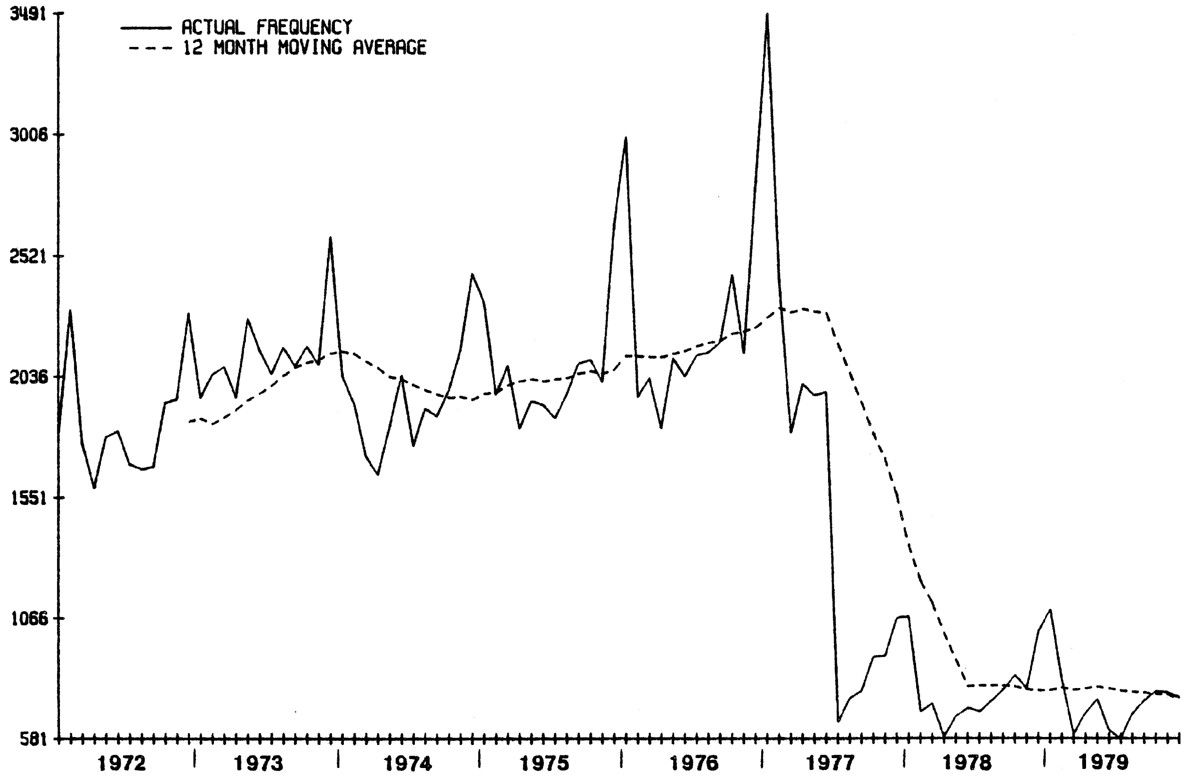


Figure D.38 All Drivers Age 20-21 Involved in Property Damage Only Crashes, State of Pennsylvania

$$Y_t = \frac{(1 - .54B)(1 - .82B^{12})u_t - 4.22}{(1 - B)(1 - B^{12})} + 862.75\ S_{3_t} + 170.10\ S_t + 108.04\ S_{2_t}$$

t-ratio	5.87	19.27	.47	2.62	.51	.32

$R^2 = .67$

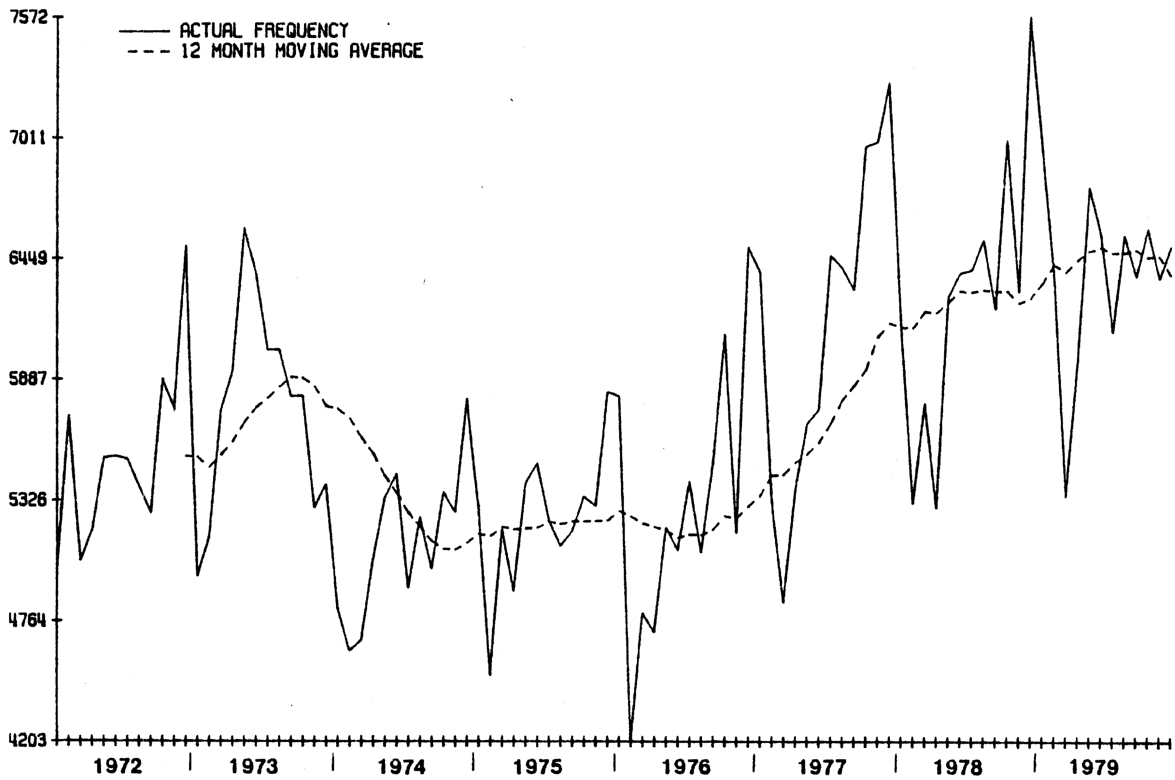


Figure D.39 All Drivers Age 22-45 Involved in Crashes Including at Least One Injury or Fatality, State of Pennsylvania

$$\log Y_t = \frac{(1 + .21B)(1 - .59B^{12})u_t + .013}{1 - B^{12}} - 1.19\, S_{3t} - .020\, S_t - .056\, S_{2t}$$

t-ratio	1.98	6.54	1.20	19.26	.32	1.28

$R^2 = .96$

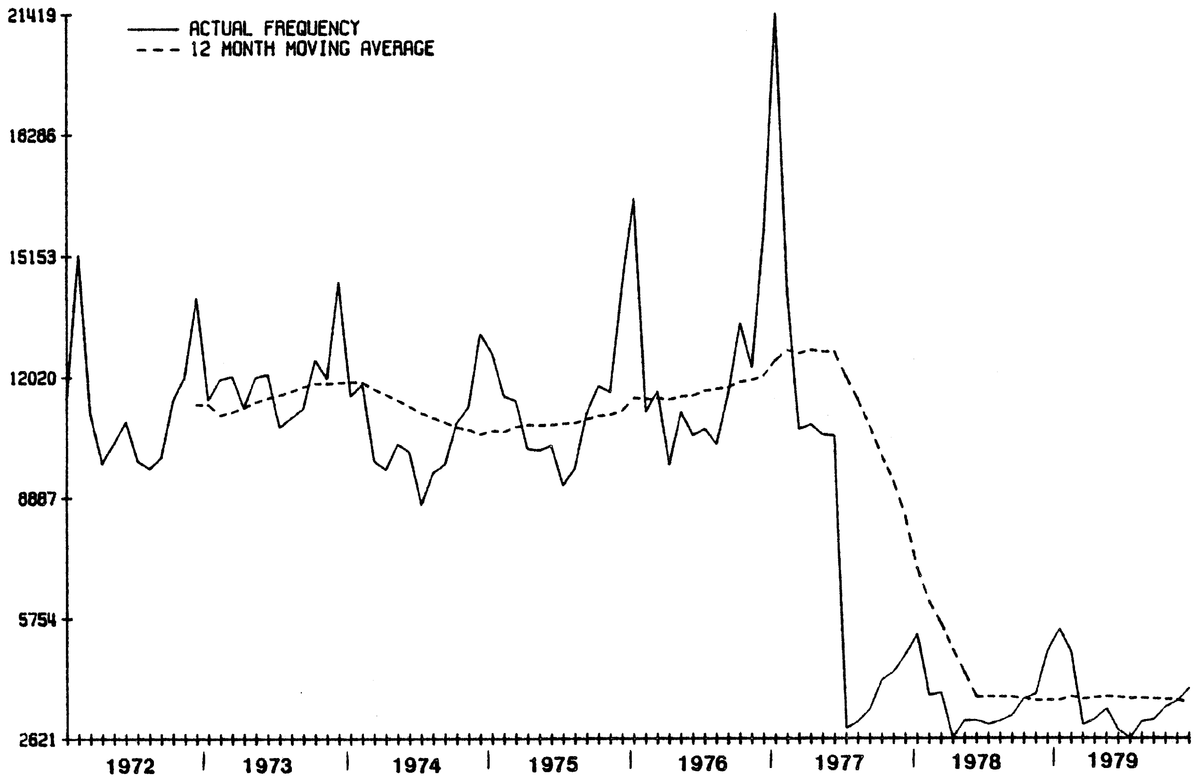


Figure D.40 All Drivers Age 22-45 Involved in Property Damage Only Crashes, State of Pennsylvania

Appendix E

Frequency of Citations for Violation of Beverage Control Laws, State of Maine

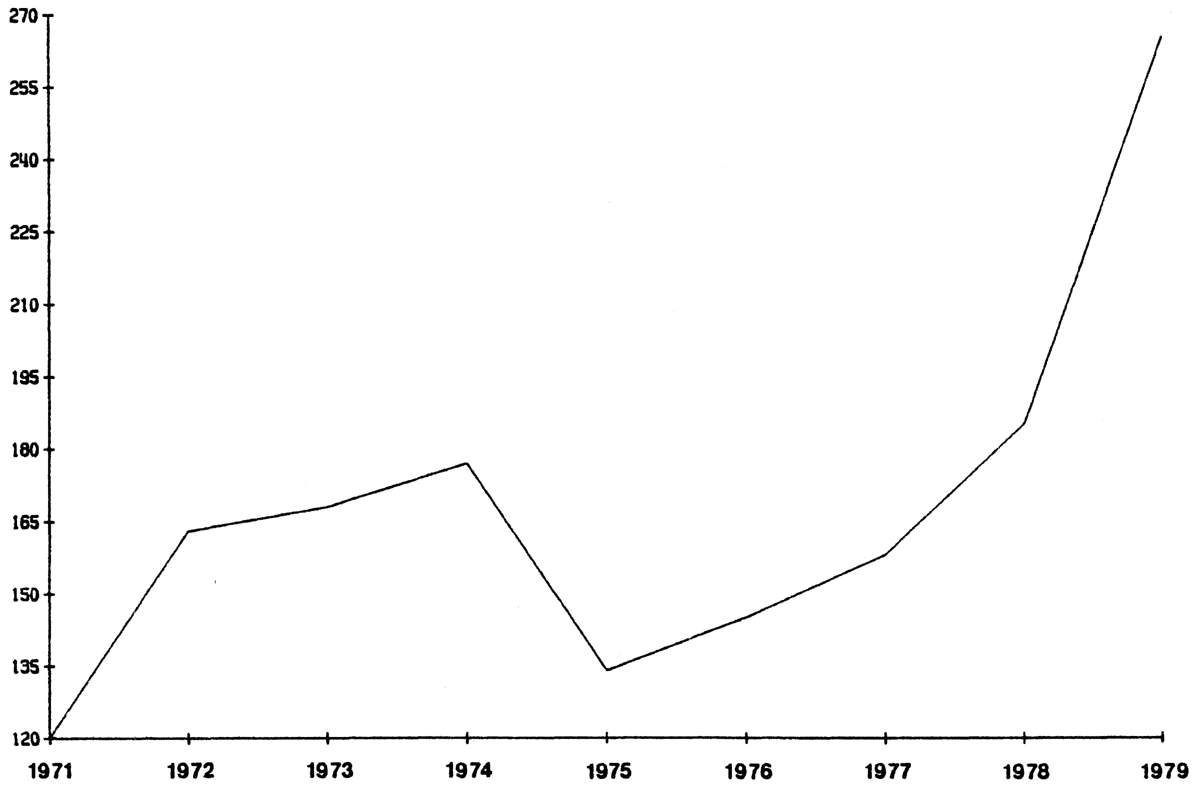


Figure E.1 Frequency of Citations Brought Before Administrative Court for Selling or Allowing Minors to Consume Alcoholic Beverages, State of Maine

Appendix F

Frequency of Citations for Violation of Beverage Control Laws, State of Michigan

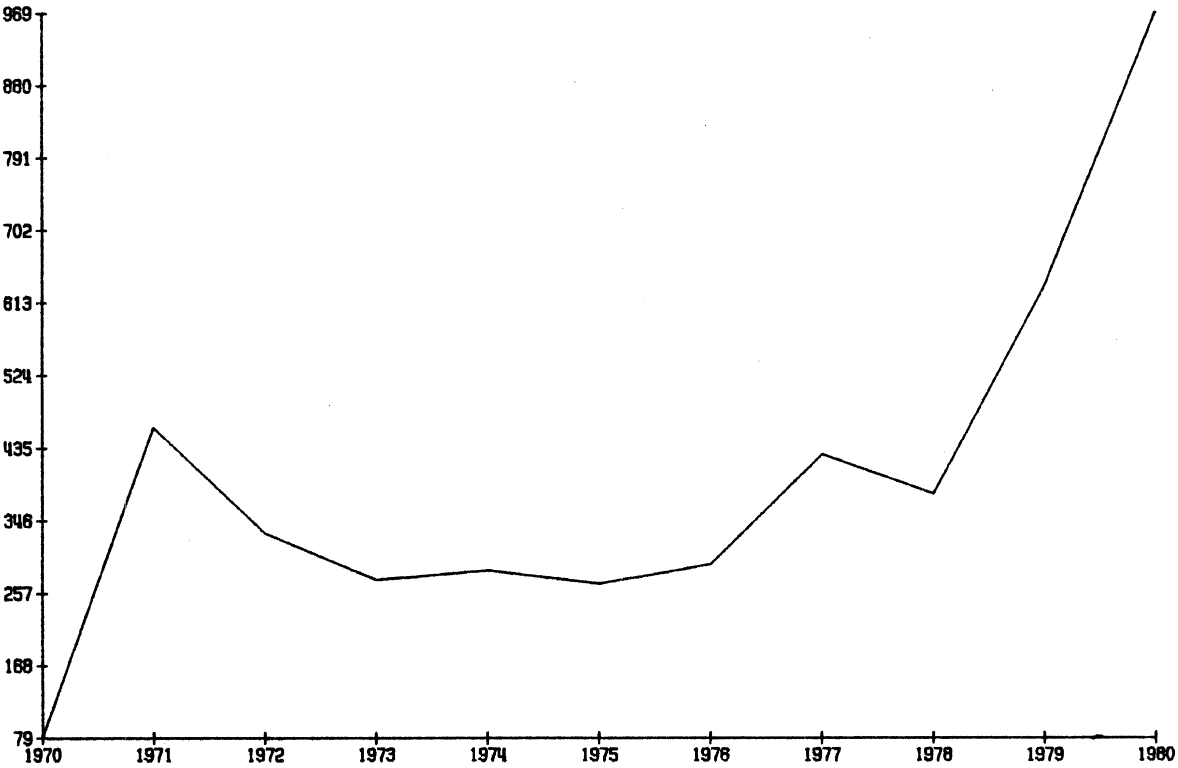


Figure F.1 Total Frequency of Citations for Selling, Serving, or Allowing Minors to Consume Alcoholic Beverages, State of Michigan

Figure F.2 Frequency of Citations for Selling, Serving, or Allowing Minors to Consume Alcoholic Beverages Where No Prosecution Was Pursued, State of Michigan

Figure F.3 Frequency of Acknowledged Citations for Selling, Serving, or Allowing Minors to Consume Alcoholic Beverages, State of Michigan

Figure F.4 Frequency of Convictions for Selling, Serving, or Allowing Minors to Consume Alcoholic Beverages, State of Michigan

