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16. Abstract

Michigan reduced its drinking age from 21 to 18 in 1972. Several studies have reported significant increases in alcohol-related traffic crashes among drivers affected by the lower drinking age. Michigan raised the drinking age from 18 to 21 in December 1978. This investigation measured the effect of the 1978 increase in the legal drinking age in Michigan on the frequency of alcohol-related traffic crash involvement among young drivers.

A 20 percent random sample of all reported motor vehicle crashes in the State of Michigan from 1972 through 1979 was analyzed. Monthly time-series of these measures were examined for drivers aged 16-17, 18-20, 21-24, and 25-45 using the Box-Jenkins time-series analysis methods. The analyses controlled for long-term trends, seasonality, and other patterns in crash frequency expected to influence the 1979 data.

All age groups had reductions in non-alcohol-related crashes in 1979. Alcohol-related crashes increased slightly for drivers aged 21-45, while these crashes decreased significantly for the 18-20-year-old drivers, who were directly affected by a higher legal drinking age (21) in 1979. 16-17-year-old alcohol-related crashes also decreased in 1979. The reductions in general non-alcohol-related crash frequencies, for all ages, were too small to account for the significant reduction in alcohol-related crash incidence for 18-20-year-old drivers.

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Although many individuals provided assistance and advice throughout the project period, the findings, conclusions, opinions, and recommendations are ours and not necessarily those of the Office of Substance Abuse Services, Michigan Department of Public Health, or the Highway Safety Research Institute of The University of Michigan.

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DISCLAIMER

The findings, conclusions, and recommendations contained in this report are those of the authors, and do not necessarily reflect the views of the Office of Substance Abuse Services, Michigan Department of Public Health, or the Highway Safety Research Institute of The University of Michigan.

1.0 INTRODUCTION

The minimum age at which beverage alcohol may be legally purchased and consumed has been a major political issue in the United States during the past decade. The current controversy began in 1970 when 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, was passed by Congress and rapidly ratified by the necessary 38 states. The amendment became effective in July, 1971. In the subsequent three years all 50 states extended the right to vote in state elections to 18 year olds as part of a broader movement to reduce the age of majority from 21 to 18. During this period, 24 states reduced their minimum legal drinking ages for all alcoholic beverages as one component of reductions in the age of majority. (1) In addition, 11 states lowered the drinking age for wine and/or beer only (National Clearinghouse for Alcohol Information, 1976, 1978). The trend toward a lower legal drinking age stopped by the end of 1973, as evidence began to accumulate that the lowered drinking age resulted in increased alcohol-related problems, particularly traffic accidents, among the 18 to 21 year old population. Since 1972 no states have lowered their legal drinking age, and beginning in 1976, the trend has reversed, with numerous states recently raising their legal drinking ages. (2)

In Michigan, the reduction in the legal drinking age from 21 to 18 for all alcoholic beverages took effect on January 1, 1972 (Michigan State Legislature, 1971). Considerable controversy in intellectual, political, law enforcement, and industrial circles surrounded the reduction in the drinking age (Michigan Council on Alcohol Problems, 1973; Michigan Licensed Beverage Association, 1973; Works, 1973; Distilled Spirits Council of the United States, 1973a, 1973b; Bowen and Kagay, 1973; Zylman, 1973, 1974). Early preliminary evidence was used to argue that substantial increases in alcohol-related traffic accidents among the 18-20 year old population resulted from the 1972 legal change (Michigan Council on Alcohol Problems, 1973). Subsequent controlled research demonstrated the adverse impact of Michigan's lower drinking age upon alcohol-related traffic accidents among youth (Douglass, 1974; Douglass and Freedman, 1977; Flora et al., 1978). Although the estimates of the magnitude of the legal impact from these studies were much smaller than those presented by partisans in the drinking age debate using preliminary evidence, they were consonant with the growing literature on the adverse effects of lower legal drinking ages in various states and Canadian provinces.

Building on the accumulating evidence documenting the adverse impact of the lower legal age upon youthful alcohol-related problems, particularly traffic accidents, those opposed to the reduced drinking age lobbied in favor of raising the drinking age. The Michigan Legislature, responding to increasing pressure, passed Public Act 94 early in 1978, which raised the legal drinking age from 18 to 19 effective December 3, 1978. Since a number of voters were not satisfied with the drinking age move from 18 to 19, the Michigan Council on Alcohol Problems' "Coalition for 21" continued their statewide petition drive that successfully placed a proposed constitutional amendment raising the drinking age to 21 on the November 1978 general election ballot. The proposal passed with a substantial margin and had the effect of raising the legal drinking age in Michigan to 21 on December 23, 1978.(3) Note that the constitutional amendment did not include a "grandfather" clause whereby 19 and 20 year olds who had had the legal right to drink prior to the effective date of the constitutional change would continue to possess that right. After December 23, 1978, persons aged 19 and 20 who had had the right to drink were no longer legally allowed to purchase alcoholic beverages. As occurred after the 1972 reduction in the legal drinking age, preliminary data were used by both supporters and opponents of the raised drinking age to bolster their positions (Distilled Spirits Council of the United States, 1979; Michigan Council on Alcohol Problems, 1979; Publicom, 1979). The need for a rigorous, controlled evaluation of the impact of the raised legal drinking age in Michigan became evident, and as a result, the Michigan Department of Public Health, Office of Substance Abuse Services initiated the present project. (4)

The goals of this investigation were twofold. The first goal was to provide objective information concerning the effect of the legal drinking age upon traffic accidents among youth to policy-makers and voters in Michigan and elsewhere who must continue to deal with the drinking age issue. (5) A major concern in discussions of social policy on the legal drinking age was the extent to which modifications in the drinking age caused changes in the motor vehicle accident experience of young drivers. As a result, a major feature of this investigation was a strong emphasis on a research design with high validity and an explicit explanation of numerous potential alternative explanations of the observed relationships between the drinking age and traffic accidents. The second goal of the present study was to utilize naturally occurring experiments with the minimum legal drinking age to test propositions based on an emerging theory concerning the impact of beverage alcohol availability on alcohol consumption and alcohol-related public health problems.

Several features of the present investigation, few of which have been included in previous research, provided a unique contribution to the literature on the drinking age. First, this study used longer time-series of observations than any drinking age evaluation conducted to date; (6) second, two measures of traffic accidents, (7) and two measures of alcohol-related accidents, (8) strengthened the construct validity of the study; third, the impact of the drinking age was assessed while explicitly incorporating the effects of the fuel shortage and national minimum speed limit reduction of early 1974 into the analyses; (9) fourth, the effect of a raised legal drinking age was systematically examined for the first time; and fifth, a comparison was made between the effects of a lowered legal age and the effects of a subsequent return to the original higher drinking age in a single geographic and socio-cultural environment. The above features of the present investigation provide important new information for input into the policy-making process with regard to the legal drinking age, and for the continued refinement of preliminary theories concerning the impact of changes in the availability of beverage alcohol on acute alcohol-related health and safety problems.

Notes to Chapter 1.0

1. States that reduced their legal drinking ages for all alcoholic beverages between 1970 and 1973 were: Alaska, Arizona, Connecticut, Delaware, Florida, Georgia, Hawaii, Idaho, Iowa, Maine, Massachusetts, Michigan, Minnesota, Montana, Nebraska, New Hampshire, New Jersey, Rhode Island, Tennessee, Texas, Vermont, West Virginia, Wisconsin, and Wyoming (National Clearinghouse for Alcohol Information, 1976).

2. States that raised their legal drinking ages after 1976 include: Illinois, Iowa, Maine, Massachusetts, Michigan, Minnesota, Nebraska, New Hampshire, New Jersey, and Tennessee (based on Hammond, 1979 and information provided by the National Clearinghouse for Alcohol Information).

3. After the constitutional amendment was approved in November 1978, the legislature passed implementation legislation that was signed by the Governor just two days before the effective date of the constitutional amendment (Public Act 531 of 1978).

4. Michigan provided an ideal site for a detailed examination of the differential effects of a lowered and raised drinking age, since it was the first state to raise its drinking age from 18 to 21 after an earlier reduction from 21 to 18.

5. Efforts to place a proposed constitutional amendment lowering the legal drinking age from 21 to 19 on the November 1980 Michigan general election ballot through the initiative process were underway when, in early July 1980, the Michigan legislature, with a substantial margin, bypassed the initiative efforts by approving a measure placing the proposed constitutional amendment on the November 1980 ballot (Detroit Free Press, 1980).

6. Twelve years of monthly fatal accident frequencies (144 observations), and eight years of monthly total accident frequencies (96 observations).

7. Frequency of crash involvement and frequency of fatal crash involvement.

8. The frequency of police-reported drinking drivers, and the frequency of surrogate measure alcohol-related crashes (i.e. late night, single-vehicle crashes involving a male driver).

9. Using the Box-Jenkins transfer function modeling techniques.

2.0 BACKGROUND LITERATURE, THEORY, AND DEVELOPMENT OF HYPOTHESES

This chapter reviews several distinct areas of research literature that are relevant for an examination of the legal drinking age issue. Included are discussions of: (A) drinking patterns among youth, (B) traffic accident experience of young drivers, (C) previous evaluations of drinking age changes, (D) general models for the prevention of alcohol-related problems, (E) a specific model of the effects of the legal drinking age, and (F) a specification of the direction and magnitude of the hypothesized effects of changes in the legal minimum drinking age in Michigan.

2.1 Alcohol and Highway Safety Among Youth

A major component in the legal drinking age debate has been the impact of modifications of the drinking age on the 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.

2.1.1 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 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, 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. The prevalence of monthly intoxication 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 the various surveys. Their best estimate of average drinking frequency among teenage drinkers aged 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, the 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 do drink regularly and a substantial number also frequently become intoxicated.

The above discussion has been limited to the 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 than the literature on adolescents. Existing surveys of college students indicate that the prevalence of drinkers 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 aged 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, O'Malley and Bachman (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). (1)

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 regularly become intoxicated appears to be increasing, with current data indicating that more than one-third of the 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.

2.1.2 Traffic Accidents. Motor vehicle accidents are the leading cause of death among youth aged 15 to 24, claiming 18,092 lives in the United States in 1977 (National Safety Council, 1979). A large number of interacting factors that have been identified as causes of traffic accidents are presented in Figures 2.1 through 2.6. Figure 2.1 depicts five broad classes of motor vehicle accident causes, while Figures 2.2 through 2.6 indicate the specific variables within each class.

Intensive investigations of random samples of accidents conducted at Indiana University by the Institute for Research in Public Safety have revealed that vehicular factors (Figure 2.3) were a definite cause of the collision in about 5 percent of the cases, and environmental factors (Figure 2.2) were a definite cause in about 20 percent of the accidents examined (Institute for Research in Public Safety, 1975). Human direct causes (Figure 2.4), 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.

As shown in Figure 2.1, the human errors that cause most collisions are often a direct result of human conditions at the time of

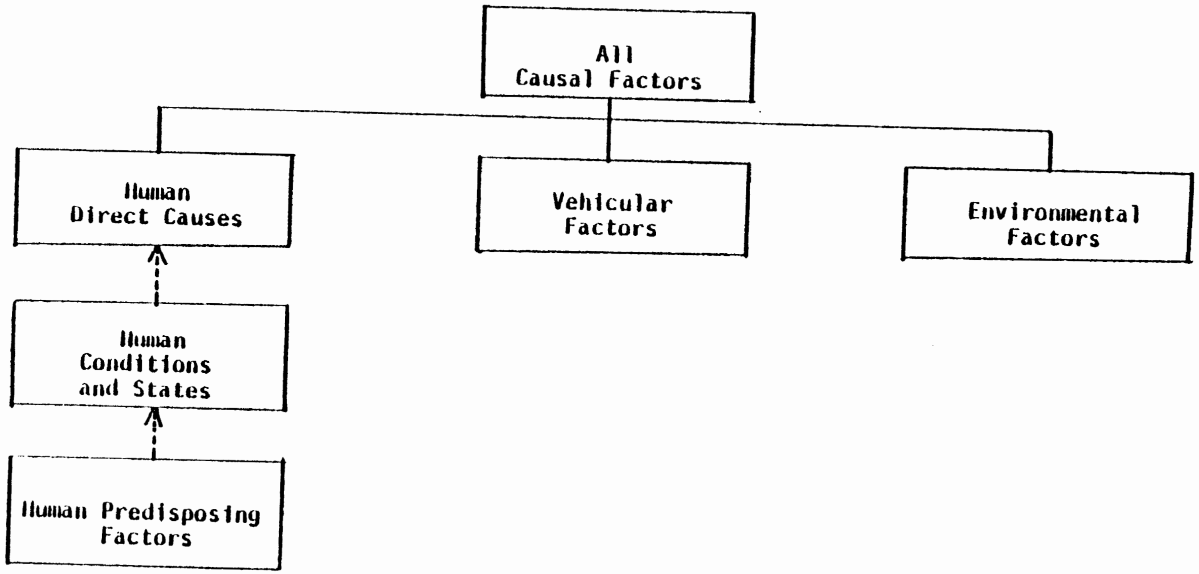

Figure 2.1 Major Categories of Causal Factors in Motor-vehicle Collisions

Source: Institute for Research in Public Safety (1975)

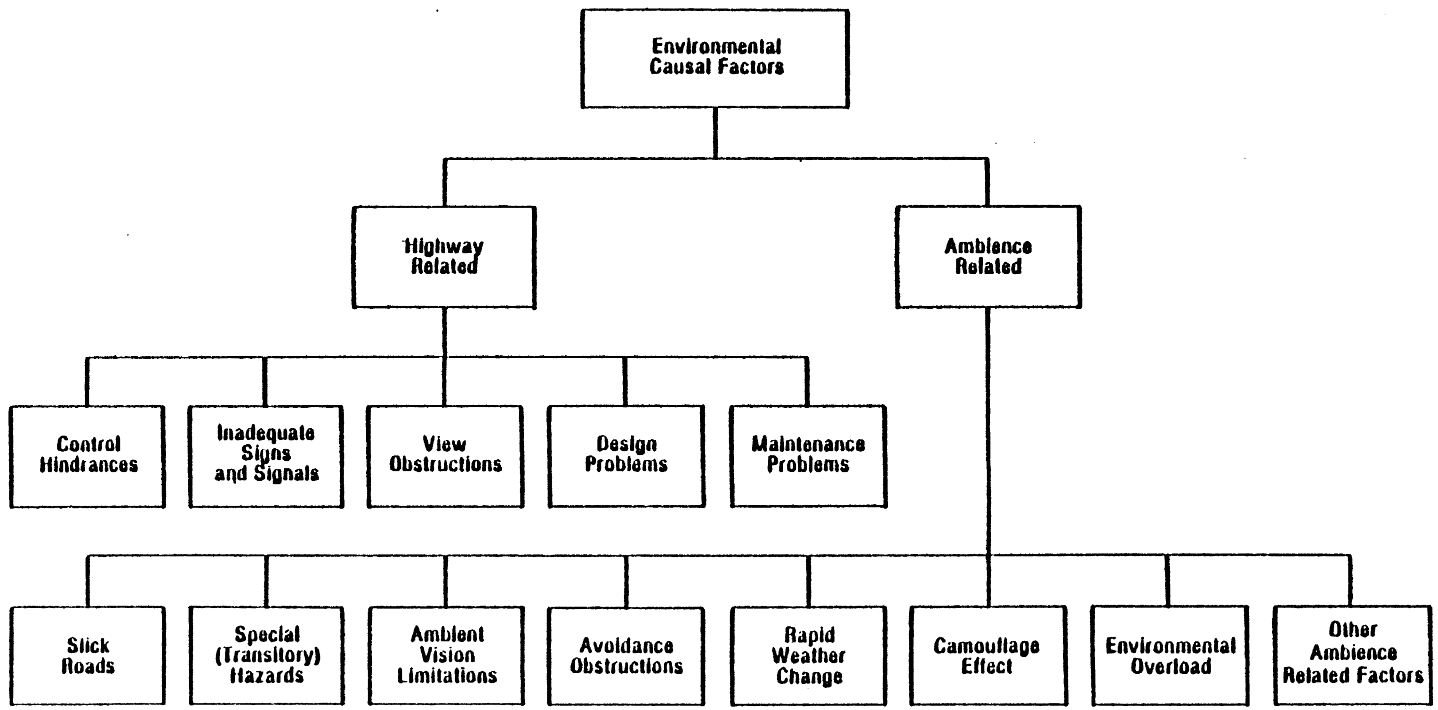

Figure 2.2 Environmental Causal Factors in Motor-vehicle Collisions

Source: Institute for Research in Public Safety (1975)

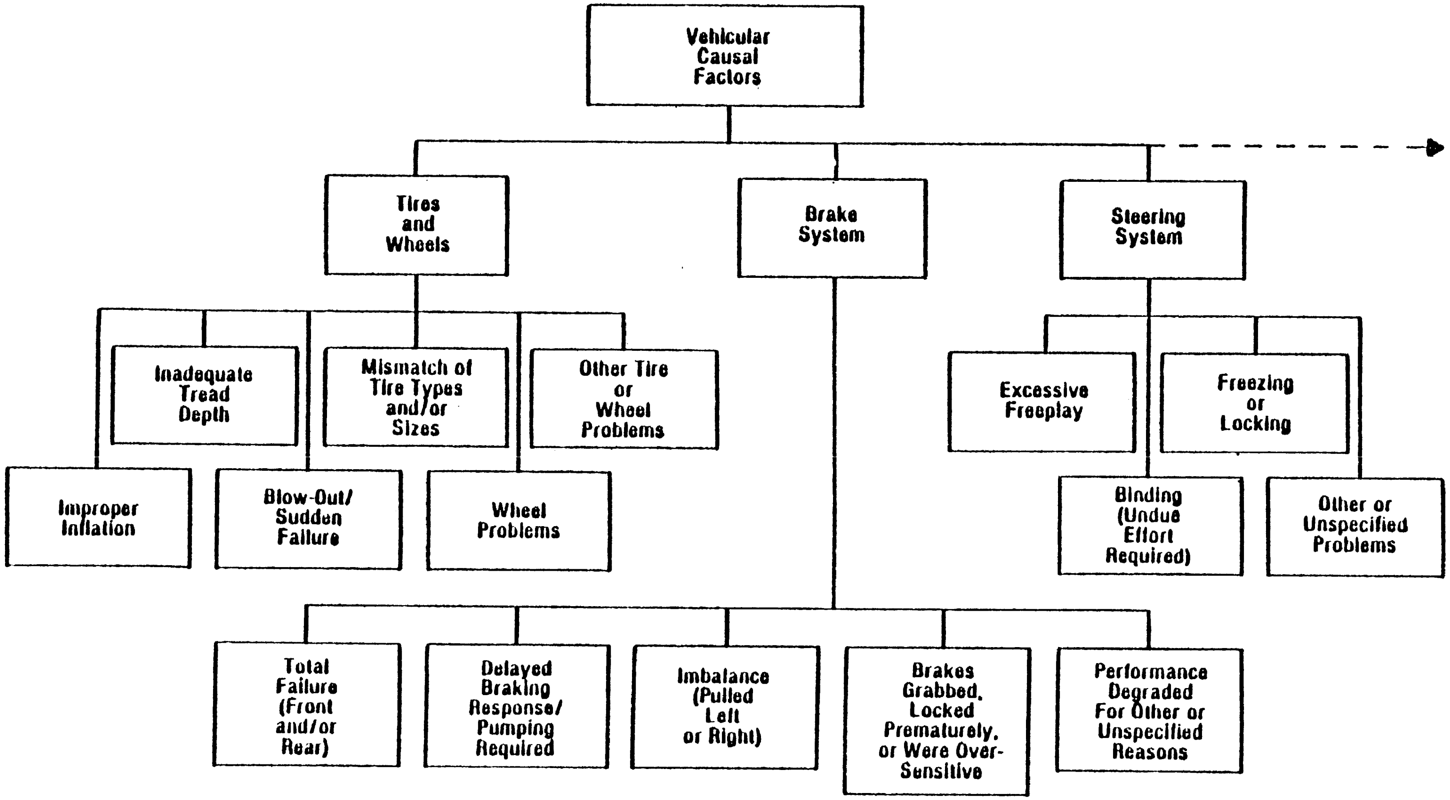

Figure 2.3 Vehicular Causal Factors in Motor-vehicle Collisions

Source: Institute for Research in Public Safety (1975)

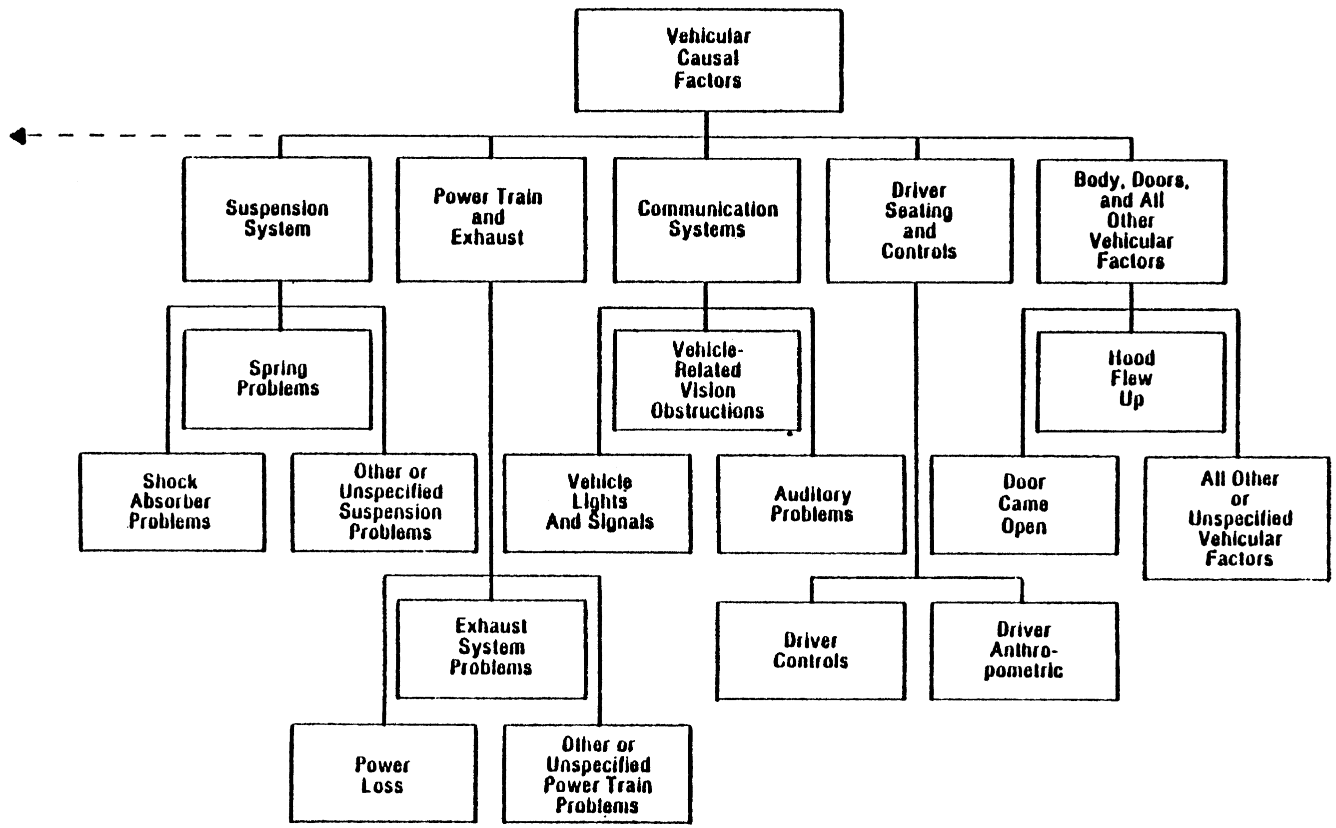

Figure 2.3(continued) Vehicular Causal Factors in Motor-vehicle Collisions

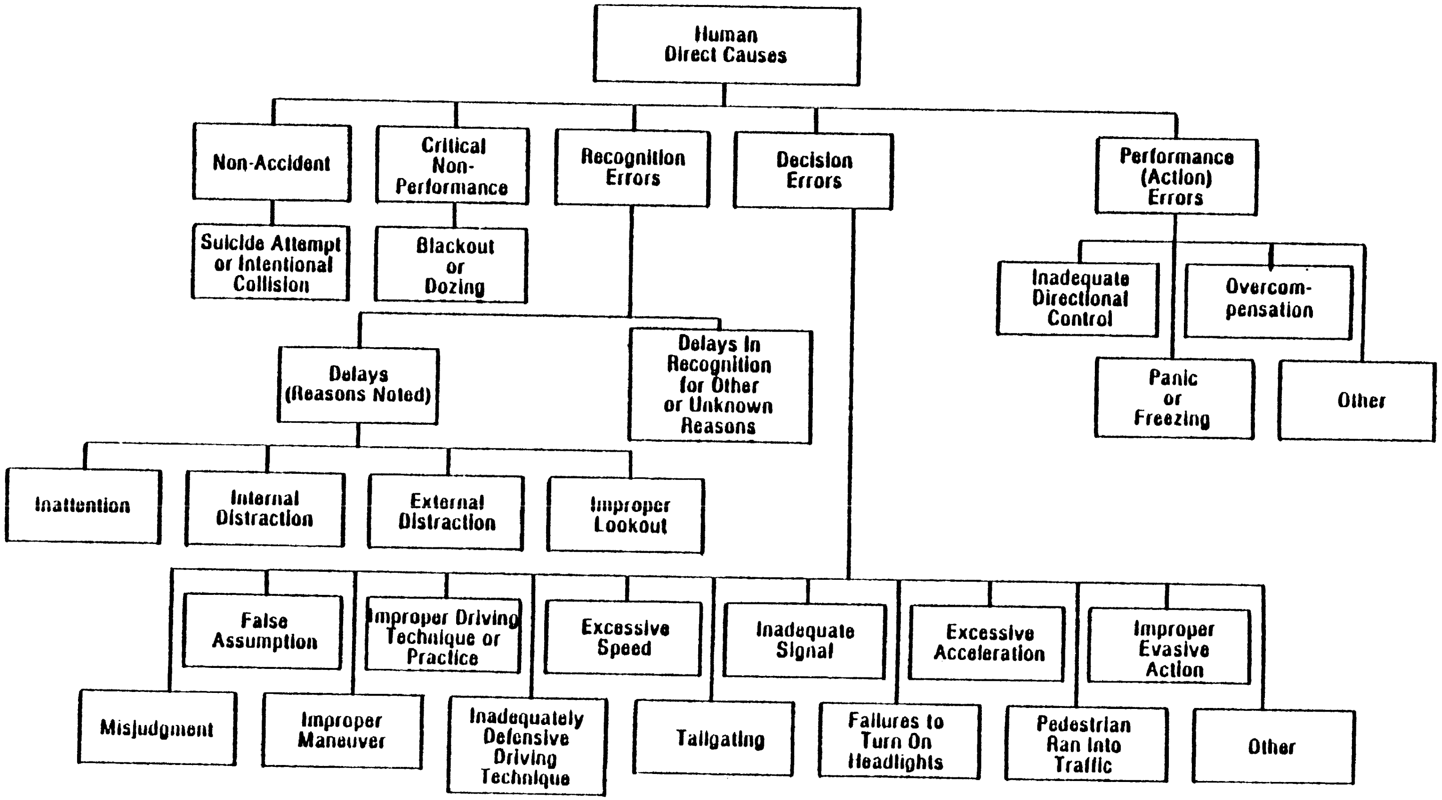

Figure 2.4 Human Direct Causes in Motor-vehicle Collisions

Source: Institute for Research in Public Safety (1975)

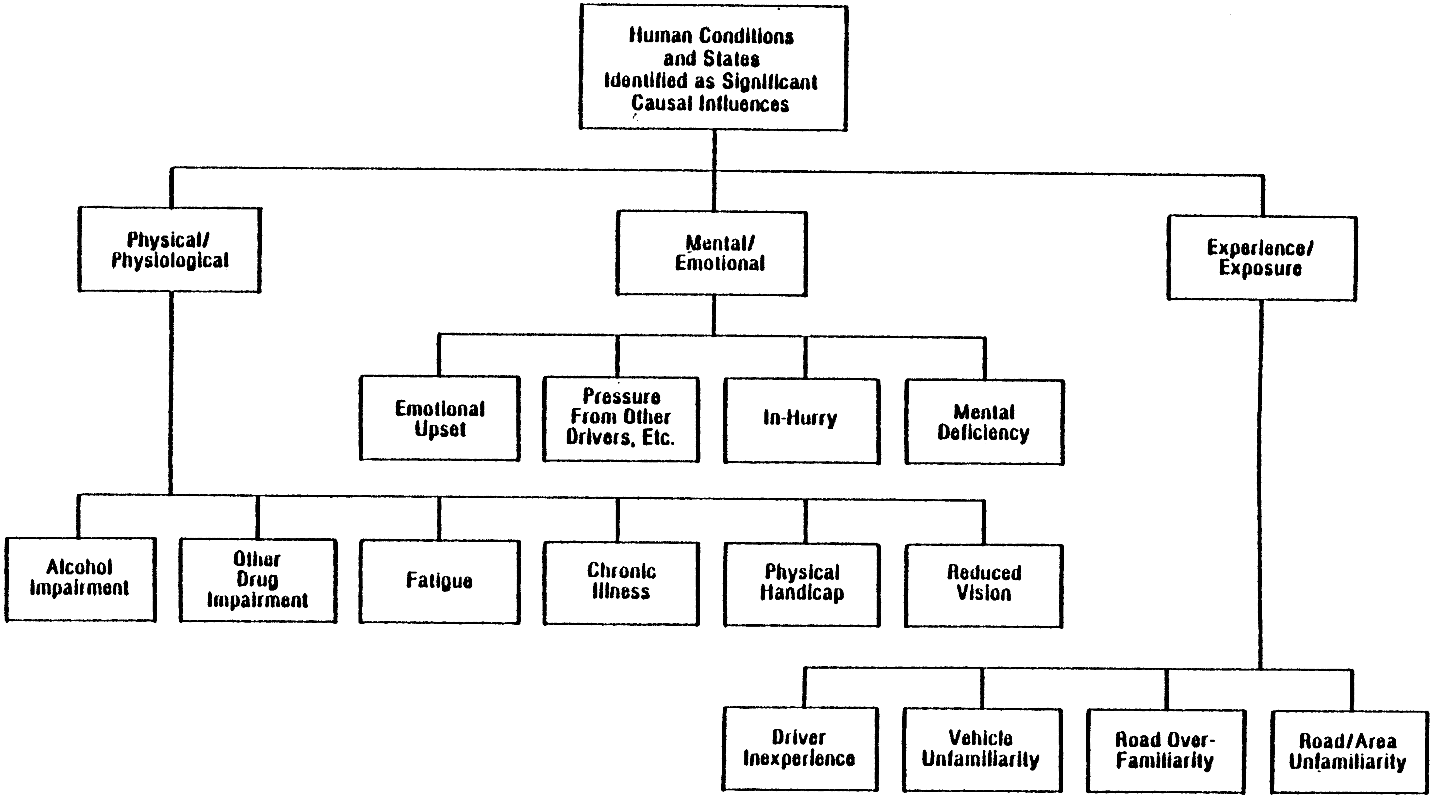

Figure 2.5 Human Conditions and States Identified as Causal Influences in Motor-vehicle Collisions

Source: Institute for Research in Public Safety (1975)

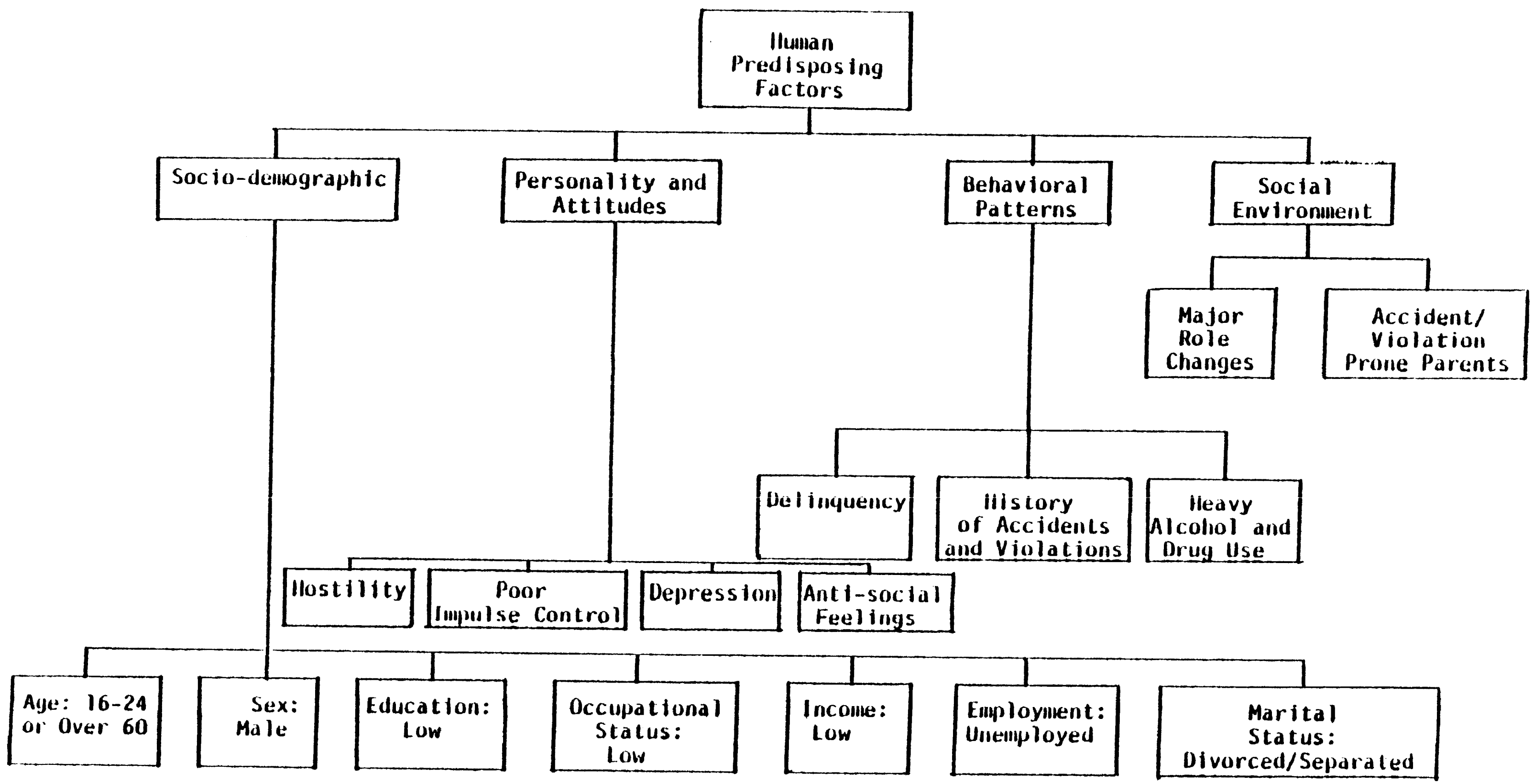

Figure 2.6 Human Predisposing Factors for Motor-vehicle Collision Involvement

Source: Based on Treat (1977) and Jones and Joscelyn (1978) the crash. (2) The multidisciplinary investigations of the 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 reiterated 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 epidemiological studies are supported by studies that include control groups, matched in time and place to samples of accidents. Such controlled studies have found that the relative risk of being involved in a crash accelerated rapidly at BACs over .08 percent (Cameron, 1977; Jones and Joscelyn, 1978). (3)

Figure 2.6 depicts a variety of individual characteristics that predispose one to the 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 twice to 10 times the rates for drivers of other age groups (Organization for Economic Cooperation and Development, 1975)

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: (A) driving at more hazardous times/locations (for example, nighttime and weekends); (B) more frequent driving with passengers present (increasing the probability of distraction); (C) driving vehicles that are in poorer condition; and (D) 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 the age group. In fact, roadside breathtest 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 was the finding that the relative risk of crash involvement at various BAC levels was higher for youth than the relative risk of crash involvement at the same BAC levels of middle-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 BAC 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 impulsivity and propensity toward risk taking behavior characteristic of adolescents and young adults (Klein, 1971; Pelz and Schuman, 1971; Makela, 1978).

2.1.3 Summary and Conclusions. The literature on motor vehicle accidents has revealed that, of the multiple environmental, vehicular, and human causes of collisions, human error predominates as the central cause of most traffic accidents. These human errors are frequently a result of the alcohol-impaired condition of the driver. The drinking patterns of young people, characterized by a high prevalence of drinkers who regularly consume large quantities of alcoholic beverages per occasion, and the 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 collision involvement. The combination of (A) high rates of motor vehicle collisions regardless of alcohol involvement (reflecting inexperience with driving), with (B) 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.

2.2 The Legal Drinking Age and Highway Safety

As a result of the drinking pattern 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 the drinking age has been the impact of changes in the 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 the legal changes on the frequency of involvement in motor vehicle collisions among young drivers. Most of the investigations of the impact of the lowered legal drinking age were based on comparisons between indices of youthful crash involvement before and after a reduction in the 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 the 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 the age of 21), or (B) comparison jurisdictions that had not experienced a contemporaneous change in the legal drinking age.

2.2.1 Studies of the Lowered Drinking Age. 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. The fatal accident frequencies for the 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 the analyses of all fatal crashes. The observed increases in fatal crash involvement among youth were substantially larger for Michigan and Ontario than they were 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.

Noar 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) Noar and Nashold used the latter finding to argue that the reduced drinking age has no effect on traffic accidents among youth. However, since the beverage of choice among young people, i.e. beer, 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 a reduced drinking age in Massachusetts using monthly time-series of traffic accidents. The 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 et al. (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 year old drivers in these states was compared with the 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 significant shifts for the 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 Michiganyouth, identified in the 1974 research, persisted over the four years after the reduced drinking age took effect (i.e. 1972 through 1975). The evaluation of the Michigan experience continued with Flora et al.'s (1978) analyses of fatal accidents in Michigan from 1968 through 1976. Although they did not use the same data analysis techniques as Douglass, the impact of the 1972 reduction in the 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 the lack of monthly data and the inability to separately analyze 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 aged 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 in 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 the 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. The frequency of alcohol-related fatalities for 15-20 year old drivers before and after a reduction in the 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 the 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 the lower legal drinking ages. Furthermore, insufficient numbers of pre-change observations were available to adequately account for the stochastic error in traffic fatality time-series. According to Warren et al., although increases in fatalities among youth occurred after the drinking age was lowered, one was not able to conclude that the increases were due to the 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 of 1970, 16-20 year old drivers exhibited 20 to 50 percent increases in alcohol-related crashes. (7) After the drinking age was lowered from 19 to 18 in June of 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 fatally injured drivers with blood alcohol concentrations of .08 percent or greater in the province of Alberta. An increase of 118 percent was observed in the 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 the legal drinking age for beer and wine in Illinois (from 21 to 19) was evaluated by the Illinois Department of Transportation (1977). Comparisons between the fatality incidence in Illinois and five control states were used as the basis for the conclusion that the lowered age in Illinois caused a 1.6 percent increase in fatalities among drivers aged 19 and 20.

It is evident from the literature reviewed above that most of the investigations of the impact of lowered legal drinking ages on motor vehicle collision involvement have found significant increases in the crash involvement frequencies of previously underage drivers that 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 the crash experience of underage drivers (usually 16 and 17 years old) following reductions in the minimum drinking age. Although it must be noted that most of these studies are characterized by methodological inadequacies, the 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, 1974a, 1974b, 1974c, 1974d, 1974e, 1976a, 1976b, 1977) has critiqued several of the studies reviewed above. He argued 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 (A) random fluctuations in traffic accident time-series, (B) the continuation of trends of increasing alcohol consumption (and alcohol-related accidents) among youth evident prior to the legal changes, or (C) 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 bases 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.

2.2.2 Studies of the Raised Drinking Age. In addition to the evaluations of the lowered drinking age, there are a small number of early reports on the 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: (A) DUIL arrests represent a different population than drivers involved in alcohol-related accidents (Organization for Economic Cooperation and Development, 1975); (B) the design was 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); (C) related to the basic inadequacy of the design was the lack of any statistical controls on time-ordered trends, seasonality, or random fluctuations in the frequency of DUIL arrests. As a result, this study provided little useful information concerning the effects of a raised drinking age.

Early reports of the effect of the raised drinking age in Michigan have also appeared. Publicom, Incorporated (1979) reported on a study sponsored by the Michigan Licensed Beverage Association and others, that compared the alcohol-related accident frequency of young drivers (based on data provided by the Michigan State Police) for the first six months of 1979 with the first six months of 1978. A 25 percent decrease in the frequency of 18-20 year old drinking-driver accident involvement was noted (from 5,521 drivers in 1978 to 4,138 in 1979). However, fatalities increased by 6 percent (from 65 in 1978 to 69 in 1979). There were no appreciable changes in alcohol-related collisions or fatalities for drivers of other age groups. Publicom, Incorporated used the data on fatalities to argue that the raised drinking age had an effect opposite of that which was intended, namely increased drinking-driver fatalities after the raised legal age. The Michigan Council on Alcohol Problems (1979), discussing the same Michigan State Police data, hint that the 25 percent decrease in alcohol-related collisions may indicate that the law has had its intended effect, although they argued that these early data were insufficient for an adequate determination of the effect of the raised drinking age. When the crash data for the last six months of 1979 were released by the Michigan State Police, the Michigan Council on Alcohol Problems (1980) reported the 21 percent reduction in police-reported alcohol-related crashes for July through December 1979 as compared to the same period in 1978. It was again argued that these data supported the effectiveness of the raised drinking age in reducing the frequency of motor vehicle collisions.

2.2.3 Summary and Conclusions. The foregoing review of the literature on the effects of changed legal drinking ages leads to the conclusion that demonstrable increases in alcohol-related traffic collisions and fatalities occurred following reductions in the legal minimum drinking age. (9) Since a major issue in the continuing public policy debate concerning the drinking age is the effect of raising the drinking age on motor vehicle crashes, it is clear that early findings based on simple comparisons between 1978 and 1979 should be replaced with findings from comprehensive controlled investigations of the impact of the raised drinking age.

2.3 Conceptual Models for the Prevention of Alcohol-related Problems.

Three basic models have emerged in the alcohol studies literature concerning the prevention of alcohol-related social and health problems (Popham et al., 1976; Room, 1978). The three models provide alternative conceptualizations of the nature of alcohol problems, widely divergent hypotheses concerning the effects of various prevention activities, and conflicting recommendations for public policy, including the minimum legal drinking age.

2.3.1 The Bimodal Model. The bimodal model argues that there are two distinct populations of alcohol consumers. First, there are normal social drinkers, who may drink alcoholic beverages regularly but do so in a moderate controlled manner, and as a result, do not experience social or health problems as a result of their drinking. Second, there are alcoholic drinkers, who, because of some particular physiological or personality characteristics, become alcoholics (i.e., addicted drinkers) and experience numerous social and health problems as a result of their chronic heavy drinking. The bimodal model is illustrated in Figure 2.7, where the distribution of drinkers according to the quantity consumed is depicted. The distribution is characterized by two modal points, the first at a low level of consumption, forming the peak of the skewed distribution of normal drinkers, the second at a high level of consumption, forming the mean of the roughly normal distribuition of alcoholic drinkers.

The model was derived from the disease concept of alcoholism, which argues that problems attributable to alcohol are caused by chronic excessive alcohol consumption, which, in turn, is a result of an

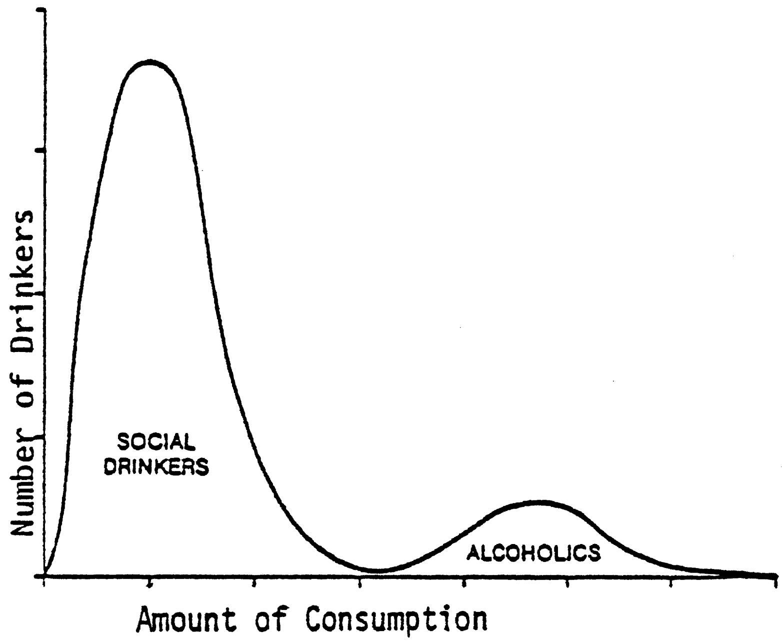

Figure 2.7 The Bimodal Model of Alcohol Consumption

Source: From Drinking by John A. Ewing and Beatrice A. Rouse, editors. Chapter 14, "Government Control Measures to Prevent Hazardous Drinking" by R. Popham, W. Schmidt, and J. deLint, page 259. Copyright © 1978 by John A. Ewing and Beatrice A. Rouse. Reprinted by permission of Nelson-Hall Publishers, Chicago.

underlying disease state. Prevention policy based on the bimodal model involves establishment of early detection case-finding programs to identify individuals with the "warning signs" of incipient alcoholism and the provision of treatment and rehabilitation services during the early stage of the disease (Rouse and Ewing, 1978:364). Prevention theorists have generally discarded the bimodal model because a substantial proportion of alcohol-related problems are associated with one's life-cycle stage and social environment, including the norms and expectations of one's reference others, as well as the ease with which one can obtain alcoholic beverages (Cahalan and Room, 1974). The situational and socio-environmental determinants of alcohol use patterns and consequent problems are especially significant for adolescents and young adults (Smart, 1979). Furthermore, there are some indications that measures aimed at reducing the consumption of the general population have similar effects on both the social drinker and the chronic alcoholic (Popham et al., 1976, 1978). As a result, the dichotomization of drinkers into social (i.e. non-problem) drinkers and alcoholic (i.e. problem) drinkers is not the most appropriate model for the prevention of a wide spectrum of alcohol-related problems.

2.3.2 The Integration Model. A second model for prevention efforts is variously known as the "integration model" (Popham et al., 1976), the "inoculation theory" (Room, 1978), or the "socio-cultural model" (Whitehead, 1977). The theory is based on anthropological and sociological studies of primitive societies and ethnic subgroups within the United States (Horton, 1943; Ullman, 1958; Snyder, 1958, 1962), which reveal that societies and subcultures characterized by widespread moderate drinking, integrated into normal daily activities (such as eating and recreation), have few alcohol-related problems. The observed correlation between a high prevalence of moderate (i.e. high frequency/low quantity per occasion) drinkers with low incidence of alcohol-related problems is used as the basis for prevention policy recommendations such as making alcohol readily available in all restaurants and places of recreation to facilitate the integration of moderate drinking into normal daily activities (Wilkinson, 1970). Another recommendation designed to reduce the mystique associated with alcohol and facilitate the development of moderate drinking, and thereby prevent alcohol-related problems, is to lower the minimum legal drinking age (Wilkinson, 1970), or even eliminate all drinking age restrictions (Chafetz, 1965; Plaut, 1967). However, as seen above in Section 2.2, when lowered legal drinking ages are implemented, they are characteristically followed by increased alcohol-related problems, particularly motor vehicle accidents, contrary to the predictions of the integration theorists. Moreover, on those occasions when other recommendations based on the integration model have been implemented, such as making alcohol more readily available by increasing the number and types of beverage outlets, the consequences have usually been the opposite of those anticipated on the basis of the integration model (Popham et al., 1976).

2.3.3 The Availability Model. The general availability model posits that the ease with which one can obtain beverage alcohol influences the amount and pattern of consumption, and as a result, influences the incidence of alcohol-related social and health problems. A major component within the broader availability theory is the single distribution model, which argues that the overall distribution of consumption of alcoholic beverages is not characterized by two separate distributions, as the bimodal model postulates, but is one continuous skewed distribution,as illustrated in Figure 2.8. This distribution of consumption has been found to characterize the drinking behavior of a variety of divergent populations (Bruun et al., 1975). One need not resolve the continuing debate in the literature concerning the specific parameters describing the distribution and their invariance across populations to use the model for the development of prevention policy. (10) The main point is that the "wetness" of the social environment in which one participates, that is, the ease with which beverage alcohol can be obtained and the social visibility of alcohol, influences the prevalence of both moderate and heavy drinkers. Thus, if one reduces the availability of alcohol through such measures as increasing the relative price, (11) reducing the hours of operation of drinking establishments, and raising the drinking age, the distribution of consumption (Figure 2.8) will shift to the left, reducing the prevalence of heavy drinkers and associated problems. There is a growing body of evidence that alcohol consumption and alcohol-related problems are related to changes in the availability of alcohol (Popham et al., 1976, 1978).

In short, the model hypothesizes that (A) a reduction in availability leads to (B) a reduction in overall consumption (i.e. the mean of the distribution shifts to the left), which leads to (C) a reduction in the prevalence of heavy drinkers (since it is assumed that the variance of the distribution remains constant), which results in (D) a reduction in problems associated with chronic heavy consumption. Although

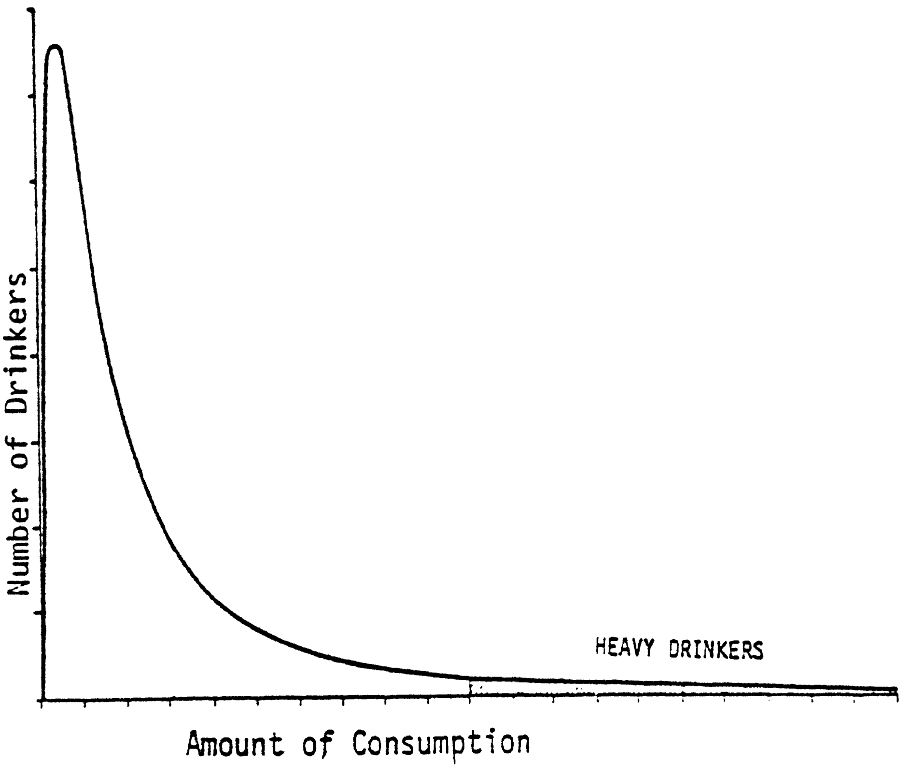

Figure 2.8 The Single Distribution Model of Alcohol Consumption

Source: From Drinking by John A. Ewing and Beatrice A. Rouse, editors. Chapter 14, "Government Control Measures to Prevent Hazardous Drinking" by R. Popham, W. Schmidt, and J. deLint, page 260. Copyright © 1978 by John A. Ewing and Beatrice A. Rouse. Reprinted by permission of Nelson-Hall Publishers, Chicago.

the single distribution model has received much attention in the prevention literature, it is only one component of a broader theory concerning the effects of alcohol availability. The focus of the single distribution model on reducing aggregate consumption as a means for the prevention of chronic alcohol-related health problems needs to be supplemented with a focus on the impact of availability on acute alcohol-related problems. With the exception of the evaluation studies of changes in the legal drinking age, virtually no theoretical or empirical work has been conducted on the relationship between various public policy controls on availability and acute alcohol-related problems (one exception is Douglass, Wagenaar, and Barkey, 1979). The model of the impact of the legal drinking age on motor vehicle collisions presented below in Section 2.3.5 is an initial step toward the development of more comprehensive models of the relationship between controls on alcohol availability and acute alcohol-related social and health problems.

2.3.4 Discussion of Prevention Models. The three models for the prevention of alcohol-related problems grew out of different sets of research findings and are focused on different kinds of alcohol problems. The bimodal model, focused on problems resulting from chronic heavy consumption, is based on the disease concept of alcoholism and is still subscribed to by numerous treatment personnel. However, empirical support for the model is lacking, and it has not proved to be useful for the design of prevention efforts. The model, in effect, states that primary prevention of alcohol-related problems is impossible until a clear understanding of the physiological causes of the disease is achieved. The single distribution model also focuses on the prevention of problems associated with chronic heavy alcohol intake. This model, in contrast to the bimodal model, argues that heavy drinkers are susceptible to the same social influences as moderate drinkers. Thus, the more visible alcohol is in one's social environment, the larger the prevalence of drinkers who consume sufficient quantities of alcohol to place them at risk of negative health outcomes as a result of their drinking. The integration model, on the other hand, focuses on the reduction of intoxication, and its associated acute problems, more than overall consumption, with its attendant chronic health problems. By making alcohol readily available as part of many normal daily activities, it is hoped that most members of the society will learn moderate drinking habits and refrain from becoming intoxicated.

Room (1978) points out that both the integration model and the single distribution model were originally developed based on cross-sectional correlations; the integration model is based on associations between widespread moderate drinking and low alcohol problems across homogeneous cultures and subcultures, and the single distribution model is based on positive correlations between aggregate consumption and alcohol problems across international and intra-national jurisdictions. Although such static correlations can be profitably used for the construction of models and the development of hypotheses concerning the prevention of alcohol problems, comprehensive controlled evaluations of natural experiments are necessary to test the validity of the divergent hypotheses. Most of the evaluations of such natural experiments to date have supported the availability model and not the integration model. These evaluative studies have revealed a critical problem in the integration theory. The theory assumes that the increase in moderate drinking, following an increase in alcohol availability, will replace existing heavy drinking practices in a population. In fact, what characteristically occurs following an increase in alcohol availability (such as a decrease in price, an increase in number, types, or hours of operation of alcohol outlets, or a decrease in the drinking age) is the initiation of new drinking practices in addition to pre-existing patterns, with a consequent increase in alcohol-related problems (Makela, 1972, 1978).

When the three models are applied specifically to the legal minimum drinking age, three different hypotheses concerning the effects of the legal changes on motor vehicle collisions emerge. First, the bimodal model would predict no impact of the legal changes, since those who are causing collisions are likely to be alcoholics or incipient alcoholics, who cannot control their drinking to adjust to changes in statutes concerning beverage alcohol. Second, the integration model predicts that a lowered drinking age would reduce collisions and a raised legal age would increase collisions, since a high drinking age would increase the mystique and desirability of alcohol and reduce the extent to which normal social controls could influence drinking patterns. Third, the availability model predicts that a raised legal drinking age would reduce alcohol-related traffic accidents by reducing the consumption of alcohol and thereby reducing the risk of collisions. Because of the evidence in support of the general availability model, and because of the literature reviewed above on the impact of changing the drinking age, the third hypothesis was adopted for the present investigation. However, before specifying in detail the expected effects of the changes in the legal drinking age in Michigan, a more detailed specification of the mechanisms through which the legal changes were expected to influence the frequency of alcohol-related motor vehicle collisions is needed.

2.3.5 A Model of the Effects of the 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 the legal drinking age cause changes in traffic crash involvement is presented in Figure 2.9. Changes in the legal drinking age influence drinking behavior and alcohol-related crash involvement by causing (A) a change in social norms concerning youthful drinking, (B) a change in the marketing activities of the beverage alcohol industry, and (C) a change in the availability of alcohol to the target age group. Drinking norms change as a result of the symbolic function of the law (Mosher, 1980; Bonnie, 1980), and as a result it becomes more acceptable for 18-20 year olds to drink regularly after a reduction in the drinking age. 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. These changes in drinking norms, according to the model, result in increased drinking among 18-20 year olds after a reduction in the drinking age. A raised drinking age is expected to have opposite effects, causing the elimination of certain drinking patterns (bar and tavern drinking, for example), and causing a reduction in the social

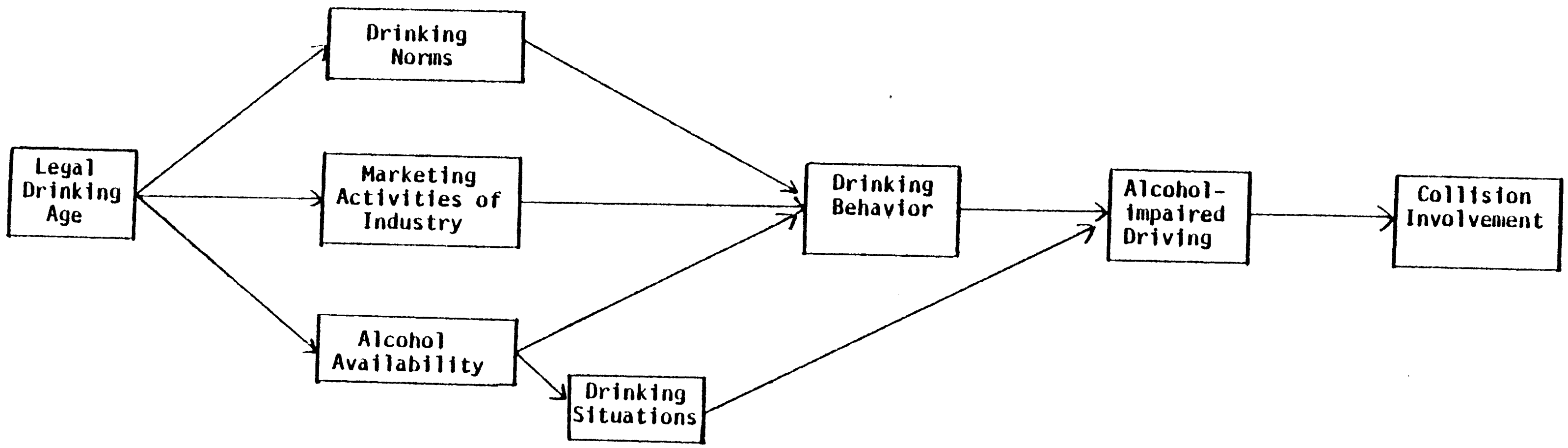

Figure 2.9 Conceptual Model of the Impact of Changes in the Legal Drinking Age on Motor-vehicle Crash Involvement

pressure to drink, since alcohol is present in fewer social situations. The high drinking age also symbolizes society's disapproval of youthful drinking.

The marketing activities of the beverage alcohol industry are also expected to depend on the 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 more establishments with entertainment near college campuses). A raised drinking age is expected to reduce these marketing practices designed to encourage youthful drinking.

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

Social policy at the aggregate level, such as a change in the legal minimum drinking age, is expected to influence a number of the components of the total cost of obtaining alcohol by underage individuals. For example, 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 risk associated with other disutilities such as 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.

Returning to the overall model in Figure 2.9, the 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.

In addition to the impact of changes in the 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 (see Figure 2.9). Lowering the drinking age leads to increased drinking in bars and taverns by the age group. Since personal automobiles are likely to be the usual mode of transportation to and from such public drinking places, the lowering of the drinking age can be expected to increase 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 additional 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, unlike 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. (12)

In short, changes in the legal drinking age, according to the model presented in Figure 2.9, 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 the drinking-driving behavior of the 18-20 year old age group. Note that the model discussed above illustrates plausible mechanisms by which the legal drinking age influences alcohol-related crash involvement frequencies. Several other socio-cultural, social-psychological, psychological, and situational exogenous variables are likely to have a causal impact on all of the variables in the system depicted in Figure 2.9. 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 the legal drinking age on the frequency of traffic accidents among youth.

2.4 Specification of Hypotheses

Two main hypotheses described in general terms in the previous section constituted the central issues of the present investigation. Specifically, they were:

> H.1 The raised legal drinking age (from 18 to 21) caused a reduction in alcohol-related motor vehicle crash involvement among 18-20 year old drivers;
>
> H.2 The lowered legal drinking age (from 21 to 18) caused an increase in alcohol-related motor vehicle crash involvement among 18-20 year old drivers.

Two corresponding hypotheses were considered for the 16-17 year old driving population, since the altered norms, marketing practices, and availability of beverage alcohol resulting from a changed drinking age may also influence the 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 the 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 aged 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, it was hypothesized that:

> H.3 The raised legal drinking age (from 18 to 21) caused a

reduction in alcohol-related motor vehicle crash involvement among underage drinkers (16-17);

H.4 The lowered legal drinking age (from 21 to 18) caused an increase in alcohol-related motor vehicle crash involvement among underage drinkers (16-17).

Hypothesis three was supported by those studies reviewed in Section 2.2 that explicitly examined the effects of a reduced drinking age on underage drinkers, where the lowered legal age was found to be associated with increased alcohol-related collisions among underage drinkers. 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 the legal changes on underage drinkers is due to prior changes in drinking norms and practices among 18-20 year olds. Therefore, it was hypothesized that:

H.5 The magnitude of the impact of changes in the legal drinking age on alcohol-related motor vehicle crash involvement among 16-17 year old drivers was smaller than the magnitude of the impact on alcohol-related crash involvement among 18-20 year old drivers.

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) 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, the final hypothesis to be tested in this investigation was that:

> H.6 A lowered legal drinking age has a greater effect than a raised legal drinking age on the frequency of alcohol-related motor vehicle crash involvement among young drivers.

Notes to Chapter 2.0

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

2. For example, Filkins et al. (1970) have found that elevated blood alcohol concentrations are strongly related to driving at excessive speeds at the time of a crash. Thus, the human condition of alcohol impairment in Figure 2.5 is causally antecedant to excessive speed in Figure 2.4, which is the human error identified as an immediate cause of collisions.

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

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.

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

6. Police reports were used as the indicator of alcohol involvement.

7. Police reports were used as the indicator of alcohol involvement.

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 of DUIL arrests in October 1979.

9 . Similar conclusions were reported in other reviews of this literature such as Smart and Goodstadt, 1977; Whitehead, 1977; Smart, 1979.

10 . For some of the arguments in this debate, see Guttorp and Song, 1977, 1979; Parker and Harmon, 1978; Schmidt and Popham, 1978; Skog, 1979a, 1979b.

11 . Relative price refers to the price of beverage alcohol in relation to personal income.

12 . In Figure 2.9 an effect of the drinking age on collision involvement independent of any change in quantity-frequency of alcohol consumption is represented by the path from legal drinking age to alcohol availability, to drinking situations, to alcohol-impaired driving, to collision involvement.

3.0 RESEARCH DESIGN AND DATA ANALYSIS METHODS

This chapter describes the methods selected to measure the effects of the changes in the legal drinking age in Michigan. The methodological issues discussed include: (A) the quasi-experimental design used in this investigation, (B) operationalization of the dependent variables (i.e. traffic accidents), (C) the validity of the overall design, and (D) the time-series statistical data analysis techniques used.

3.1 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 18-20 year old drivers randomly assigned to a condition of legal availability of beverage alcohol (drinking age 18), to 18-20 year old drivers randomly assigned to a condition of no legal availability of beverage alcohol (drinking age 21). Since such random assignment was impossible, one of the quasi-experimental designs had to be used (Campbell and Stanley, 1966; Cook and Campbell, 1976; Cook and Campbell, 1979). Of the numerous quasi-experimental designs in use, the non-equivalent multiple time-series design rules out the largest number of plausible alternative explanations for a postulated causal relationship. In this research, the postulated causal relationship was 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 as follows:

$$O_1 O_2 O_3 \cdots O_{n_1} \quad I_1 \quad O_{n_1+1} O_{n_1+2} O_{n_1+3} \cdots O_{n_1+n_2} \quad I_2 \quad O_{n_1+n_2+1} O_{n_1+n_2+2} \cdots O_{n_1+n_2+n_3}$$

$$O_1 O_2 O_3 \cdots O_{n_1} \qquad O_{n_1+1} O_{n_1+2} O_{n_1+3} \cdots O_{n_1+n_2} \qquad O_{n_1+n_2+1} O_{n_1+n_2+2} \cdots O_{n_1+n_2+n_3}$$

where each O_i represents the number of crash involvements in a particular month, I_1 represents the lowering of the drinking age in 1972, n_1 is the number of monthly observations before the drinking age was lowered, n_2 is the number of monthly observations between the lowered and raised drinking age, I_2 represents the raising of the drinking age in 1978, and n_3 is the number of monthly observations after the drinking age was raised. The second row in the design diagram represents a comparision time-series, not influenced by the interventions included in the first row. Although the diagram depicts only one experimental and one comparison series, multiple measures of motor vehicle crash involvement and multiple comparison groups were included in the design.

3.2 Operationalization and Data Collection

The design called for measures of traffic accident frequency that were hypothesized to be affected by a change in the legal drinking age, and control measures that were not likely to be affected by changes in the legal drinking age. The two experimental groups consisted of 18-20 and 16-17 year old drivers in Michigan. The impact of the changes in the legal drinking age on the accident involvement of these two experimental groups was compared with "control" or comparison groups consisting of 21-24 and 25-45 year old drivers in Michigan. The complete design,

Table 3.1 Full design matrix depicting age groups, types of accidents, and operationalized measures used*

Age Groups	All Crashes: 1972-1979			Fatal Crashes: 1968-1979	
	HNBD	HBD	3FS	TOTAL	3FS
Experimental					
18-20 years old					
16-17 years old					
Comparison					
21-24 years old					
25-45 years old					

*NOTES:
1. HBD refers to Had Been Drinking according to police reports.
2. HNBD refers to Had Not Been Drinking according to police reports.
3. 3FS refers to three-factor-surrogate, that is, late night, single-vehicle crashes with a male driver.

including the experimental and control groups and the multiple operationalizations of the dependent variable, traffic accidents, is depicted in Figure 3.1.

Two major sets of data were used to implement the design illustrated above. The first dataset consisted of measures of traffic accident incidence based on all crash-involved drivers as reported to the Michigan State Police. Computer tapes were obtained from the Michigan State Police containing records on every reported accident in the State of Michigan from January of 1972 through December of 1979. To reduce the volume of data to a more manageable size, a random sample of 20 percent of all accidents during this time period was selected. (1)

New files were constructed containing all of the traffic units (i.e. vehicles) involved in each sampled accident. These files, with vehicle-drivers as cases, were used to construct monthly time-series traffic crash involvement frequency variables for the January 1972 through December 1979 time period. The final time-series measure of total crash involvement incidence was the monthly frequency of drivers of passenger cars, trucks, or motorcycles involved in a crash. (2)

Since the changes in the legal drinking age were expected to affect the frequency of automobile crash involvement through their influence on alcohol-related crashes, two measures of alcohol-related crashes were analyzed for each age group. The first measure was the monthly frequency of crash involvement in which the police accident report form indicated that the driver "had been drinking" (HBD). Since this measure of alcohol-related traffic accidents was subject to unreliability in police reporting practices, a second more reliable measure of alcohol-related traffic crash involvement was also used.

The second measure was the "three factor surrogate" (3FS), developed by the Highway Safety Research Institute, at The University of Michigan in earlier research on lowered legal drinking ages (Douglass et al., 1974). Analyses of crash data from various jurisdictions, different time periods, and of drivers of a wide range of age groups, revealed that a consistent subset of all alcohol-related crash involvements was identified by three parameters, namely, sex of driver, time of crash, and number of moving vehicles involved in the crash. Specifically, single-vehicle crashes with a male driver occurring between 9 P.M. and 6 A.M. were 58 to 63 percent alcohol-related as measured by the HBD designation on the police accident report form. This proportion was relatively consistent regardless of the precise operational definition of alcohol involvement in the official crash reports. Furthermore, it is unlikely that police officer discretion or bias would affect the reporting of the driver's sex, number of vehicles involved, or time of the crash. Thus, the three-factor-surrogate, being operationally consistent, provided a reliable alternative to reported alcohol involvement based on the subjective assessments of the investigating police officer.