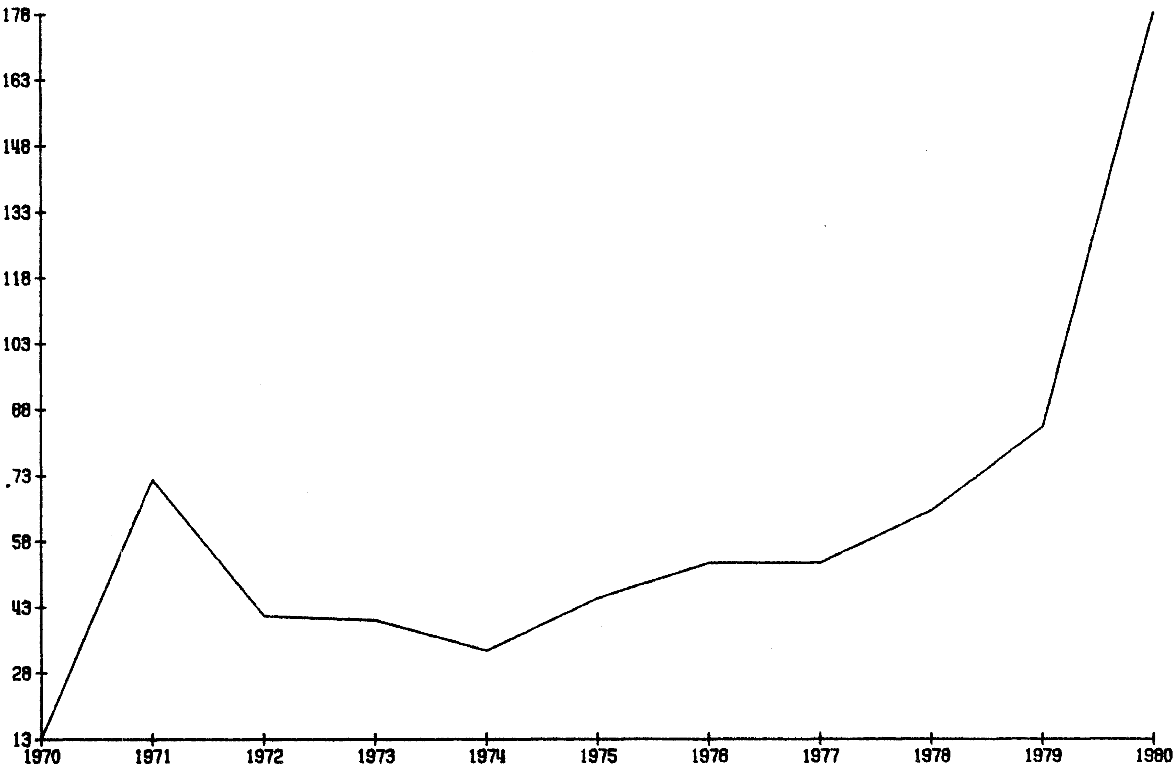


Figure F.5 Frequency of Citations for Selling, Serving, or Allowing Minors to Consume Alcoholic Beverages Dismissed After Hearings, State of Michigan

Appendix G

Sales of Alcoholic Beverages, State of Maine

$$Y_t = \frac{(1 - .36B)(1 - .84B^{12})u_t + 27.61}{1 - B^{12}} - 14.22\ S_{6_t} + 46.87\ S_t$$

t-ratio	4.00	23.13	7.45	.73	2.48

$$R^2 = .66$$

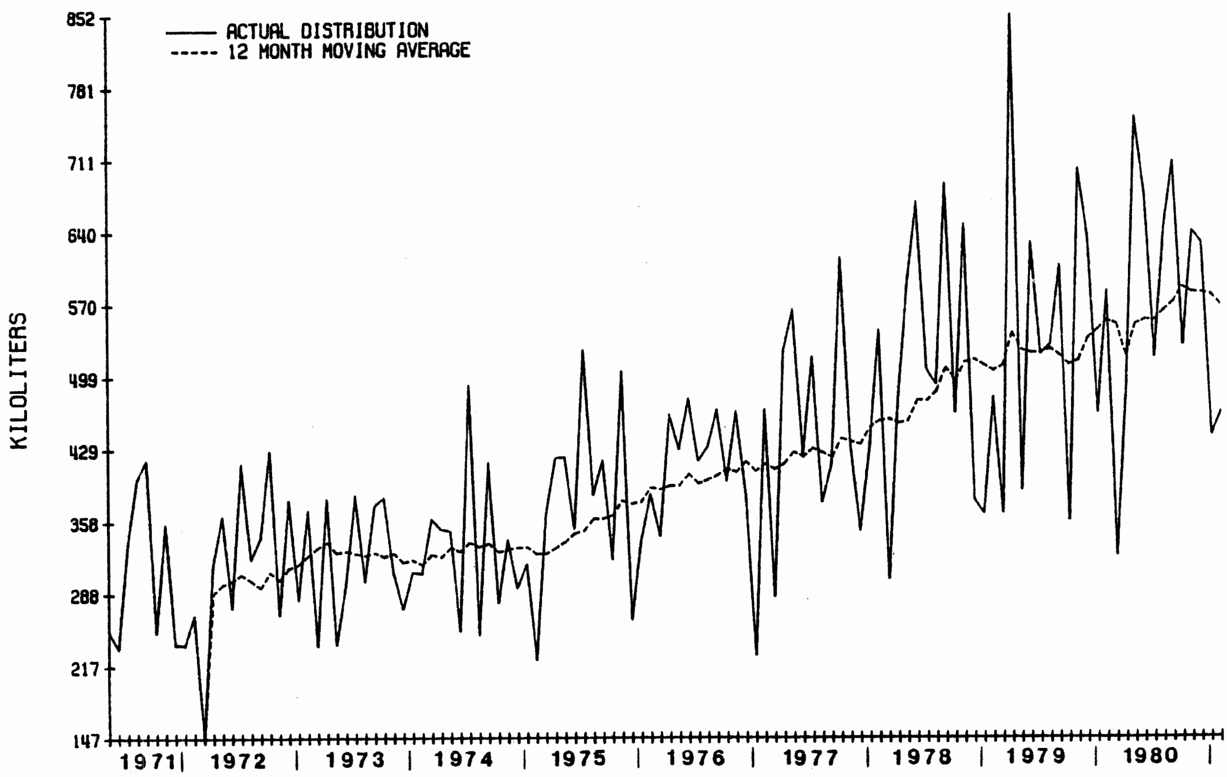


Figure G.1 Wine Distribution in the State of Maine

$$Y_t = \frac{(1 - .34B^2)(1 - .90B^{12})u_t + 317.24}{(1 - B^{12})} + 179.40\ S_{6t} - 1114.17\ S_t$$

t-ratio	4.21	35.63	10.19	1.14	6.78

$R^2 = .83$

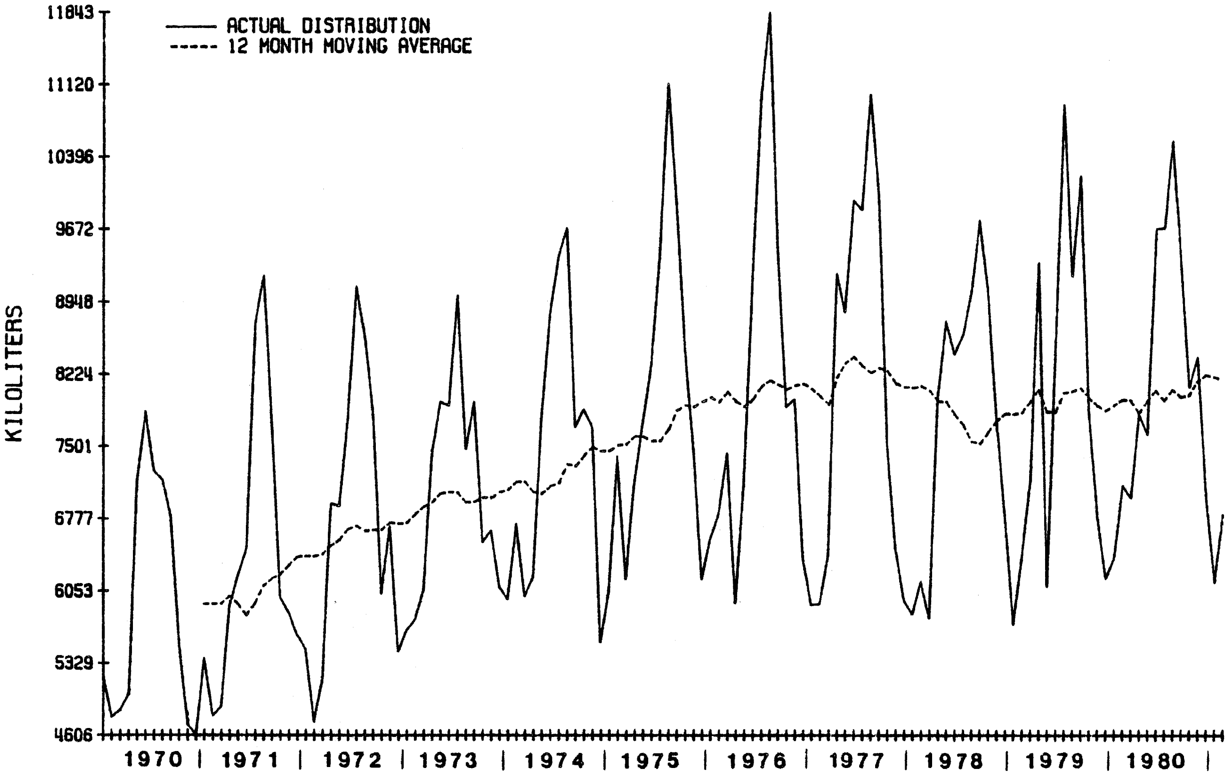


Figure G.2 Beer Distribution in the State of Maine

$$Y_t = \frac{(1 + .18B^2 + .16B^3)(1 - .91B^{12})u_t + 15.56}{1 - B^{12}} - 23.34\, S_{6_t} + 25.66\, S_t$$

t-ratio 2.10 1.90 29.51 4.09 1.20 1.26

$$R^2 = .88$$

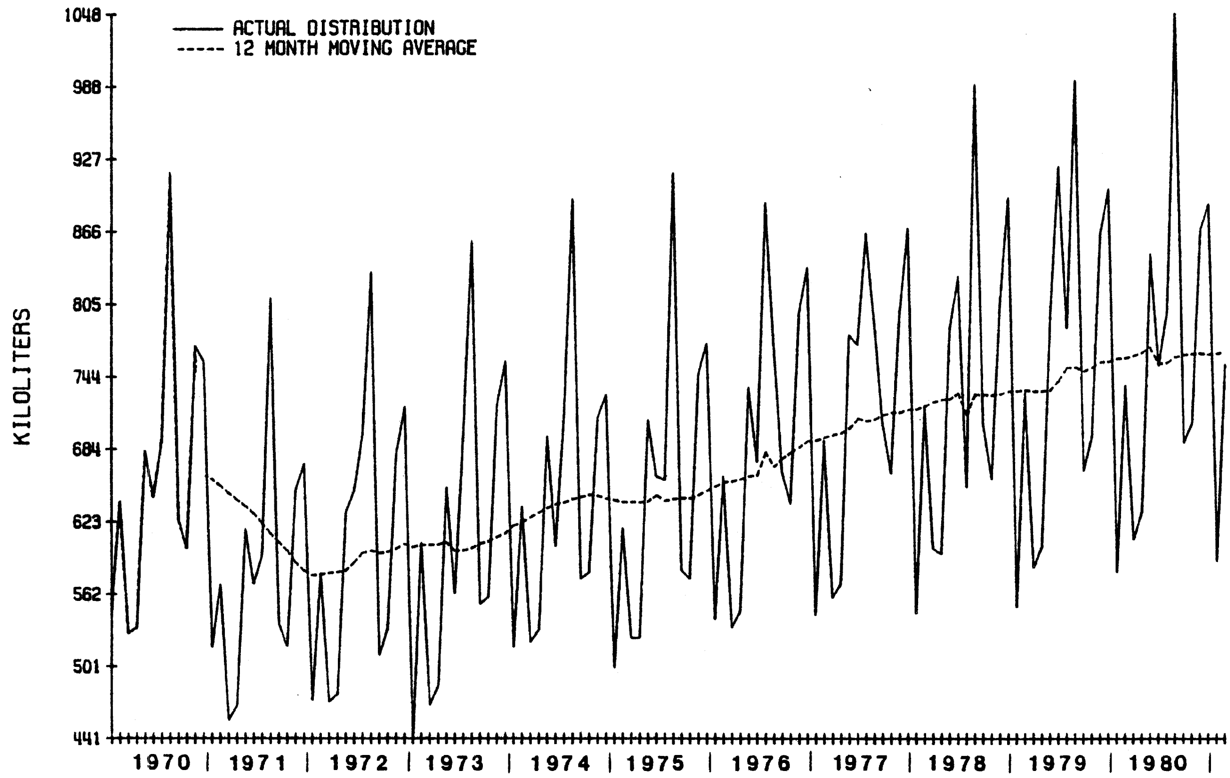


Figure G.3 Distilled Spirits Distribution in the State of Maine

Appendix H

Sales of Alcoholic Beverages, State of Michigan

$$y_t = \frac{(1-.86B^{12})u_t + 144}{1 - B^{12}} + 664\ S_{7_t} + 166\ S_{8_t} - 87\ S_{2_t}$$

t-ratio 31.44 6.70 4.89 1.19 .66

$$R^2 = .78$$

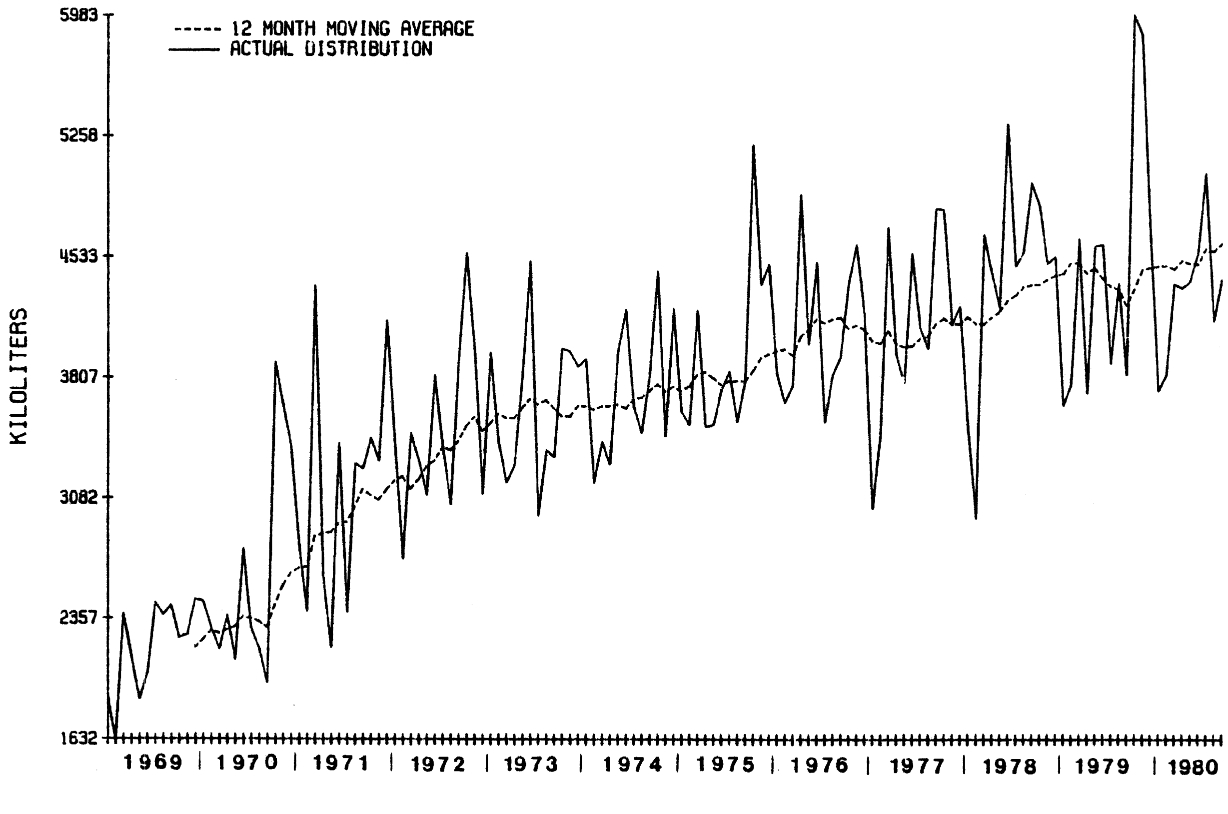


Figure H.1 Wine Distribution in the State of Michigan

$$y_t = \frac{(1+.32B)(1-.92B^{12})u_t + 1225}{1 - B^{12}} + 1462\ S_{8_t} - 5384\ S_{2_t}$$

t-ratio 4.38 40.04 4.04 .77 2.97

$R^2 = .79$

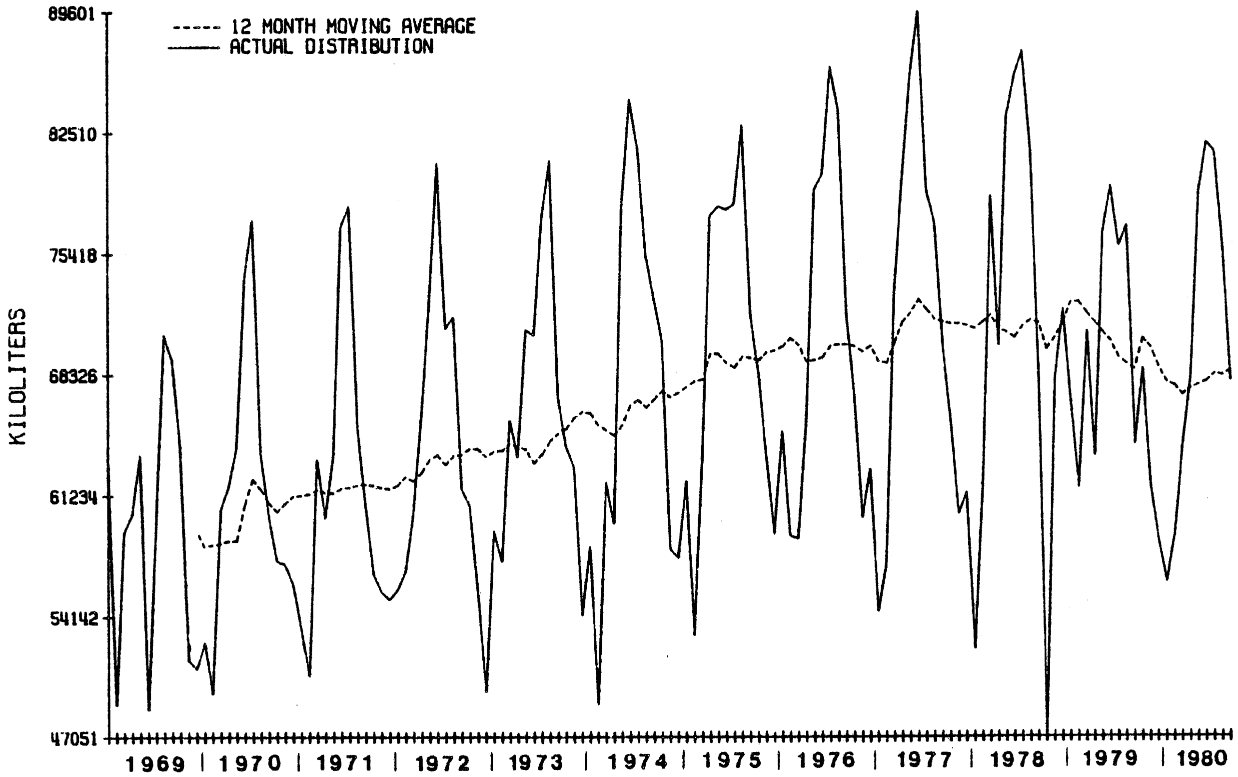


Figure H.2 Total Beer Distribution in the State of Michigan

$$y_t = \frac{(1+.32B)(1-.92B^{12})u_t + 1220}{1 - B^{12}} + 1049\ S_{8_t} - 7659\ S_{2_t}$$