The three factor surrogate was especially useful for comparative analyses of crash-involved drivers across age groups and jurisdictions, where the consistency of the reporting of alcohol involvement in traffic crashes may vary considerably. Since the operational consistency of the outcome measures is especially important in the analysis of time-series (Kendall, 1976), the three-factor-surrogate was an important supplementary measure of alcohol-related accidents. It should be pointed out, however, that the correlation between the two measures of alcohol-related accidents is not perfect, with the 3FS measure including only about one-third to one-half of all drivers designated as HBD (Flora et al., 1978). In short, although the 3FS measure was an imperfect reflection of alcohol-related accidents, its operational consistency over time made it a useful measure for time-series analyses. (3)

The first time-series crash file included the monthly frequency from January 1972 through December 1979 of "had not been drinking" (HNBD) drivers, "had been drinking" (HBD) drivers, and three-factor-surrogate (3FS) drivers, stratified by age groups as indicated in Figure 3.1. This file was not extended to the years prior to 1972 (when the legal drinking age was lowered from 21 to 18) because of severe reporting inadequacies in the Michigan State Police master files. From 1968 through 1971 there were a large number of major urban reporting jurisdictions (including major cities such as Detroit, Lansing, and Grand Rapids) that did not report non-fatal traffic crashes to the Michigan State Police for substantial periods of time. For this reason, the data on all collisions (fatal and non-fatal) could not be used in the full quasi-experimental design evaluating the differential effects of lowering the legal drinking age and subsequently returning it to its former level. The measures of driver crash involvement discussed above were, therefore, only used to evaluate the impact of the 1978 increase in the legal drinking age.

The complete design, examining both the lowered and raised drinking ages, was implemented using the fatal accident measures depicted in the second half of Figure 3.1. The Michigan State Police master tape files of all reported accidents used as the basis for the driver crash files, with the addition of the master files for January 1968 through December 1971, were used to construct time-series variables of the monthly frequency of drivers involved in fatal crashes. (4) The fatal files, because of the much smaller number of cases than the crash files, were based on a census of all fatal accidents in the State of Michigan. In contrast to the total crash involvement data, fatal crashes have been well-reported throughout the 1968 to 1979 time period, and the reported monthly frequency of fatal crashes was an accurate reflection of fatal crash experience in Michigan. However, with regard to the measurement of drinking drivers involved in fatal crashes, the HBD/HNBD measure was not used because of high rates of missing data in the early years (from 11 to 29 percent of drivers involved in fatal accidents had missing data on the HBD/HNBD variable in the late 1960s and early 1970s), and data collection system changes that significantly affected the reporting of HBD drivers.

The first important change in the measurement of HBD drivers occurred in January of 1971 when a major change in the police accident report form involved the deletion of the category "not known if drinking" as a valid response to the HBD/HNBD item. The result was that drivers previously placed in the "not known if drinking" category were now coded by police officers either as "had been drinking" or "had not been drinking." Consequently, the frequency of HBD drivers increased substantially during January 1971 when the new form was implemented (Douglass and Freedman, 1977). The second major change in the measurement of HBD drivers was the Fatal Accident Reporting System (FARS), initiated by the National Highway Traffic Safety Administration, which became fully operational in 1974 (United States Department of Transportation, 1977).

FARS resulted in a significant reduction in the amount of missing data for the HBD/HNBD variable. Because of these two major operational inconsistencies in the measurement of HBD drivers prior to 1974, the three factor surrogate was relied upon as the measure of the frequency of drinking drivers involved in fatal accidents.

The original research plan provided for a determination of the differential effects of the lowered and raised legal drinking age using consistent time-series of the incidence of fatalities from 1968 through 1979. However, preliminary analyses of the fatality time-series revealed that the small monthly count of fatalities, especially when stratified by age and the 3FS measure, precluded an adequate determination of the effects of the lowered and raised drinking age on highway safety (see Section 4.3). A large proportion of the total variance in fatality incidence was due to random variation, and could not be accounted for in baseline time-series models. As a result, the major emphasis was placed on the time-series based on a 20 percent sample of all crash involvement (including both fatal and non-fatal crashes). Since these more adequate crash involvement data were only available after 1972, the effect of the lowered drinking age was not examined in detail.

The differential effects of the lowered and raised drinking age were assessed by comparing the results reported in Chapter 4.0, concerning the effect of the raised legal age, with previous time-series investigations of the effect of the lowered drinking age in Michigan. Previous time-series investigations of the Michigan experience with the lowered drinking age were limited to analyses of those Michigan jurisdictions with consistently reported motor vehicle collision frequencies over the baseline period prior to the 1972 reduction in the drinking age (approximately 55 percent of all Michigan reporting jurisdictions had complete crash involvement files for the 1968 through 1971 period; see Douglass and Freedman, 1977). The actual shift in crash involvement frequency associated with the lowered drinking age in Michigan identified in the earlier research is not directly comparable to the shifts in frequency associated with the raised drinking age identified in this research, because this study included all reporting jurisdictions in Michigan. The percentage changes in crash involvement associated with the lowered and raised drinking age from the two studies are comparable, however, and will be used to determine the extent to which the raised drinking age reversed the effect of the lowered legal age.

3.3 Design Validity

Design validity involves consideration of the ability of the research design to adequately answer the research question. In the present case, the fundamental research question is, do changes in the legal drinking age in Michigan cause changes in alcohol-related crash incidence among the affected age groups?

In order to determine the strength of the design in answering the research question (the validity of the design) it is essential to take the position of devil's advocate and identify the potential alternative explanations for an apparent or measured change in the phenomenon under investigation, in the present case, alcohol-related traffic crashes among young drivers. The non-equivalent multiple time-series quasi-experimental design used in this research is a superior design to determine if legal drinking age changes cause changes in alcohol-related crash frequencies among young drivers. In addition to the basic design structure involving experimental and comparison groups, the use of multiple measures of alcohol involvement, including official "had been drinking" figures and the three-factor-surrogate measure, greatly strengthens the design validity by providing a control over potential measurement inconsistencies.

In addition to the design structures and measurement features used here, the state of the art Box-Jenkins analysis methodology, discussed in detail in Section 3.4, is the most appropriate analytic approach given the availability of a large amount of data over an extensive period of time. A full, technical discussion of design validity and specific controls for numerous potential threats to the validity of the research conclusions is found in Appendix B.

3.4 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 is 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 is a powerful and versatile strategy for modeling time-series variables that produces unbiased estimates of error variance in the presence of serially correlated observations. (5) Recent methodological developments in the use of transfer functions along with the Auto Regressive Integrated Moving Average (ARIMA) modeling strategy place these analysis techniques at the state of the art for the analysis of time-series quasi-experiments (see Box and Tiao, 1975; Hibbs, 1977; McCleary and Hay, 1980). These techniques identify a wide variety of patterns in the dependent time-series variables, provide a sensitive test of intervention effects, and allow the analysis of a variety of intervention effect patterns. (6)

The purpose of the data analyses in this investigation was to determine the impact of the changes in the legal drinking age on each dependent variable. After the effects of the legal changes on each variable were determined through the statistical analysis procedures described below, the effects were compared across those measures expected to be influenced by the legal changes and those not expected to be influenced by the interventions. The present section discusses the 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 4.0 on the results of the statistical analyses.

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 thus provide a benchmark for the assessment of any intervention effects. The ARIMA model accounts for the variance in the dependent series that is due to identifiable trend, 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

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

and is identified as ARIMA (p,d,q)(P,D,Q)s, where p is the order of the auto-regressive process, d is the degree of non-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 any 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.

The initial specification of the ARIMA model for a particular series was made on the basis of an examination of a plot of the raw series and the autocorrelation and partial autocorrelation functions estimated from the series observations. An examination of the raw time-series plot provided initial information as to the trend and seasonal characteristics of the series, facilitating the identification of differencing factors and the seasonal span. The plot of the raw series was also used to check for constant variance across the series; if the variance appeared non-constant, appropriate transformations were performed before proceeding. (7) Theoretical auto and partial autocorrelation functions corresponding to various ARIMA models have been identified. A preliminary ARIMA (p,d,q)(P,D,Q)s model was identified on the basis of an examination of the estimated auto and partial autocorrelations, assessing the degree to which the actual autocorrelations fit one of the theoretically expected patterns.

After the order of the ARIMA model was identified on the basis of a plot of the raw data and the auto and partial autocorrelation functions, preliminary estimates of the parameters of the identified model were calculated on the basis of the estimated autocorrelations. These preliminary estimates were input as starting values to obtain maximum likelihood estimates of the parameters using a non-linear iterative computer estimation program. (8)

Following the initial estimation of an ARIMA model is perhaps the most important step in the Box-Jenkins modeling strategy. 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-invertability required for the particular model form under consideration (Box and Jenkins, 1976). Second, the estimated parameters should be significantly different from zero. Third, the correlations between 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 an insignificant Q-statistic (Box and Pierce, 1970). Fifth, the autocorrelation function should not reveal significant correlations at the first few lags or the first seasonal lag.

The nature of any inadequacies observed were used to re-specify the model. After re-specification, preliminary estimates of the parameters of the revised model were calculated. 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 squares was selected. Using such an iterative procedure of model building, a parsimonious model, accounting for all of the significant autocorrelation patterns in the series, was obtained.

All of the specific ARIMA 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 the time-series is stationary, that is, that the series has a constant mean, that all random errors (u_t

in equation 1) are independently drawn from the same distribution over time and thus are characterized by constant variance, and that 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 constant mean in the original series is not strictly required, because the model remains appropriate provided a constant mean is obtained after using the appropriate differencing factors on the original series. (9) If a constant mean is obtained after differencing, the series is said to exhibit "homogeneous non-stationary behavior" (Box and Jenkins, 1976:11).

The discussion of statistical conclusion validity in Appendix B notes the importance of ensuring that the data under investigation meet the assumptions of the statistical procedures used. An important strength of the Box-Jenkins modeling strategy is that an assessment of the extent to which the assumptions 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 were white noise (i.e. independently distributed with constant variance). (10) The assurance that the assumptions of the model were met was an important factor increasing the statistical conclusion validity of the study findings.

After an optimal ARIMA model of the series was identified, transfer functions representing the hypothesized effects of the drinking age changes were added to the ARIMA noise model. The general form of the transfer function is

$$(2) \qquad y_t = \frac{(\omega_0 - \omega_1 B - \ldots \omega_s B^s)}{(1 - \delta_1 B - \ldots \delta_r B^r)} (I_{t-b})$$

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 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 two main interventions of interest in the present investigation were the lowering of the legal drinking age in January of 1972 and the raising of the drinking age in December 1978. In addition, since it has been established that the fuel shortage, national minimum 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 decrease in frequency in early 1974. (11) Each of the exogenous factors was modeled with a simple form of the general transfer function model shown in equation 2.

Two specific forms of the general transfer function model were considered for the drinking age change, a gradual permanent impact model ($\omega/1-B\delta_1$ with I_t defined as a step function), and an abrupt permanent impact model (ωI_t with I_t defined as a step function). (12) 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 drinking age change. The impact patterns assessed by the models are shown in Figures 3.1 through 3.4. Preliminary analyses revealed that the effect of the raised drinking age was adequately represented by an abrupt permanent impact model. Two factors influenced the decision to use the abrupt permanent impact model. First, the effects of the raised drinking age on crash frequencies were evident soon after the legal change went into effect; that is, no gradual impact was observed. Second, the small number of observations (12 months) after the raised drinking age was insufficient to adequately estimate the gradual impact transfer function model.

Two forms of the general transfer function model (equation 2) were also considered to account for the fuel shortage and related factors. Existing literature on the impact of the events of early 1974 revealed an abrupt reduction in crashes, with a substantial portion of the impact dissipating over time, although a demonstrable permanent crash or fatality reduction was evident (O'Day et al., 1975; Seila et al.,1977; United

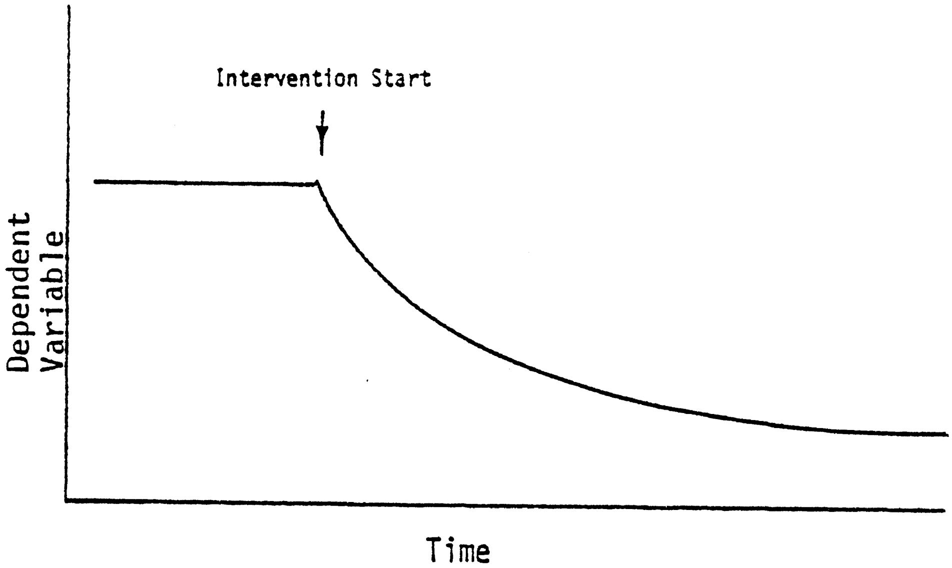

Figure 3.1 Negative Impact Pattern Estimated by the rsb (1,0,0) Transfer Function Model with a Step Function Input

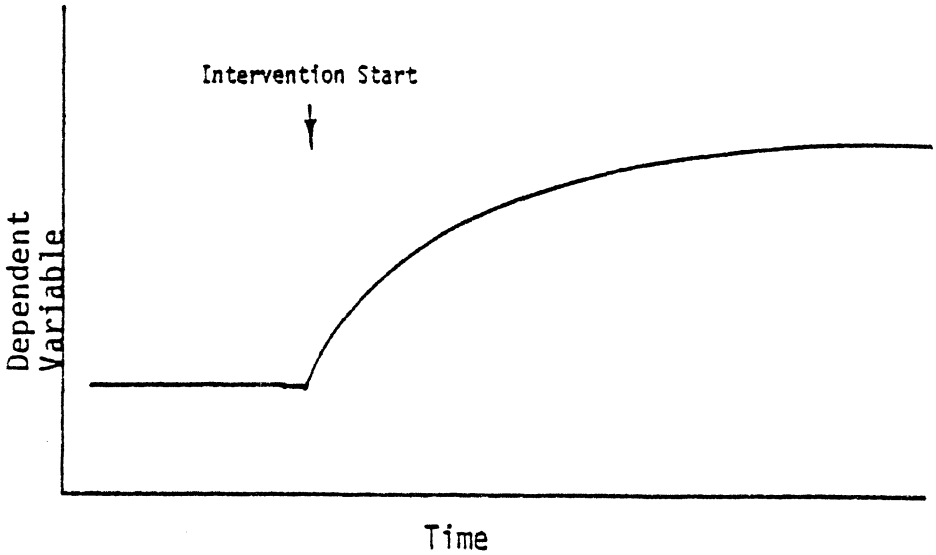

Figure 3.2 Positive Impact Pattern Estimated by the rsb (1,0,0) Transfer Function Model with a Step Function Input

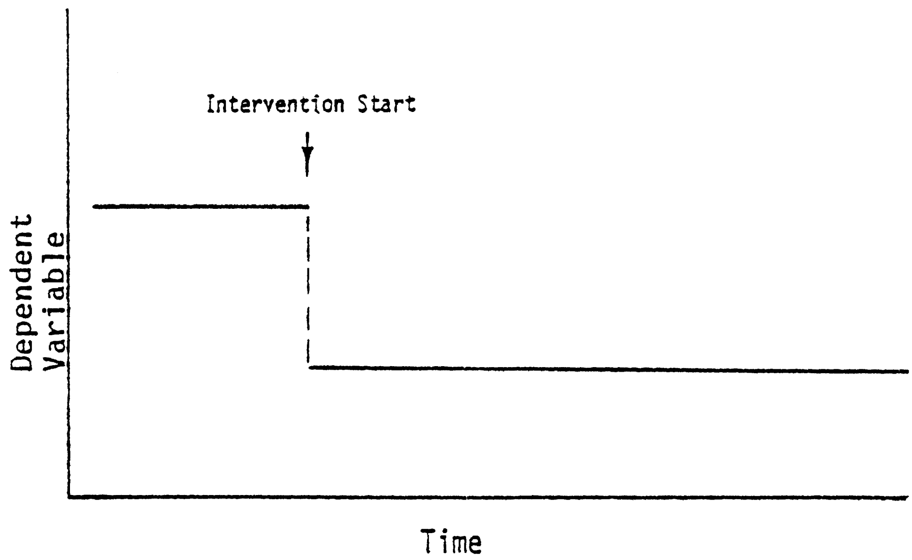

Figure 3.3 Negative Impact Pattern Estimated by the rsb (0,0,0) Transfer Function Model with a Step Function Input

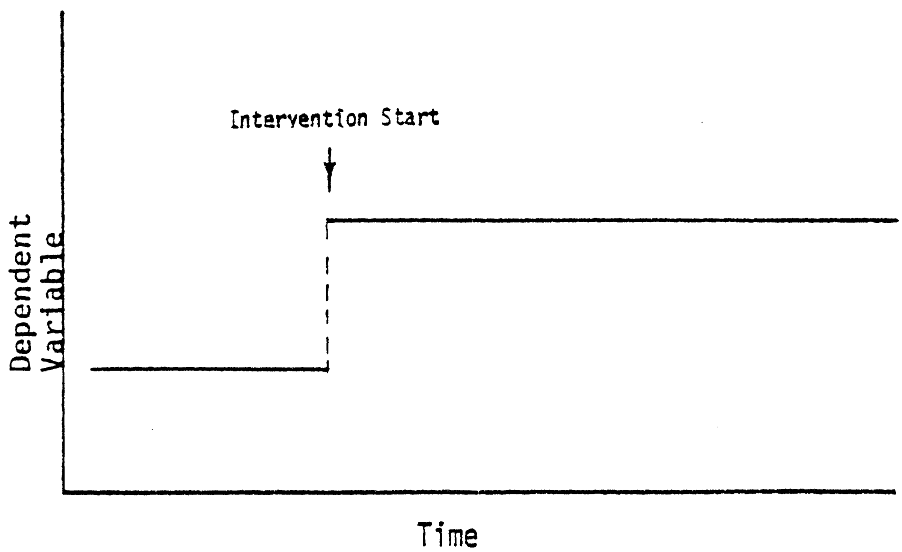

Figure 3. 4 Positive Impact Pattern Estimated by the rsb (0,0,0) Transfer Function Model with a Step Function Input

States Department of Transportation, 1978; Wiorkowski and Heckhard, 1977). As a result, both the abrupt permanent impact model (Figures 3.3 and 3.4) and the abrupt temporary impact model (Figures 3.5 and 3.6) were considered to account for the effect of the fuel shortage. In the analyses of each dependent variable, the model with the best fit to the data was selected to represent the effects of the fuel shortage and related factors of early 1974.

The transfer functions representing hypothesized intervention effects were combined with the identified ARIMA model appropriate for a particular dependent variable and the combined model parameters were simultaneously estimated using a non-linear iterative computer estimation program developed by Box and Jenkins (1970, 1976) and marketed by National CSS, Incorporated (1974). (13) The general form of the combined ARIMA/transfer function model (depicting only one transfer function) applied to each dependent time-series variable is

$$\text{(3)}\quad y_t = \underbrace{\left[\frac{(1 - \Delta_1 B^S - \dots \Delta_Q B^{sQ})(1 - \theta_1 B - \dots \theta_q B^q)u_t + \alpha}{(1 - \Gamma_1 B^S - \dots \Gamma_P B^{sP})(1 - \phi_1 B - \dots \phi_p B^p)(1 - B^s)^D (1 - B)^d}\right]}_{\text{Noise (ARIMA) model}} + \underbrace{\left[\frac{(\omega_0 - \omega_1 B - \dots \omega_s B^s)}{(1 - \delta_1 B - \dots \delta_r B^r)}(I_{t-b})\right]}_{\text{Intervention (transfer function) model}}$$

The estimation results of the combined model were evaluated on the basis of the same criteria used to evaluate the preliminary noise model. Additional criteria were applied to the transfer function parameters. First, estimates of δ had to be within the limits required for system stability (Box and Jenkins, 1976:346). Second, the parameter estimates had to be interpretable in terms of theoretical expectations and known characteristics of the dependent variable. For example, the

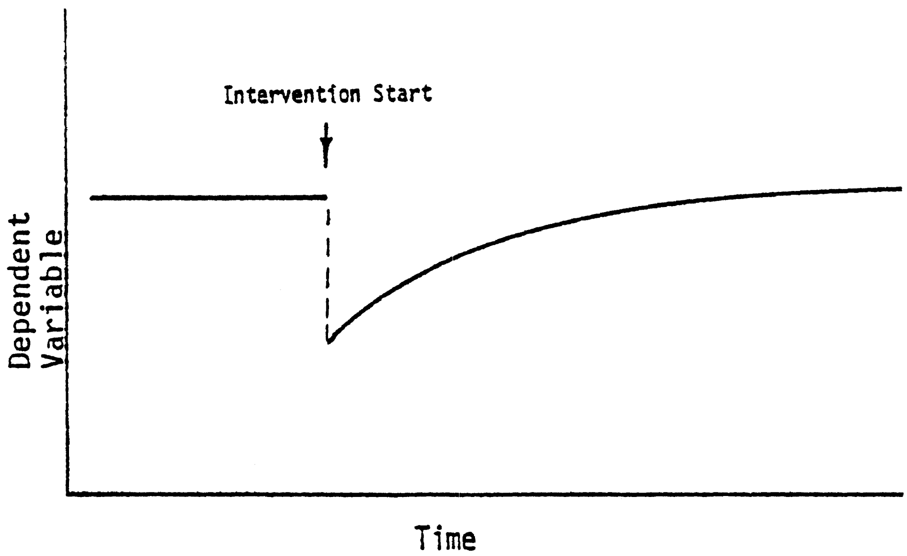

Figure 3.5 Negative Impact Pattern Estimated by the rsb (1,0,0) Transfer Function Model with a Pulse Function Input

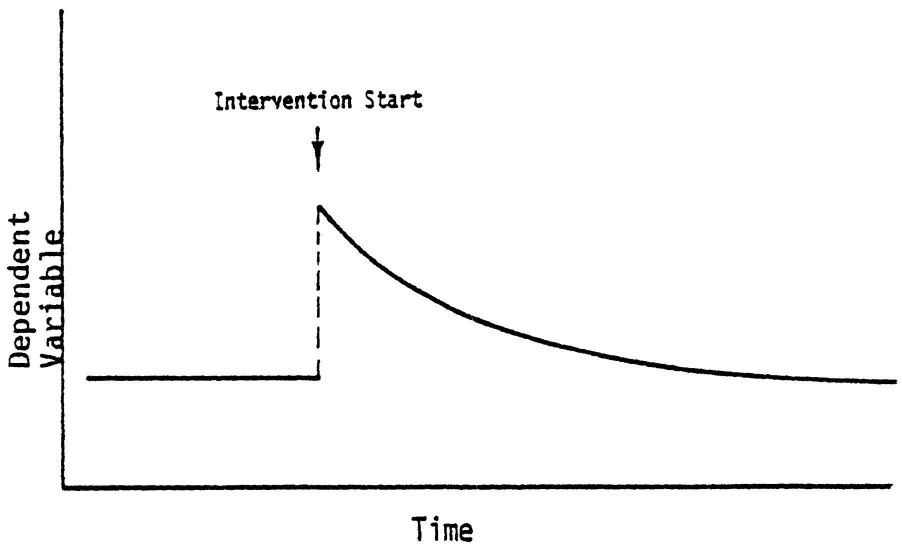

Figure 3.6 Positive Impact Pattern Estimated by the rsb (1,0,0) Transfer Function Model with a Pulse Function Input

estimate of δ_1 should not be negative, indicating an oscillating impact pattern. The estimate of δ_1 also should not be extremely close to unity in an rsb (1,0,0) model with a step function input, since such a result implies a permanent change in slope of the dependent variable associated with the intervention. An estimated intervention impact of a change from a positive or zero slope to a negative slope, for example, would imply that at some point after the intervention no more accidents would occur, since a line with a negative slope eventually crosses the x-axis.

Inadequacies in the combined model, detected when evaluating the estimation results, were used to guide re-specification of the model. The specification, estimation, and evaluation process was continued until an adequate model was obtained. The values of the transfer function parameter estimates of the final model, along with unbiased estimates of their standard errors, were used to determine the existence of any 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.

In summary, the data analysis analysis strategy was as follows. First, an ARIMA noise model was built by repeating the specification, estimation, and evaluation process until an adequate model was obtained. Second, transfer functions for the raised drinking age and the 1974 fuel shortage were added to the noise model and the combined noise and intervention model was estimated. The combined model was evaluated and the re-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 of the raised legal drinking age on that particular time-series dependent variable. This data analysis strategy was repeated for each dependent variable, and the results of these analyses were compared across experimental age groups (16-17 and 18-20) and comparison age groups (21-24 and 25-45) as called for in the research design.

Notes to Chapter 3.0

1. The Michigan State Police master files contained approximately 625,000 cases (vehicles) per year. The selection of a 20 percent random sample reduced the number of cases to about 125,000 per year.

2. Traffic units excluded from the time-series included busses, farm or construction equipment, pedalcycles, pedestrians, and other miscellaneous motor vehicles and non-motor vehicles included in the original Michigan State Police files.

3. The results of chemical tests for blood alcohol concentration was another potential measure of alcohol-related accidents. However, since more than 75 percent of all crash-involved drivers in Michigan reported as "had been drinking" were not tested for blood alcohol concentration (Flora et al., 1978), this measure was of limited utility for the present investigation.

4. As with the crash files, only drivers of passenger cars, trucks, and motorcycles were included in the fatal crash variables.

5. Reid provided evidence of the superiority of the Box-Jenkins methodology by applying five different time-series analysis and 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).

6. See Glass, Willson and Gottman (1975:44) for a description of possible intervention effect patterns.

7. Range-mean plots can also be used to check for non-constant variance.

8. The program used for this stage of the analysis is BSAD:TIME, developed by The University of Michigan, School of Business Administration.

9. Differencing refers to the calculation of the differnce or change between adjacent observations in the series. For example, the first difference of a series Y_t is $Y_t - Y_{t-1}$; the second difference of a series is the first difference of the first differences.

10. A more general discussion of the importance of examining residuals to ensure that assumptions were not violated was provided by Draper and Smith (1966).

11. Similar effects of fuel shortages and reduced speed limits have been found in other developed countries such as Australia (Road Safety and Traffic Authority of Victoria, Australia, 1978), Great Britain (Scott and Berton, 1976), and New Zealand (Toomoth, 1975).

12. Techniques for specifying the form of the transfer function model on the basis of the cross correlations between the 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 involves dummy input variables and output accident variables with large variances, such empirical transfer function indentification 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.

13. Those models which were linear in the parameters were estimated using a conventional OLS regression program.

4.0 RESULTS

The data analysis results are presented in four sections. The first two sections discuss the set of variables based on a 20 percent sample of all crashes. Since these data were not available prior to 1972, the effect of the lowered drinking age was not evaluated. The first section is a detailed discussion of the analyses of the frequency of three-factor-surrogate crashes among 18-20 year old drivers, to illustrate the Box-Jenkins method. The final results of the other total crash variables are presented in Section 4.2. Section 4.3 presents the results of the analyses of fatal crash frequencies from 1968 through 1979, encompassing both the lowered and raised drinking age changes.

4.1 An Example of the Box-Jenkins Method: Three-factor-surrogate Crash Frequency Among Drivers Aged 18-20

As discussed in Section 3.4, there are two broad stages in the Box-Jenkins time-series analysis method. First, a parsimonious ARIMA (i.e. baseline) model is specified, estimated, and evaluated, and second, the resulting ARIMA model is combined with transfer functions, representing hypothesized intervention effects. The combined model's parameters are then simultaneously estimated.

The first step in the ARIMA model identification process is the examination of a plot of the raw time-series. The variable used in this example, depicted in Figure 4.1, is the frequency of "three factor surrogate"(i.e. late-night, single-vehicle, male driver) crashes among

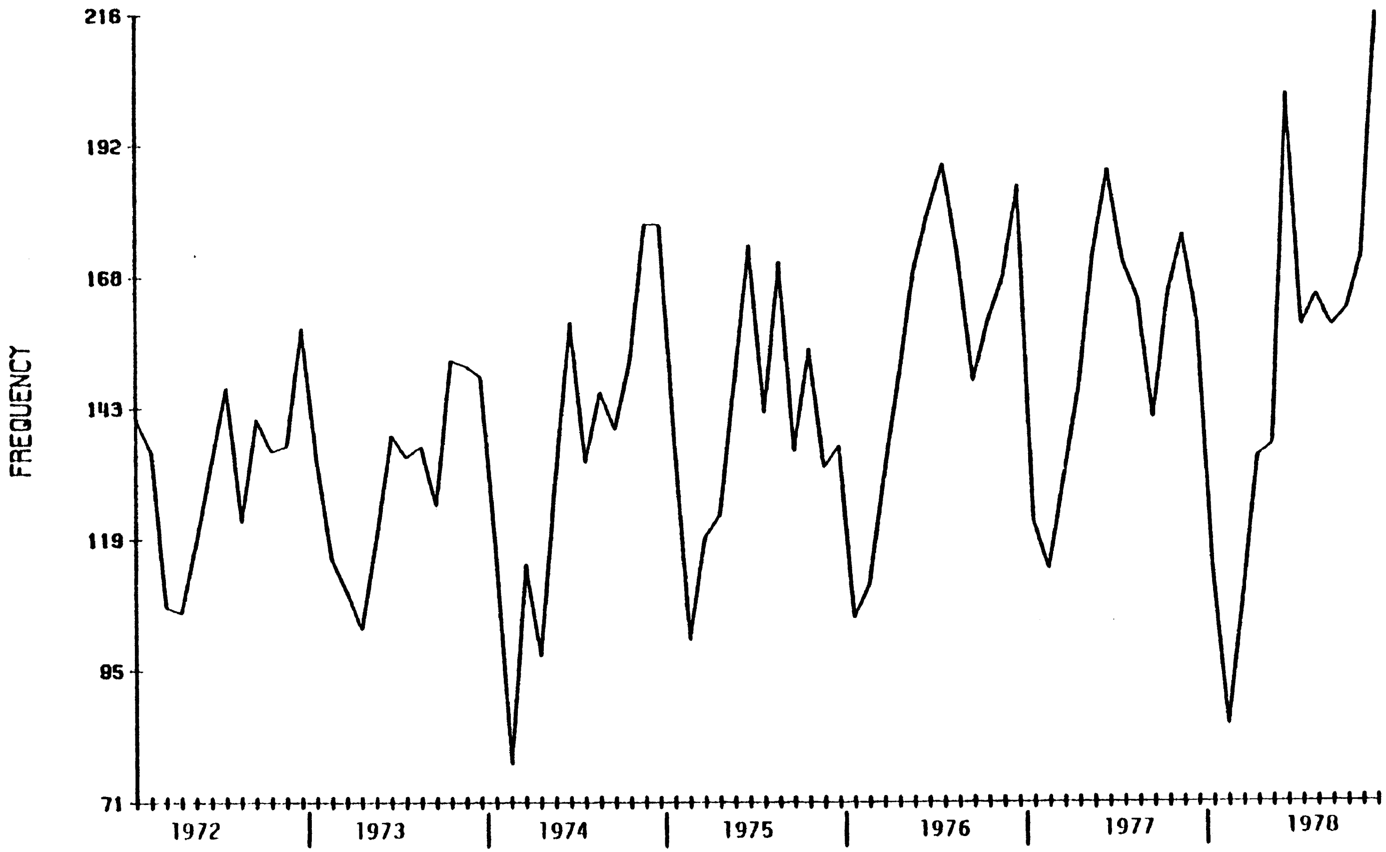

Figure 4.1 Frequency of Three-factor-surrogate Crash Involvement Among 18 - 20 Year Old Drivers in Michigan, 1972 - 1978

18-20 year old drivers in Michigan from January 1972 through December 1978.

Based on the plot of the raw data series for the baseline 1972 through 1978 period (Figure 4.1), it appeared that there was no dominant trend or other non-stationarities in the level of the series. A strong seasonal component was evident, with the frequency of 3FS collisions regularly high in the summer months and low in the winter months. The raw data plot does not reveal any systematic changes in the variance of the series over time, obviating the need for data transformations.

The second step in the ARIMA model identification process is the examination of the autocorrelation function of the data series, shown in Figure 4.2. Significant autocorrelations were evident at lags 1, 11, 12, and 24. The first two autocorrelations appeared to decay exponentially, indicating the presence of a first-order auto-regressive component. The seasonal autocorrelations at lags 12, 24, and 36 also exhibited a decaying pattern, indicating the presence of a first-order seasonal auto-regressive component.

In addition to the autocorrelation function, the partial autocorrelation function was used to identify a preliminary noise model for each crash frequency time-series. The partial autocorrelation function for 3FS crash frequency among 18-20 year old drivers supported the identification of the ARIMA (1,0,0)(1,0,0)12 model. (1) The partial autocorrelation function (Figure 4.3) had spikes at lags 1 and 12, with a drop off after the first lag and a drop off at the seasonal lags after lag 12, the pattern theoretically expected from an ARIMA (1,0,0)(1,0,0)12 model.

```
AUTOCORRELATIONS
******************************************************************************
DIFFERENCING:              0                                     VARIABLE:        9
SEASONAL DIFFERENCING:     0                                     LABEL: F3S18.C
SEASONAL SPAN:             0                                     CASES:   1-  84
******************************************************************************
            -1.0                             0.0                              1.0
LAG   VALUE .................................+.................................
  1  0.5689 .                                *******++++++++++++++             .
  2  0.2531 .                                *********                         .
  3 -0.0377 .                              ***                                 .
  4 -0.1245 .                            *****                                 .
  5 -0.0171 .                               **                                 .
  6  0.0283 .                                *                                 .
  7 -0.0845 .                             ****                                 .
  8 -0.1532 .                           ******                                 .
  9 -0.1327 .                           ******                                 .
 10  0.0947 .                                ****                              .
 11  0.3757 .                                **********+++                     .
 12  0.5779 .                                **********++++++++                .
 13  0.3653 .                                ************                      .
 14  0.0863 .                                ***                               .
 15 -0.0934 .                             ****                                 .
 16 -0.1040 .                            *****                                 .
 17 -0.0417 .                              ***                                 .
 18  0.0341 .                                **                                .
 19 -0.0562 .                              ***                                 .
 20 -0.0847 .                             ****                                 .
 21 -0.0372 .                              ***                                 .
 22  0.1256 .                                *****                             .
 23  0.3376 .                                ***********                       .
 24  0.4417 .                                **************+                   .
 25  0.2298 .                                ********                          .
 26  0.0056 .                                *                                 .
 27 -0.1460 .                           ******                                 .
 28 -0.1195 .                            *****                                 .
 29 -0.0605 .                              ***                                 .
 30 -0.0118 .                               **                                 .
 31 -0.0794 .                             ****                                 .
 32 -0.1103 .                            *****                                 .
 33 -0.0901 .                             ****                                 .
 34  0.0326 .                                **                                .
 35  0.1398 .                                *****                             .
 36  0.1954 .                                *******                           .
            .................................+.................................
```

Figure 4.2 Autocorrelation Function of the Frequency of Three-factor-surrogate Crash Involvement Among 18 - 20 Year Old Drivers

```
PARTIAL AUTOCORRELATIONS
**********************************************************************************
DIFFERENCING:            0                                     VARIABLE:        9
SEASONAL DIFFERENCING:   0                                        LABEL: F3S18.C
SEASONAL SPAN:           0                                        CASES:   1-  84
**********************************************************************************
            -1.0                              0.0                              1.0
LAG    VALUE .................................+..................................
  1   0.5689 .                                 *******************               .
  2  -0.1043 .                             *****                                 .
  3  -0.2053 .                          ********                                 .
  4   0.0141 .                                 *                                 .
  5   0.1652 .                                 ******                            .
  6  -0.0548 .                               ***                                 .
  7  -0.2444 .                         *********                                 .
  8  -0.0069 .                                **                                 .
  9   0.1154 .                                 ****                              .
 10   0.2448 .                                 ********                          .
 11   0.2468 .                                 ********                          .
 12   0.3007 .                                 **********                        .
 13  -0.2065 .                          ********                                 .
 14  -0.1705 .                           *******                                 .
 15   0.0626 .                                 ***                               .
 16   0.0734 .                                 ***                               .
 17  -0.1256 .                            ******                                 .
 18   0.0767 .                                 ***                               .
 19   0.0827 .                                 ***                               .
 20   0.0760 .                                 ***                               .
 21   0.0393 .                                 **                                .
 22   0.0341 .                                 **                                .
 23   0.0339 .                                 **                                .
 24   0.0317 .                                 **                                .
 25  -0.1254 .                            ******                                 .
 26  -0.0316 .                               ***                                 .
 27   0.0087 .                                 *                                 .
 28   0.0436 .                                 **                                .
 29  -0.0477 .                               ***                                 .
 30   0.0032 .                                 *                                 .
 31  -0.0015 .                                **                                 .
 32  -0.0398 .                               ***                                 .
 33  -0.1094 .                             *****                                 .
 34  -0.0667 .                              ****                                 .
 35  -0.1259 .                            ******                                 .
 36  -0.0551 .                               ***                                 .
             .................................+..................................
```

Figure 4.3 Partial Autocorrelation Function of the Frequency of Three-factor-surrogate Crash Involvement Among 18 - 20 Year Old Drivers

After the order of the ARIMA noise model was determined by examining the autocorrelations and partial autocorrelations, preliminary estimates of the identified model's parameters were calculated on the basis of the estimated autocorrelations using the formulae and charts provided by Box and Jenkins (1976). (2) The preliminary estimates were then input into an iterative maximum likelihood estimation computer program, the results of which are presented in Table 4.1.

The results of the ARIMA model estimation were used to assess the adequacy of the specified model on the basis of several criteria. First, the parameter estimates were examined to ensure that the values of the estimates were within acceptable limits determined by the stationarity-invertability requirements of the particular model (Box and Jenkins, 1976). Second, the residual correlogram was examined for the presence of significant autocorrelations, especially at the first few lags or the seasonal lag. A non-signficant Q-statistic indicated that the overall residual autocorrelation function was "flat," that is, did not deviate from zero autocorrelation more than would be expected by chance alone. In those cases where a significant Q-statistic was obtained and/or significant autocorrelations remained in the residuals, the residual autocorrelation function was used to re-specify the model, and the revised model was then re-estimated and re-evaluated.

Model adequacy is also indicated by parameter estimates that are significantly different from zero. Table 4.1 reveals that the seasonal auto-regressive parameter and the first-order auto-regressive parameter were significant. A fourth criterion for model adequacy is the correlation matrix of the parameter estimates. Very high correlations

Table 4.1 ARIMA Model Estimation Results for the Frequency of Three-factor-surrogate Crash Involvement Among 18 - 20 Year Old Drivers in Michigan

ESTIMATION SUMMARY TERMINATION:SSQ CONVERGENCE

VARIABLE: 9

DIFFERENCING:	0	LABEL:	F3S18.C
SEASONAL DIFFERENCING:	0	CASES:	1- 84
SEASONAL SPAN:	12	ADJUSTED SSQ:	0.25763E+05
TRANSFORMATIONS:	NONE		

PARAMETER NUMBER	PARAMETER TYPE	ORDER	BEGINNING VALUE	ESTIMATED VALUE	95 PER CENT LOWER LIMIT	UPPER LIMIT
1	DELTA		0.10000E+03	0.25440E+02	0.85864E+01	0.42295E+02
2	AR	1	0.57000E+00	0.50347E+00	0.29043E+00	0.71651E+00
3	ARS	1	0.58000E+00	0.64463E+00	0.43596E+00	0.85330E+00

RESIDUAL AUTOCORRELATIONS:	CASES	DF	Q	SIG
	1- 84	17	0.10281E+02	.8914

1- 10	-0.05	0.14	-0.03	-0.16	0.13	0.03	-0.04	-0.04	-0.12	-0.04
ST.E.	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12
11- 20	0.03	-0.06	0.09	-0.07	-0.01	-0.02	-0.11	0.11	-0.05	0.01
ST.E.	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12

PARAMETER CORRELATION MATRIX

	1	2	3
1	1.0000		
2	-0.4922	1.0000	
3	-0.7507	-0.1776	1.0000

between the parameters may be an indication of redundancy in the model that could be reduced by simplifications in the specified model. One consequence of high parameter correlations, according to McCleary and Hay (1980:303), is that the sum of squares function

> . . . may not have one clearly defined minimum, but rather several minima, each associated with a particular configuration of the redundant parameters. When the (non-linear estimation) algorithm attempts to solve a function of this sort, it may oscillate between several minima without ever converging.

Although the correlation between the seasonal auto-regressive and the constant terms was relatively high (-.76), the decision was made to retain the constant term in the preliminary noise model and reassess the need for the constant term when the combined ARIMA/transfer function model was evaluated.

For several of the variables examined in the present study, an examination of the autocorrelations and partial autocorrelations for the appropriately transformed and differenced data revealed that more than one model could plausibly be specified to account for the observed pattern of serial correlations. In such cases maximum likelihood parameter estimates were obtained for each plausible model. Each model was assessed using the criteria discussed above and any modified models that appeared necessary were also evaluated. If more than one resulting ARIMA model met all of the evaluative criteria, the model with the lowest sum of squares was selected to represent the baseline series.

The second major stage of the Box-Jenkins intervention analysis strategy is the identification, estimation, and evaluation of a transfer function model to describe the nature of the intervention impact on the criterion variable. The form of the initial transfer functions for each of the accident series was selected on the basis of the hypothesized intervention effects. The major exogenous factor of interest, the raised legal drinking age, was represented by an abrupt, permanent impact pattern transfer function model.

A second major exogenous factor influencing the frequency of motor vehicle crashes between 1972 and 1979 was the fuel shortage and maximum legal speed limit reduction of early 1974. To reduce the residual error variance and more accurately assess the impact of the raised drinking age, a first-order dynamic transfer function was included to account for the changes in crash frequency associated with the events of early 1974.

In summary, the complete model included: (A) a transfer function for the determination of the raised drinking age impact, (B) a dynamic transfer function controlling for the effects of the fuel shortage/speed limit reduction of 1974, and (C) a parsimonious ARIMA model controlling for trends, seasonality, and other autocorrelation components in the criterion time-series. The parameters of this combined model were simultaneously estimated.

The estimation results are presented in Table 4.2. Since the estimate of the constant term was not significantly different from zero, it was likely that a more parsimonious model, without a constant term, would also adequately account for the pattern of crash frequency over time. The moderately high correlations between the constant and the auto-regressive parameters noted earlier (Table 4.1), indicated that the sum squares function might not have a steep depression but rather a

Table 4.2 Initial Estimation Results for Combined ARIMA/Transfer Function Model of Three-factor-surrogate Crash Frequency Among Drivers Aged 18 - 20

Noise Model: ARIMA (1,0,0)(1,0,0)12 with no transformations
Fuel Shortage Transfer Function: rsb (1,0,0) with pulse function input
Raised Drinking Age Transfer Function: rsb (0,0,0) with step function input

	Parameter Estimates	Standard Errors
Fuel Shortage	ω = -17.27	14.03
	δ = .71	.39
Raised Drinking Age	ω = -29.86	8.34
	ϕ_1 = .34	.11
	Γ_1 = .74	.09
	α = 12.91	13.27

shallow trough. Based on these considerations, the model's parameters were re-estimated without a constant term included. The results, presented in Table 4.3, indicated that the model adequately and parsimoniously accounted for the frequency of 3FS crashes among drivers aged 18-20 over the 1972 through 1979 time period (Figure 4.4). First, the noise model parameters and the auto-regressive parameter in the fuel shortage transfer function met the requirements for system stability. Second, the noise model parameters were significantly different from zero. Third, none of the residual autocorrelations were significantly different from zero (the Q-statistic was 18.01 for lags one through 24; $p>.05$). Fourth, all of the parameter correlations were .37 or less. Finally, the full model accounted for about 67 percent of the variance of the raw time-series. The goodness of fit of the model to the data can be seen in Figure 4.5, where the actual crash frequency and the frequency predicted by the final model are plotted on the same graph.

On the basis of the criteria discussed above, it was clear that an adequate model of the frequency of 3FS crashes among drivers 18-20 had been achieved, and the model could therefore be used to assess the changes in crash frequency associated with raising the legal minimum drinking age. The estimation results indicated that after the drinking age was raised in December of 1978, there was an average reduction of 27.5 crashes per month in the time-series analyzed (Table 4.3); this effect was statistically significant with $p<.01$. The average monthly reduction of 27.5 crashes over the first 12 months after the drinking age was raised represents a 17.74 percent reduction in late-night, single-vehicle, male, 18-20 year old driver crash involvements when compared to the frequency of such crashes

Table 4.3 Final Estimation Results for Combined ARIMA/Transfer Function Model of Three-factor-surrogate Crash Frequency Among Drivers Aged 18 - 20

Noise Model: ARIMA (1,0,0)(1,0,0)12 with no transformations
Fuel Shortage Transfer Function: rsb (1,0,0) with pulse function input
Raised Drinking Age Transfer Function: rsb (0,0,0) with step function input

	Parameter Estimates	Standard Errors
Fuel Shortage	ω = -16.91	14.10
	δ = .71	.40
Raised Drinking Age	ω = -27.50	8.06
	ϕ_1 = .35	.11
	Γ_1 = .73	.09

Residual Variance = 320 R-sqr = .67 Q = 18.01

Residual Autocorrelations: Approx. standard error = .11

1:-.09	2: .19	3: .00	4:-.17	5: .08
6:-.07	7:-.07	8:-.03	9:-.08	10:-.07
11: .13	12:-.17	13: .07	14:-.05	15:-.06
16:-.03	17:-.13	18:-.04	19:-.03	20:-.07
21:-.01	22:-.09	23: .08	24: .13	

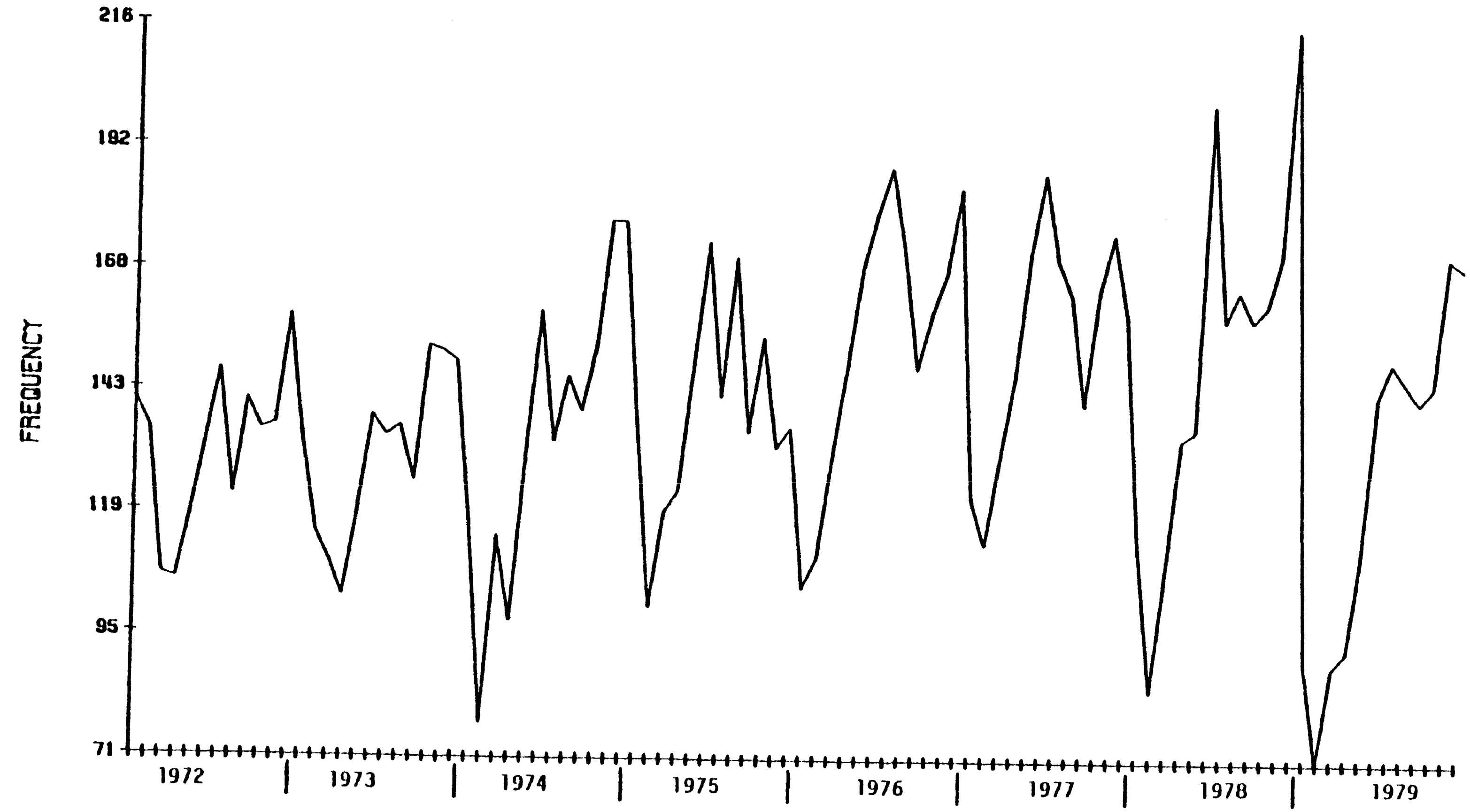

Figure 4.4 Frequency of Three-factor-surrogate Crash Involvement Among 18 - 20 Year Old Drivers in Michigan, 1972 - 1979

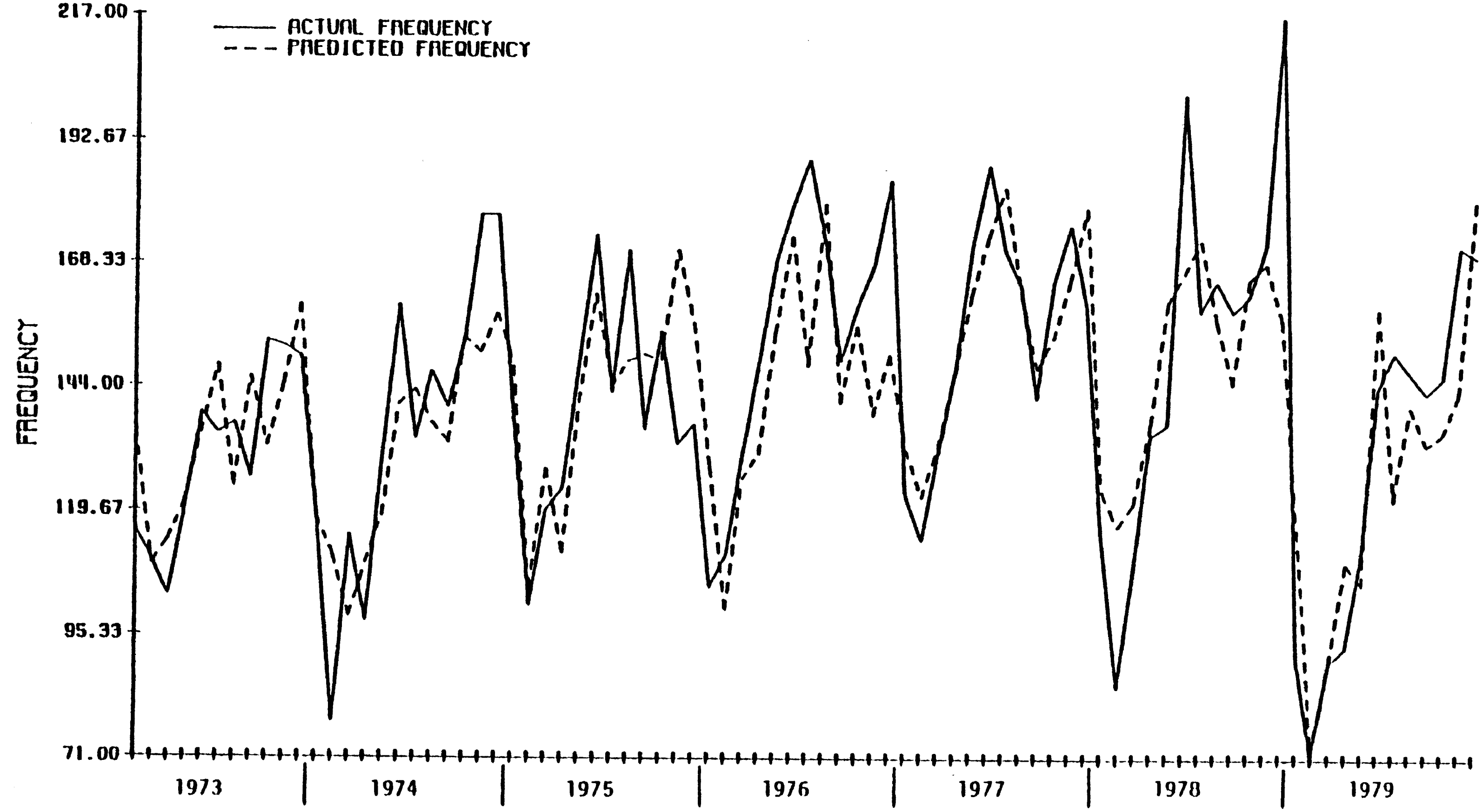

Figure 4.5 Actual and Predicted Frequency of Three-factor-surrogate Crash Involvement Among 18 - 20 Year Old Drivers in Michigan, 1973 - 1979

expected had there been no change in the drinking age. The 17.74 percent reduction in crashes can be interpreted as the net effect associated with the raised drinking age, controlling for the effects of (A) the fuel shortage/speed limit reduction of early 1974, (B) trend and seasonal variation in crash frequency, and (C) random variation in the frequency of motor vehicle crashes.

However, the drinking age transfer function estimate of -27.5 crashes cannot be directly used as a point estimate of the actual number of 3FS crashes prevented by raising the drinking age, since the model was estimated using a time-series based on a random 20 percent sample of all reported crashes. The best point estimate of the actual number of crashes prevented by the legal change is obtained by multiplying the transfer function point estimate (i.e., -27.5) by the inverse of the sampling fraction (i.e., 5), resulting in the estimate of 137.5 crash involvements per month prevented by the legal change. Over the first twelve months after the drinking age was raised, therefore, an estimated 1650 3FS crashes among 18-20 year old drivers were prevented.

Although not the focus of the present investigation, the full model results presented in Table 4.3 also provide information concerning changes in 3FS crashes associated with the fuel shortage/speed limit factors. The results indicated that a statistically non-significant, temporary reduction in 3FS crashes occurred in early 1974. It should be noted, however, that the fuel shortage/speed limit effect estimates based on the analysis of 1972 through 1979 crash frequencies should be interpreted with caution, since the point estimates were based on a short baseline series. As discussed in Chapter 3.0, the main purposes for including the transfer function for the fuel shortage/speed limit effects in the analyses were: (A) to determine the effects associated with the modifications in the legal drinking age independent of the well established impact of the fuel shortage and speed limit reduction, and (B) to reduce the residual error variance (and consequenctly increase the precision of the drinking age parameter estimates) by accounting for this major exogenous shock to the system causing the crash time-series.

In summary, the iterative specification, estimation, and evaluation strategy of modeling time-series suggested by Box and Jenkins resulted in an ARIMA model that adequately represented the autocorrelation structure of the monthly frequency of 3FS crashes among 18-20 year old drivers. The ARIMA model was combined with two transfer functions, representing the effects of the 1974 fuel shortage/speed limit reduction and the hypothesized effects of raising the legal minimum drinking age. The iterative specificaton, estimation, evaluation process was repeated for the combined ARIMA/transfer function model. The final resulting model revealed a highly significant reduction in 3FS crash frequency associated with raising the drinking age, with a magnitude of approximately 18 percent, or 137.5 crash involvements per month.

4.2 Time-series Models of Michigan Total Crash Frequencies, 1972 - 1979

The iterative model building strategy was applied to each of the time-series included in the full design matrix (see Table 3.1). The estimation results for each of the variables based on the 20 percent random sample file are presented below. Included for each variable are: (A) a plot of the raw series (Figures 4.6 to 4.15), and (B) the final combined ARIMA/transfer function model estimation results (Tables 4.4 to 4.14). (3) The full complement of diagnostic statistics are included for each model, verifying its appropriateness for estimation of the effect of the raised drinking age.

The first hypothesis of this investigation was that raising the legal minimum drinking age would result in reduced alcohol-related traffic crashes among 18-20 year old drivers. The time-series modeling results, summarized in Table 4.15, revealed highly significant reductions both in police-reported had-been-drinking crashes and three-factor-surrogate alcohol-related crashes among 18-20 year old drivers after the drinking age was raised. Police-reported HBD crashes dropped by 30.72 percent, and 3FS crashes were down by 17.75 percent from what would have been expected had there been no drinking age change. (4)

The main "control" series specific to 18-20 year old drivers was the frequency of police-reported "had not been drinking" crashes. A small reduction in HNBD crashes was evident, but it was not statistically significant and small in magnitude compared to the drop in the frequency of HBD or 3FS crashes (Table 4.15). The observed substantial reductions in HBD and 3FS alcohol-related crash frequencies, and no significant change in HNBD non-alcohol-related crashes, provided strong support for hypothesis one, that is, that the raised legal drinking age caused a reduction in alcohol-related traffic accidents among drivers aged 18-20.

It was also hypothesized that the raised legal drinking age would cause a reduction in alcohol-related crash involvement among drivers aged 16-17. Analyses of 3FS crashes among drivers of this age group revealed a significant reduction associated with the raised legal age

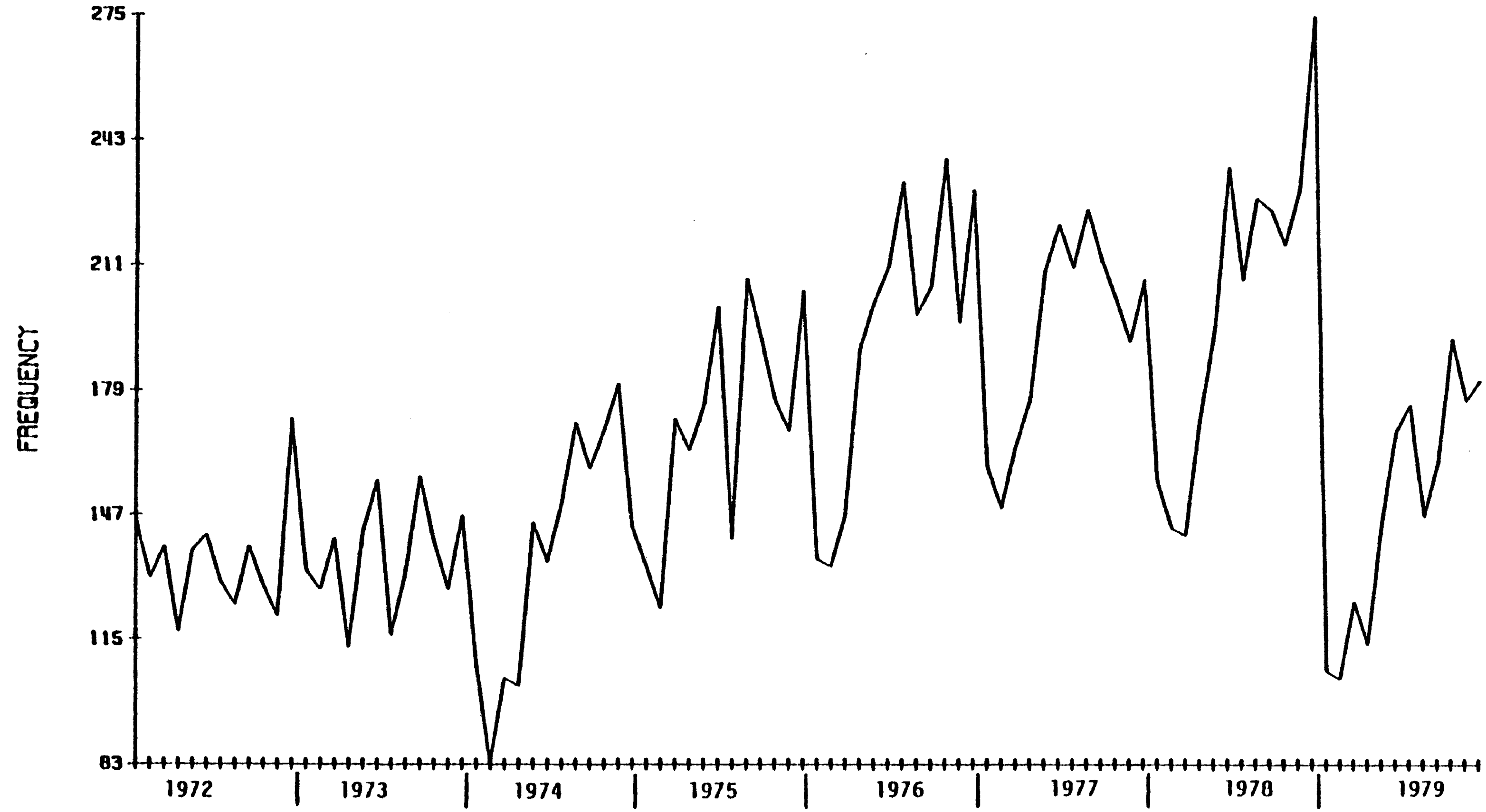

Figure 4.6 Frequency of Had-been-drinking Crash Involvement Among 18 - 20 Year Old Drivers in Michigan, 1972 - 1979

Table 4.4 Final Estimation Results for Combined ARIMA/Transfer Function Model of Had-been-drinking Crash Frequency Among Drivers Aged 18 - 20

Noise Model: ARIMA (3,0,0)(1,0,0)12 with log transformation
Fuel Shortage Transfer Function: rsb (0,0,0) with four month pulse function input
Raised Drinking Age Transfer Function: rsb (0,0,0) with step function input

Parameter	Estimates	Standard Errors
Fuel Shortage	ω = -.293	.055
Raised Drinking Age	ω = -.367	.063
	ϕ_1 = .080	.113
	ϕ_2 = .021	.112
	ϕ_3 = .335	.113
	Γ_1 = .792	.084
	α = .331	.195

Residual Variance = .0165 R-sqr = .77 Q = 27.75

Residual Autocorrelations: Approx. standard error = .11

1:-.04	2: .02	3:-.02	4: .03	5:-.09
6: .02	7: .12	8:-.10	9:-.21	10: .10
11: .10	12:-.19	13: .31	14: .05	15:-.10
16:-.16	17:-.07	18:-.11	19:-.06	20:-.05
21: .07	22:-.19	23: .07	24: .07	

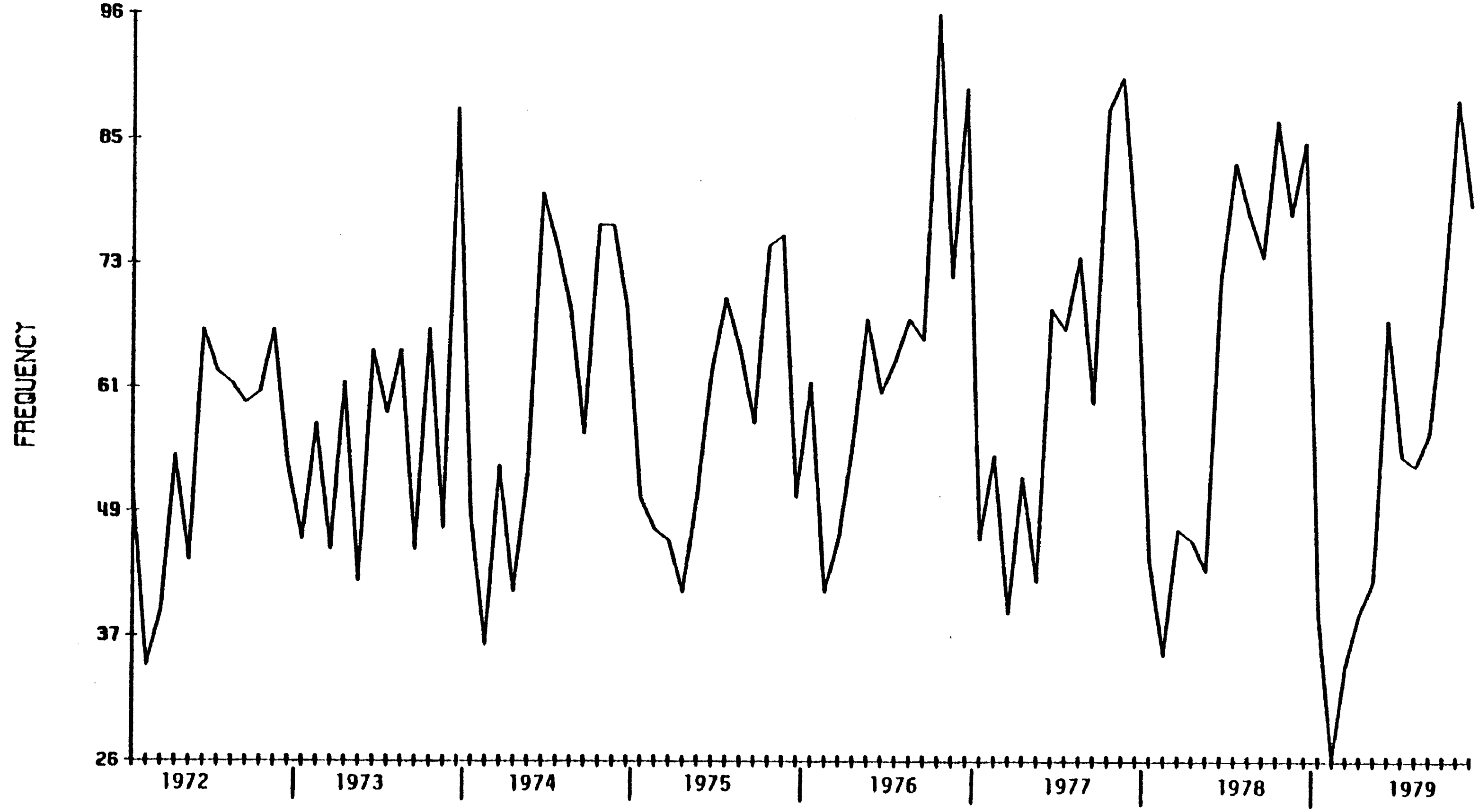

Figure 4.7 Frequency of Three-factor-surrogate Crash Involvement Among 16 - 17 Year Old Drivers in Michigan, 1972 - 1979

Table 4.5 Final Estimation Results for Combined ARIMA/Transfer Function Model of Three-factor-surrogate Crash Frequency Among Drivers Aged 16 - 17

Noise Model: ARIMA (0,0,0)(1,1,0)12 with no transformations
Raised Drinking Age Transfer Function: rsb (0,0,0) with step function input

	Parameter Estimates	Standard Errors
Raised Drinking Age	ω = -9.45	3.05
	Γ_1 = -.50	.10

Residual Variance = 112   R-sqr = .65   Q = 20.26

Residual Autocorrelations: Approx. standard error = .11

1:-.11	2: .10	3:-.16	4: .04	5:-.24
6: .05	7:-.15	8: .11	9:-.02	10:-.04
11: .13	12:-.11	13:-.04	14:-.06	15: .09
16:-.17	17: .07	18:-.02	19: .09	20:-.10
21: .00	22: .07	23: .09	24:-.16	