t-ratio 4.40 36.82 4.09 .56 4.28

$R^2 = .76$

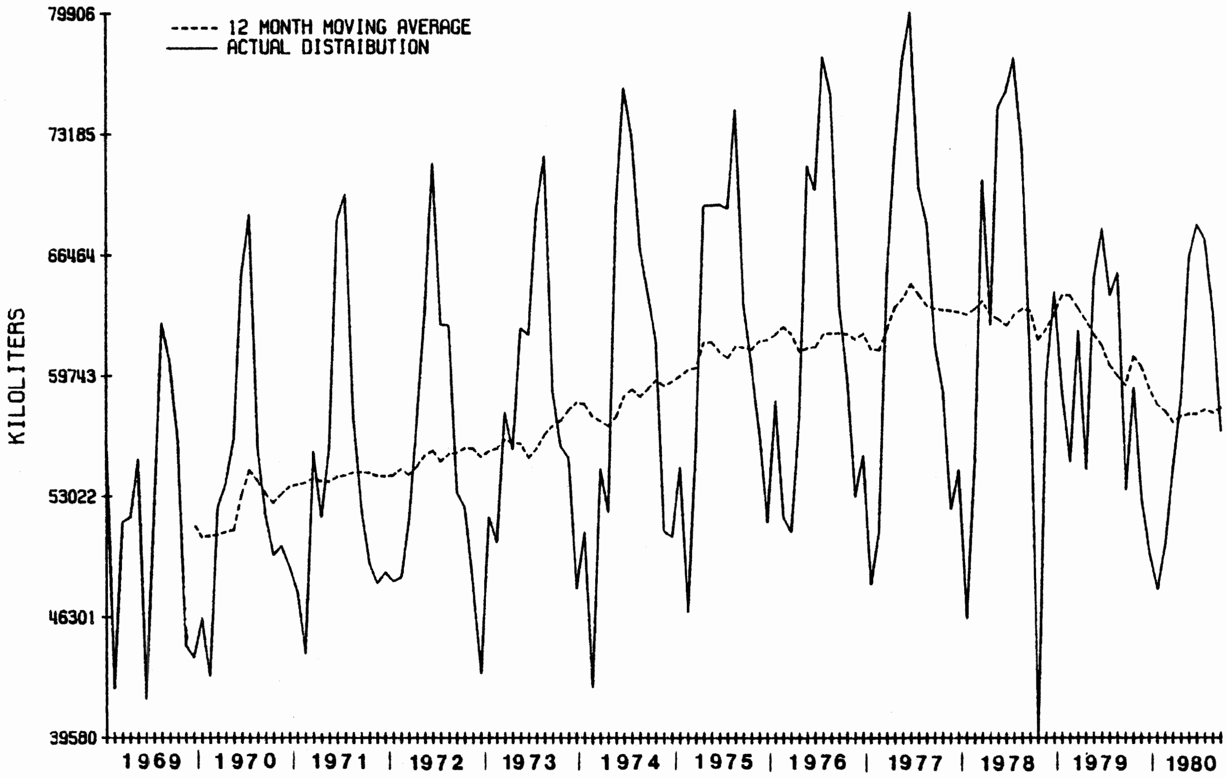


Figure H.3 Package Beer Distribution in the State of Michigan

$$y_t = \frac{(1-.23B)u_t}{1 - B^{12}} + \frac{1321}{1-.87B} P_t + 1600\, S_{2t} + 1194\, S_{9t}$$

t-ratio	2.60	6.30/25.65	11.89	7.57

$R^2 = .84$

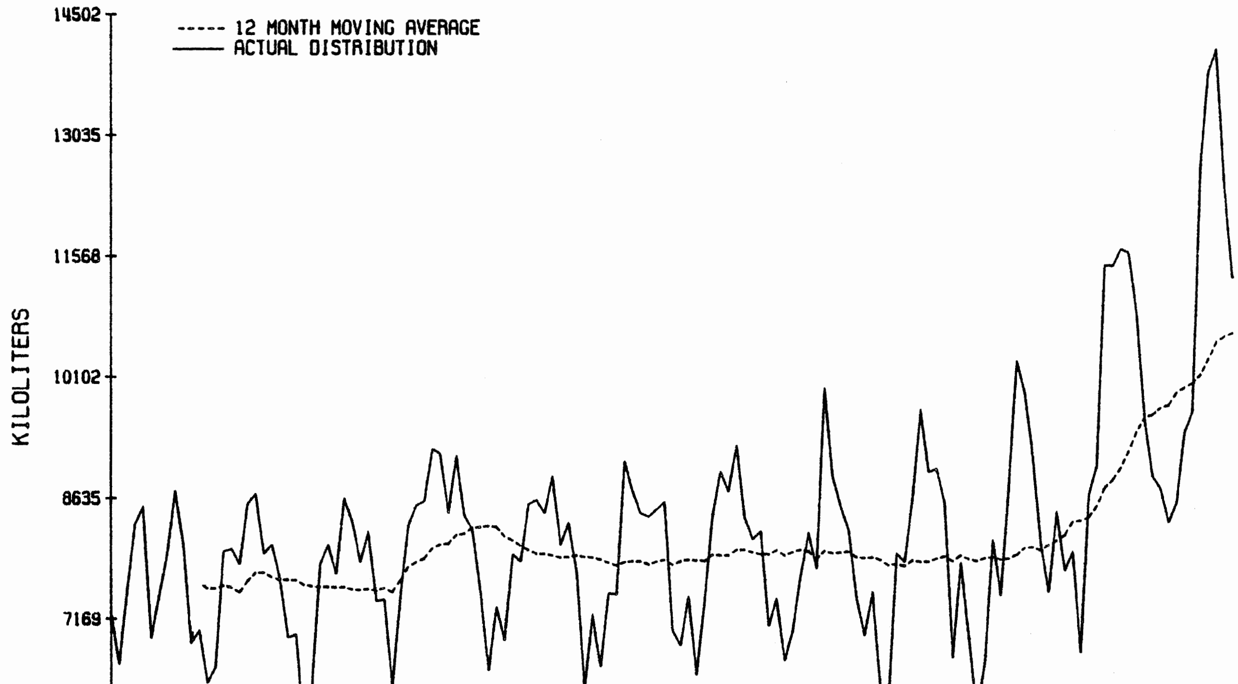


Figure H.4 Draft Beer Distribution in the State of Michigan

Appendix I

Sales of Alcoholic Beverages, State of New Hampshire

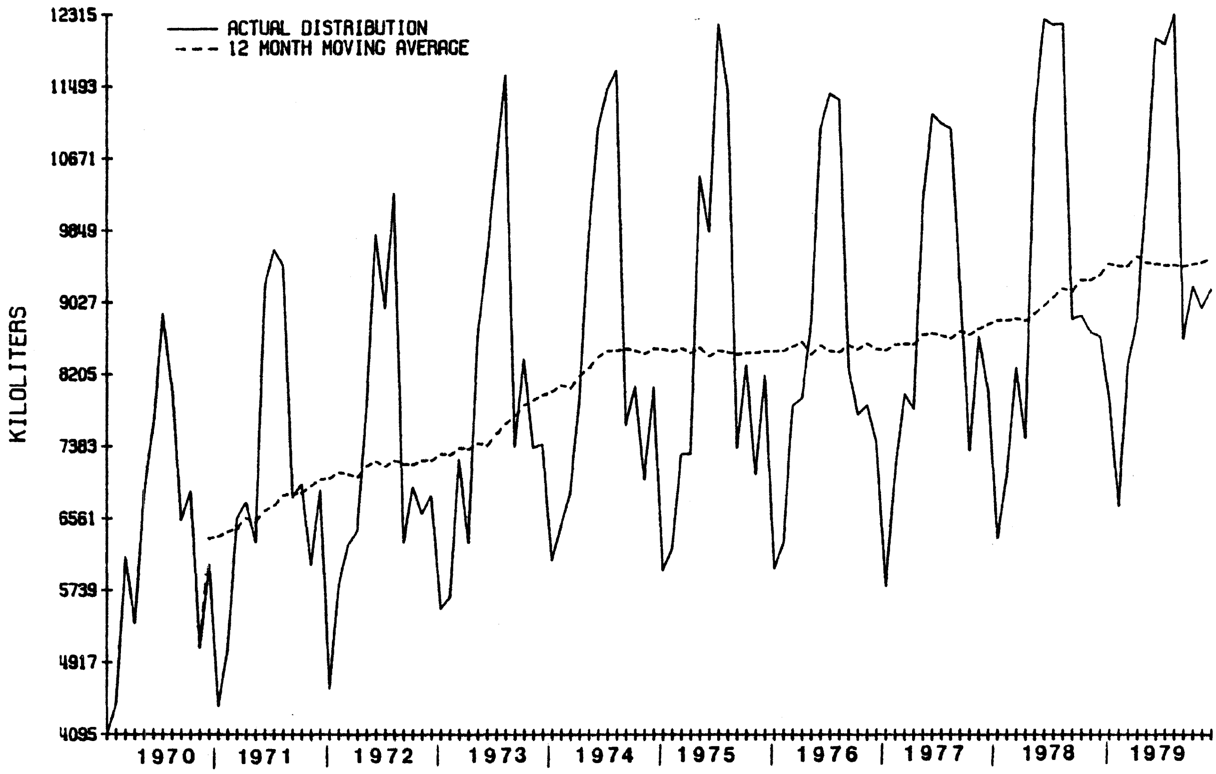


Figure I.1 Total Beer Distribution in the State of New Hampshire

$$Y_t = \frac{(1 - .88B^{12})u_t + 184.69}{1 - B^{12}} + 539.71\ S_{10_t} + 258.64\ S_{5_t}$$

t-ratio 28.45 4.49 2.82 1.45

$R^2 = .93$

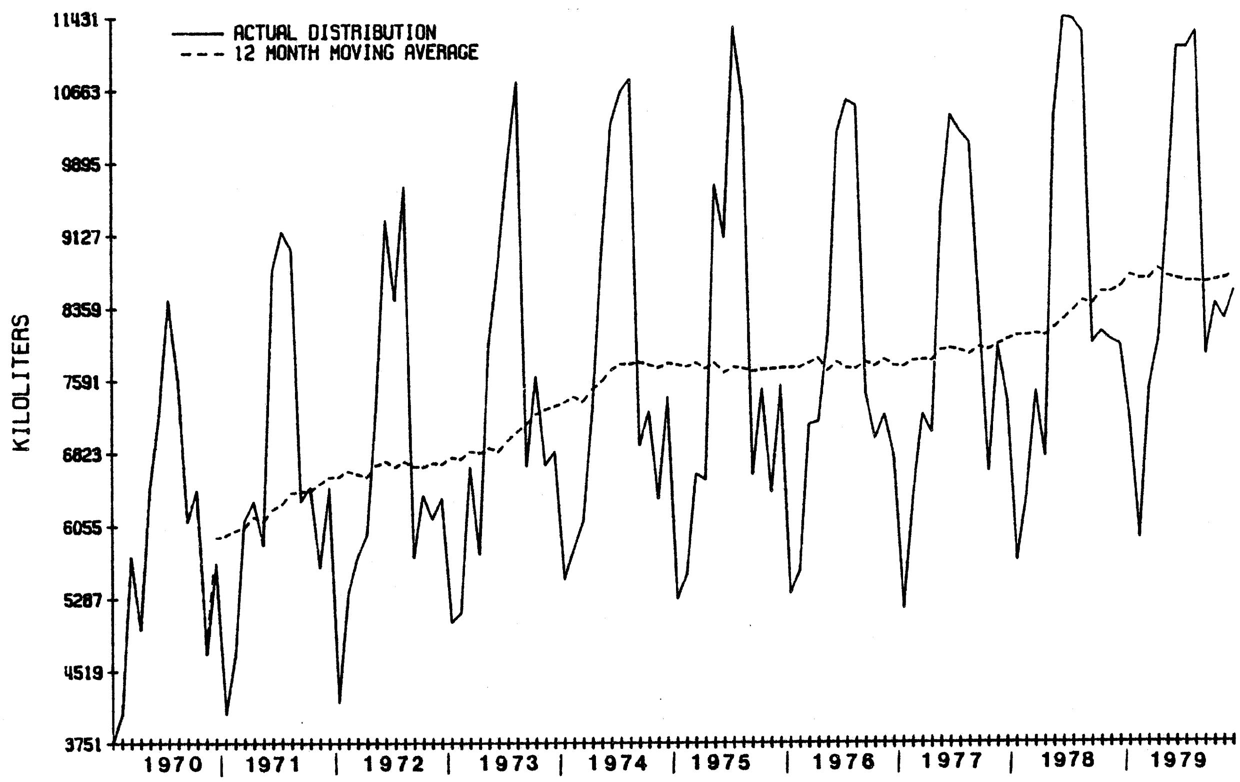


Figure I.2 Package Beer Distribution in the State of New Hampshire

$$\text{Jan. 1970 - Dec. 1973 } Y_t = \frac{(1 - .15B - .76B^4)(1 + .74B^{12})u_t + 4.65}{1 - B^{12}} + 67.81\, S_{10_t}$$

t-ratio 1.56 8.28 10.33 2.94 2.46

$$R^2 = .96$$

$$\text{Jan. 1974 - Dec. 1979 } Y_t = \frac{(1 - .20B + .32B^3)u_t}{1 - B^{12}} + 11.30\, S_{5_t} + 56.47\, S_{2_t}$$

t-ratio 1.59 2.43 .80 3.91

$$R^2 = .91$$

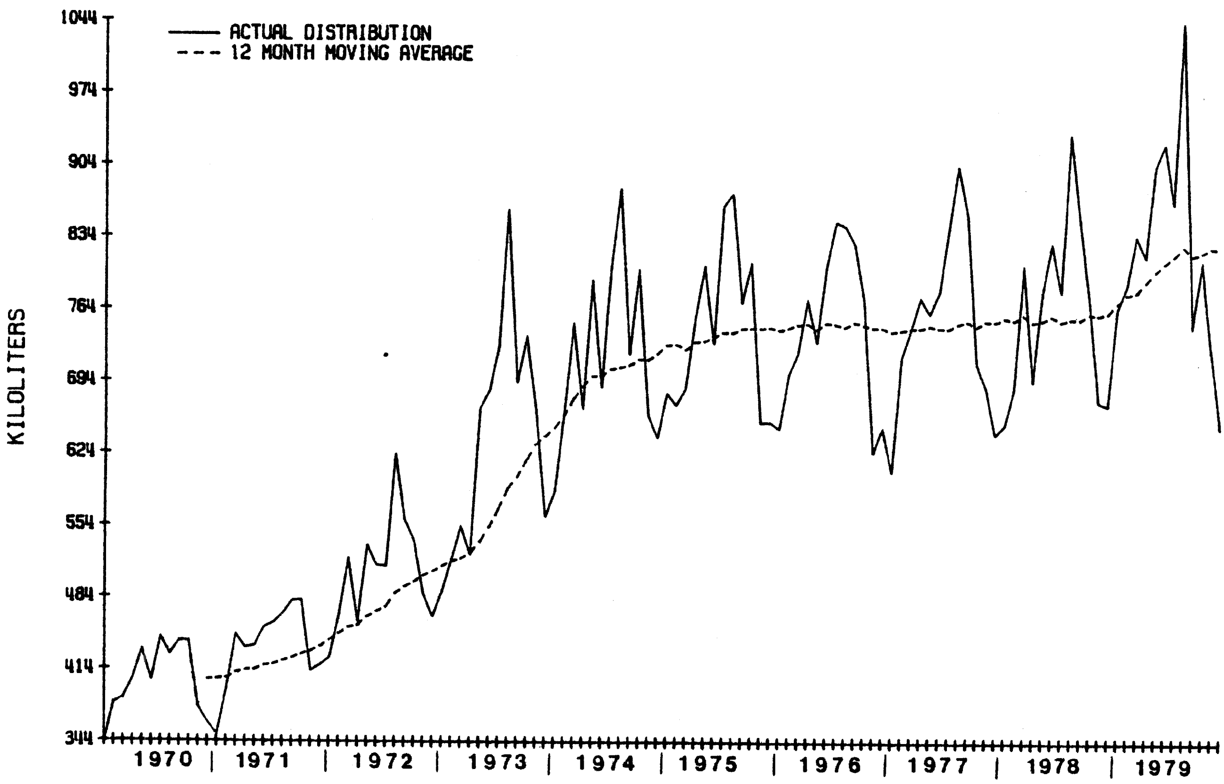


Figure I.3 Draft Beer Distribution in the State of New Hampshire

Appendix J

Sales of Alcoholic Beverages, United States

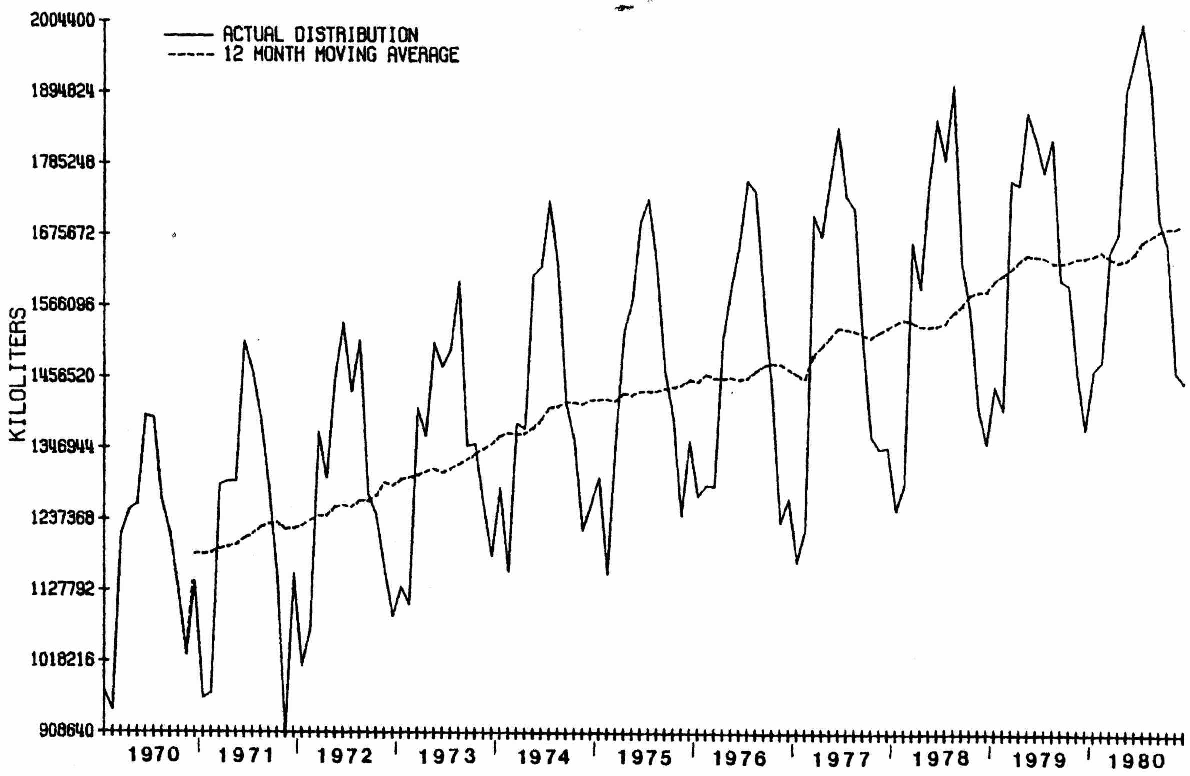


Figure J.1 Total Beer Distribution in the United States

$$Y_t = \frac{(1 - .31B^4)(1 - .90B^{12})u_t + 44614}{1 - B^{12}} + 30431.03\, S_{8t} + 17099.64\, S_t - 13407.80\, S_{2t}$$

t-ratio 3.54 32.85 15.41 2.01 1.04 .91

$$R^2 = .93$$

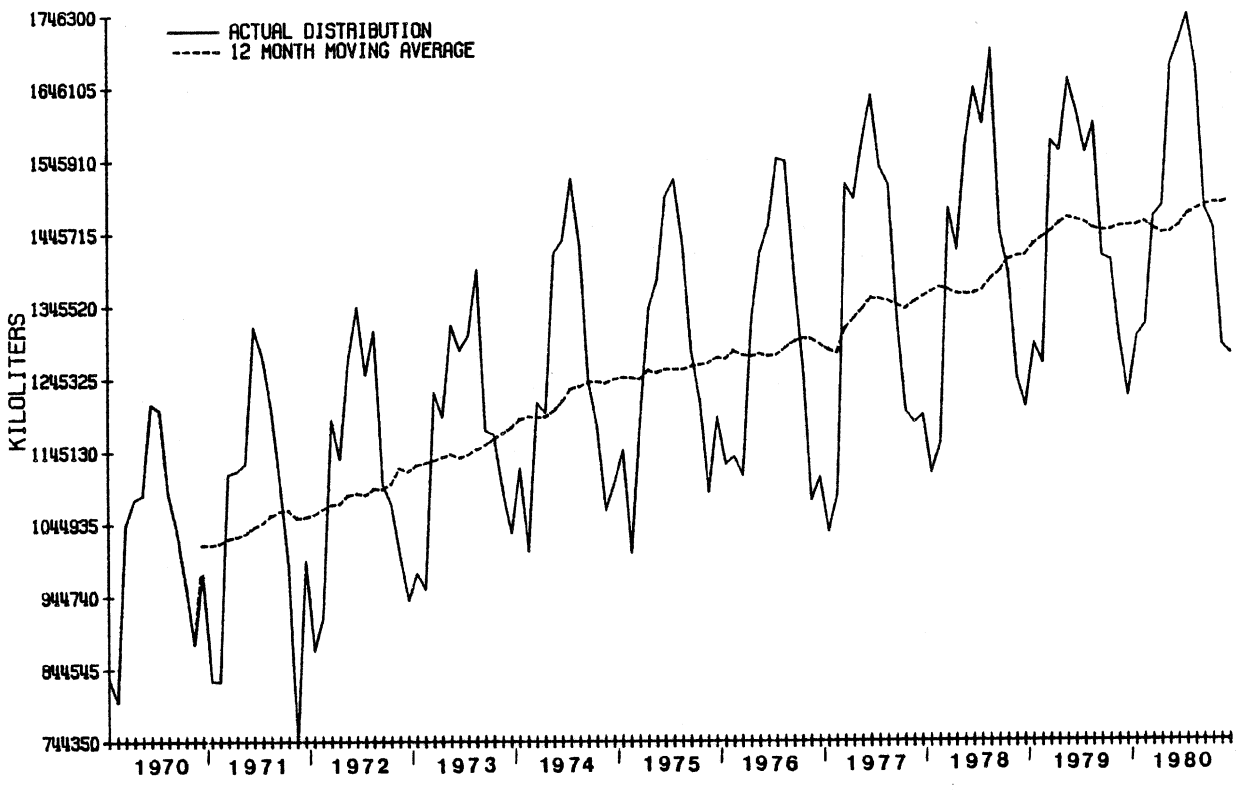


Figure J.2 Package Beer Distribution in the United States

$$Y_t = \frac{u_t + 1632}{(1 + .24B)(1 - B^{12})} + 1045.78\, S_{8_t} + 2765.19\, S_t + 11515.18\, S_{2_t} + 14162.27\, S_{9_t}$$

t-ratio 2.67 1.73 .52 1.38 5.75 7.08

$$R^2 = .89$$

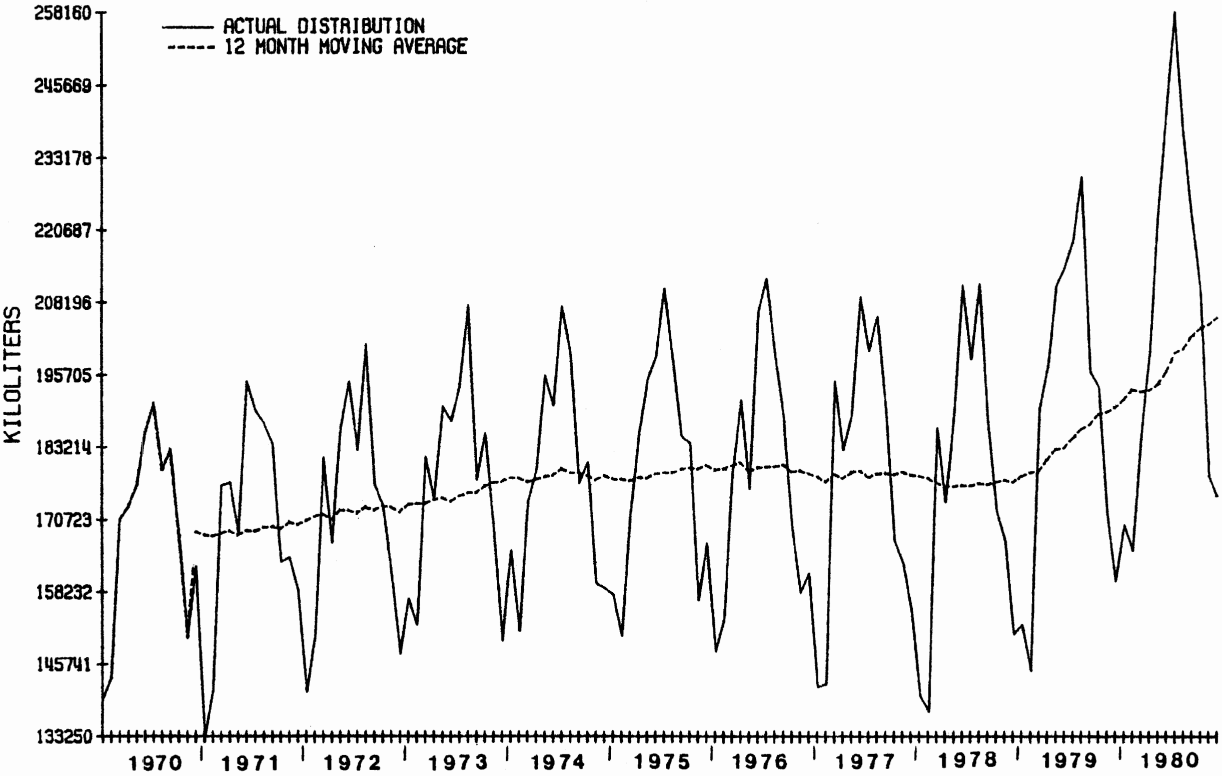


Figure J.3 Draft Beer Distribution in the United States

Appendix K

Crash Frequency Plots and Time-series Models, State of New York, Excluding New York City

$$Y_t = \frac{(1 - .58B^5)(1 - .78B^{12})u_t}{1 - B^{12}} + 5.25\ S_t + 11.20\ S_{2t}$$

t-ratio	4.84	13.88	4.04	7.04

$$R^2 = .73$$

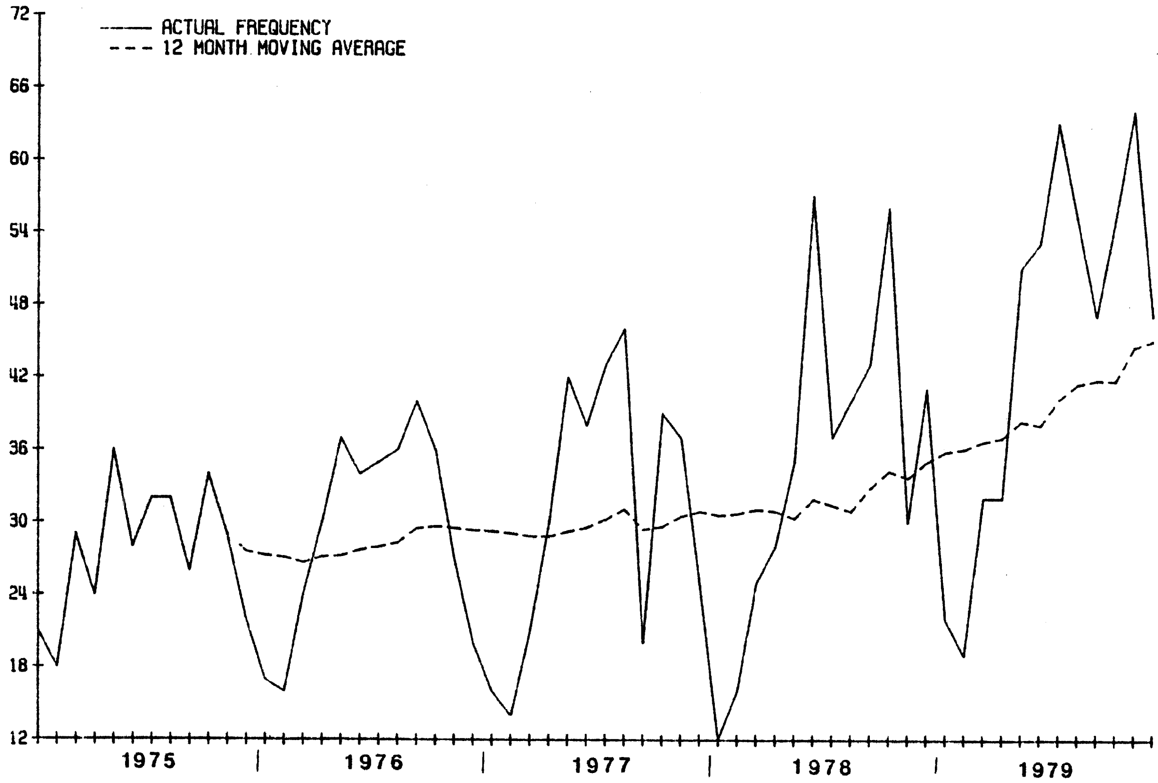


Figure K.1 Police-reported Had Been Drinking Drivers Age 16-17 Involved in Crashes Including at Least One Injury or Fatality, State of New York

$$Y_t = (1 + .17B)u_t + 5.47 + .16\ S_t + 1.95\ S_{2t}$$

t-ratio 1.26 10.39 .17 1.64

$$R^2 = .07$$

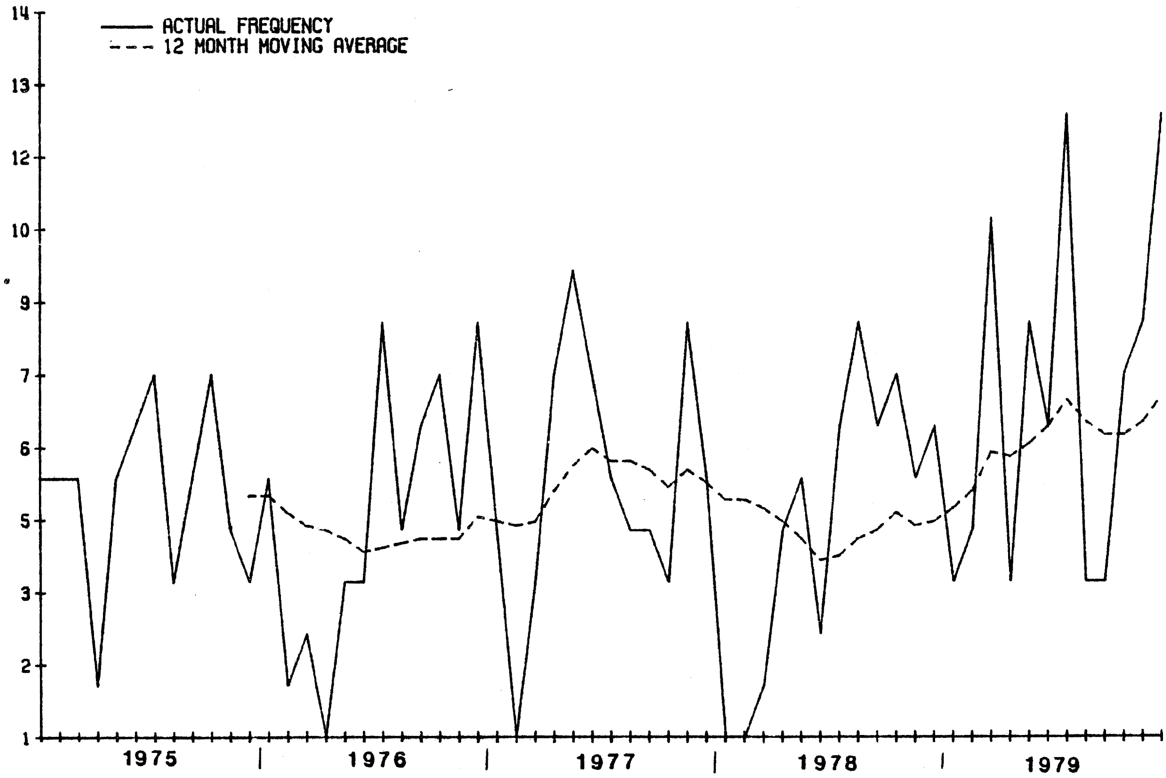


Figure K.2 Police-reported Had Been Drinking Drivers Age 16-17 Involved in Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 - .81B^{12})u_t}{1 - B^{12}} + 5.62\ S_t - 21.50\ P_{2_t} + 3.20\ S_{2_t}$$