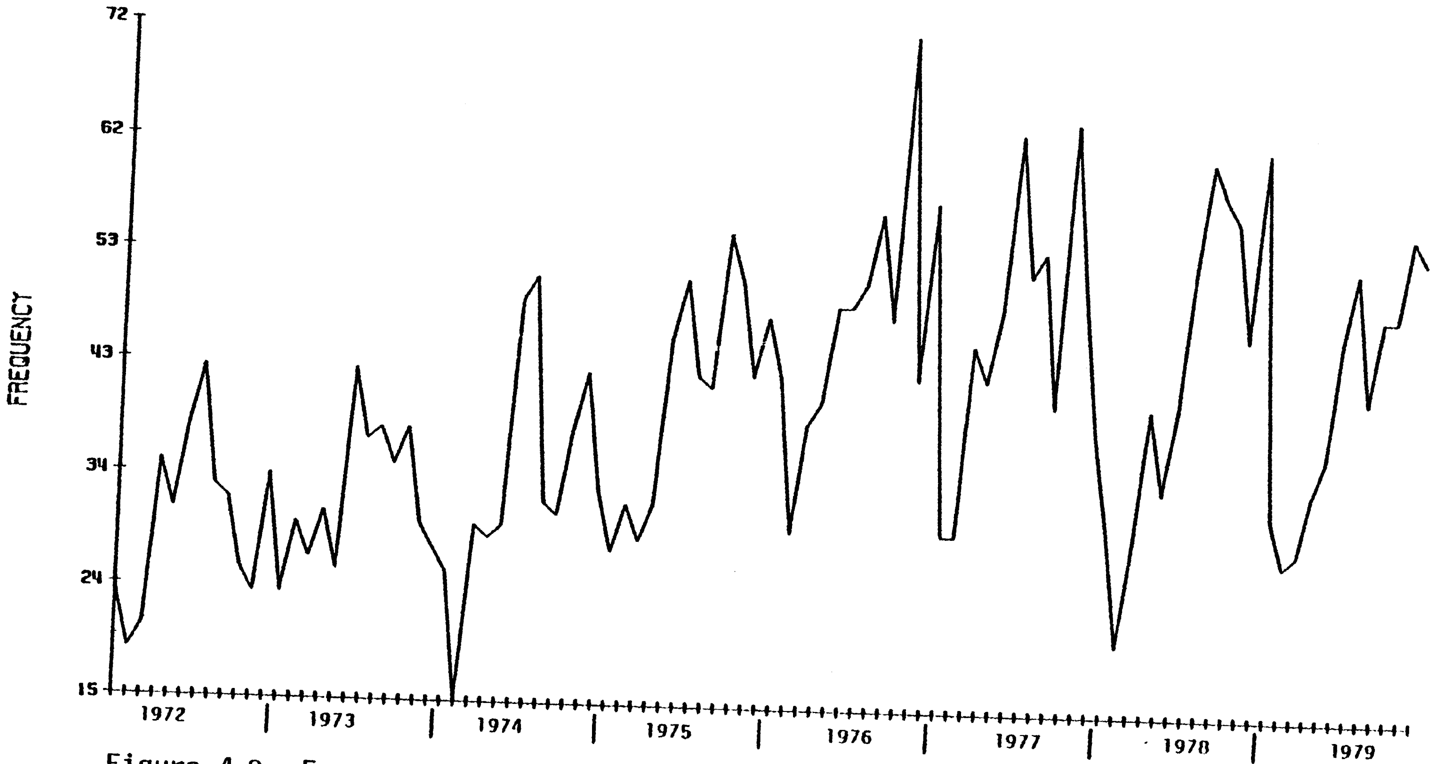

Figure 4.8 Frequency of Had-been-drinking Crash Involvement Among 16 - 17 Year Old Drivers in Michigan, 1972 - 1979

Table 4.6 Final Estimation Results for Combined ARIMA/Transfer Function Model of Reported Had-been-drinking Crash Frequency Among Drivers Aged 16 - 17

Noise Model: ARIMA (1,0,0)(1,0,0)12 with no transformations
Fuel Shortage Transfer Function: rsb (1,0,0) with pulse function input
Raised Drinking Age Transfer Function: rsb (0,0,0) with step function input

	Parameter Estimates	Standard Errors
Fuel Shortage	$\omega = -7.88$	5.10
	$\delta = .90$	.13
Raised Drinking Age	$\omega = -3.40$	3.36
	$\phi_1 = .19$	.12
	$\Gamma_1 = .54$	.10
	$\alpha = 4.56$	2.82

Residual Variance = 75 R-sqr = .57 Q = 22.38

Residual Autocorrelations: Approx. standard error = .11

1:-.01	2: .05	3: .04	4: .05	5:-.02
6:-.17	7:-.02	8:-.09	9:-.15	10: .15
11: .15	12:-.17	13: .15	14: .10	15: .06
16:-.12	17:-.06	18: .04	19:-.22	20:-.09
21:-.03	22:-.01	23:-.04	24: .10	

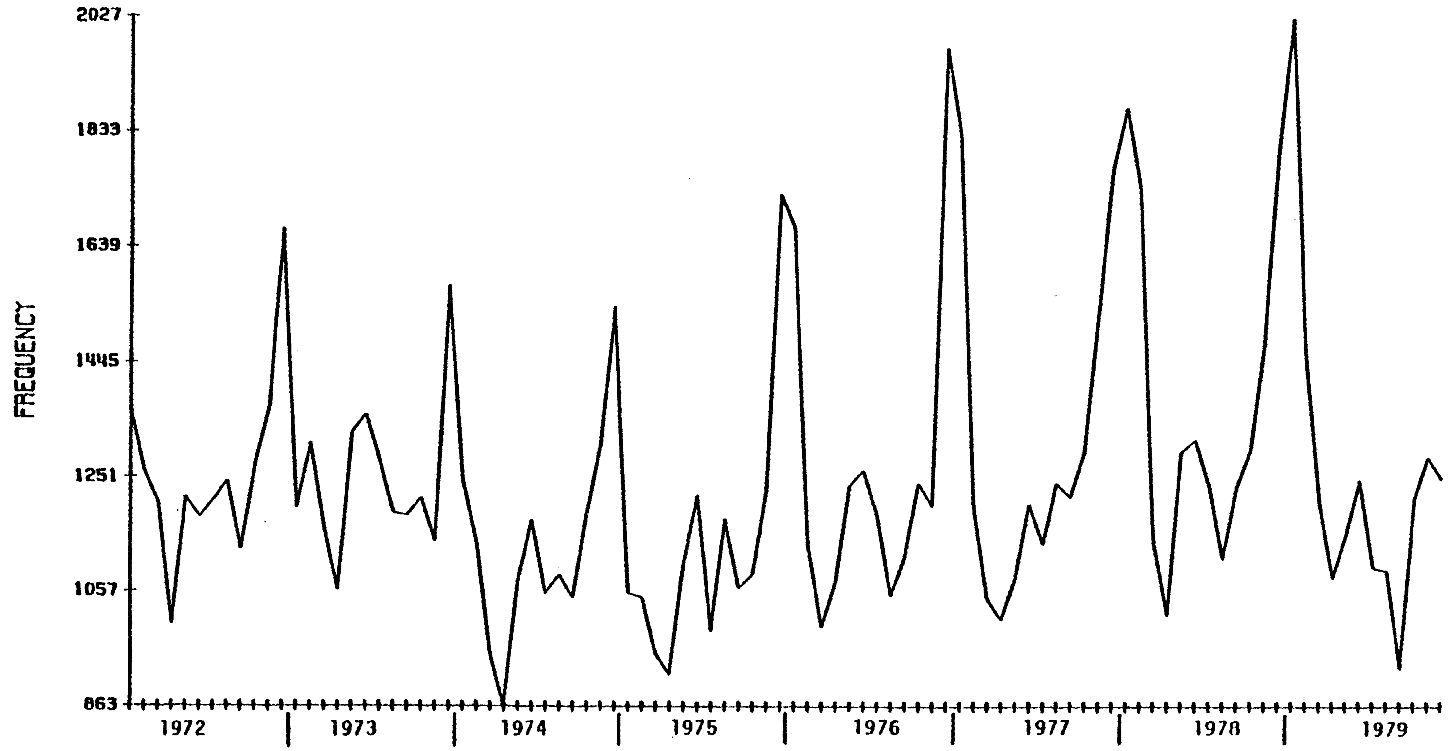

Figure 4.9 Frequency of Had-not-been-drinking Crash Involvement Among 18 - 20 Year Old Drivers in Michigan, 1972 - 1979

Table 4.7 Final Estimation Results for Combined ARIMA/Transfer Function Model of Reported Had-not-been drinking Crash Frequency Among Drivers Aged 18 - 20

Noise Model: ARIMA (1,0,0)(1,0,0)12 with no transformations
Fuel Shortage Transfer Function: rsb (0,0,0) with step function input
Raised Drinking Age Transfer Function: rsb (0,0,0) with step function input

	Parameter Estimates	Standard Errors
Fuel Shortage	ω = -86.05	73.13
Raised Drinking Age	ω = -92.05	65.59
	ϕ_1 = .33	.11
	Γ_1 = .74	.08

Residual Variance = 22,728 R-sqr = .66 Q = 25.91

Residual Autocorrelations: Approx. standard error = .11

1: .01	2:-.13	3: .19	4:-.05	5: .00
6: .02	7: .00	8: .02	9:-.09	10: .05
11: .16	12:-.17	13: .20	14: .20	15:-.19
16: .07	17: .04	18:-.11	19: .02	20:-.10
21:-.07	22:-.10	23:-.10	24: .13	

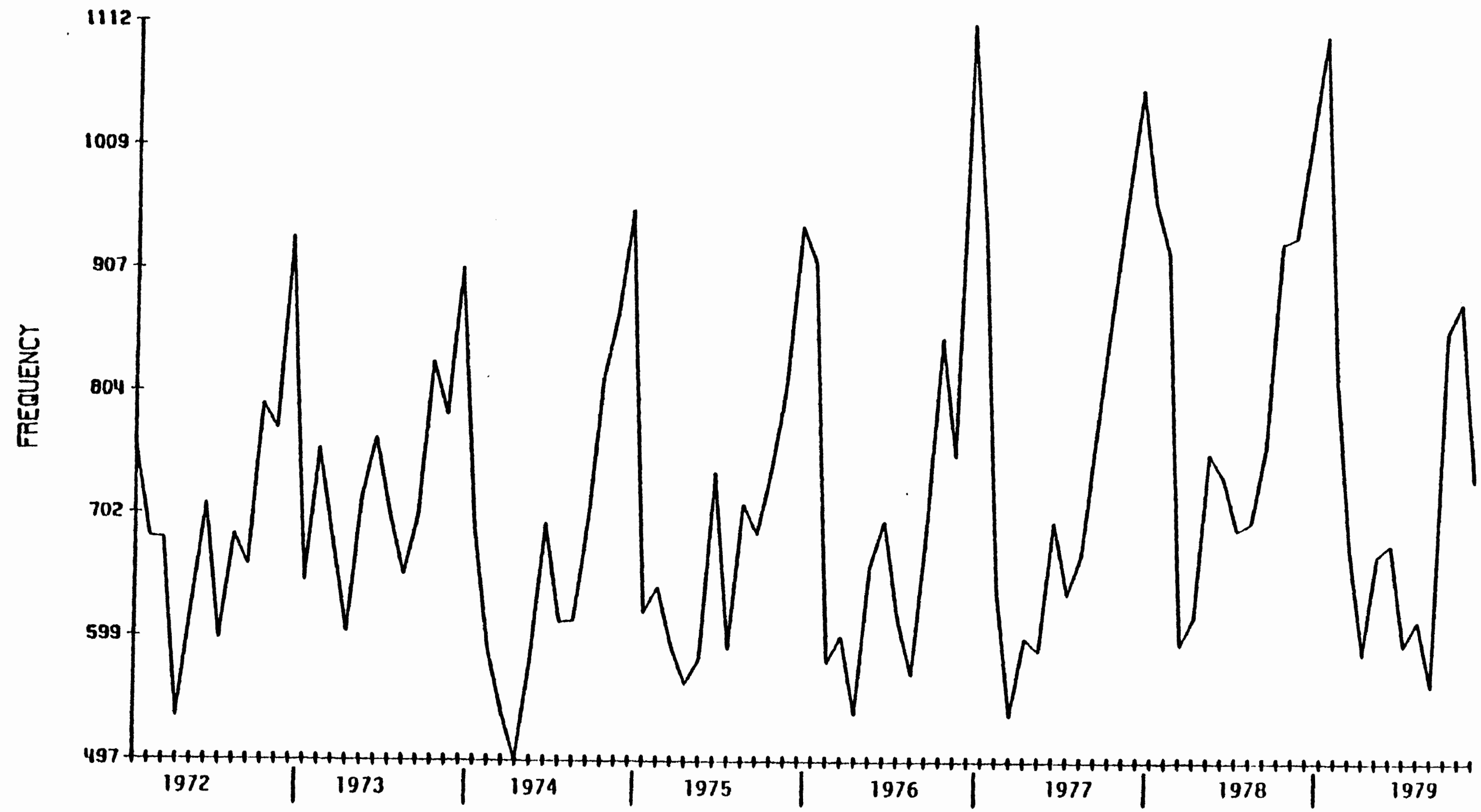

Figure 4.10 Frequency of Had-not-been-drinking Crash Involvement Among 16 - 17 Year Old Drivers in Michigan, 1972 - 1979

Table 4.8 Final Estimation Results for Combined ARIMA/Transfer Function Model of Reported Had-not-been-drinking Crash Frequency Among Drivers Aged 16 - 17

Noise Model: ARIMA (0,0,0)(1,1,0)12 with no transformations
Fuel Shortage Transfer Function: rsb (0,0,0) with step function input
Raised Drinking Age Transfer Function: rsb (0,0,0) with step function input

	Parameter Estimates	Standard Errors
Fuel Shortage	ω = -41.92	26.50
Raised Drinking Age	ω = -55.98	27.16
	Γ_1 = -.27	.13

Residual Variance = 8300 R-sqr = .68 Q = 16.42

Residual Autocorrelations: Approx. standard error = .11

1: .05	2: .13	3: .21	4: .05	5: .04
6:-.04	7:-.05	8:-.06	9: .09	10:-.03
11: .10	12:-.05	13: .14	14: .05	15:-.09
16: .07	17:-.03	18:-.06	19:-.10	20:-.06
21:-.10	22:-.20	23:-.16	24:-.04	

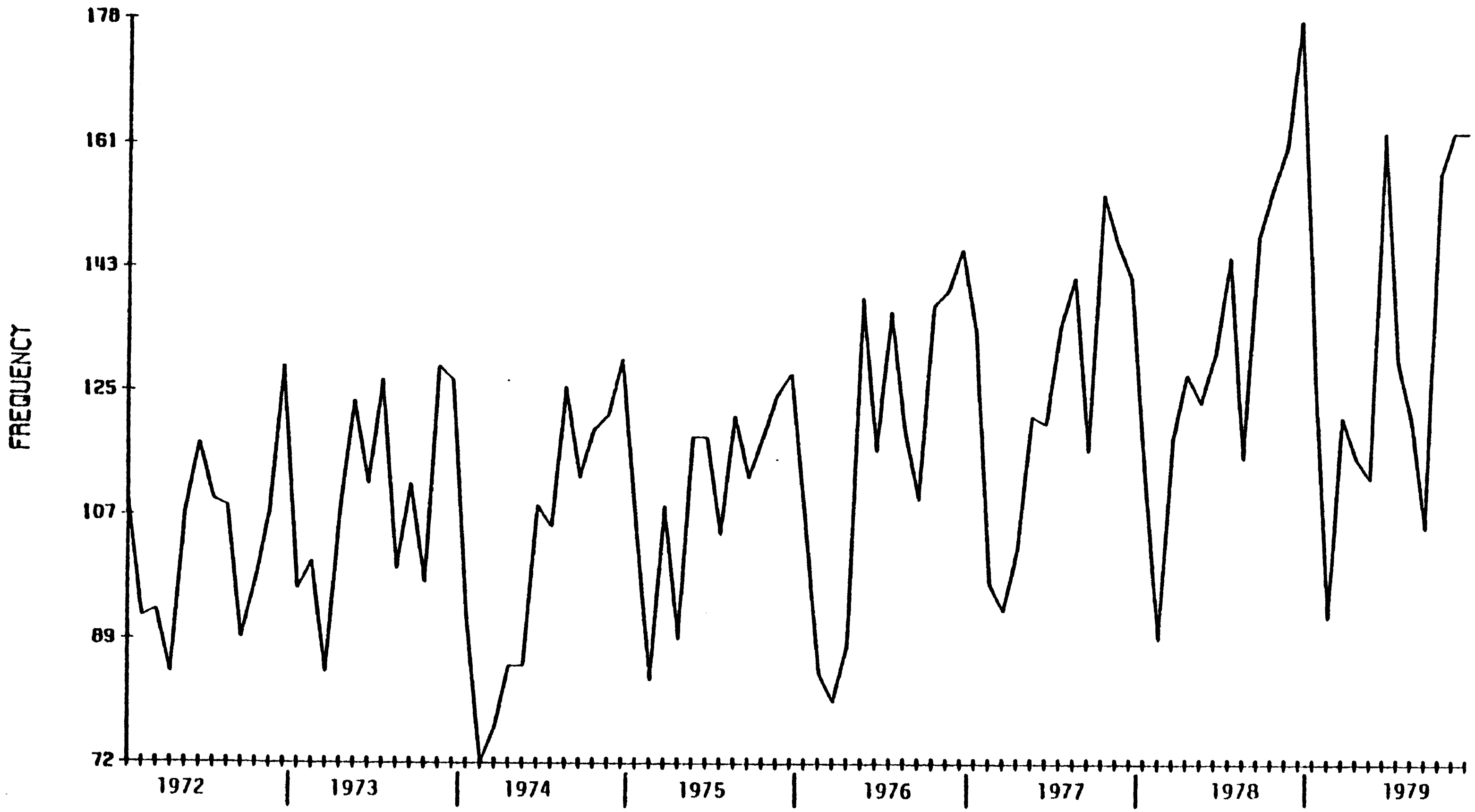

Figure 4.11 Frequency of Three-factor-surrogate Crash Involvement Among 21 - 24 Year Old Drivers in Michigan, 1972 - 1979

Table 4.9 Final Estimation Results for Combined ARIMA/Transfer Function Model of Three-factor-surrogate Crash Frequency Among Drivers Aged 21 - 24

Noise Model: ARIMA (0,0,2)(0,1,1)12 with no transformations
Fuel Shortage Transfer Function: rsb (0,0,0) with step function input
Raised Drinking Age Transfer Function: rsb (0,0,0) witn step function input

	Parameter Estimates		Standard Errors
Fuel Shortage	ω =	7.07	6.14
Raised Drinking Age	ω =	2.96	6.69
	θ_1 =	-.10	.12
	θ_2 =	-.33	.12
	Δ_1 =	.50	.13

Residual Variance = 241 R-sqr = .66 Q = 20.63

Residual Autocorrelations: Approx. standard error = .11

1:-.02	2:-.09	3: .12	4:-.12	5: .01
6: .18	7: .04	8: .09	9: .11	10:-.29
11: .03	12:-.02	13:-.01	14: .16	15: .08
16: .03	17:-.03	18:-.12	19:-.03	20: .14
21: .03	22: .06	23: .15	24:-.14	

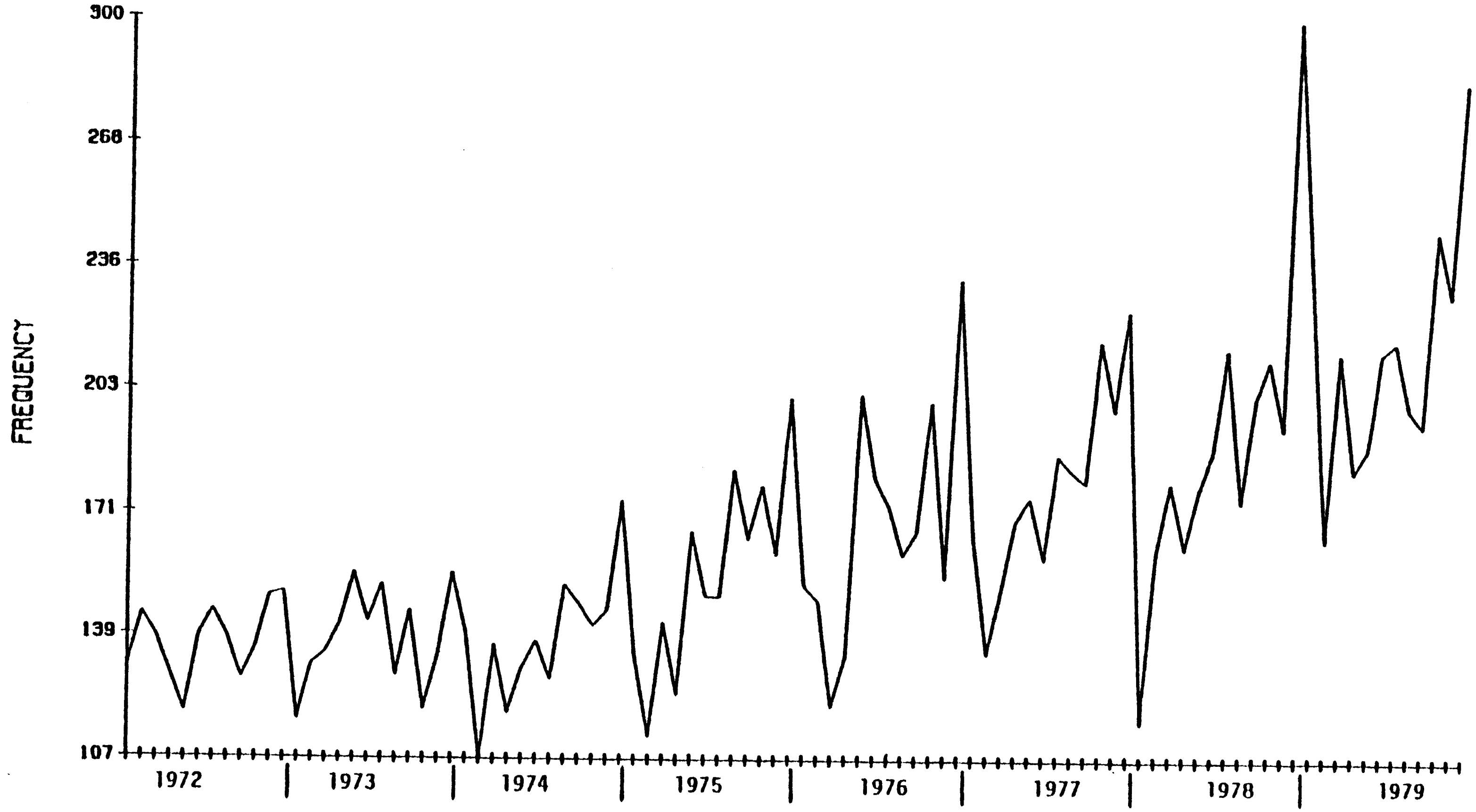

Figure 4.12 Frequency of Had-been-drinking Crash Involvement Among 21 - 24 Year Old Drivers in Michigan, 1972 - 1979

Table 4.10 Final Estimation Results for Combined ARIMA/Transfer Function Model of Reported Had-been-drinking Crash Frequency Among Drivers Aged 21 - 24

Noise Model: ARIMA (0,0,0)(1,1,0)12 with log transformation
Raised Drinking Age Transfer Function: rsb (0,0,0) with step function input

	Parameter Estimates		Standard Errors
Raised Drinking Age	ω =	.09	.05
	Γ_1 =	.002	.009

Residual Variance = .0247 R-sqr = .52 Q = 26.68

Residual Autocorrelations: Approx. standard error = .11

1: .08	2:-.09	3: .10	4: .08	5:-.02
6: .02	7: .18	8: .03	9: .00	10: .10
11: .05	12:-.36	13:-.06	14: .17	15:-.04
16: .03	17: .06	18:-.06	19:-.22	20:-.06
21: .05	22:-.05	23:-.10	24:-.03	

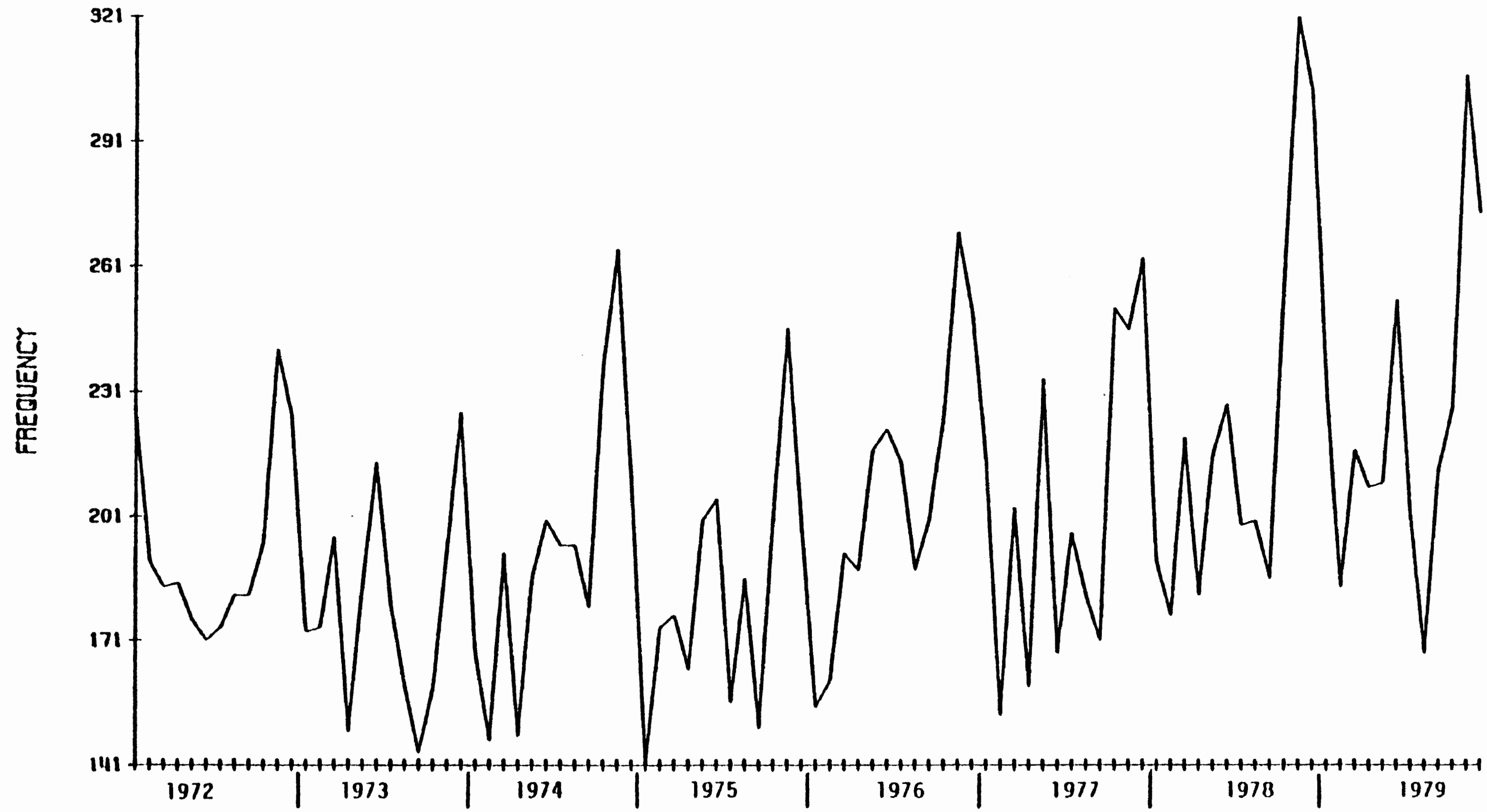

Figure 4.13 Frequency of Three-factor-surrogate Crash Involvement Among 25 - 45 Year Old Drivers in Michigan, 1972 - 1979

Table 4.11 Final Estimation Results for Combined ARIMA/Transfer Function Model of Three-factor-surrogate Crash Frequency Among Drivers Aged 25 - 45

Noise Model: ARIMA (2,0,0)(1,1,0)12 with no transformations
Raised Drinking Age Transfer Function: rsb (0,0,0) with step function input

	Parameter Estimates		Standard Errors
Raised Drinking Age	ω =	3.00	12.22
	ϕ_1 =	.09	.12
	ϕ_2 =	.35	.12
	Γ_1 =	-.44	.11

Residual Variance = 613 R-sqr = .68 Q = 21.39

Residual Autocorrelations: Approx. standard error = .11

1:-.10	2:-.05	3: .02	4:-.14	5: .04
6: .00	7: .03	8:-.02	9:-.11	10:-.01
11:-.09	12:-.07	13: .04	14:-.10	15: .07
16:-.18	17:-.06	18: .03	19:-.06	20: .09
21: .02	22:-.11	23: .33	24:-.24	

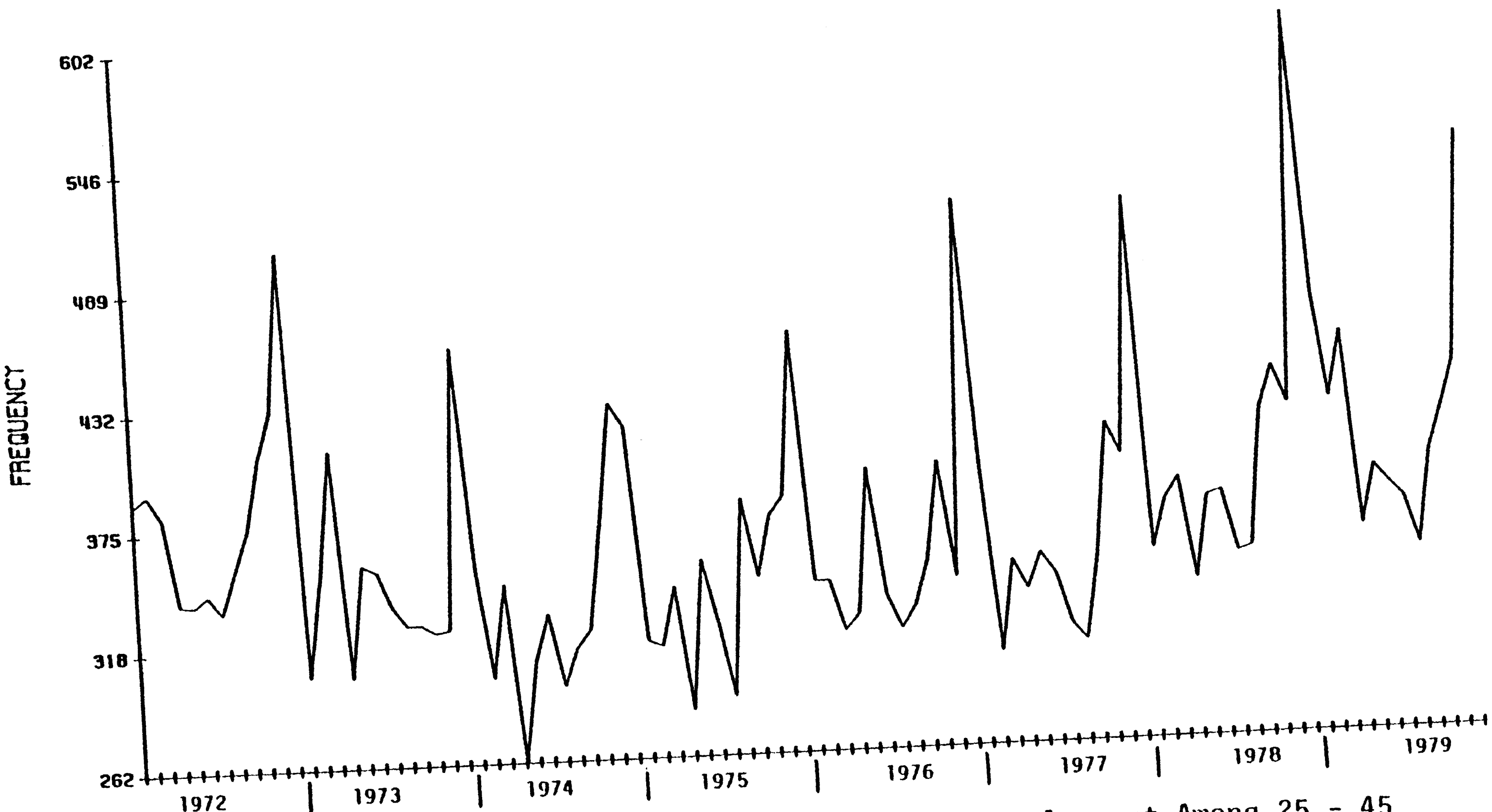

Figure 4.14 Frequency of Had-been-drinking Crash Involvement Among 25 - 45 Year Old Drivers in Michigan, 1972 - 1979

Table 4.12 Final Estimation Results for Combined ARIMA/Transfer Function Model of Reported Had-been-drinking Crash Frequency Among Drivers Aged 25 - 45

Noise Model: ARIMA (1,0,0)(1,0,0)12 with no transformations
Fuel Shortage Transfer Function: rsb (0,0,0) with step function input
Raised Drinking Age Transfer Function: rsb (0,0,0) with step function input

	Parameter Estimates	Standard Errors
Fuel Shortage	ω = -46.49	19.02
Raised Drinking Age	ω = 21.12	16.92
	ϕ_1 = .36	.10
	Γ_1 = .73	.08

Residual Variance = 1401 R-sqr = .66 Q = 17.64

Residual Autocorrelations: Approx. standard error = .11

1:-.02	2:-.04	3: .25	4: .02	5: .05
6: .11	7: .00	8:-.05	9: .02	10: .19
11: .04	12:-.16	13:-.03	14: .12	15:-.07
16:-.05	17: .05	18:-.12	19:-.02	20: .07
21:-.07	22:-.12	23: .05	24: .04	