t-ratio	15.52	1.72	1.93	.87

$R^2 = .73$

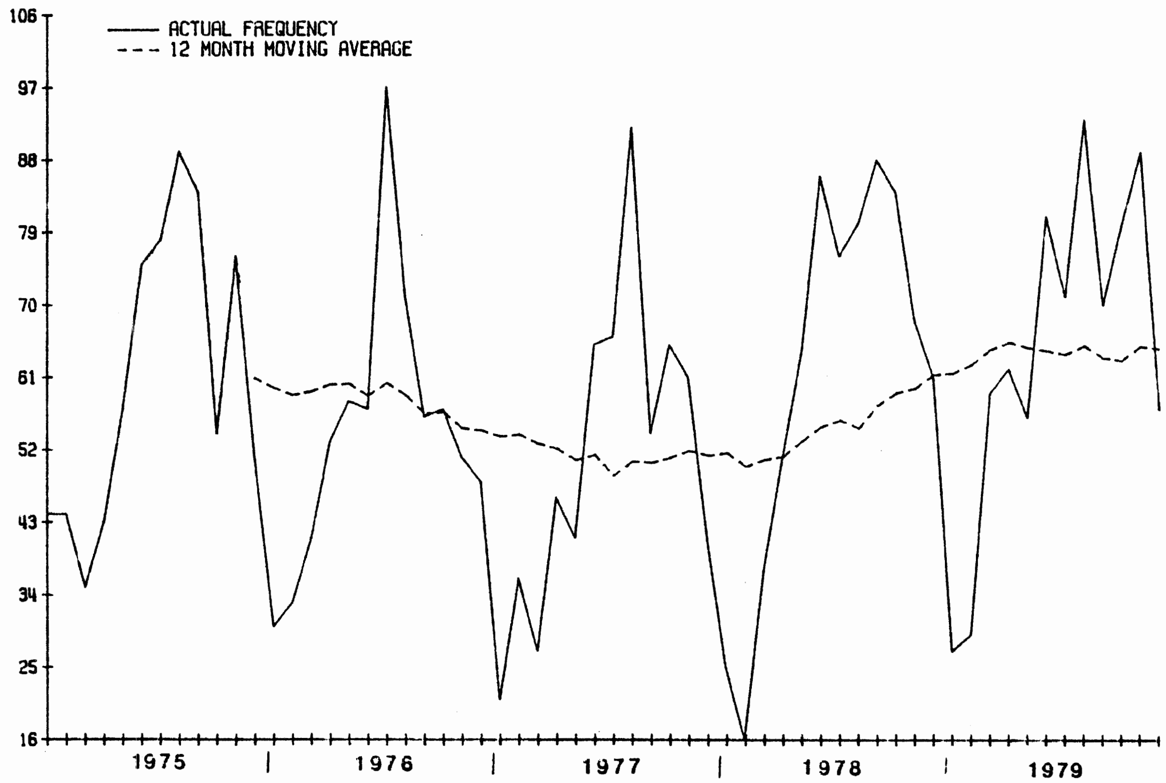


Figure K.3 Male Drivers Age 16-17 Involved in Late-night, Single-vehicle Crashes Including at Least One Injury or Fatality, State of New York

$$\log Y_t = (1 + .27B + .28B^2)u_t + 2.67 - .74\ S_t + .03\ S_{2t}$$

t-ratio 2.07 2.13 23.64 3.67 .11

$$R^2 = .44$$

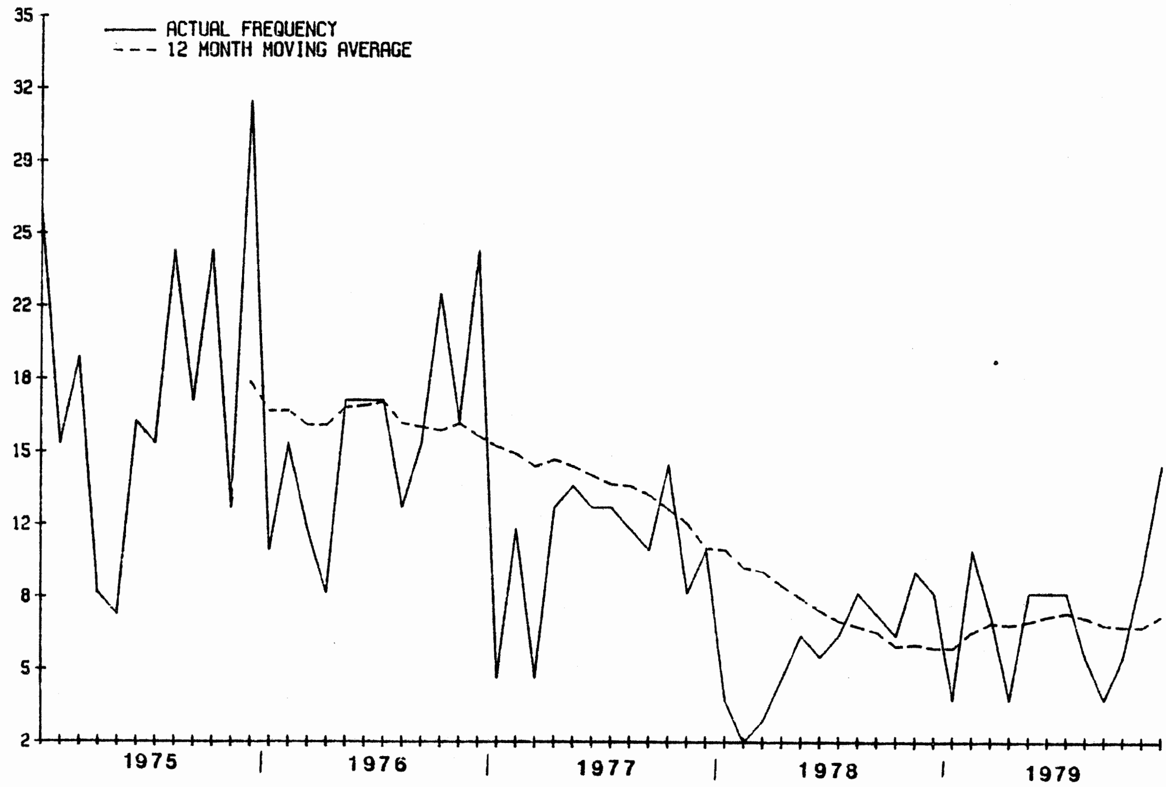


Figure K.4 Male Drivers Age 16-17 Involved in Late-night, Single-vehicle, Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 + .62B^3)(1 - .82B^{12})u_t}{1 - B^{12}} - 3.43\ S_t - 19.61\ P_{2_t} + 1.10\ S_{2_t}$$

t-ratio	6.90	14.86	.70	2.02	.21

$$R^2 = .83$$

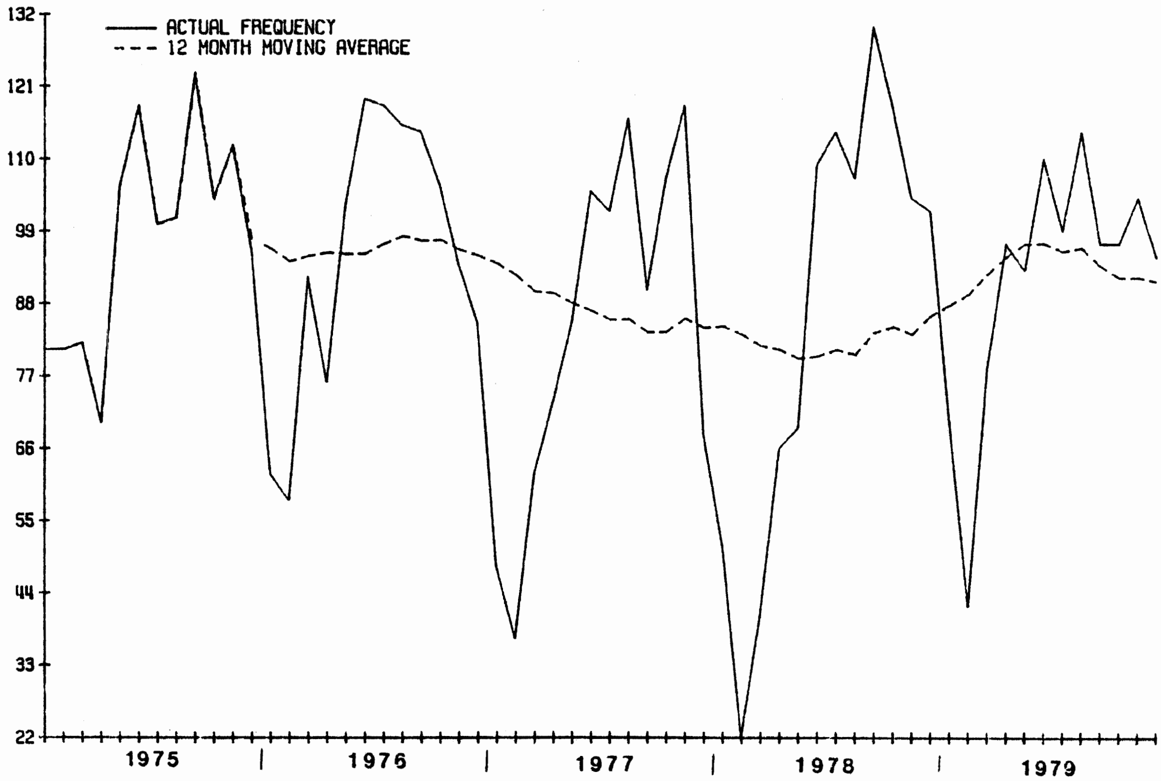


Figure K.5 Male Drivers Age 16-17 Involved in Daytime, Single-vehicle Crashes Including at Least One Injury or Fatality, State of New York

$$\log Y_t = \frac{(1 - .78B^{12})u_t - .27}{1 - B^{12}} - .34\, S_t + .02\, S_{2t}$$

t-ratio	14.56	4.77	2.47	.19

$R^2 = .78$

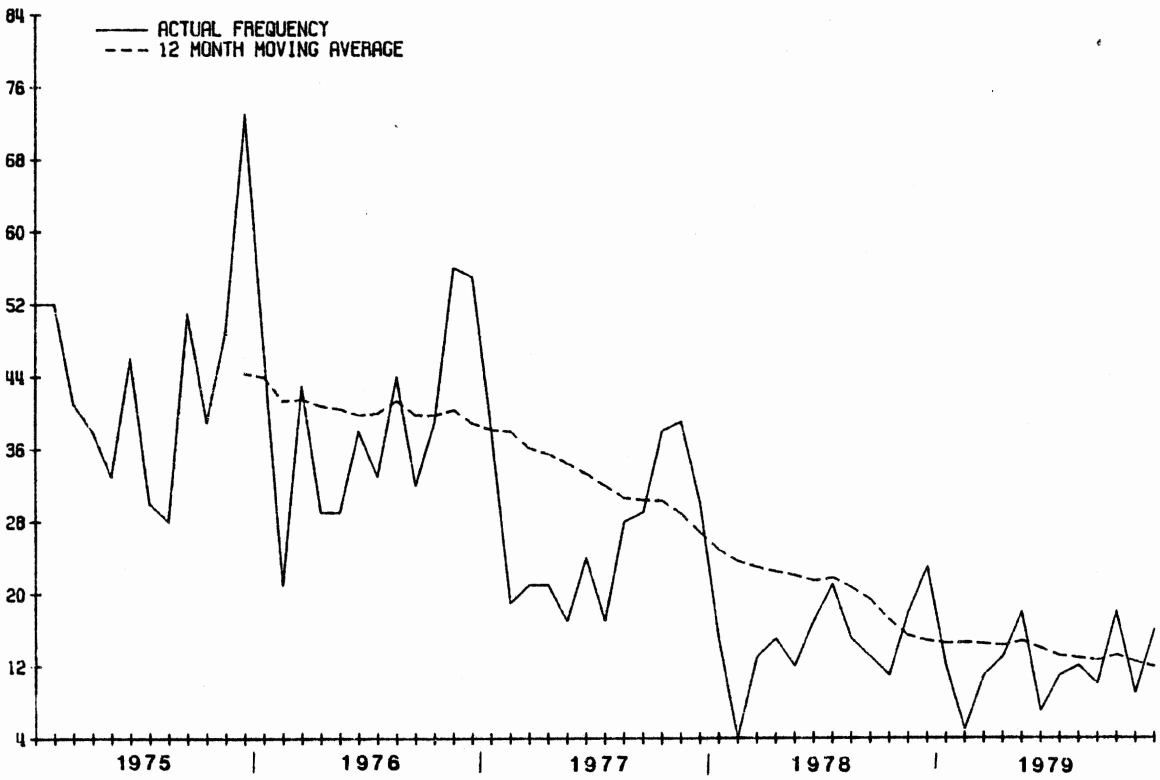


Figure K.6 Male Drivers Age 16-17 Involved in Daytime, Single-vehicle, Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 + .26B)(1 - .82B^2)u_t + 12.73}{1 - B^{12}} + 5.38\ S_t + 23.74\ S_{2t}$$

t-ratio 1.97 14.23 2.54 .43 2.28

$R^2 = .82$

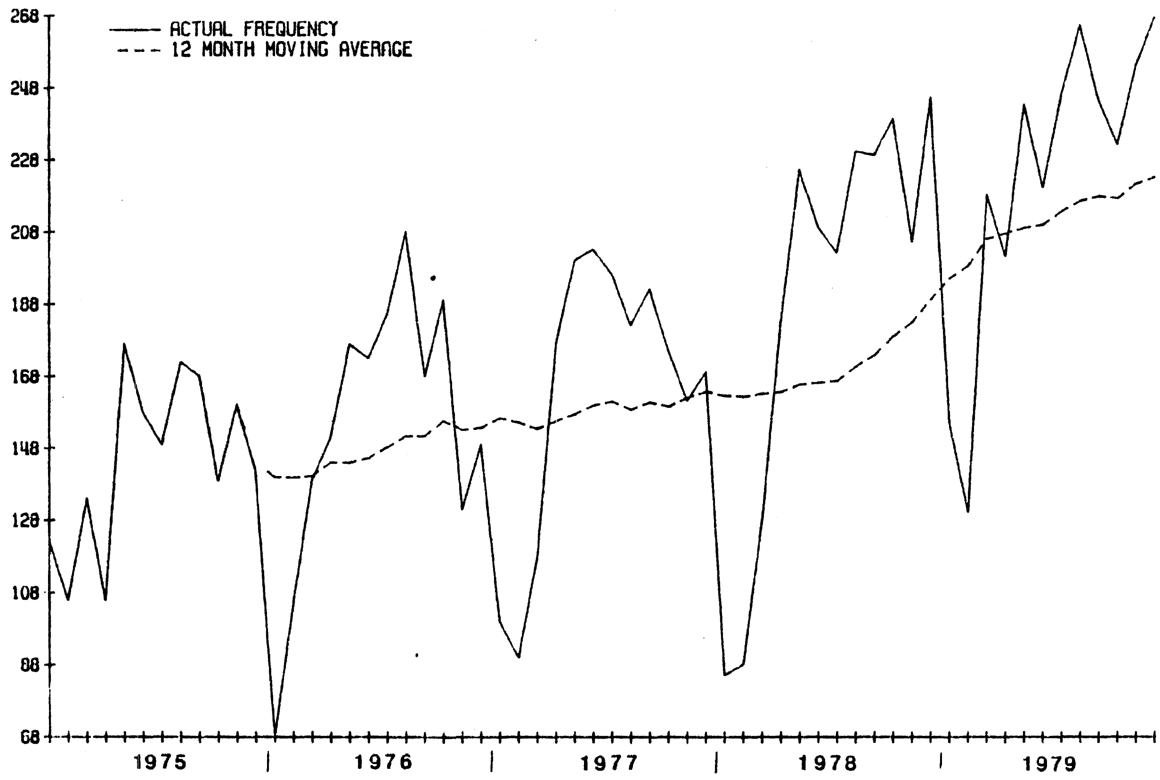


Figure K.7 Police-reported Had Been Drinking Drivers Age 18-20 Involved in Crashes Including at Least One Injury or Fatality, State of New York

$$Y_t = \frac{(1 - .82B^{12})\,u_t}{1 - B^{12}} + 3.54\,S_t - 1.54\,S_{2t}$$

t-ratio 15.17 2.05 .79

$$R^2 = .28$$

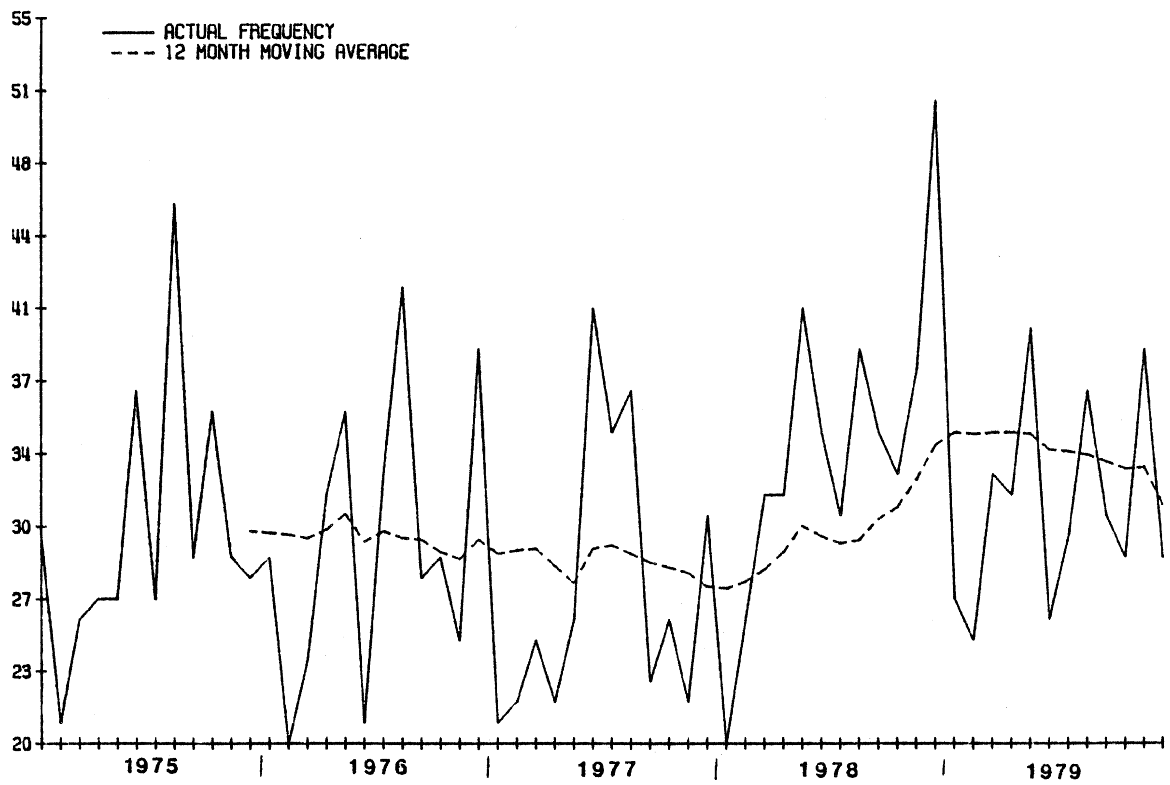


Figure K.8 Police-reported Had Been Drinking Drivers Age 18-20 Involved in Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 + .16B)(1 - .88B^{12})u_t}{1 - B^{12}} - 3.43\ S_t - 57.59\ P_{2t} + 32.72\ S_{2t}$$