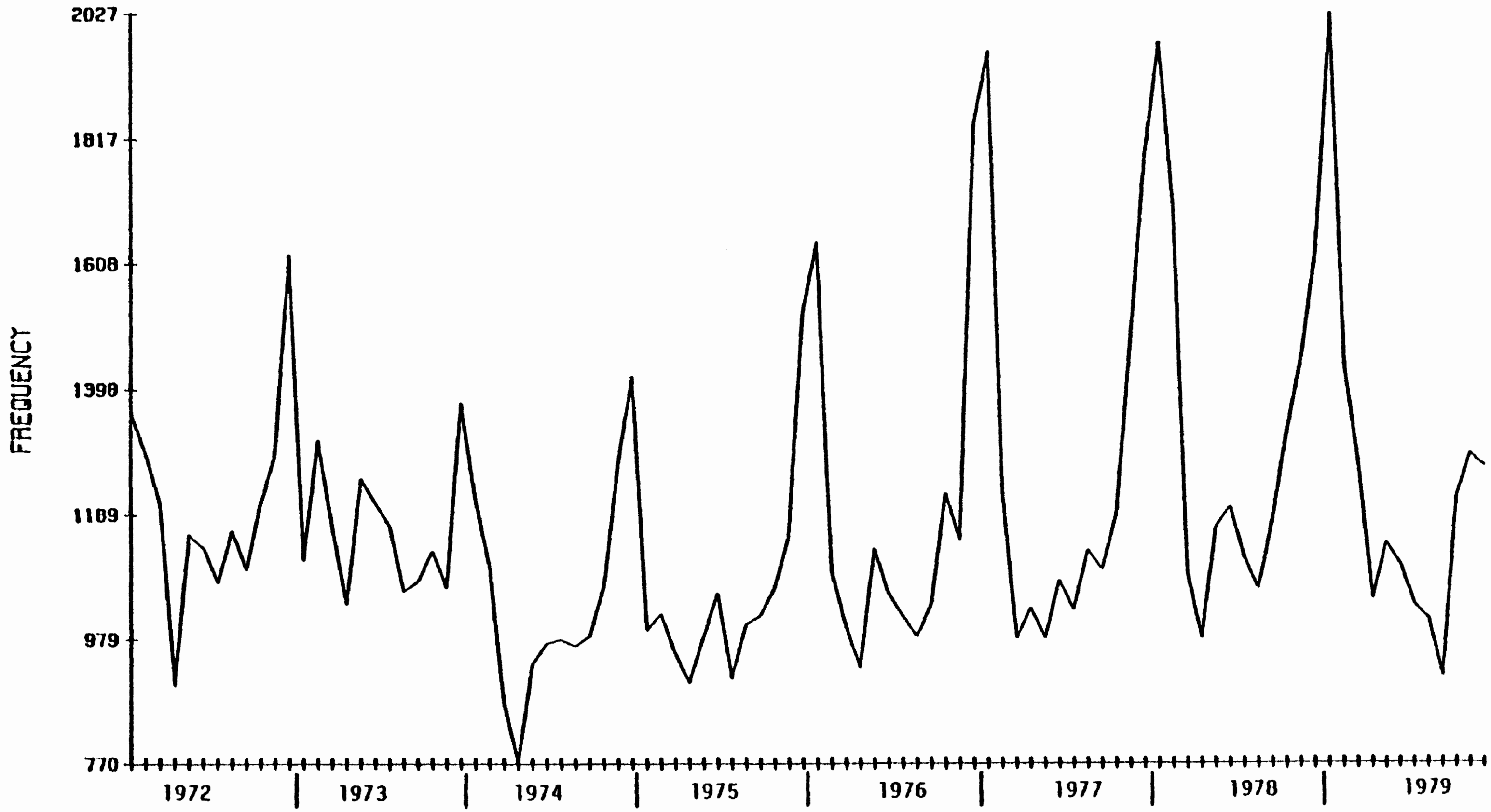

Figure 4.15 Frequency of Had-not-been-drinking Crash Involvement Among 21 - 24 Year Old Drivers in Michigan, 1972 - 1979

Table 4.13 Final Estimation Results for Combined ARIMA/Transfer Function Model of Reported Had-not-been-drinking Crash Frequency Among Drivers Aged 21 - 24

Noise Model: ARIMA (1,0,0)(1,0,0)12 with no transformations
Fuel Shortage Transfer Function: rsb (0,0,0) with step function input
Raised Drinking Age Transfer Function: rsb (0,0,0) with step function input

	Parameter Estimates	Standard Errors
Fuel Shortage	ω = -60.41	78.36
Raised Drinking Age	ω = -42.32	69.24
	ϕ_1 = .37	.11
	Γ_1 = .74	.09

Residual Variance = 23,244 R-sqr = .69 Q = 17.82

Residual Autocorrelations: Approx. standard error = .11

1: .00	2:-.04	3: .15	4: .05	5:-.04
6:-.01	7: .05	8:-.02	9:-.03	10: .07
11: .18	12:-.10	13: .26	14: .14	15:-.13
16:-.01	17: .02	18:-.06	19:-.05	20:-.09
21:-.02	22:-.07	23:-.06	24: .08	

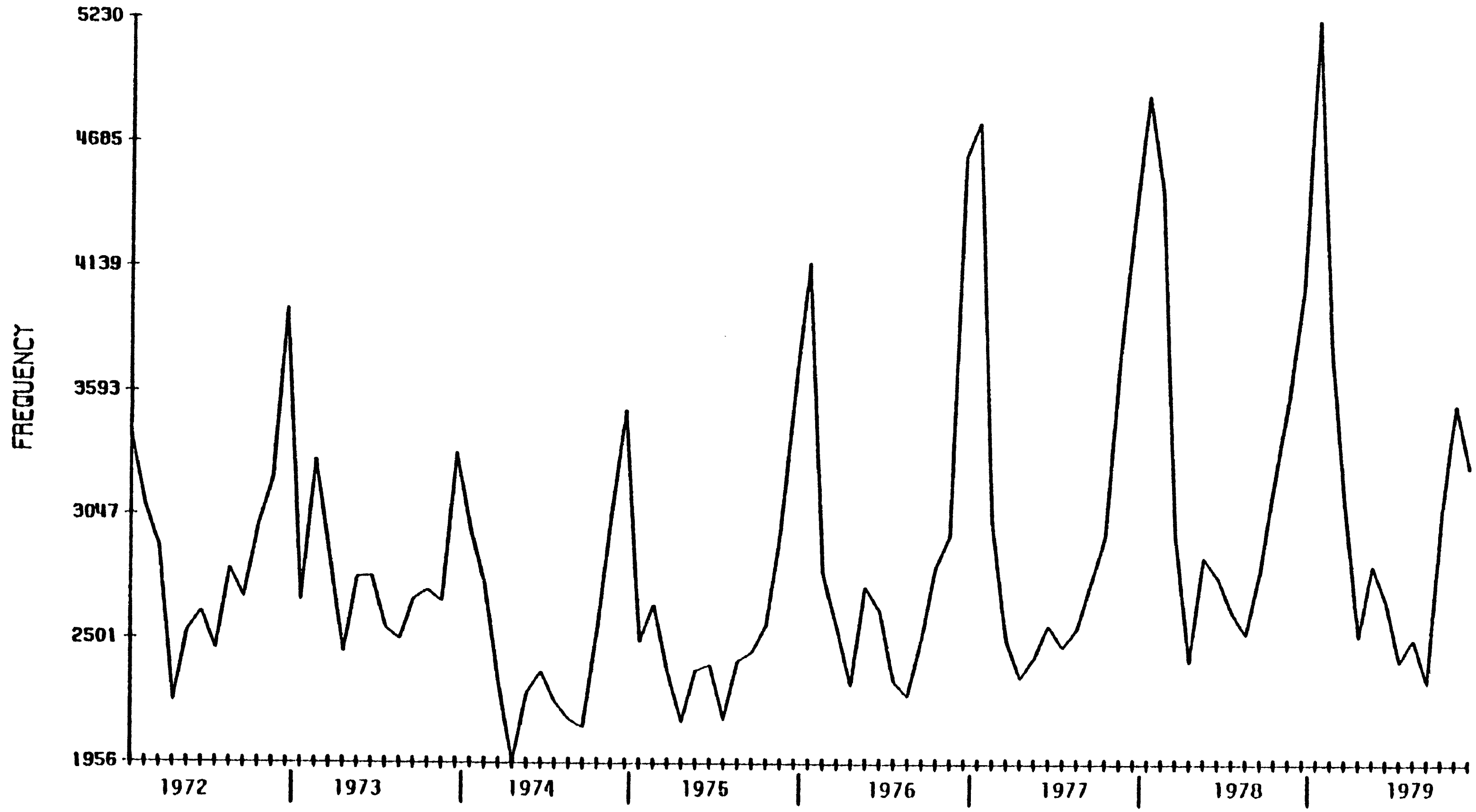

Figure 4.16 Frequency of Had-not-been-drinking Crash Involvement Among 25 - 45 Year Old Drivers in Michigan, 1972 - 1979

Table 4.14 Final Estimation Results for Combined ARIMA/Transfer Function Model of Reported Had-not-been-drinking Crash Frequency Among Drivers Aged 25 - 45

Noise Model: ARIMA (1,0,0)(1,0,0)12 with no transformations
Fuel Shortage Transfer Function: rsb (0,0,0) with step function input
Raised Drinking Age Transfer Function: rsb (0,0,0) with step function input

	Parameter Estimates	Standard Errors
Fuel Shortage	ω = -57.17	163.08
Raised Drinking Age	ω =-147.34	179.46
	ϕ_1 = .32	.11
	Γ_1 = .80	.08

Residual Variance = 145,979 R-sqr = .72 Q = 23.89

Residual Autocorrelations: Approx. standard error = .11

1: .00	2:-.03	3: .16	4: .09	5: .01
6:-.02	7: .03	8: .00	9:-.01	10: .06
11: .27	12:-.14	13: .19	14: .19	15:-.10
16:-.09	17:-.02	18:-.06	19:-.08	20:-.06
21:-.02	22:-.02	23:-.17	24: .14	

Table 4.15 Summary of Transfer Function Estimates of the Impact of the Raised Legal Drinking Age on a 20 Percent Random Sample of Motor Vehicle Crashes in Michigan

	Age of Driver			
	16 - 17	18 - 20	21 - 24	25 - 45
HNBD Crashes	-56.0 (27.2)* -7.1%	-92.0 (65.6) -6.8%	-42.3 (69.2) -3.3%	-147.3 (179.5) -4.5%
HBD Crashes	-3.4 (3.4) -7.4%	-.376 (.063)** -30.7%	.09 (.05)* +9.4%	21.1 (16.9) +5.4%
3FS Crashes	-9.5 (3.1)** -14.7%	-27.5 (8.1)** -17.7%	3.0 (6.7) +2.3%	3.0 (12.2) +1.3%

Notes:
1. Standard errors are in parentheses following each point estimate.
2. Point estimates significant at the .05 level are identified with a single asterisk, those significant at the .01 level are identified with double asterisks, using a one-tailed test.
3. Percentage change figures are included below the transfer function estimates

(Table 4.15). The frequency of 3FS crash-involved drivers was down an average of 47.25 crashes per month over the first year after the drinking age was raised. The estimated reduction of 567 crash involvements over the first 12 months following implementation of the raised drinking age (i.e. 47.25 per month for 12 months), represents a 14.74 percent decrease from what one would have expected on the basis of the 7 year baseline period.

Analyses of police-reported HBD 16-17 year old crash-involved drivers, however, indicated no significant change in frequency associated with the raised drinking age change (Table 4.15). Although not statistically significant, the raised drinking age transfer function parameter estimate was in the expected direction, with an estimated reduction of 17 HBD driver involvements per month associated with raising the legal drinking age.

Analyses of police-reported HNBD crash involvement of drivers aged 16-17 identified a significant reduction in crash frequency concomitant with the raised drinking age (Table 4.15). The estimated average reduction of 280 crash involvements per month represents 7.12 percent fewer police-reported HNBD crash-involved drivers in 1979 than one would have expected given the 1972 through 1978 baseline trends.

The finding of a significant drop in HNBD crash involvement and no significant change in HBD crashes among 16-17 year old drivers appears to indicate that raising the drinking age caused non-alcohol-related crashes to increase with no effect on alcohol-related crashes. However, it is important to remember that the HBD and HNBD variables were only indicators of the underlying concepts. In Appendix B the threats to internal validity of instrumentation and selection-instrumentation interaction, and the threats to construct validity of "mono-operation bias" and "mono-method bias" are discussed. In short, all of these validity threats are concerned with the extent to which the indicator used (i.e. HBD/HNBD) is a consistent and valid measure of the concept "alcohol-related crash involvement." These threats to valid causal conclusions concerning the impact of the drinking age on youthful crash involvement were reduced by the inclusion of the 3FS measure of alcohol-related accidents.

In the present case, a significant drop in HNBD crash involvement and no significant change in HBD crashes was found. At face value, these findings suggest that there was a significant drop in non-alcohol-related crash involvement among drivers aged 16-17 after the drinking age was raised. A general reduction in crash involvement of the age group due to some factor unrelated to the drinking age may account for the significant drop in both HNBD and 3FS crash involvement. However, the reduction in alcohol-related crashes as measured by the 3FS variable was twice as large as the reduction in HNBD crashes, perhaps indicating that the reduction in HNBD crashes was a result of a decrease in that proportion of the HNBD series representing alcohol-related crashes that were reported as HNBD. A proportion of alcohol-related crashes among 16-17 year olds may, in fact, have been included in the HNBD series because of reluctance on the part of the investigating police officer to report the presence of alcohol in a crash involving an underage driver. In any event, support for the hypothesis was provided by analyses of the more reliable 3FS measure, and it was cautiously concluded that the raised drinking age may have had some effect on alcohol-related collision involvement among drivers aged 16-17.

It was also hypothesized that the effect of the drinking age on drivers aged 16-17 would be less than the impact on the focal 18-20 age group. Comparisons of the analyses of the more reliable alcohol-related crash indicator, the three-factor-surrogate, for the two age groups revealed that the percentage reduction in crash frequency was somewhat smaller for the 16-17 group than for 18-20 year old drivers (Table 4.15). In addition, the decrease in HBD crashes for drivers aged 16-17 was much smaller than the decrease identified for drivers aged 18-20. The findings for the 16-17 age group, although indicative of some effect of the raised drinking age, were more ambiguous than the clearcut effects observed for the 18-20 age group, and the effect as measured by the 3FS variable was smaller in magnitude for drivers aged 16-17 than for those aged 18-20. The results were consonant with the hypothesis that a raised legal drinking age has less effect on underage drivers than those directly affected by the legal change.

In addition to examining the effect of the raised drinking age on the frequency of alcohol-related crashes among 16-20 year old drivers, the same measures of both alcohol-related and non-alcohol-related accidents were examined for older drivers. Comparisions between the crash experience of young drivers with the crash experience of older drivers controls for the possibility that observed shifts in crash involvement among young drivers were simply due to general downward shifts in collision frequencies among all drivers. Summary results of the iterative time-series modeling process for the 3FS and HBD measures of alcohol-related crashes and the HNBD measure of non-alcohol-related crashes, for drivers aged 21-24 and 25-45, are also presented in Table 4.15. A significant increase of about 9 percent ($p<.05$) in HBD crash involvement was identified for drivers aged 21-24. Although the other measures of alcohol-related accidents for the comparison groups aged 21-24 and 25-45 revealed no significant changes, it was instructive to note that they all had positive coefficients, compared to the consistently negative coefficients for the HBD and 3FS measures for drivers under 21. The differences between the younger and older drivers can be easily seen by comparing the plot of HBD frequency for 18-20 year olds (Figure 4.6) with the plot of HBD frequency for 21-24 year olds (Figure 4.12). A clear drop occurred in 1979 for the 18-20 group, while the frequency for the 21-24 group increased. Such a pattern of findings further supports the hypothesis that the reductions in alcohol-related crash involvement for drivers under 21 was caused by some factor specific to that age group, i.e., the legal drinking age, and not a result of general reducions in alcohol-related crash involvement for all drivers.

No statistically significant changes in HNBD crash involvement were identified for drivers over the age of 21. Furthermore, an examination of non-alcohol-related crash involvement across the four age groups, revealed negative parameter estimates for all age groups (Table 4.15). Although only the estimated reduction in HNBD crash involvement for drivers aged 16-17 was statistically significant, the consistently negative estimates across all age groups indicated that there was a small reduction in general crash involvement in 1979. The raw frequency plots of HNBD crash involvement (Figures 4.9, 4.10, 4.15, and 4.16) demonstrated the reduced HNBD frequency for all of the age groups in 1979 as compared to previous years. The economic recession in Michigan, increased motor fuel prices, and a moderate fuel shortage may account for the small reduction in overall crash involvement. The number of HNBD crash involvements for all of the age groups appeared particularly lower than expected for November and December of 1979. The unusually mild winter weather, with the concomitant lack of snow and associated driving hazards, may have caused the substantial reduction in crash frequencies in late 1979.

The implications for a determination of the causal effect of the raised drinking age was that a small part of the reduction in HBD and 3FS alcohol-related crash involvement may be due to the general reduction in crash involvement in 1979. It was clear from the pattern of findings shown in Table 4.15, however, that the general reduction in non-alcohol-related crash involvement could account for only a small portion of the statistically significant and substantial reductions in 3FS and HBD crashes among drivers under 21.

4.3 Time-series Models of Michigan Fatal Crash Frequencies, 1968 - 1979

Data on Michigan fatalities were available for the entire 1968 through 1979 period including several years prior to the lowered legal drinking age in 1972, the seven years during which the drinking age was 18, and one year after the return to a drinking age at 21. As was discussed in Section 3.2, the fatal crash frequencies were not stratified by the police reported HBD/HNBD variable because of instrument changes and data collection problems over the 1968 to 1972 time period. As a result, the total frequency of fatalities and the frequency of alcohol-related fatalities as measured by the three-factor-surrogate were examined for each of the four age groups.

The original design called for the explicit testing of hypotheses concerning the differential effect of the lowered and raised legal drinking age using the time-series analysis methods discussed in Section 3.4. Traffic fatalities are relatively rare events, however, and the fatal crash time-series had low monthly counts, especially when stratified by age and the 3FS indices, compared to the time-series variables based on a 20 percent sample of all crashes presented in the previous section. One consequence of the low monthly frequency was a larger random error component in the series. The volatility of the fatality time-series could be seen by comparing the plots of the total crash series (Figures 4.6 through 4.16) with those of the fatality series (Figures 4.17 through 4.24). The contrast was most dramatic for the variables of primary interest, i.e., underage drinkers involved in 3FS fatal crashes (compare Figures 4.4 and 4.7 with 4.17 and 4.19). The unpredictability of the fatality time-series was also evident in the preliminary modeling of 3FS fataltities for drivers under 21. The percentage of total variance in the fatality variables accounted for was less than half the percentage accounted for by the total crash models presented in Section 4.2. As a result of these characteristics of the fatality variables, statistical time-series intervention models were not constructed. Suggestive results were based on a visual examination of the 12 year fatality time-series variables.

The time-series plot of the frequency of 3FS fatal crash

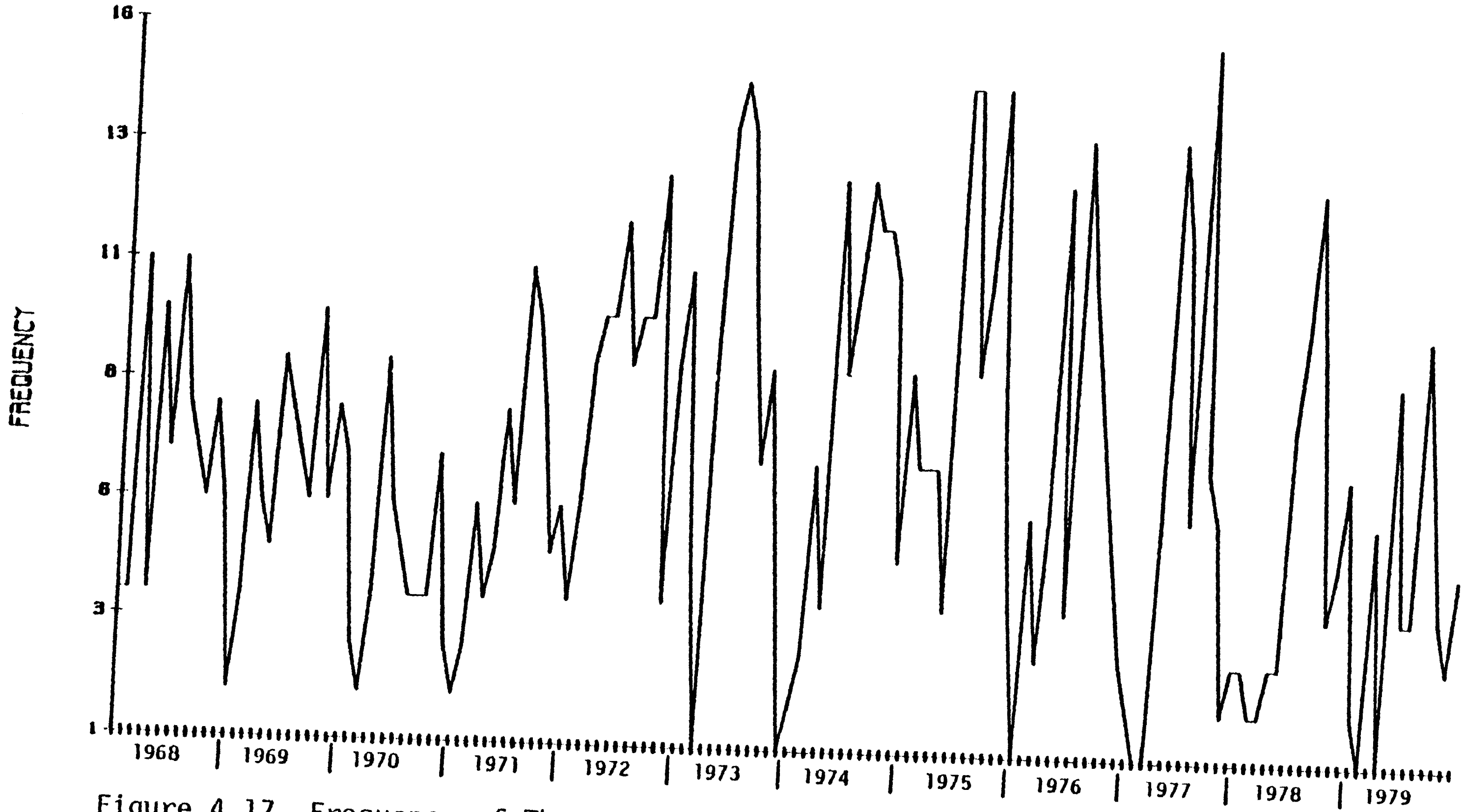

Figure 4.17 Frequency of Three-factor-surrogate Fatal Crash Involvement Among 18 - 20 Year Old Drivers in Michigan, 1968 - 1979

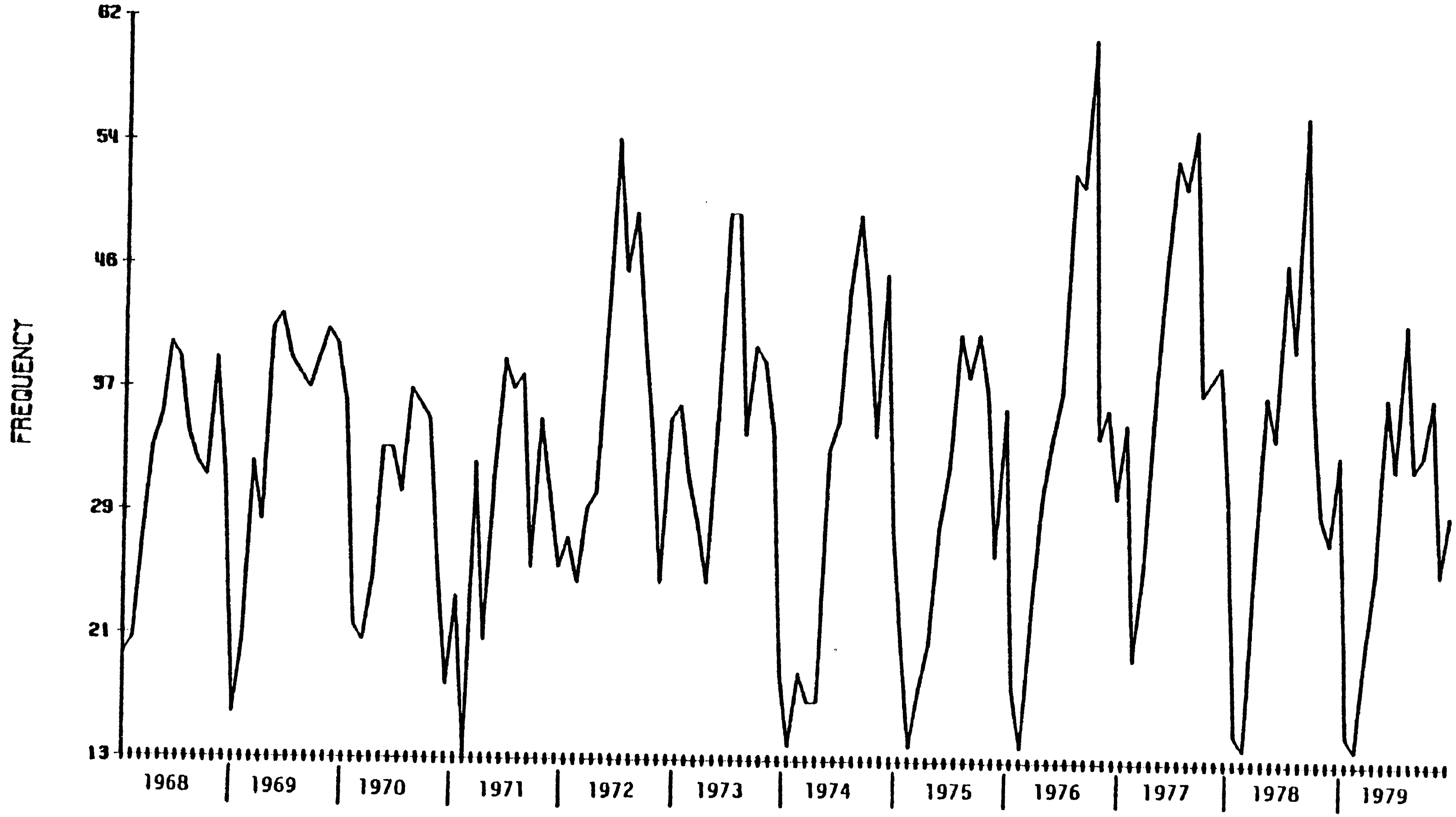

Figure 4.18 Frequency of Total Fatal Crash Involvement Among 18 - 20 Year Old Drivers in Michigan, 1968 - 1979

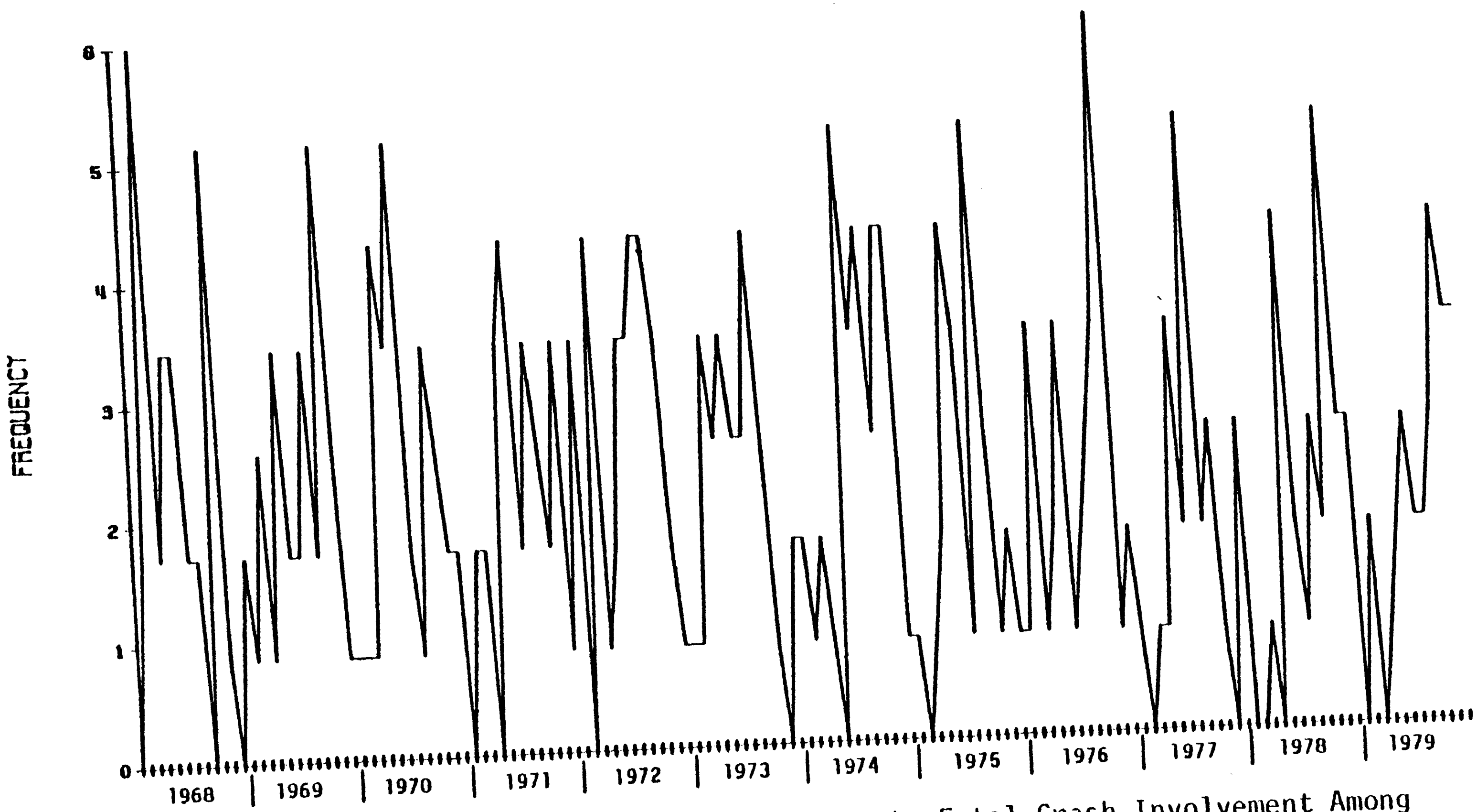

Figure 4.19 Frequency of Three-factor-surrogate Fatal Crash Involvement Among 16 - 17 Year Old Drivers in Michigan, 1968 - 1979

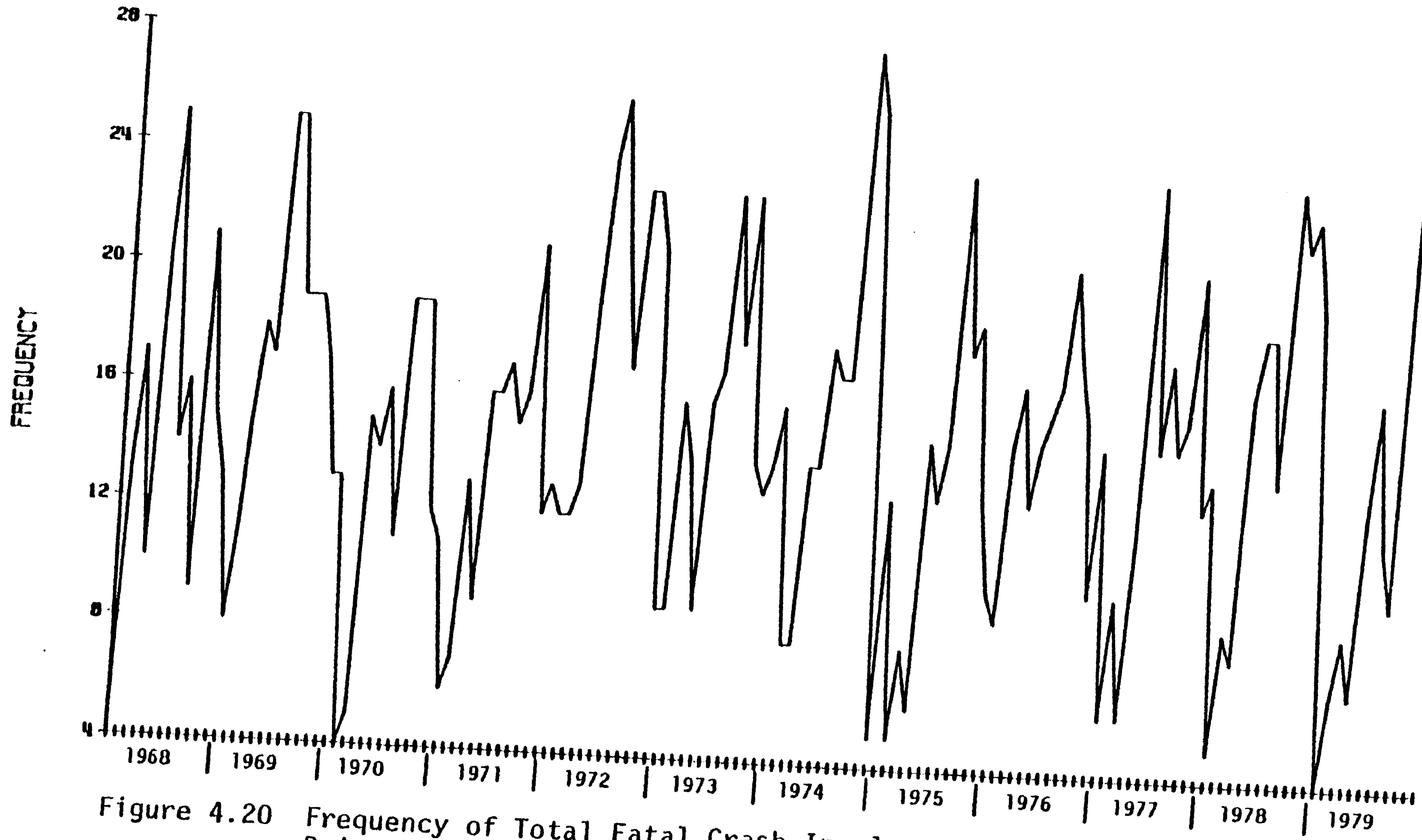

Figure 4.20 Frequency of Total Fatal Crash Involvement Among 16 - 17 Year Old Drivers in Michigan, 1968 - 1979