t-ratio	1.47	18.56	.39	2.29	3.59

$R^2 = .88$

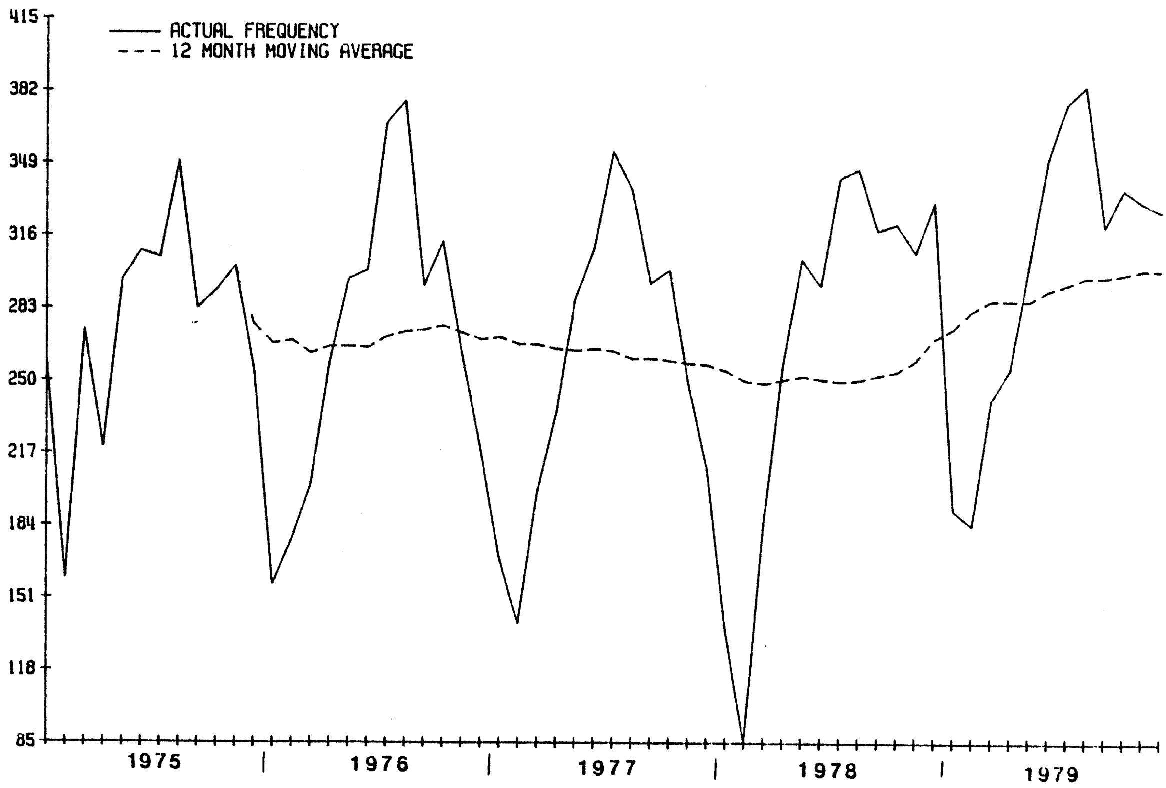


Figure K.9 Male Drivers Age 18-20 Involved in Late-night, Single-vehicle Crashes Including at Least One Injury or Fatality, State of New York

$$\log Y_t = \frac{(1 - .23B - .45B^2)(1 - .74B^{12})u_t}{(1 - B^1)(1 - B^{12})} - .27\ S_t - .27\ P_{2t} + .30\ S_{2t}$$

t-ratio 1.54 3.26 11.11 1.53 1.69 1.72

$$R^2 = .84$$

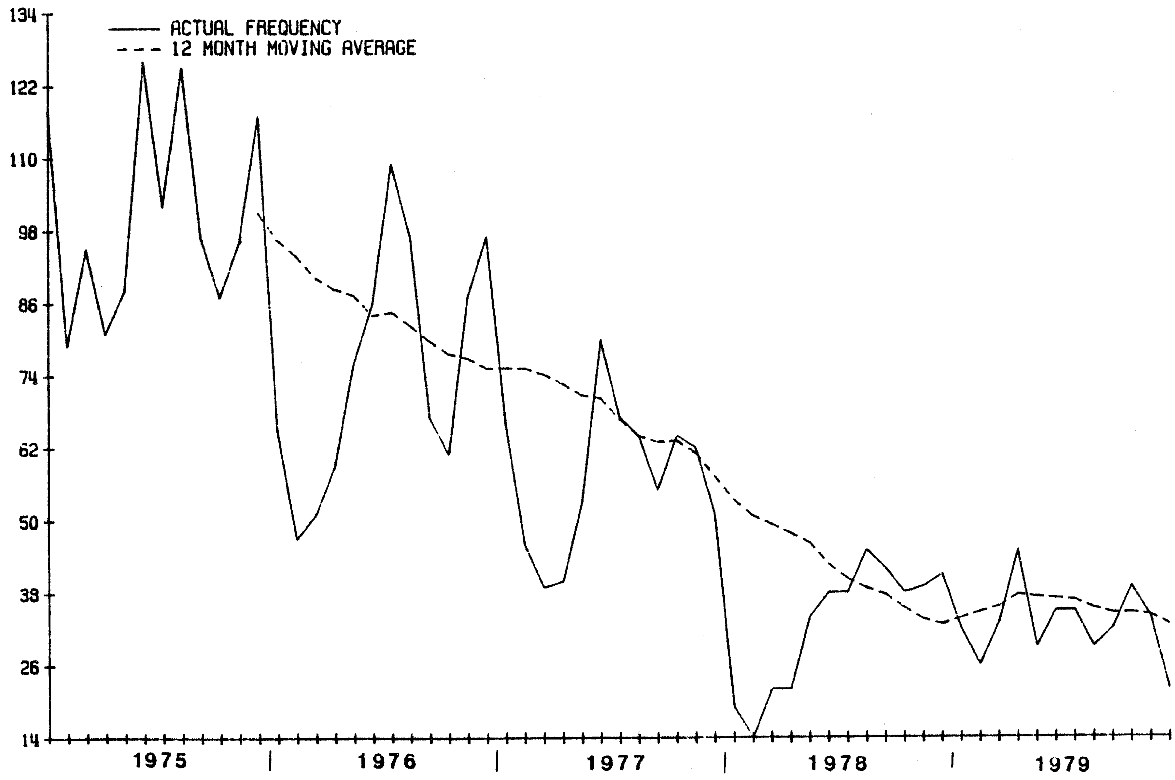


Figure K.10 Male Drivers Age 18-20 Involved in Late-night, Single-vehicle, Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 - .81B^{12})u_t - 8.24}{1 - B^{12}} - .07\ S_t - 41.12\ P_{2_t} + 7.00\ S_{2_t}$$

t-ratio	13.67	2.34	.01	2.15	.95

$R^2 = .78$

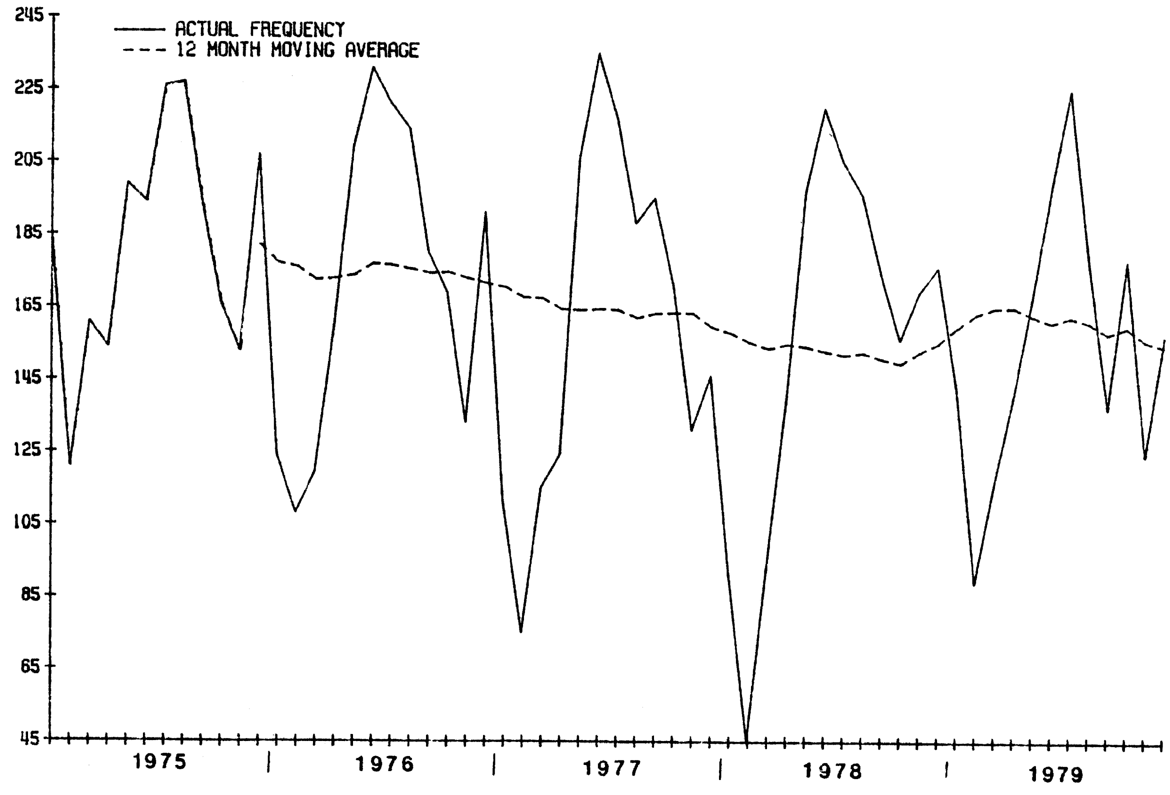


Figure K.11 Male Drivers Age 18-20 Involved in Daytime, Single-vehicle Crashes Including at Least One Injury or Fatality, State of New York

$$\log Y_t = \frac{(1 + .26B + .28B^2)(1 - .78B^{12})u_t - .34}{1 - B^{12}} - .26\ S_t + .38\ S_{2t}$$

t-ratio 1.83 1.97 11.82 6.10 1.89 3.13

$R^2 = .87$

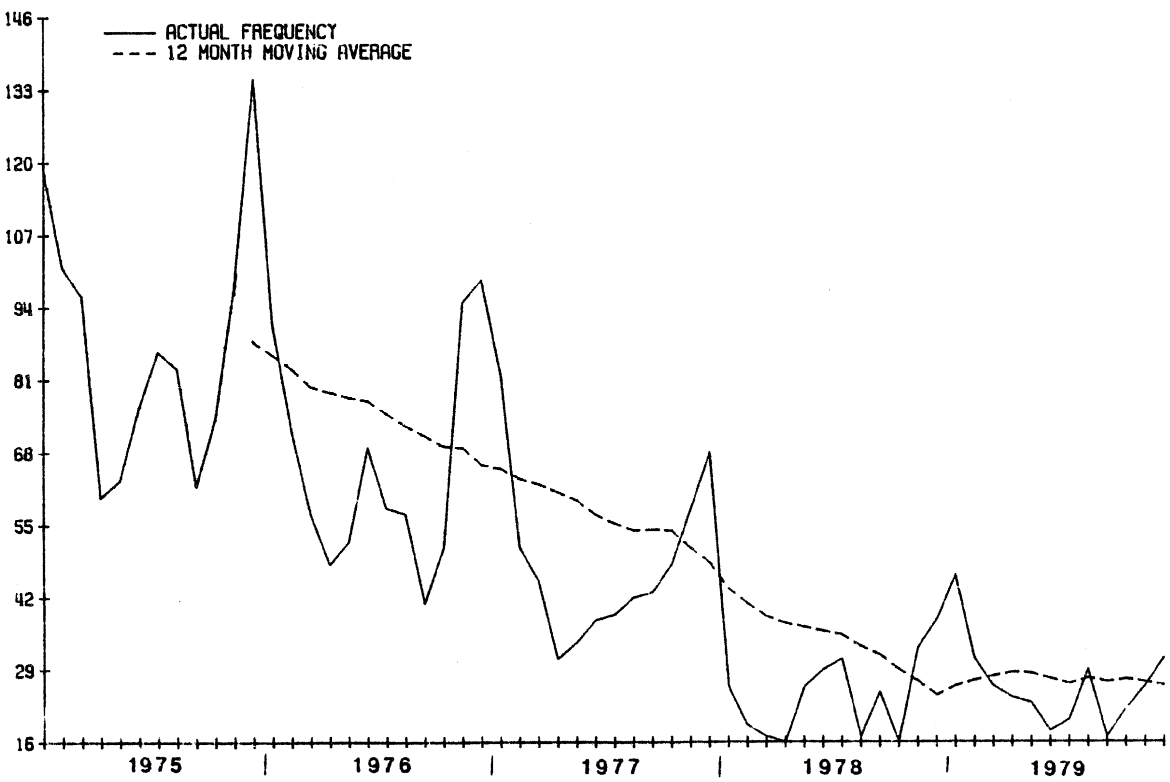


Figure K.12 Male Drivers Age 18-20 Involved in Daytime, Single-vehicle Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 - .84B^{12})u_t}{1 - B^{12}} + 21.54\ S_t - 22.22\ P_{2t} + 31.09\ S_{2t}$$

t-ratio 17.84 5.04 1.52 6.61

$$R^2 = .86$$

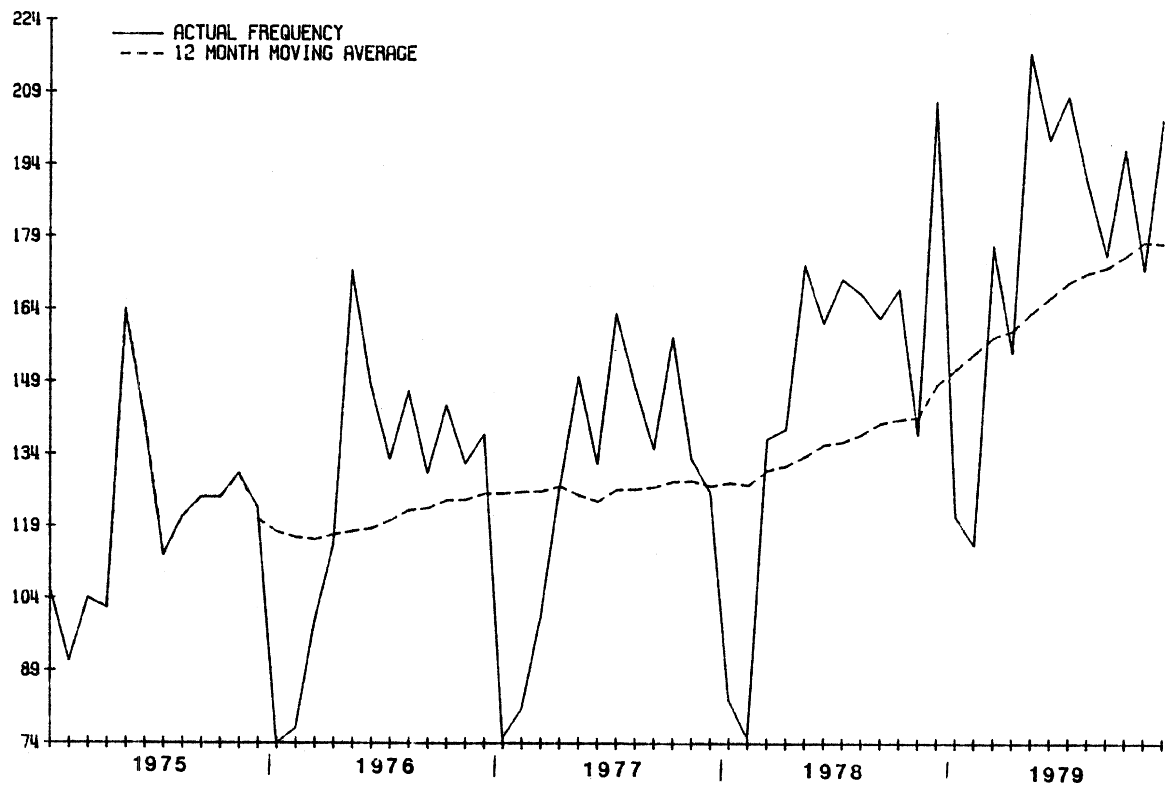


Figure K.13 Police-reported Had Been Drinking Drivers Age 21-23 Involved in Crashes Including at Least One Injury or Fatality, State of New York