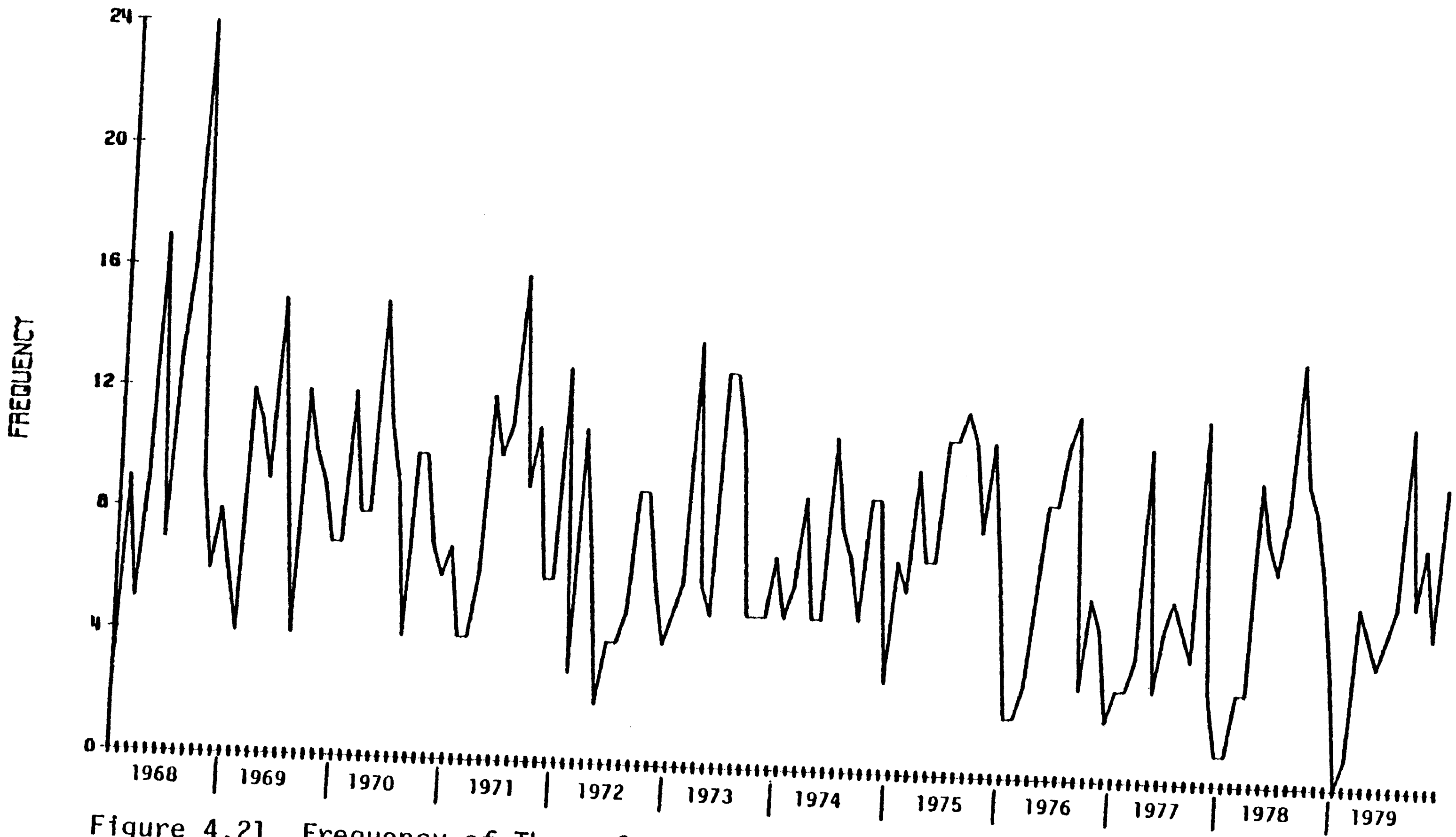

Figure 4.21 Frequency of Three-factor-surrogate Fatal Crash Involvement Among 21 - 24 Year Old Drivers in Michigan, 1968 - 1979

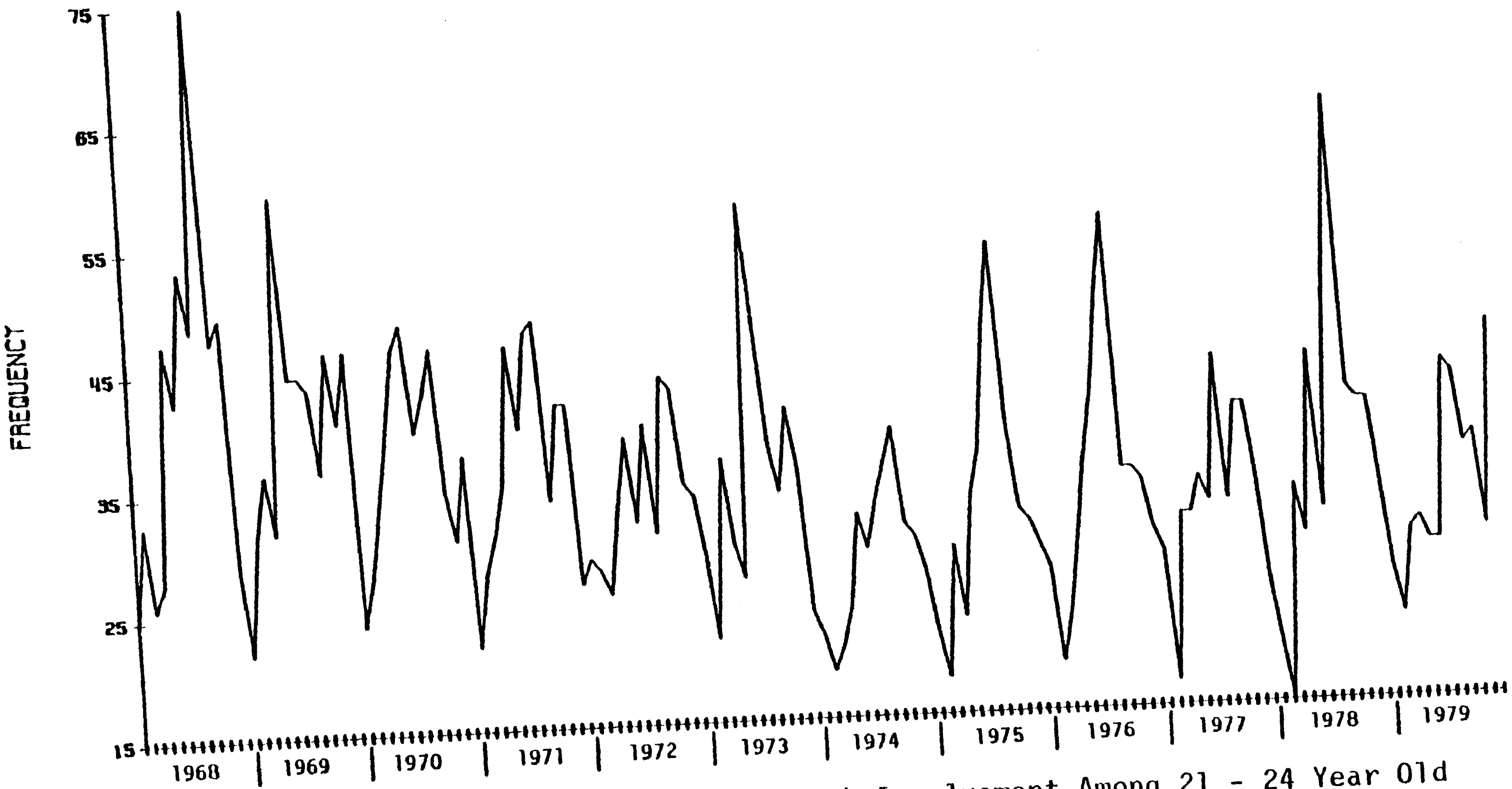

Figure 4.22 Frequency of Total Fatal Crash Involvement Among 21 - 24 Year Old Drivers in Michigan, 1968 - 1979

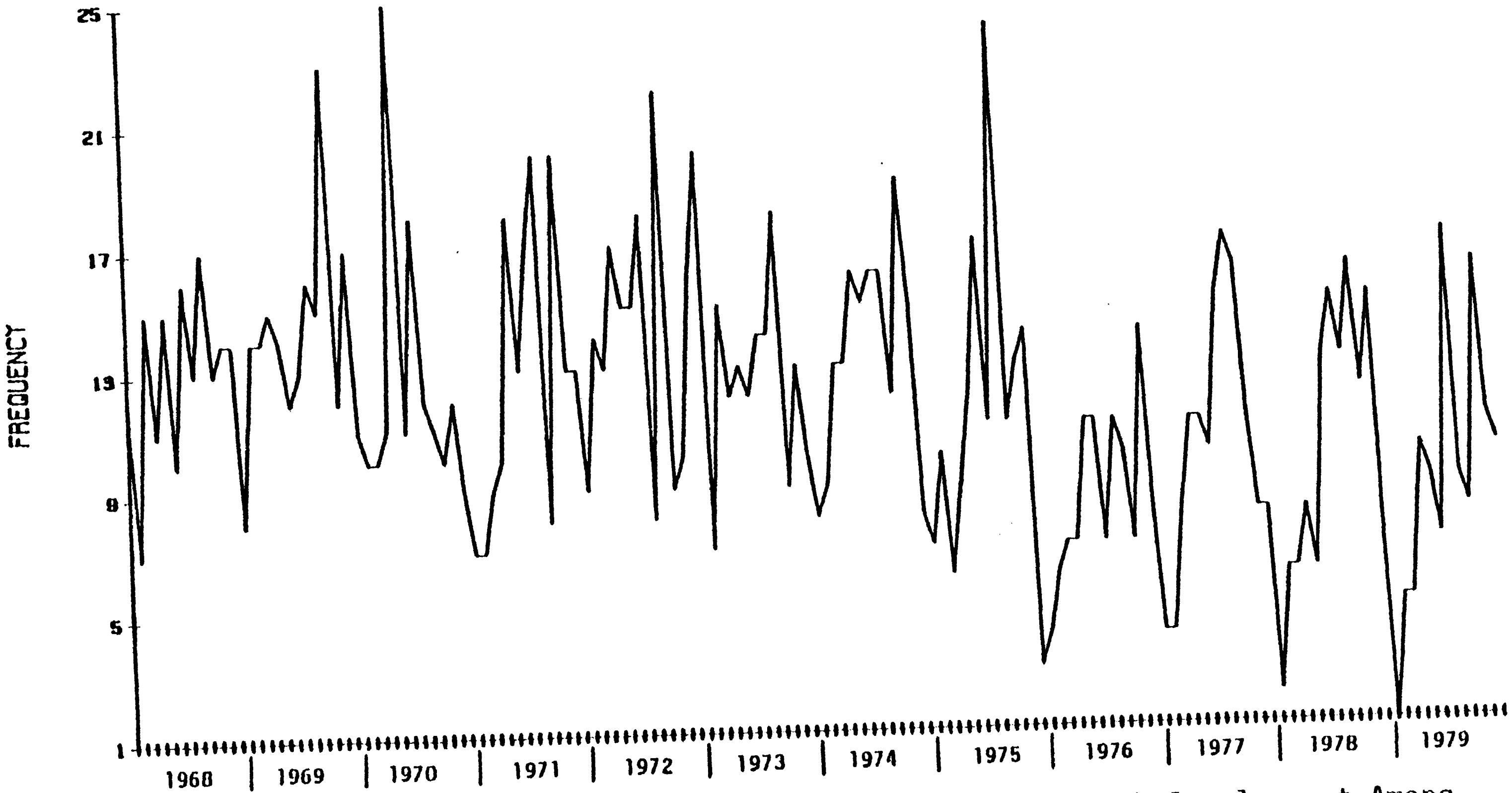

Figure 4.23 Frequency of Three-factor-surrogate Fatal Crash Involvement Among 25 - 45 Year Old Drivers in Michigan, 1968 - 1979

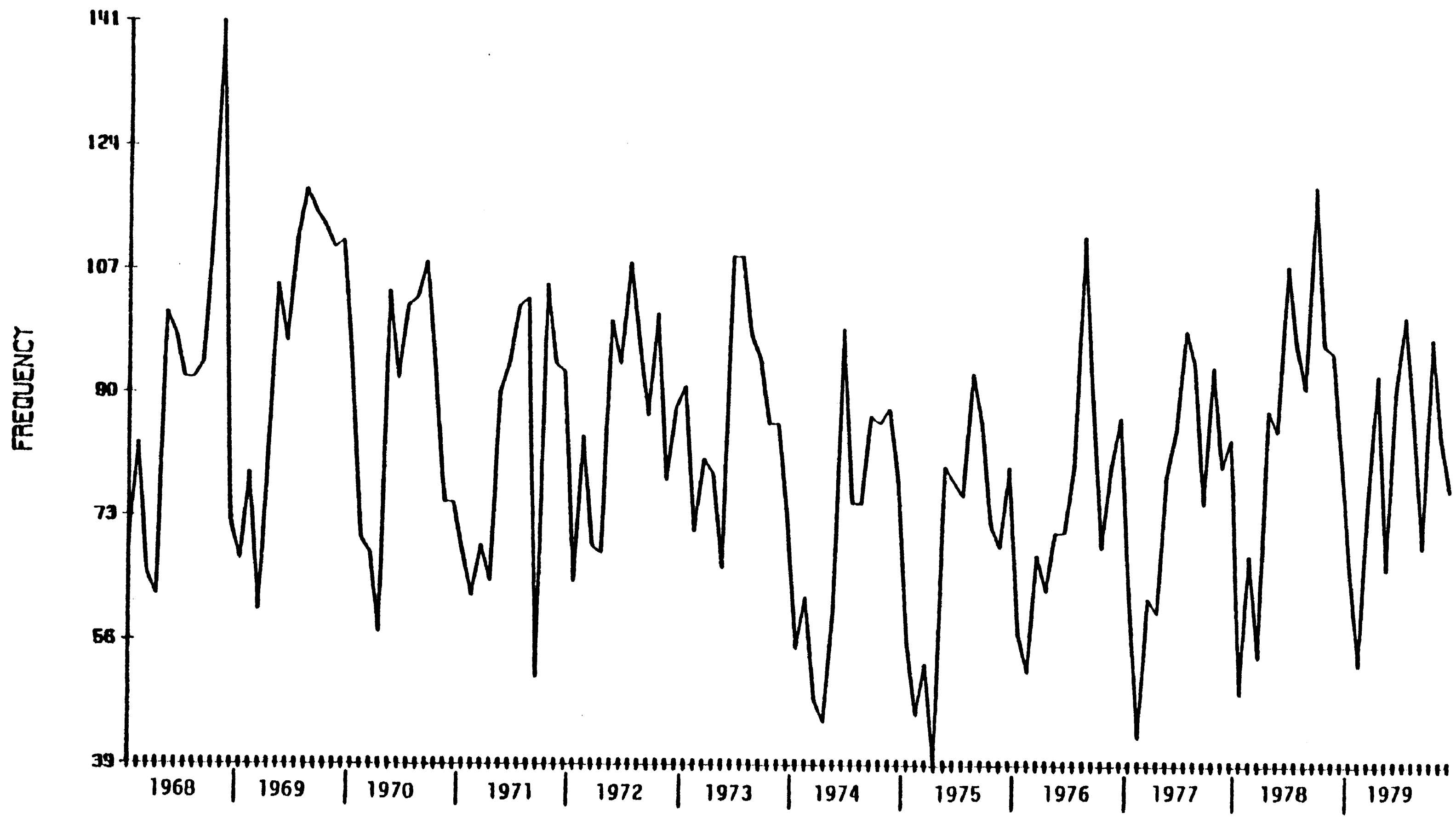

Figure 4.24 Frequency of Total Fatal Crash Involvement Among 25 - 45 Year Old Drivers in Michigan, 1968 - 1979

involvement among drivers aged 18-20 (Figure 4.17) revealed increased monthly frequencies in 1972 after the drinking age was lowered and decreased frequencies in 1979 after the legal age was returned to its pre-1972 level. One might argue that a similar pattern was evident for total fatal crash involvement among 18-20 year olds (Figure 4.18). No obvious shifts in the frequency of 3FS or total fatal crash involvement for drivers aged 16-17 were associated with the lowered drinking age in 1972 or the raised drinking age in 1978 (Figures 4.19 and 4.20). Three-factor-surrogate fatal crash involvement for drivers aged 21-24 and 25-45 did not change appreciably when the drinking age was changed. The frequency of total fatal crash involvement among the 21-24 and 25-45 groups, however, appeared to decline slightly in 1979 compared to previous years (Figures 4.22 and 4.24).

The observed changes in fatal crash frequencies based on a visual examination of the 12 year time-series plots should be interpreted very cautiously because of the large amount of "noise" or random error in the time-series. Irregular fluctuations in the frequency of alcohol-related fatalities among young drivers in Michigan made it difficult to detect small changes in the extent of the drinking-driving problem among youth using the fatal crash involvement time-series. Given the available data, it must be tentatively concluded that there was no demonstrable effect of the raised drinking age on the frequency of alcohol-related fatalities in Michigan. Further analyses of the fatality data, using yearly aggregates and alternative analysis techniques, were underway at the time this was written. (5)

A plausible explanation for the lack of a significant change in alcohol-related fatal crash involvement associated with the raised drinking age, in contrast to the findings for total alcohol-related crash involvement, might be suggested. Fatal alcohol-related crash involved drivers tend to have the highest blood alcohol concentrations of all drinking drivers. As a result, fatal alcohol-related crash involved drivers are likely to be heavier drinkers than drinking drivers involved in non-fatal crashes. It is reasonable to argue that the heaviest drinkers among the youthful drinking-driver population (i.e., those with the highest chance of being involved in a fatal crash), are the least likley to be influenced by the altered drinking norms, industry marketing practices, and alcohol availability resulting from a change in the legal drinking age (see Figure 2.9). In constrast, youthful social drinkers are less likely to have extremely high blood alcohol concentrations when driving after drinking, and therefore are more likely to be involved in a non-fatal alcohol-related collision. Youthful social drinkers are also likely to be more influenced by availability and legal norms concerning drinking than heavy drinkers. In short, if alcohol-related fatal crash involvement is viewed as an indicator of alcohol-related problems among heavier drinkers, and alcohol-related non-fatal crash involvement is viewed as an indicator of alcohol-related problems among more moderate drinkers, one could conclude that changes in the legal drinking age have a larger effect on the incidence of alcohol-related problems among moderate drinkers than on the incidence of alcohol-related problems among heavy drinkers.

In summary, since the monthly frequency of fatalities was much less predictable than the frequency of total crashes, it was more difficult to identify significant changes in the frequency of fatal crashes associated with exogenous factors such as modifications in the minimum drinking age. Although some changes in alcohol-related fatality frequency associated with the legal drinking age were noted, they could not be confidently attributed to the legal drinking age changes. Because of their reduced usefulness for legal impact analysis using time-series methods, and because fatalities represent only a small fraction of total youthful alcohol-related crash involvement, little emphasis has been placed on the results of the separate analyses of that subset of all crashes involving one or more fatalities.

Notes to Chapter 4.0

1. See Section 3.4 for a definition of each term in the "ARIMA (1,0,0)(1,0,0)12" nomenclature.

2. The parameter starting values are based on the theoretical relationships between autocorrelations and model parameters, substituting sample autocorrelation estimates for the corresponding population values.

3. The final results of the ARIMA modeling stage for each series can be found in the Appendix.

4. Percentage figures for those variables not log transformed were calculated as follows: percent change equals $(12x_1 / x_3)100$, where x_1 equals the transfer function point estimate of change in monthly number of crash involvements associated with the intervention, x_2 equals sum of actual 20 percent sample crash involvement frequency for the 12 months of 1979, and x_3 equals $x_2 - 12x_1$, that is, the expected number of 20 percent sample crash involvements for 1979 had there been no drinking age effect. Percentage figures for those variables that were log transformed were calculated as follows (McCleary and Hay, 1980:174): percent change equals $(e^{\omega} - 1)100$.

5. The aggregation of the frequency of fatal crash involvement for one year before and one year after the raised drinking age, and assessments of the effect of the raised drinking age using alternative data analysis techniques were underway at The University of Michigan, Highway Safety Research Institute at the time this was written. The principal authors of an evaluation of the effect of the lowered drinking age on fatal crash involvement (Flora et al., 1978) used the same methods to evaluate the effect of the raised drinking age on fatalities. Although the method does not control for long term patterns in the outcome variables, it avoids some of the problems encountered when analyzing fatalities in a time-series design.

5.0 THE RAISED LEGAL DRINKING AGE AND AGGREGATE ALCOHOL CONSUMPTION IN MICHIGAN

Although assessments of the effects of changes in the legal drinking age have largely been concerned with the incidence of motor vehicle collisions among youth, a major intervening variable between legal drinking age modifications and changes in the frequency of alcohol-related traffic collisions is the amount and pattern of youthful alcohol consumption (see Figure 2.9). In this chapter, the limited research on changes in youthful alcohol consumption following reductions in minumum age of purchase statutes is reviewed, and changes in aggregate beverage alcohol sales in Michigan associated with the raised drinking age are examined.

5.1 Literature Review

Existing literature on the effects of changing the drinking age on youthful alcohol consumption has focused on three main types of alcohol consumption data: (A) self-reported consumption, (B) perceptions of youthful consumption patterns reported by school officials, and (C) 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 the 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 unambigously 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 Weschler (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. (1) 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 aged population in the states examined. They found that 42 percent of the 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 frequenctly 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 obvious 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 were 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 draught beer, packaged beer, wine, and distilled spirits in Michigan over an eight year period. A statistically significant increase in draught beer sales was associated with lowering the drinking age. The authors attributed the shift in draught 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.

The existing literature concerning the effect of reduced legal drinking ages on beverage alcohol consumption among youth has significant methodological limitations and provides inconsistent results. Even less is known about the effect of raising the drinking age, in spite of a definite trend toward a higher minimum alcohol purchasing age in recent years. To help fill the gaps in present knowledge, an examination of monthly aggregate beer and wine distribution volumes in the State of

Michigan was conducted.

5.2 Method

Data obtained from the Michigan Beer and Wine Wholesalers Association were used to construct monthly time-series of the aggregate volumes of packaged beer, draught beer, and wine distributed in the State of Michigan. These data were obtained for the eleven year period from January of 1969 through February of 1980 (see Figures 5.1, 5.2, and 5.3). Long series of observations were required to assess the degree to which beverage distribution volumes in 1979, after the drinking age was raised, were different from what would have been expected given the long term patterns in apparent alcohol consumption.

Shifts in the volume of beverage alcohol distributed in Michigan at the time the drinking age was raised could have been statistically tested using the Box-Jenkins intervention analysis techniques discussed in Section 3.4. However, because of confounding events coincident with the raised drinking age, and because of the lack of age specific alcohol consumption data, simple shifts in aggregate alcohol sales associated with the raised drinking age were not expected. Without age-specific alcohol consumption data, conclusions concerning the effect of the drinking age on the drinking practices of youth must be made cautiously. If changing the drinking age does influence consumption among young people, such an effect would have to be large before it would be evident in the aggregate sales data. Therefore, rather than a hypothesis testing analysis, such as was reported in Chapter 4.0, an exploratory examination of changes in alcohol distribution during 1979 and early 1980 was conducted.

The data analyses began with a careful examination of each time-series plot for changes in the aggregate sales of alcoholic beverages associated with raising the legal drinking age. In addition to visual examinations of the raw data plots, the general multiplicative seasonal Auto Regressive Integrated Moving Average (ARIMA) time-series modeling strategy developed by Box and Jenkins (1976) was used to build a parsimonious model that adequately accounted for the pattern of autocorrelation in each variable. The iterative specification, estimation, and evaluation modeling strategy was applied to the 1968 through 1978 baseline period of each time-series. The resulting models were used to forcast beverage distribution for 1979 and early 1980 and the actual distribution figures were compared to the forecasted values. Substantial deviations of the actual distribution volumes from the forecasted values based on previous distribution patterns were considered indicative of the effects of exogenous factors such as the increase in the legal drinking age, the ban on non-returnable beverage containers, and the Michigan economic downturn of 1979. (2)

5.3 Results

A Seasonal Auto-Regressive-Integrated-Moving-Average model was identified as the best description of wholesale packaged beer shipments from 1969 through 1978 (Figure 5.1). The identified ARIMA model, shown in Table 5.1, was used to forecast packaged beer distribution for the subsequent 14 months. A comparison of the forecasted and actual values (Table 5.2), indicated that the actual packaged beer distribution for 10 of the 14 post drinking age change months were 5 to 20 percent lower than

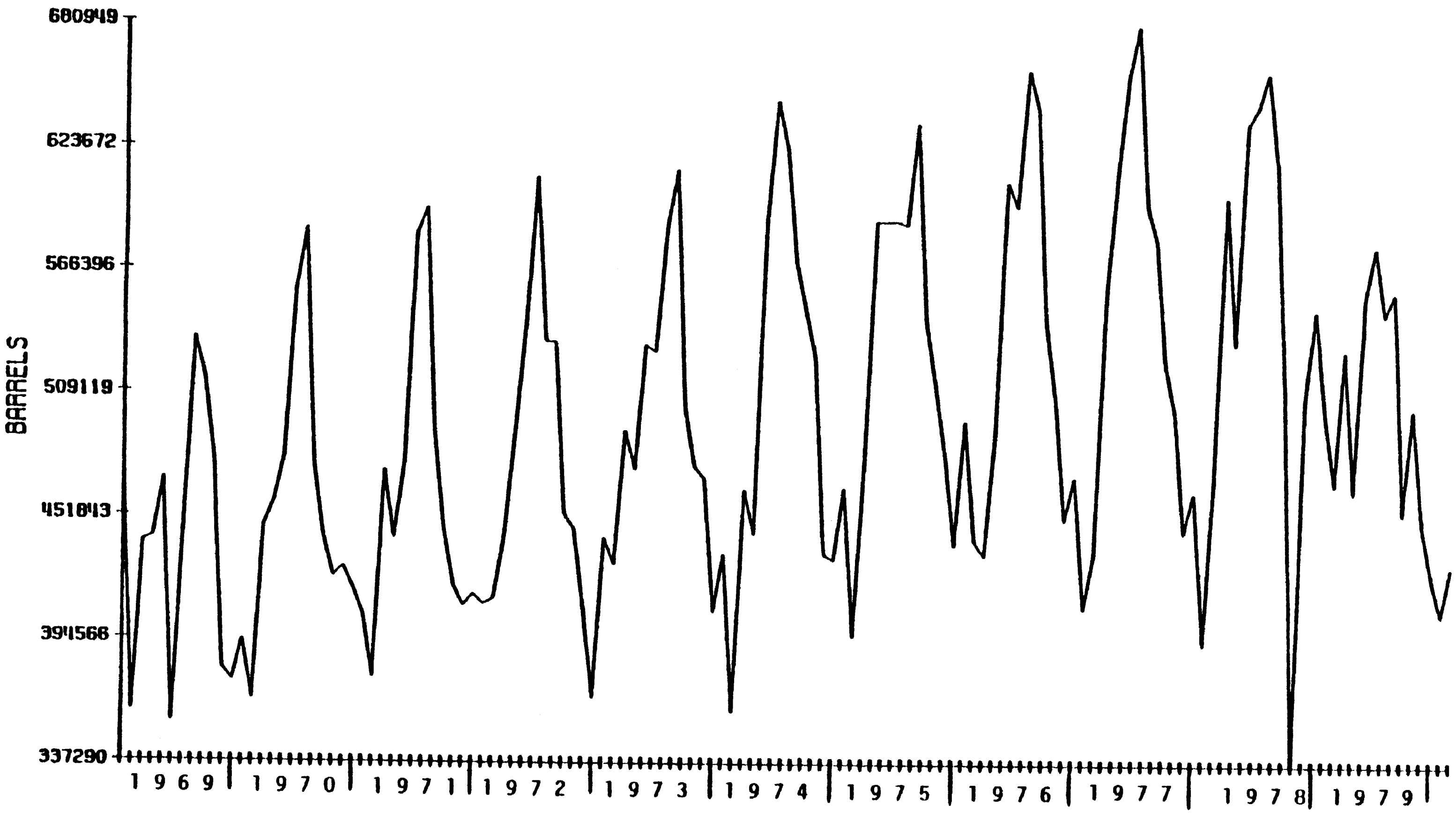

Figure 5.1 Wholesale Distribution of Packaged Beer in the State of Michigan: January 1969 through February 1980

Table 5.1 Estimated Baseline Model of Packaged Beer Distribution: January 1969 Through December 1978

Model Form: ARIMA $(1,0,0)(1,1,0)_{12}$ with no transformations

Parameter Estimates	95 Percent Confidence Interval
ϕ_1 = .2576	.0661 to .4491
Γ_1 = -.4022	-.6000 to -.2044

Q-statistic = 16.54 with 18 degrees of freedom

R^2 = .65

Table 5.2 Comparison of Forecasted and Actual Packaged Beer Distribution: January 1979 Through February 1980

Month	Percent Change	Actual Value	Forecasted Value	95 Percent Confidence Interval
January	+18.77	500,590	421,480	324,130 - 518,830
February	+1.56	467,930	460,720	360,190 - 561,250
March	-9.37	530,220	585,030	484,290 - 685,770
April	-17.93	464,500*	565,980	465,230 - 666,740
May	-13.87	555,220	644,600	543,850 - 745,360
June	-12.13	578,620	658,530	557,770 - 759,200
July	-13.78	546,980	634,440	533,690 - 735,200
August	-7.45	557,570	602,480	501,720 - 703,230
September	-12.01	454,620	516,700	415,940 - 617,450
October	+24.71	503,320	403,590	302,830 - 504,340
November	-6.71	450,190	482,680	381,920 - 583,430
December	-17.42	424,990	514,650	413,900 - 615,410
January	-.70	407,490	410,370	294,050 - 526,690
February	-7.41	429,640	464,030	346,750 - 581,310

*Significantly different from forecasted value with $p \leq .05$.

expected given the baseline data.

Important deviations from the overall pattern of lower than expected packaged beer distribution were present. First, the actual distribution for October 1979 was about 25 percent higher than forecasted. The forecasted value for October 1979 was low because of the unusually low volume for October 1978. Since the year immediately prior to the forecasts (i.e. the last year of the baseline period) has a disproportionate influence on the forecast values, the unusually low volume for October 1978 caused a low forecast for October 1979. As a result, the actual October 1979 distribution was 25 percent higher than the forecast.

A second deviation from the overall reduction in packaged beer distribution was a 19 percent higher than forecasted volume for January 1979. The distribution volume in February 1979 was also higher than predicted, although only marginally (1.6 percent). As a result of the higher than expected distribution volumes for the early months of 1979, and the lower than predicted distribution for the summer months, the variation in packaged beer distribution was substantially less in 1979 compared to the baseline years.

In short, two changes in the volume of packaged beer distribution in Michigan were found when comparing the first 14 months after the drinking age was raised to the previous 10 year period. First, an overall reduction in packaged beer distribution was evident. Second, higher than forecasted distribution for the first two months of 1979 combined with lower than forecasted distribution volumes for the summer months, resulted in a reduction in the seasonal variation in apparent packaged beer consumption.

The aggregate distribution of draught beer (Figure 5.2) from 1969 through 1978 was also modeled with a specific form of the general seasonal multiplicative ARIMA model. The identified baseline model (Table 5.3) was used to generate the forecasts presented in Table 5.4. An examination of the time-series plot and the "percent change" column of Table 5.4 indicated that there was an overall increase in draught beer distribution in the first 14 months after the legal drinking age was raised. (3) Only three months deviated from the pattern of increased draught beer sales; sales were lower than forecasted in February, March, and November of 1979. The deviations from the pattern of increased draught beer consumption were small, however, and were attributed to random error.

A first-order moving average model was identified as the best description of wine distribution in Michigan from 1969 through 1978 (Figure 5.3). Using this baseline model (Table 5.5), the forecasts presented in Table 5.6 were generated. The actual values were generally lower than forecasted, indicating a reduction in wine distribution from what one would have expected given previous trends. An initial examination of the time-series plot (Figure 5.3) might lead one to conclude that there was no change in total wine distribution after the drinking age was raised in December of 1978. The reduction in wine distribution was evident in Table 5.6 because the model on which the forecasts were based included a significant constant term (equal to 5608 gallons per month), representing the slope of the baseline trend. Since the forecasting model assumed the baseline trend evident over the 1969

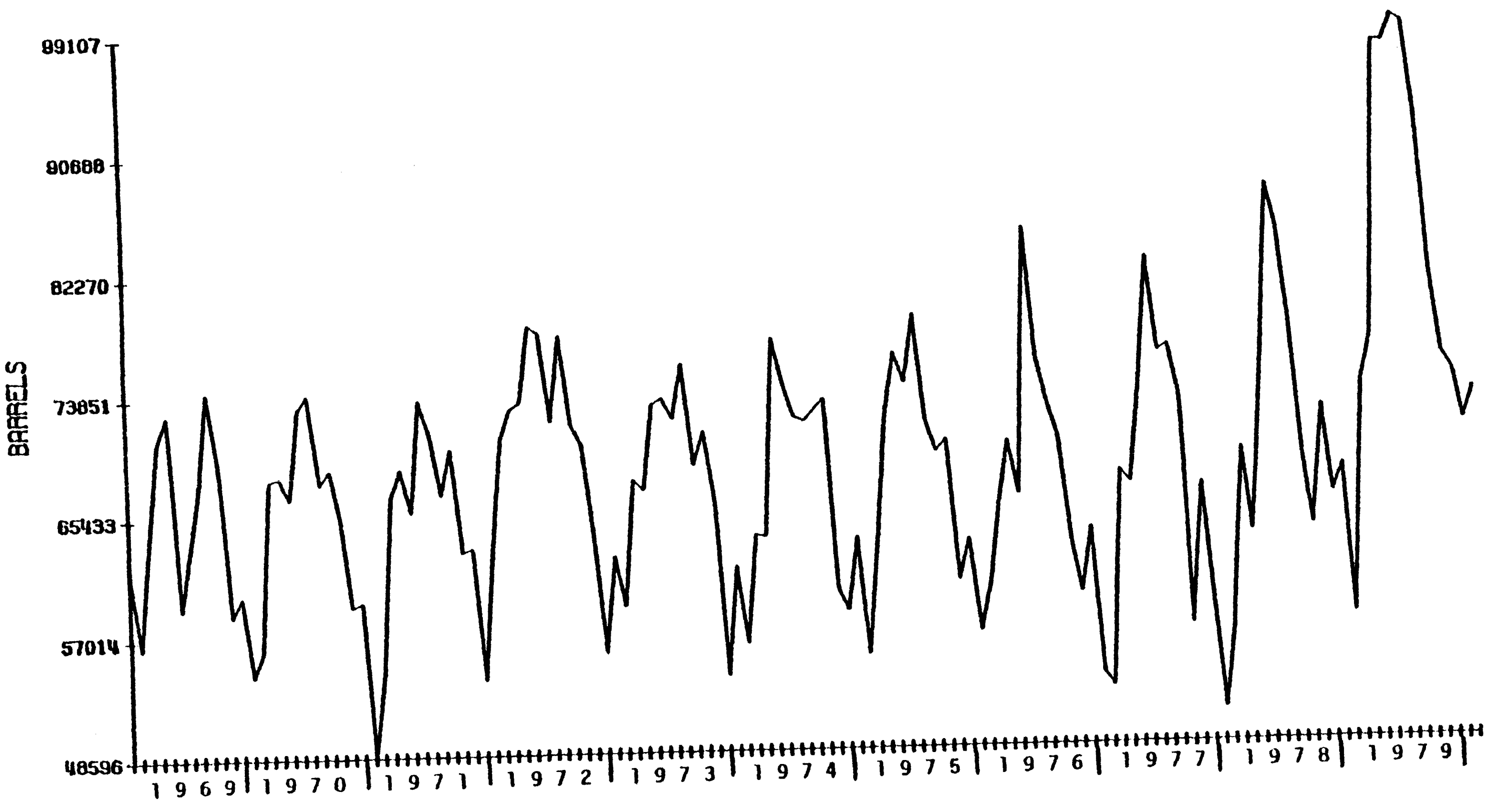

Figure 5.2 Wholesale Distribution of Draught Beer in the State of Michigan: January 1969 through February 1980

Table 5.3 Estimated Baseline Model of Draught Beer Distribution: January 1969 Through December 1978

Model Form: ARIMA $(2,1,0)(1,1,0)_{12}$ with no transformations

Parameter Estimates	95 Percent Confidence Interval
$\phi_1 = -.6783$	-.8546 to -.5020
$\phi_2 = -.4463$	-.6204 to -.2723
$\Gamma_1 = -.2314$	-.4303 to -.0325

Q-statistic = 22.66 with 17 degrees of freedom

$R^2 = .57$

Table 5.4 Comparison of Forecasted and Actual Draught Beer Distribution: January 1979 Through February 1980

Month	Percent Change	Actual Value	Forecasted Value	95 Percent Confidence Interval
January	+18.13	67,816	57,409	46,883 - 67,935
February	-7.25	57,427	61,918	50,800 - 73,036
March	-1.25	73,698	74,631	62,933 - 86,329
April	+9.24	76,690	70,205	56,780 - 83,630
May	+20.97	97,437*	80,548	66,352 - 94,744
June	+5.52	97,346	92,252	77,315 - 107,190
July	+12.41	99,107	88,165	72,256 - 104,070
August	+18.33	98,727	83,434	66,783 - 100,080
September	+21.92	92,339	75,740	58,375 - 93,105
October	+20.11	81,571	67,915	49,800 - 86,031
November	-1.46	75,532	76,650	57,857 - 95,443
December	+6.02	74,351	70,130	50,682 - 89,579
January	+14.72	70,825	61,738	38,422 - 85,054
February	+9.59	72,929	66,546	41,999 - 91,093

*Significantly different from forecasted value with $p \leq .05$.