$$Y_t = u_t + 23.91 + 1.59\,S_t + 4.17\,S_{2_t}$$

t-ratio 24.67 .89 1.87

$$R^2 = .11$$

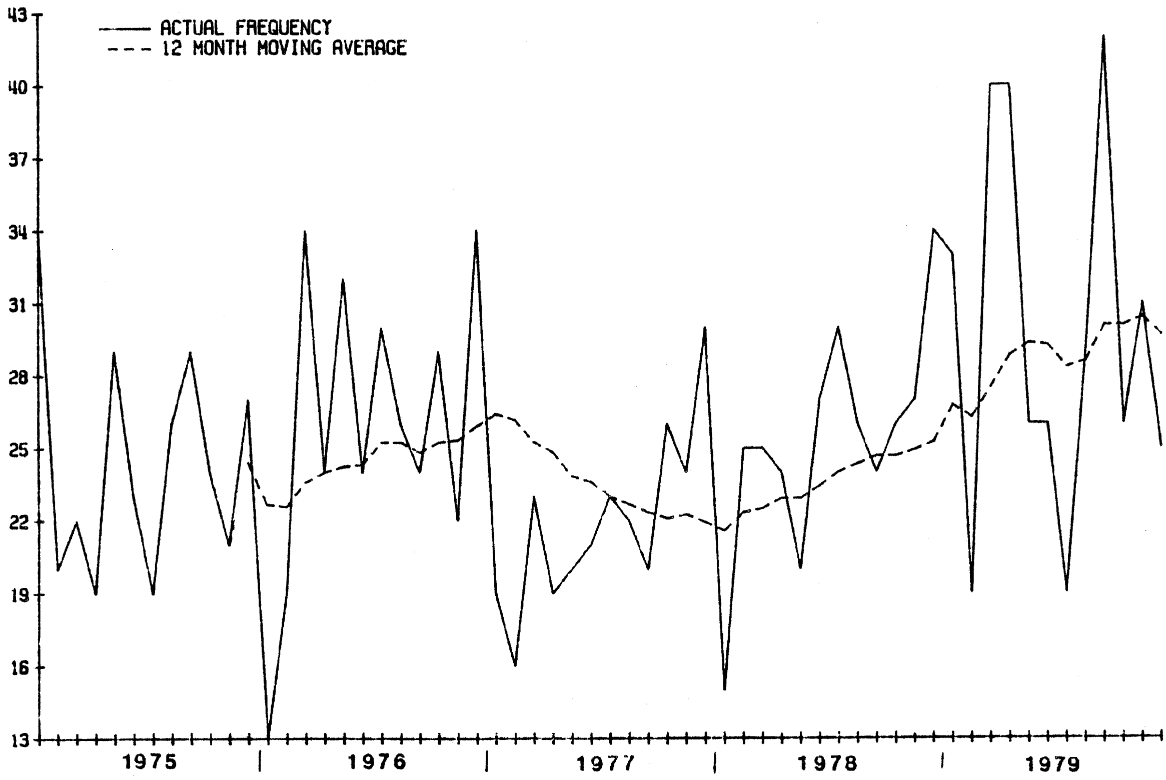


Figure K.14 Police-reported Had Been Drinking Drivers Age 21-23 Involved in Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 + .47B^2)u_t}{1 - B^{12}} - 5.29\, S_t - 30.62\, P_{2_t} + 24.32\, S_{2_t}$$

t-ratio	3.91	.58	2.02	2.57

$$R^2 = .74$$

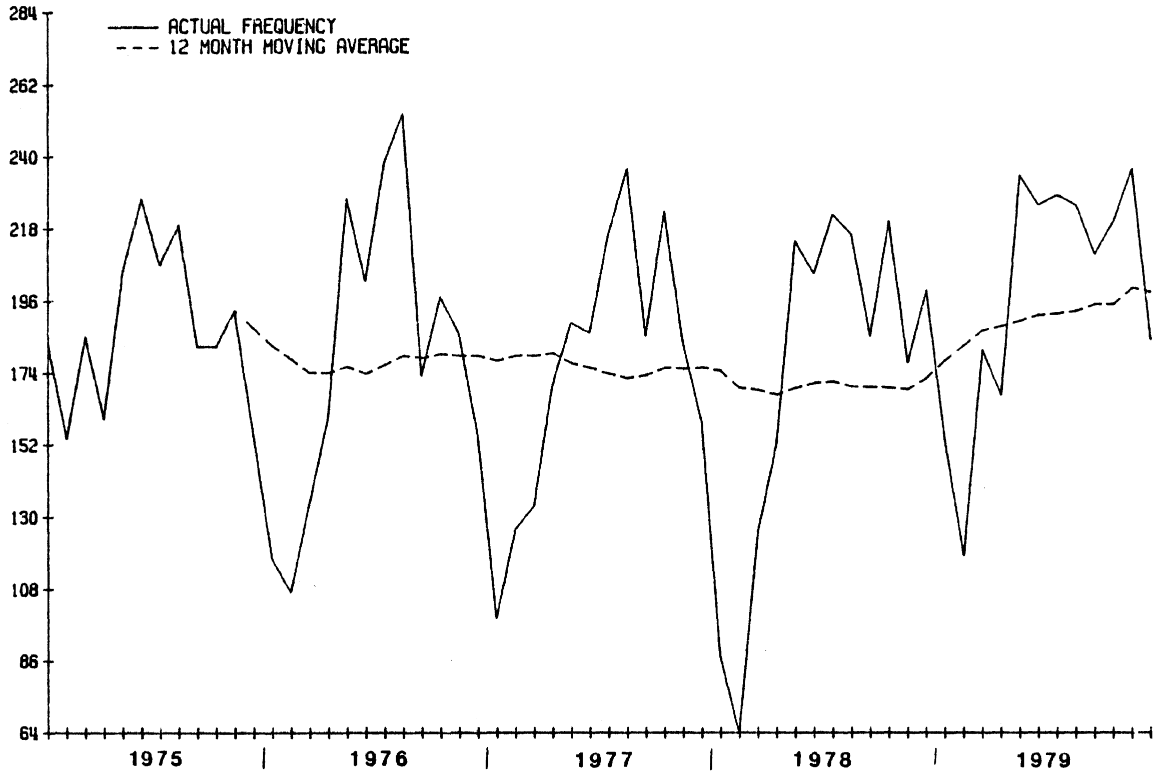


Figure K.15 Male Drivers Age 21-23 Involved in Late-night, Single-vehicle Crashes Including at Least One Injury or Fatality, State of New York

$$\log Y_t = \frac{(1 - .63B)(1 - .84B^{12})u_t - .24}{1 - B^{12}} - .35\, S_t - 1.87\, P_{2t} + .30\, S_{2t}$$

t-ratio	5.46	13.94	12.02	6.74	8.51	7.23

$R^2 = .82$

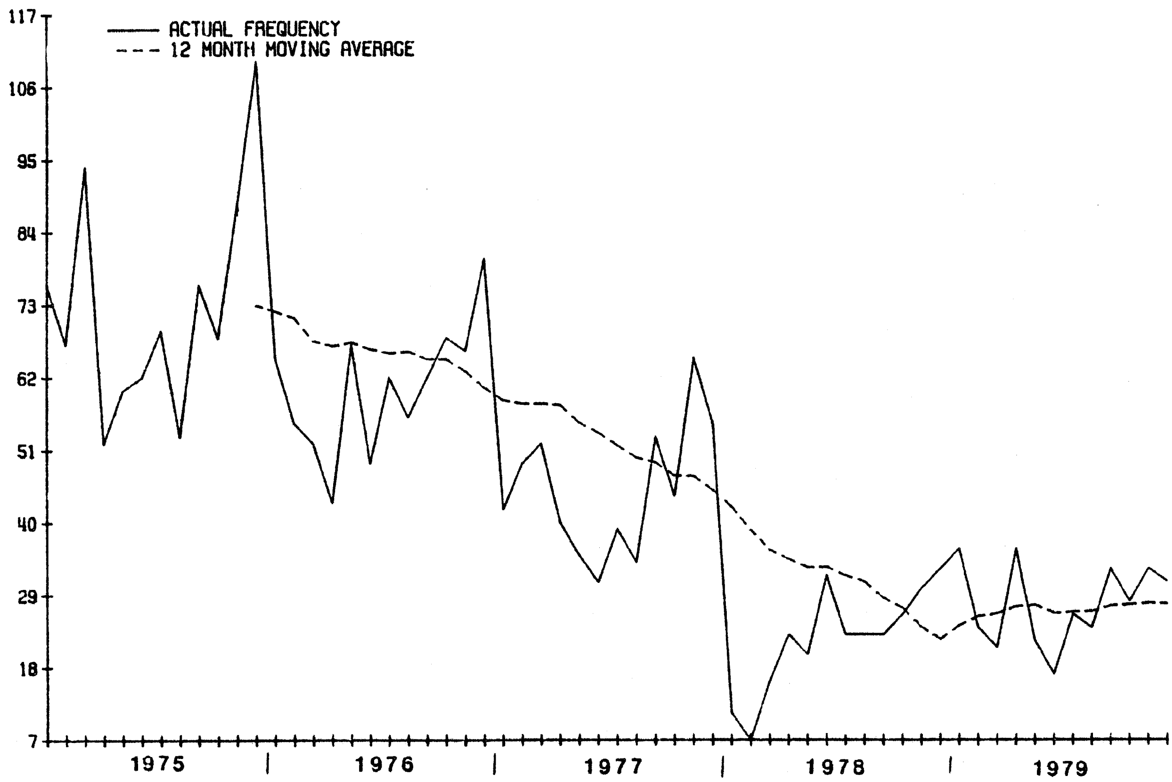


Figure K.16 Male Drivers Age 21-23 Involved in Late-night, Single-vehicle, Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 - .82B^{13})u_t - 3.99}{1 - B^{12}} - .96\ S_t - 32.70\ P_{2t} + 4.01\ S_{2t}$$

t-ratio	14.90	2.21	.22	5.01	1.01

$R^2 = .88$

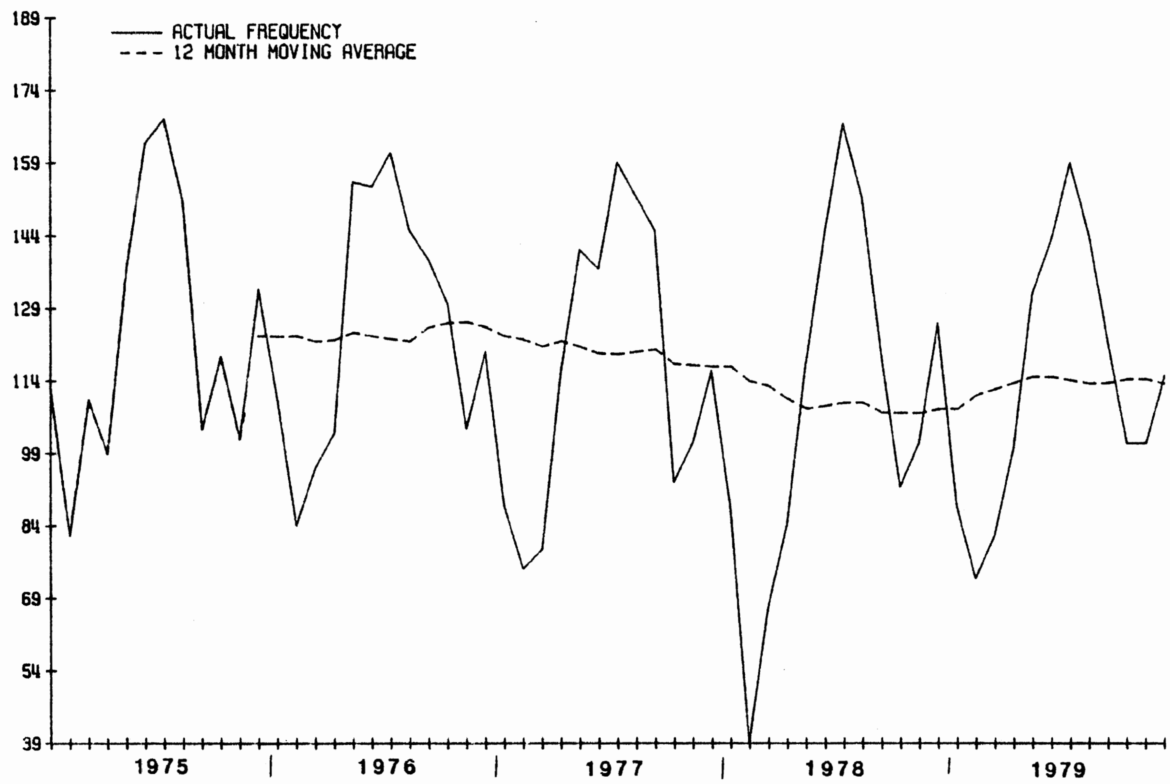


Figure K.17 Male Drivers Age 21-23 Involved in Daytime, Single-vehicle Crashes Including at Least One Injury or Fatality, State of New York

$$\log Y_t = \frac{(1 - .77B^{12})u_t - .26}{1 - B^{12}} - .39\ S_t + .04\ S_{2t}$$

t-ratio 14.23 5.94 3.68 .42

$$R^2 = .87$$

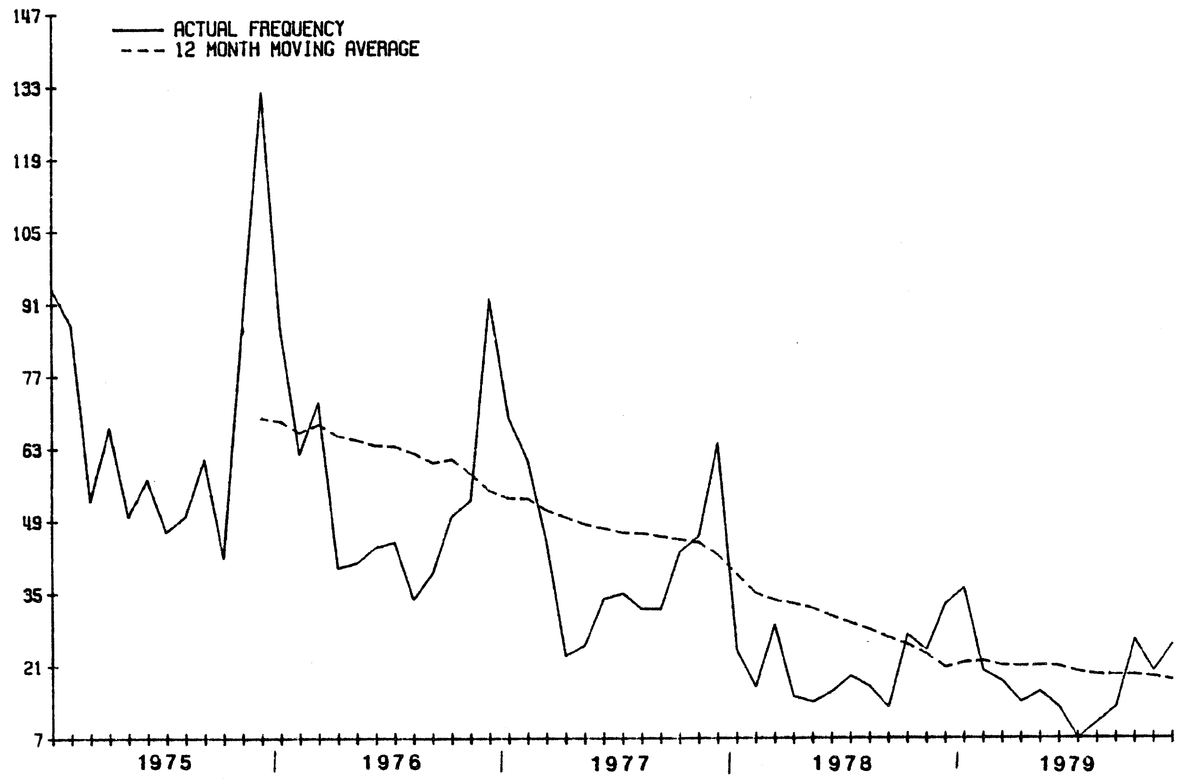


Figure K.18 Male Drivers Age 21-23 Involved in Daytime, Single-vehicle Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 - .76B^{12})u_t}{1 - B^{12}} + 27.52\ S_t + 56.83\ S_{2t}$$

t-ratio 13.09 2.81 4.97

$R^2 = .78$

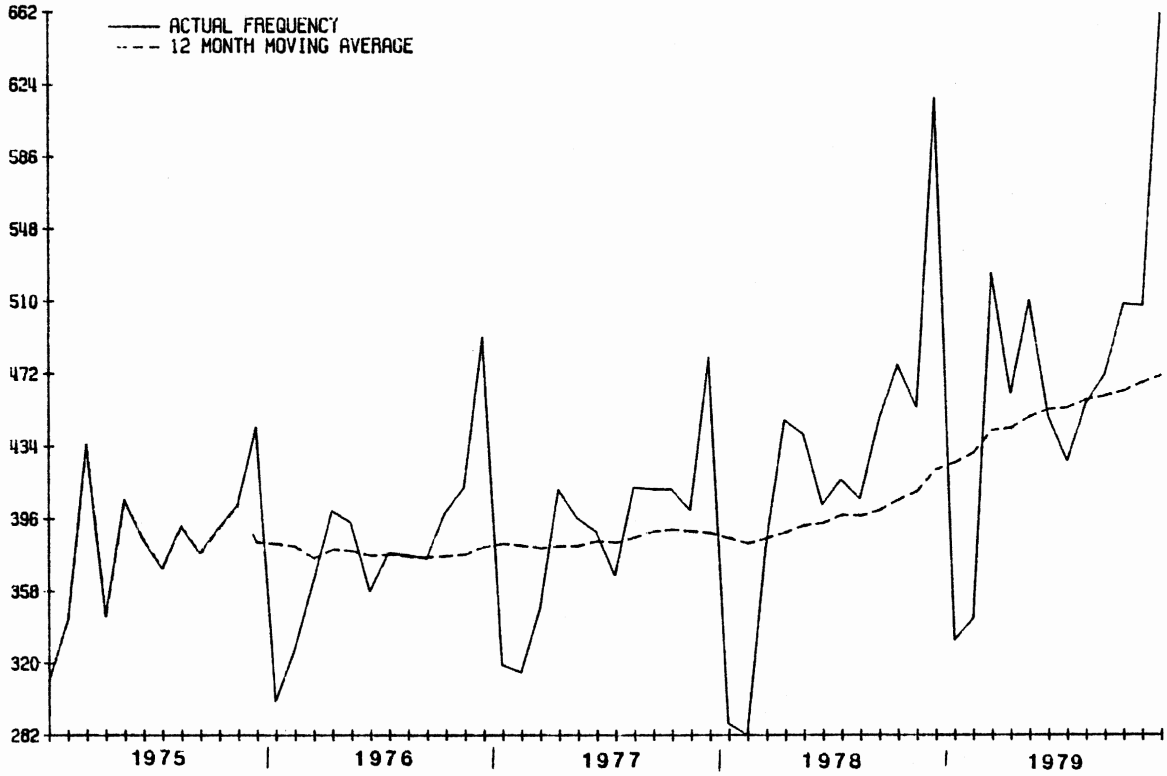


Figure K.19 Police-reported Had Been Drinking Drivers Age 24-45 Involved in Crashes Including at Least One Injury or Fatality, State of New York

$$Y_t = \frac{(1 - .83B^{12})u_t - 7.78}{1 - B^{12}} + 12.03\ S_t + 2.09\ S_{2t}$$

t-ratio 15.06 3.94 2.46 .52

$R^2 = .57$

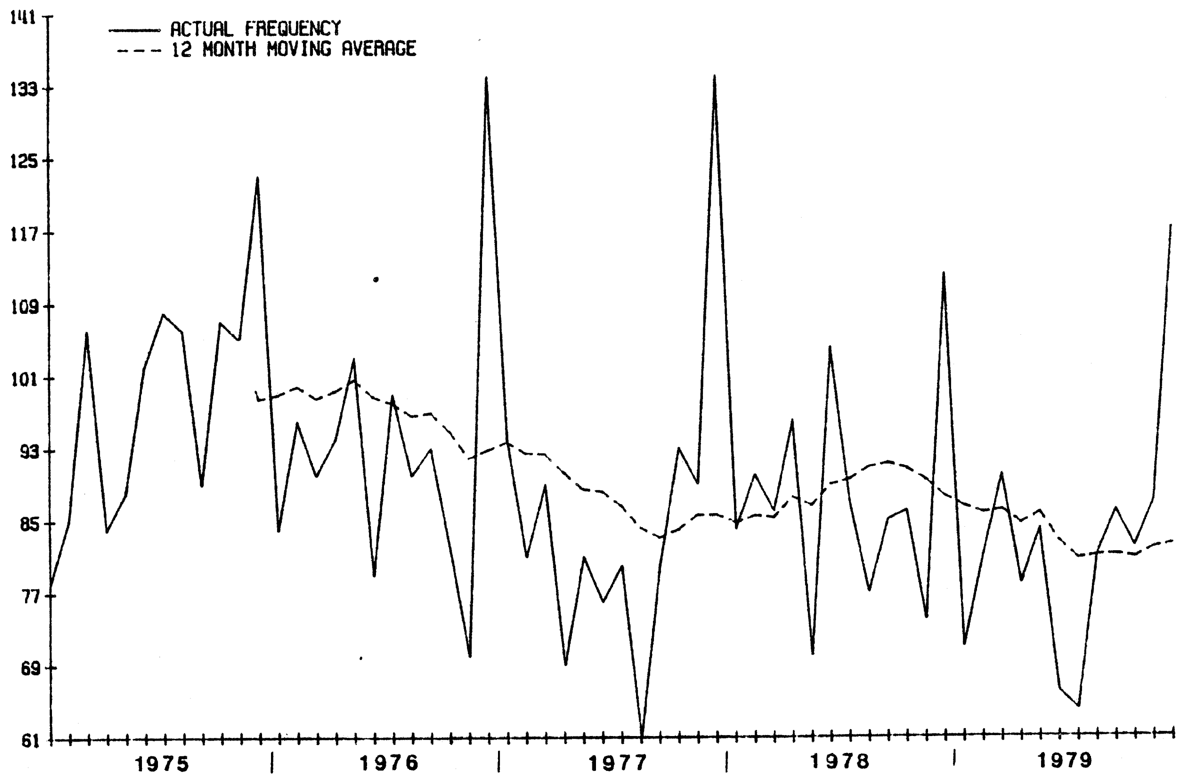


Figure K.20 Police-reported Had Been Drinking Drivers Age 24-45 Involved in Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 - .84B^{12})u_t - 14.70}{1 - B^{12}} + 7.88\ S_t - 83.08\ P_{2t} + 59.62\ S_{2t}$$

t-ratio 13.52 2.36 .50 2.43 4.64

$R^2 = .71$

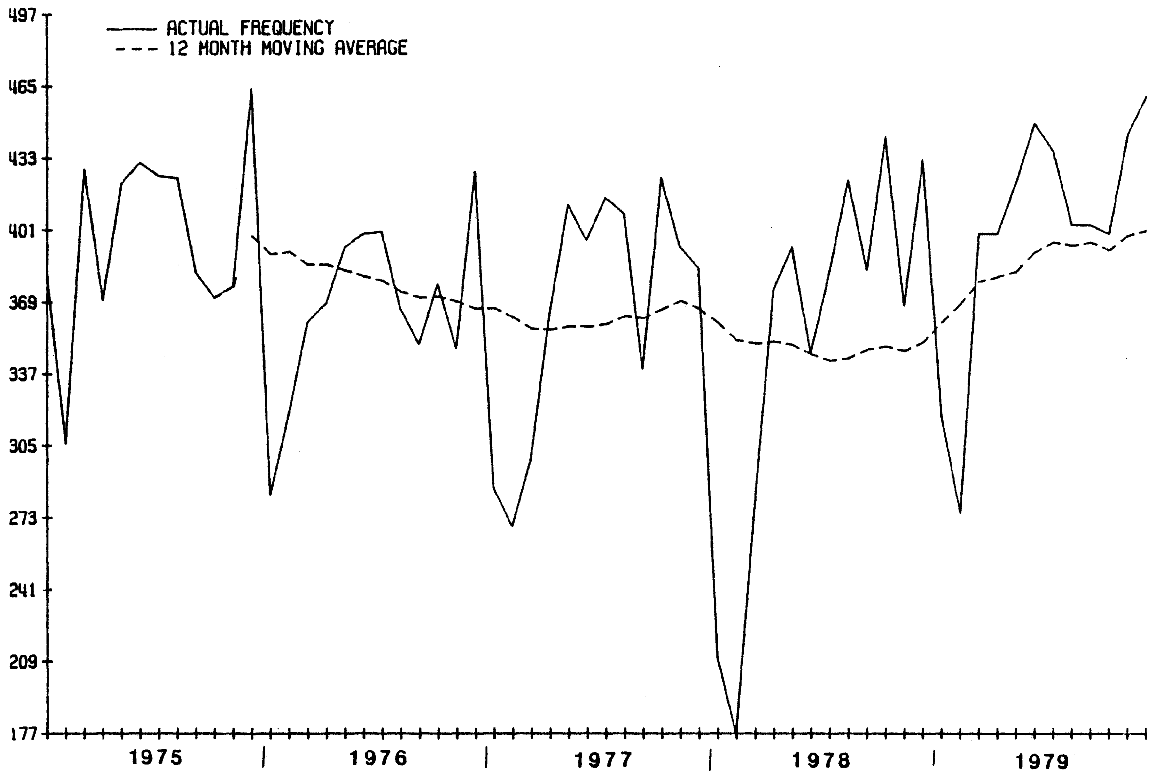


Figure K. 21 Male Drivers Age 24-45 Involved in Late-night, Single-vehicle Crashes Including at Least One Injury or Fatality, State of New York

$$\log Y_t = \frac{(1 + .46B)(1 - .76B^{12})u_t - .15}{1 - B^{12}} - .65\, S_t + .06\, S_{2t}$$

t-ratio 3.47 12.12 2.33 4.05 .44

$$R^2 = .76$$

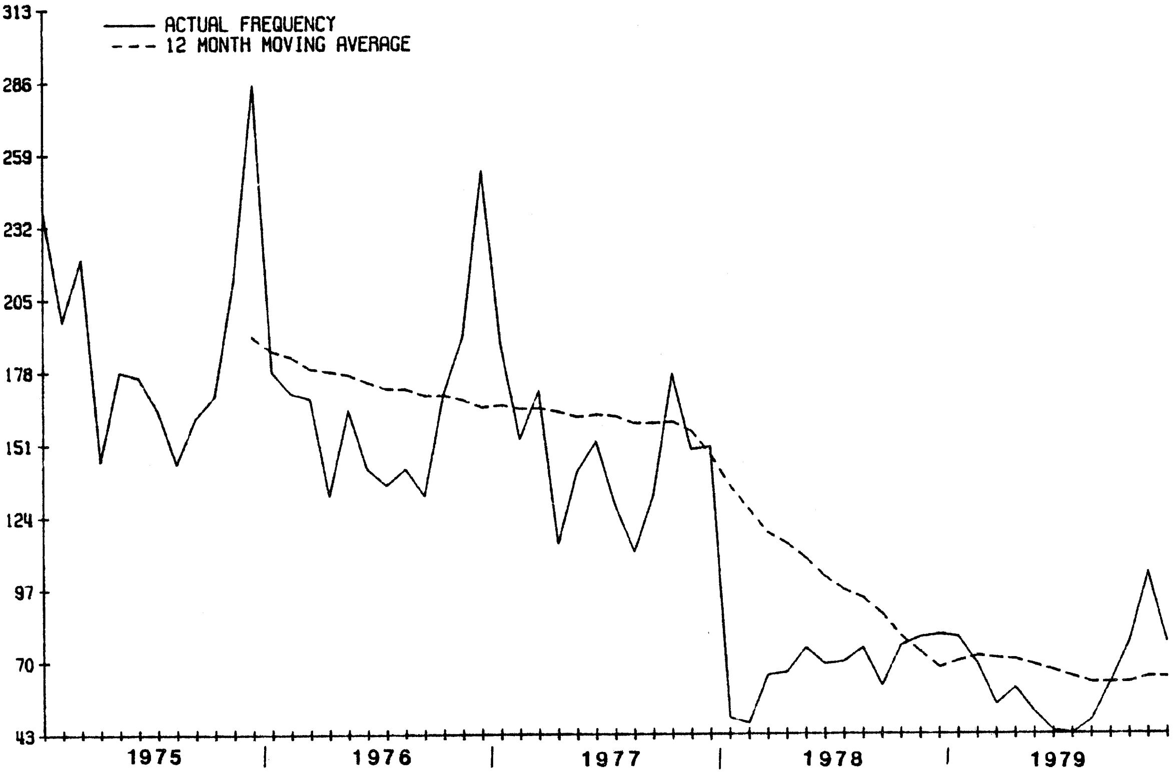


Figure K.22 Male Drivers Age 24-45 Involved in Late-night, Single-vehicle Property Damage Only Crashes, State of New York

$$Y_t = \frac{(1 - .31B)(1 - .81B^{12})u_t}{1 - B^{12}} - 32.71\ S_t - 115.50\ P_{2t} + 7.57\ S_{2t}$$

t-ratio	2.35	15.91	7.07	5.45	1.46

$R^2 = .86$

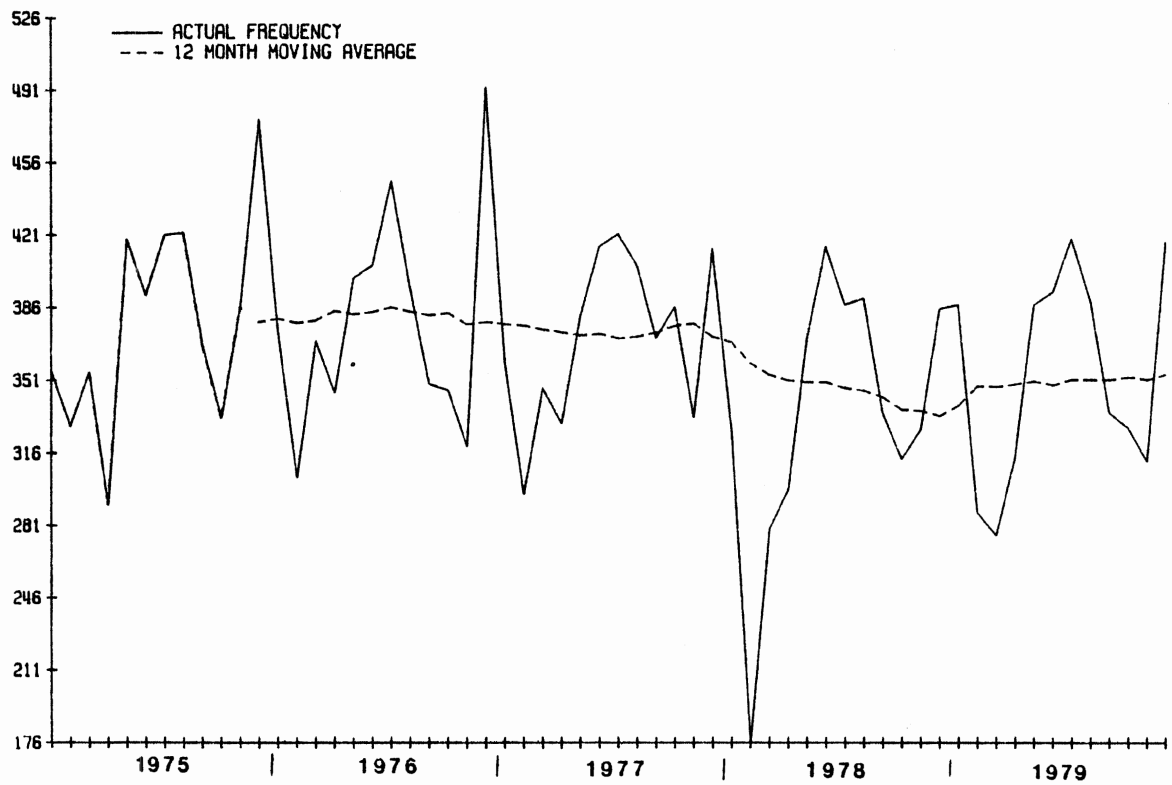


Figure K.23 Male Drivers Age 24-45 Involved in Daytime, Single-vehicle Crashes Including at Least One Injury or Fatality, State of New York

$$\log Y_t = \frac{(1 + .41B)(1 - .80B^{12})u_t - .18}{1 - B^{12}} - .60\ S_t + .07\ S_{2t}$$

t-ratio 3.17 13.76 3.39 4.70 .59

$R^2 = .90$

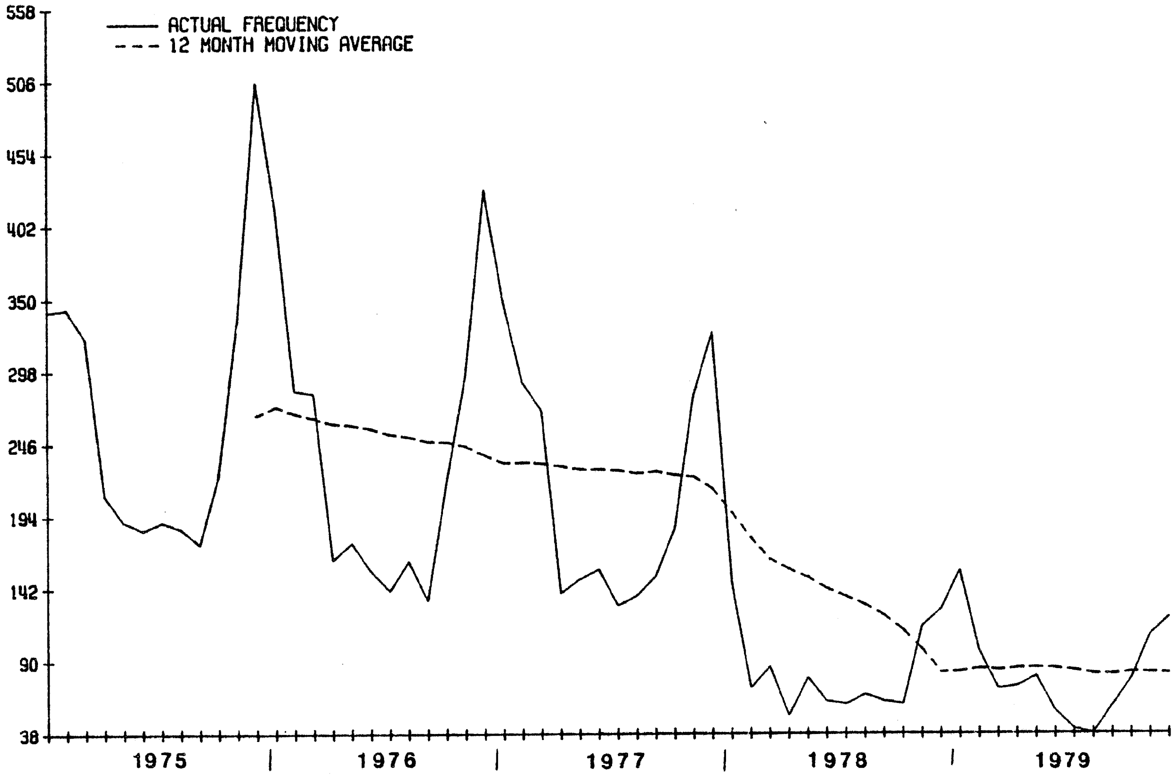


Figure K.24 Male Drivers Age 24-45 Involved in Daytime, Single-vehicle Property Damage Only Crashes, State of New York

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