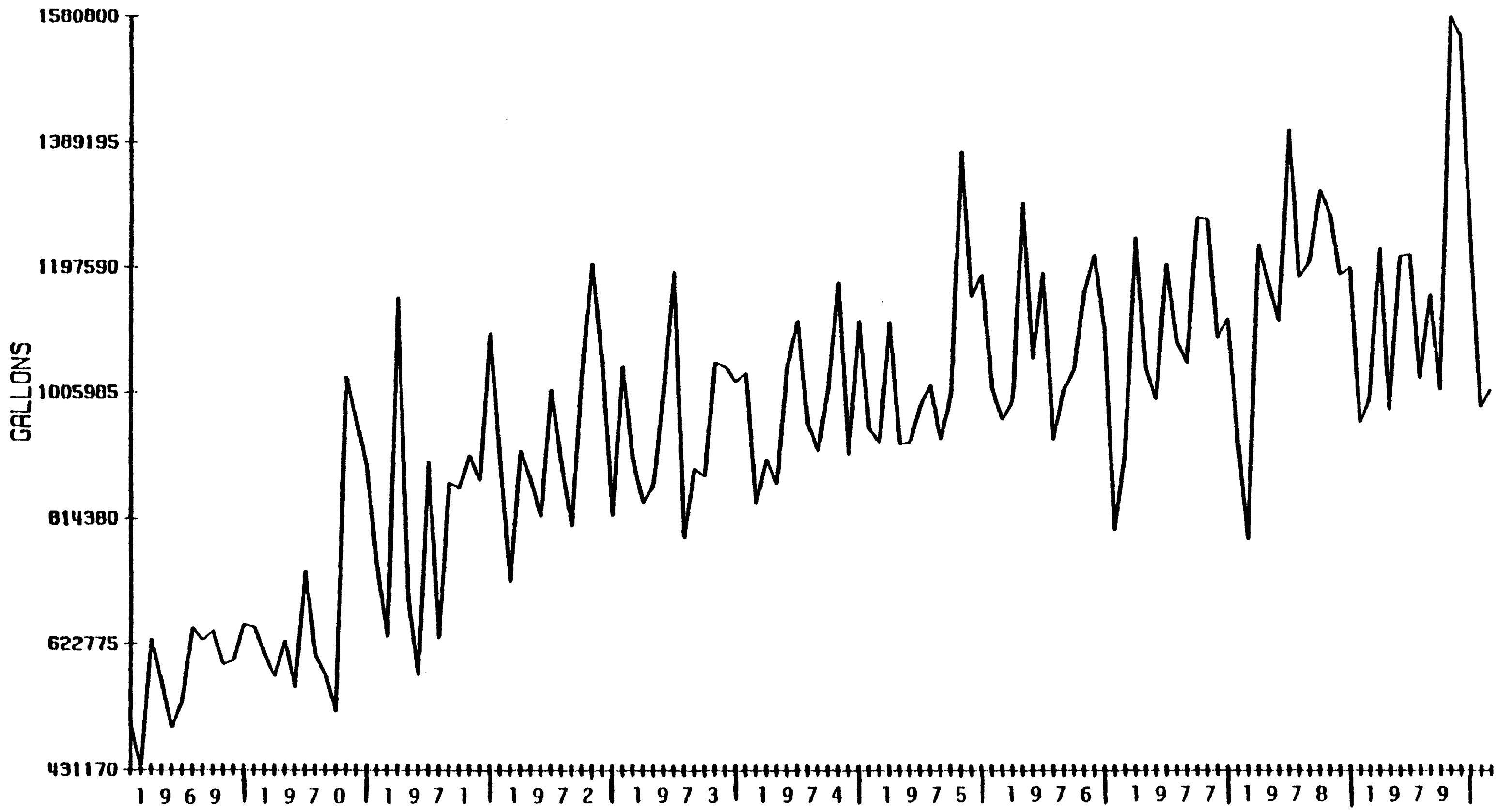

Figure 5.3 Wholesale Distribution of Wine in the State of Michigan: January 1969 through February 1980

Table 5.5 Estimated Baseline Model of Wine Distribution: January 1969 Through December 1978

Model Form: ARIMA (0,1,1)(0,0,0) with no transformations

Parameter Estimates	95 Percent Confidence Intervals
$\theta_1 = .9027$	.8171 to .9882
$\alpha = 5608$	2936 to 8281

Q-statistic = 23.32 on 18 degrees of freedom

$R^2 = .63$

Table 5.6 Comparison of Forecasted and Actual Wine Distribution: January 1969 Through February 1980

Month	Percent Change	Actual Value	Forecasted Value	95 Percent Confidence Interval
January	-21.59	960,830*	1,225,400	962,120 - 1,488,700
February	-19.23	994,280	1,231,000	966,490 - 1,495,500
March	-.89	1,225,600	1,236,600	970,860 - 1,502,400
April	-21.10	980,130	1,242,200	975,230 - 1,509,200
May	-2.70	1,214,100	1,247,800	979,620 - 1,516,000
June	-3.00	1,215,800	1,253,400	984,000 - 1,522,900
July	-18.39	1,027,400	1,259,000	988,400 - 1,529,700
August	-8.68	1,154,900	1,264,700	992,800 - 1,536,500
September	-20.51	1,009,700	1,270,300	997,200 - 1,543,300
October	+23.90	1,580,800*	1,275,900	1,001,600 - 1,550,100
November	+20.98	1,550,400	1,281,500	1,006,000 - 1,556,900
December	-3.92	1,236,700	1,287,100	1,010,400 - 1,563,700
January	-23.87	984,140*	1,292,700	1,014,900 - 1,570,500
February	-22.29	1,008,900*	1,298,300	1,019,300 - 1,577,300

*Significantly different from forecasted value with $p \leq .05$.

through 1978 period would continue, most of the forecasted values were larger than the actual values, which did not follow the upward trend. The deviations of the actual values from the forecasts indicated, therefore, that there apparently was a change in slope starting at the beginning of 1979, with the upward trend identified during the baseline period no longer evident.

Two months deviate from the overall pattern of lower than expected wine distribution in 1979 and early 1980. Wine distribution in October and November 1979 was 24 and 21 percent higher than forecasted, respectively. Except for these two months, wine distribution after the drinking age was raised was consistently lower than predicted using the 10 year baseline period.

5.4 Discussion

In summary, packaged beer distribution for January 1979 through February 1980 was clearly lower than expected, and draught beer was clearly higher than expected given the trends evident over the previous 10 years. Wine distribution fell somewhat for most of 1979, but rebounded late in the year. A portion of the decrease in packaged beer sales may have been due to the raised drinking age, but other factors were also present. A main confounding factor was the ban on non-returnable beverage containers in Michigan, which was implemented in the same month the drinking age was raised. The resulting increase in packaged beer prices (Michigan State Legislature, 1979) may have caused a shift to the less expensive draught beer by those who consumed bottled beer in public drinking establishments. (4) The increased price of bottled beer and the inconvenience of returnable containers may have caused consumers residing near bordering states with non-returnable containers to purchase their packaged beer across state lines.

The substantially increased sales of draught beer was contrary to the hypothesis that the raised drinking age would reduce on-premise draught beer consumption by reducing the population of legal drinkers. It is important to note, however, that only a small proportion of total draught beer distribution represents consumption by 18-20 year old drinkers. The increased distribution volumes may reflect changes in consumption among drinkers 21 and over. A plausible explanation of the increased draught beer sales is that the economic recession in Michigan increased draught beer consumption among unemployed workers. Another consideration is that draught beer is not solely consumed on-premise. Part of the increased draught beer sales in 1979 may be a result of an increased number of "kegger" parties among 18-20 year olds, where a legal drinker purchases a keg of draught beer for consumption off premise at a party attended by underage drinkers.

Finally, the lower than expected distribution of wine for most of 1979 could be interpreted as a result of the raised drinking age. However, the high wine distribution figures for October and November 1979 complicate such an interpretation.

One can only speculate as to the causal structure underlyling the observed changes in beverage alcohol distribution in Michigan in 1979 and early 1980. Without age specific consumption data the effect of the raised drinking age could not be unambiguously determined. Furthermore, detailed information on the drinking practices of various subpopulations within the state as identified by stratification variables such as income level and employment status is necessary for an assessment of the relative influence of economic conditions, price changes in various beverage categories, and the legal drinking age, on individual drinking patterns.

Notes to Chapter 5.0

1. The legal drinking age in Massachusetts was lowered from 21 to 18 in 1973.

2. See McCleary and Hay (1980:222-224) for a discussion of the limitations of using univariate forecasts for an assessment of the effects of exogenous factors on time-series measures.

3. The percent change figures represent the difference of the actual value for a particular month from the forecasted value expressed as a percentage.

4. In public drinking establishments in Michigan, draught beer is consistently the lowest priced alcoholic beverage (Douglass et al., 1980).

6.0 SUMMARY AND CONCLUSIONS

The present study has investigated a complicated relationship between a legal change and a major public health problem. Discussed below are (A) the findings and conclusions of this research, (B) recommendations for further research, and (C) implications and recommendations for public health policy.

6.1 Summary of Findings

The most important hypothesis of this research was that the raised legal minimum drinking age (from 18 to 21) caused a reduction in alcohol-related motor vehicle crash involvement among drivers aged 18-20 (see Section 2.4). The data on crash involvement in Michigan clearly supported this hypothesis. Controlling for trends, seasonality, and other patterns in the frequency of police-reported "had been drinking" (HBD) crash involvement among 18-20 year old drivers, a reduction of 31 percent occurred in the first 12 months after the drinking age was raised from 18 to 21 in December of 1978.

To control for potential unreliability in police-reported alcohol-involvement, a "three factor surrogate" (3FS) measure of alcohol-related crash involvement was also used. Analyses of late-night, single-vehicle crashes with a male driver, of which a majority have been consistently identified as involving a drinking driver, revealed a statistically significant reduction of 18 percent among drivers aged 18-20 after the higher legal drinking age was implemented. In terms of the actual reduction in the frequency of collision involvement, an estimated reduction of 138 alcohol-related crash involvements per month occurred after the drinking age was raised. Over the first 12 months after implementation of the higher drinking age in Michigan, therefore, an estimated 1650 fewer alcohol-related crash involvements occurred than would have been expected, given the trends evident during the 1972 through 1978 baseline period.

Analyses of non-alcohol-related crash involvement among 18-20 year olds identified a non-significant 7 percent drop in 1979. Since the significant crash reductions for 18-20 year olds were not found for general non-alcohol-related crashes, one cannot attribute the observed reductions in HBD and 3FS crash involvement to increased fuel prices, economic recession, and other such confounding factors. If one deducts the (non-significant) 7 percent reduction in "had not been drinking" (HNBD) crash involvement from the more conservative drinking age impact estimated, i.e. an 18 percent reduction in 3FS crash involvement, an 11 percent reduction in alcohol-related crash involvement remains, even after the (non-significant) effects of other factors are subtracted. It is clear that general reductions in crash involvement due to potential confounding factors cannot explain away the substantial reduction in alcohol-related crash involvement among drivers aged 18-20 after the drinking age was raised.

In addition to analyses of all alcohol-related crash involvement (including property damage, injury, and fatal collsions), separate analyses of fatal crash involvement were conducted. Preliminary analyses did not reveal substantial changes in 3FS fatal crash involvement that could reliably be attributed to the raised drinking age. See Section 4.3 for a discussion of the limitations on separate analyses of fatalities.

The second hypothesis was that lowering the legal drinking age from 21 to 18 in 1972 caused an increase in alcohol-related crash involvement. Inconsistencies in the recording of non-fatal crash involvement in several Michigan jurisdictions prior to 1972 precluded the use of those data for an evaluation of the lowered drinking age in the present study. Accurate counts of fatal crash involvement were available for the 1968 through 1979 period. Examination of the time-series plots of fatal crash involvement provided some evidence that the lowered drinking age was associated with increased alcohol-related fatal crash frequencies, but the small monthly count of age-specific fatalities precluded any reliable conclusions. The best estimate of the effect of the lowered drinking age on alcohol-related crash involvement remains that of Douglass and Freedman (1977). They analyzed a set of Michigan jurisidictions with complete accident reporting over the 1968 through 1975 period, using a time-series design. The results revealed a 17 percent ($p<.06$) increase in total (non-fatal and fatal) alcohol-related crash involvement (as measured by the 3FS indicator) among drivers aged 18-20 associated with the lowered drinking age. Since total crash involvement among 18-20 year old drivers was up only 3 percent, and since alcohol-related crash involvememt of drivers over 21 was up only 3 percent, the 17 percent increase in alcohol-related crash involvement among young drivers was attributed to the raised drinking age.

Hypotheses three through five stated that the raised and lowered drinking age would cause changes in alcohol-related crash involvement of drivers aged 16-17, although with a smaller magnitude of impact than the focal 18-20 age group. The results of the current research provided some support for these hypotheses. First, with regard to the effect of the raised drinking age, a statistically significant 15 percent reduction in 3FS crash involvement occurred at the time the drinking age was raised. An estimated reduction of 47 crash involvements per month was associated with the raised drinking age. The results were more ambiguous than the results for the 18-20 age group, however, since only a small, non-statistically significant reduction in "had been drinking" crash involvement was identified for drivers aged 16-17.

The exact reasons for this discrepancy are unknown. However, the three-factor-surrogate is generally considered the more reliable measure, because the subjective "had been drinking" measure may be influenced by numerous uncontrolled influences, particularly for underage youth. As a result, it is cautiously concluded that alcohol-related crashes among 16-17 year old drivers did decrease subsequent to the higher legal drinking age. Since "had not been drinking" crash involvement also experienced a significant 7 percent decrease, part of the 15 percent decrease in alcohol-related (i.e., 3FS) crash involvement may have been caused by factors unrelated to the drinking age. The remaining 8 percent (i.e., 15 less 7) decrease in 3FS crash involvement can be considered the drinking age effect, supporting the hypothesis that the raised drinking age has an effect on drivers aged 16-17 that is smaller in magnitude than the effect on drivers aged 18-20.

With regard to the effect of the lowered drinking age on drivers aged 16-17, examination of the frequency of fatal 3FS crash involvement did not reveal any significant effects. Douglass and Freedman's (1977) analyses of both fatal and non-fatal alcohol-related crash involvement for Michigan jurisdictions with consistently reported crash involvement data also found no significant effect of the lowered drinking age on drivers aged 16-17.

In short, the lowered drinking age did not have a demonstrable effect on alcohol-related crash involvement of underage drinkers. There is some evidence that the raised drinking age may be associated with reduced alcohol-related collsion involvement among 16-17 year old drivers. However, inconsistent results across the HBD and 3FS measures, and the signficant drop in non-alcohol-related crash involvement for the age group, indicate that one cannot unequivocably conclude that the raised drinking age caused reduced alcohol-related crash involvement among drivers aged 16-17.

The final hypothesis proposed in Section 2.4 was that the lowered legal drinking age had a greater effect on collision involvement than the raised drinking age. This hypothesis was not supported by the findings. Douglass and Freedman (1977:46) reported a 35 percent increase in total (i.e. fatal, injury, and property damage) HBD crash involvement, and a 17 percent increase in 3FS crash involvement among drivers aged 18-20 after the drinking age was lowered in 1972. The present research identified a 31 percent reduction in total HBD crash involvement and an 18 percent reduction in 3FS crash involvement among 18-20 year old drivers after the drinking age was raised in 1978. The magnitudes of the two estimated legal impacts were remarkably similar, with the raised drinking age from 18 to 21 apparently reversing the effect of the earlier reduction of the legal age from 21 to 18.

Since alcohol consumption is the major intervening variable between changes in the legal drinking age and changes in alcohol-related crash involvement, the aggregate distribution of alcoholic beverages in Michigan was examined for 1969 through early 1980. Packaged beer sales were lower than expected in 1979, draught beer sales were higher than expected, and wine sales were down slightly from what one would have expected given the baseline trends. No conclusion as to the effect of the raised drinking age on beverage consumption could be made, however, because of several other factors that were likely to have influenced beverage sales in 1979, and because age-specific alcohol consumption data were not available.

6.2 Recommendations for Research

Age-specific impact assessments of the raised legal drinking age should be conducted. Analyses should be conducted of individual ages in addition to the 18-20 aggregation used in the current research. Although the costs involved in separate impact analyses of 18, 19, and 20 year old crash involved youth would be substantially greater than aggregated analyses, the increased precision of the results would be highly useful.

Evaluation of the raised legal drinking age should be repeated in two to four years. The present study has evaluated the initial effects of the change of Michigan's legal drinking age to 21 on traffic safety. The Michigan Department of Public Health, Office of Substance Abuse Services has previously sponsored research to assess the long term effects of the 1972 change to an 18 year old drinking age; such a commitment to followup evaluation should be continued. It will not be known if the effects identified in this research are lasting or temporary if the present analyses are not replicated with data for a longer time period after the drinking age was raised.

Future analyses should focus on all alcohol-related crashes and not exclusively on fatal alcohol-related crashes. Reliance on fatal crashes as the principal dependent variable in an evaluation of a change in the legal drinking age is not advised. The problem with basing decisions solely on fatal accidents is that more than crash causation factors influence the distinction between any alcohol-related crash and a fatal alcohol-related crash. The proximity and quality of emergency medical care, seat-belt usage, crashworthiness of the vehicle, and other factors are as important as the causes of the crash in determining whether a crash is to be labeled "fatal." Many of the factors that determine whether a crash will be fatal are independent of crash causation, and therefore, add unnecessary variability to the data. The public health issue is not solely fatality production, i.e. mortality, but all alcohol-related crashes in which injuries have occurred, i.e., total alcohol-related traffic crash morbidity.

Reliable measures of alcohol-related crash frequencies should be used in future evaluations of the legal drinking age or other changes in alcohol availability. The subjectivity and unknown influences on officially reported "had been drinking" alcohol involvement in Michigan official crash records is not a problem that will soon be resolved for all levels of crash severity. Therefore, it is recommended that in addition to officially reported alcohol involvement, alternative measures continue to be used as indicators of alcohol-related traffic crash involvement. In addition to the three-factor-surrogate measure used in the present study, separate analyses of weekend accidents, and separate analyses of accidents stratified by severity would provide additional insights into the effects of changes in alcohol availability on alcohol-related traffic safety problems.

The pre-driving drinking environment and drinking practices of youth should be investigated. Research on the drinking practices of youth, with an emphasis on behavioral patterns preceeding driving, should be conducted. These pre-driving drinking practices should be examined for location, social environment, peer structure, demographic, and other characteristics which would provide a better understanding of the linkages between drinking behavior and driving behavior. These studies could become the basis for future changes in alcohol-specific laws and policies, as well as other prevention program development.

6.3 Recommendations for Public Policy

Alcohol control policy and legislation has historically been used to accomplish many purposes. In addition to protecting the public health, these laws have been used to reflect social, moral, or political standards, to ensure a stable market for beverage alcohol, and to create mechanisms for governmental revenues. The domain of this research was exclusively that of public health. Although other considerations enter into a determination of the minimum age at which alcoholic beverages can be legally purchased, the recommendations below are based solely on the public health implications of the research findings concerning the effect of the drinking age on alcohol-related motor vehicle crash involvement.

The legal drinking age at 21 should be sustained. Rarely in the field of public health is it possible to identify a legal or policy change which has a demonstrable effect on a major cause of morbidity. Few traffic safety prevention programs that have been evaluated scientifically have been found to have prevented significant numbers of alcohol-related traffic accidents among young drivers. The change in Michigan's legal drinking age in December, 1978 from 18 to 21 produced a significant improvement in the public health of 18-20 year old youth. This research has provided clear evidence that the higher legal drinking age has led to a significant reduction in alcohol-related traffic accidents among 18-20 year old drivers, while older drivers, during the same time period, experienced no changes or slightly increased frequency of alcohol-related traffic collisions. The higher drinking age can be considered a successful public health countermeasure against a leading cause of morbidity 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 the 21 year old drinking age should be sustained. (1)

Other major changes in alcohol availability should be evaluated for public health effects. Since 1976 the Office of Substance Abuse Services has supported ongoing research on the relationships between alcohol availability and alcohol-related social, health, and safety problems in Michigan. These studies have been concerned with the lowering and raising of the legal drinking age, licensing and regulatory activities of the Michigan Liquor Control Commision, and the variability of retail prices of alcoholic beverages. Governmental actions, either through administrative policy or regulatory changes, or legislation, frequently have direct implications for alcohol availability. For example, degregulation of distilled spirits prices, changes in state alcohol tax formulae, and zoning and other local ordinance modifications should be adequately evaluated regarding their consequences for alcohol-related morbidity and mortality. Research conducted since 1976 on the Michigan experience has revealed that modifications in alcohol availability were associated with changes in the incidence of acute alcohol-related problems. The Office of Substance Abuse Services is encouraged to continue to take advantage of opportunities to measure the effects of new legislation and regulations, and to use the results to guide the formulation of public policies designed to prevent alcohol abuse and other alcohol-related problems.

Notes to Chapter 6.0

1. 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).

APPENDIX A

BASELINE ARIMA TIME-SERIES MODEL ESTIMATION RESULTS

Table A.1 ARIMA Model Estimation Results for the Frequency of Had-been-drinking Crash Involvement Among 18 - 20 Year Old Drivers in Michigan

ESTIMATION SUMMARY — TERMINATION:SSQ CONVERGENCE

DIFFERENCING:	0	VARIABLE:	7
SEASONAL DIFFERENCING:	0	LABEL:	HBD18.C
SEASONAL SPAN:	12	CASES:	1- 84
TRANSFORMATIONS:	LOG	ADJUSTED SSQ:	0.17684E+01

PARAMETER NUMBER	PARAMETER TYPE	PARAMETER ORDER	BEGINNING VALUE	ESTIMATED VALUE	95 PER CENT LOWER LIMIT	95 PER CENT UPPER LIMIT
1	DELTA		0.10836E+01	0.94184E+00	0.39534E+00	0.14883E+01
2	AR	1	0.58276E+00	0.66178E+00	0.48458E+00	0.83898E+00
3	ARS	1	0.48603E+00	0.45476E+00	0.23770E+00	0.67182E+00

RESIDUAL AUTOCORRELATIONS:

CASES	DF	Q	SIG
1- 84	17	0.19674E+02	.2912

1- 10	-0.17	0.09	0.23	-0.04	-0.02	0.12	0.07	0.02	-0.09	0.16
ST.E.	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12
11- 20	0.09	-0.10	0.25	-0.06	0.02	0.01	0.08	0.03	-0.01	0.06
ST.E.	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13

PARAMETER CORRELATION MATRIX

	1	2	3
1	1.0000		
2	-0.7422	1.0000	
3	-0.4864	-0.2225	1.0000

Table A.2 ARIMA Model Estimation Results for the Frequency of Three-factor-surrogate Crash Involvement Among 16 - 17 Year Old Drivers in Michigan

```
ESTIMATION SUMMARY                                     TERMINATION:SSQ CONVERGENCE
**********************************************************************************
                                                              VARIABLE:    6
DIFFERENCING:             Ø                                     LABEL:F3S16.C
SEASONAL DIFFERENCING:    1                                     CASES:    1-  84
SEASONAL SPAN:           12                             ADJUSTED SSQ:Ø.9226ØE+Ø4
TRANSFORMATIONS:        NONE
**********************************************************************************
PARAMETER   PARAMETER      BEGINNING      ESTIMATED           95 PER CENT
 NUMBER    TYPE  ORDER       VALUE          VALUE       LOWER LIMIT   UPPER LIMIT
----------------------------------------------------------------------------------
    1       ARS    1      -.5ØØØØE+ØØ    -.51592E+ØØ    -.72211E+ØØ   -.3Ø974E+ØØ
**********************************************************************************
RESIDUAL AUTOCORRELATIONS:   CASES            DF            Q              SIG
                             13-  84          19       Ø.19315E+Ø2        .4368
----------------------------------------------------------------------------------
 1- 1Ø     -Ø.21   Ø.13  -Ø.13  -Ø.Ø1  -Ø.16   Ø.Ø1  -Ø.1Ø   Ø.1Ø  -Ø.Ø8   Ø.Ø2
 ST.E.      Ø.12   Ø.12   Ø.12   Ø.13   Ø.13   Ø.13   Ø.13   Ø.13   Ø.13   Ø.13

11- 2Ø      Ø.12  -Ø.17   Ø.Ø3  -Ø.15   Ø.1Ø  -Ø.19   Ø.Ø5  -Ø.1Ø   Ø.14  -Ø.Ø6
 ST.E.      Ø.13   Ø.13   Ø.14   Ø.14   Ø.14   Ø.14   Ø.14   Ø.14   Ø.14   Ø.15
**********************************************************************************
```

Table A.3 ARIMA Model Estimation Results for the Frequency of Had-been-drinking Crash Involvement Among 16 - 17 Year Old Drivers in Michigan

```
ESTIMATION SUMMARY                                    TERMINATION:SSQ CONVERGENCE
*******************************************************************************
                                                            VARIABLE:    4
DIFFERENCING:            0                                     LABEL:HBD16.C
SEASONAL DIFFERENCING: 0                                       CASES:    1-  84
SEASONAL SPAN:          12                             ADJUSTED SSQ:0.66253E+04
TRANSFORMATIONS:         NONE
*******************************************************************************
PARAMETER   PARAMETER      BEGINNING      ESTIMATED            95 PER CENT
 NUMBER    TYPE  ORDER       VALUE          VALUE       LOWER LIMIT  UPPER LIMIT
-------------------------------------------------------------------------------
    1      DELTA          0.18000E+02   0.12397E+02   0.63849E+01  0.18410E+02
    2      AR       1     0.60000E+00   0.49239E+00   0.28457E+00  0.70022E+00
    3      ARS      1     0.52000E+00   0.38365E+00   0.14963E+00  0.61766E+00
*******************************************************************************
RESIDUAL AUTOCORRELATIONS:   CASES          DF            Q             SIG
                              1-  84        17       0.18068E+02        .3846
-------------------------------------------------------------------------------
 1- 10    -0.10   0.09   0.08   0.09   0.01  -0.08   0.05   0.07  -0.13   0.17
 ST.E.     0.11   0.11   0.11   0.11   0.11   0.11   0.11   0.11   0.11   0.12

11- 20     0.12  -0.05   0.18   0.10   0.11  -0.06  -0.01   0.14  -0.16  -0.09
 ST.E.     0.12   0.12   0.12   0.12   0.12   0.13   0.13   0.13   0.13   0.13
*******************************************************************************
PARAMETER CORRELATION MATRIX
-------------------------------------------------------------------------------
       1         2         3
 1   1.0000
 2  -0.6207    1.0000
 3  -0.5223  -0.2809    1.0000
*******************************************************************************
```

Table A.4 ARIMA Model Estimation Results for the Frequency of Had-not-been-drinking Crash Involvement Among 18 - 20 Year Old Drivers in Michigan

ESTIMATION SUMMARY TERMINATION:SSQ CONVERGENCE

DIFFERENCING:	0	VARIABLE:	17
SEASONAL DIFFERENCING:	0	LABEL:	
SEASONAL SPAN:	12	CASES:	1- 84
TRANSFORMATIONS:	NONE	ADJUSTED SSQ:	0.17977E+07

PARAMETER NUMBER	PARAMETER TYPE	PARAMETER ORDER	BEGINNING VALUE	ESTIMATED VALUE	95 PER CENT LOWER LIMIT	95 PER CENT UPPER LIMIT
1	DELTA		0.50000E+03	0.22194E+03	0.73791E+02	0.37008E+03
2	AR	1	0.51000E+00	0.40286E+00	0.19453E+00	0.61119E+00
3	ARS	1	0.64000E+00	0.70993E+00	0.54120E+00	0.87866E+00

RESIDUAL AUTOCORRELATIONS:	CASES	DF	Q	SIG
	1- 84	17	0.16255E+02	.5058

1- 10	0.02	-0.11	0.15	-0.03	0.05	0.08	-0.01	-0.00	-0.04	0.03
ST.E.	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
11- 20	0.14	-0.09	0.23	0.11	-0.21	0.03	-0.01	-0.07	0.09	-0.06
ST.E.	0.11	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.13

PARAMETER CORRELATION MATRIX

	1	2	3
1	1.0000		
2	-0.5097	1.0000	
3	-0.8471	0.0028	1.0000

Table A.5 ARIMA Model Estimation Results for the Frequency of Had-not-been-drinking Crash Involvement Among 16 - 17 Year Old Drivers in Michigan

```
ESTIMATION SUMMARY                                          TERMINATION:SSQ CONVERGENCE
***************************************************************************************
                                                               VARIABLE:  16
DIFFERENCING:              0                                      LABEL:
SEASONAL DIFFERENCING:     1                                      CASES:    1-   84
SEASONAL SPAN:            12                               ADJUSTED SSQ:0.49940E+06
TRANSFORMATIONS:           NONE
***************************************************************************************
PARAMETER   PARAMETER      BEGINNING      ESTIMATED              95 PER CENT
 NUMBER     TYPE  ORDER      VALUE          VALUE         LOWER LIMIT   UPPER LIMIT
---------------------------------------------------------------------------------------
    1       ARS     1     -.32000E+00    -.34891E+00     -.59865E+00   -.99183E-01
***************************************************************************************
RESIDUAL AUTOCORRELATIONS:    CASES              DF              Q               SIG
                             13-  84             19        0.17736E+02          .5401
---------------------------------------------------------------------------------------
 1- 10      0.14    0.19    0.25    0.12    0.09    0.04    0.00   -0.05   0.15   -0.08
 ST.E.      0.12    0.12    0.12    0.13    0.13    0.13    0.13    0.13   0.13    0.14

11- 20      0.10   -0.07    0.15    0.07   -0.10    0.13    0.02   -0.02   0.07   -0.02
 ST.E.      0.14    0.14    0.14    0.14    0.14    0.14    0.14    0.14   0.14    0.14
***************************************************************************************
```

Table A.6 ARIMA Model Estimation Results for the Frequency of Three-factor-surrogate Crash Involvement Among 21 - 24 Year Old Drivers in Michigan

ESTIMATION SUMMARY TERMINATION:SSQ CONVERGENCE

VARIABLE: 12

DIFFERENCING:	0	LABEL:	
SEASONAL DIFFERENCING:	1	CASES:	1- 84
SEASONAL SPAN:	12	ADJUSTED SSQ:	0.18505E+05
TRANSFORMATIONS:	NONE		

PARAMETER NUMBER	PARAMETER TYPE	PARAMETER ORDER	BEGINNING VALUE	ESTIMATED VALUE	95 PER CENT LOWER LIMIT	95 PER CENT UPPER LIMIT
1	ARS	1	-.35000E+00	-.32470E+00	-.58333E+00	-.66067E-01

RESIDUAL AUTOCORRELATIONS:	CASES	DF	Q	SIG
	13- 84	19	0.22834E+02	.2447

1- 10	0.07	0.22	0.07	-0.14	0.08	0.03	0.09	-0.02	0.10	-0.31
ST.E.	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.13
11- 20	0.02	-0.17	-0.02	0.14	0.06	0.16	0.05	0.05	-0.15	0.13
ST.E.	0.14	0.14	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15

Table A.7 ARIMA Model Estimation Results for the Frequency of Had-been-drinking Crash Involvement Among 21 - 24 Year Old Drivers in Michigan

```
ESTIMATION SUMMARY                                      TERMINATION:SSQ CONVERGENCE
***********************************************************************************
                                                              VARIABLE:  10
DIFFERENCING:            0                                       LABEL:HBD21.C
SEASONAL DIFFERENCING: 1                                         CASES:    1-  84
SEASONAL SPAN:          12                                ADJUSTED SSQ:0.14857E+01
TRANSFORMATIONS:         LOG
***********************************************************************************
PARAMETER    PARAMETER      BEGINNING      ESTIMATED              95 PER CENT
 NUMBER     TYPE  ORDER       VALUE          VALUE         LOWER LIMIT   UPPER LIMIT
-----------------------------------------------------------------------------------
    1       ARS     1      -.36000E+00    -.11481E+00     -.38183E+00   0.15221E+00
***********************************************************************************
RESIDUAL AUTOCORRELATIONS:    CASES             DF              Q               SIG
                             13-  84            19        0.16604E+02         .6167
-----------------------------------------------------------------------------------
 1- 10      0.07  -0.08   0.13   0.12   0.03   0.02   0.18   0.13   0.06   0.03
 ST.E.      0.12   0.12   0.12   0.12   0.12   0.12   0.12   0.13   0.13   0.13

11- 20      0.09  -0.18  -0.09   0.15  -0.04   0.00   0.07  -0.09  -0.21  -0.07
 ST.E.      0.13   0.13   0.13   0.13   0.14   0.14   0.14   0.14   0.14   0.14
***********************************************************************************
```

Table A.8 ARIMA Model Estimation Results for the Frequency of Three-factor-surrogate Crash Involvement Among 25 - 45 Year Old Drivers in Michigan

ESTIMATION SUMMARY — TERMINATION:SSQ CONVERGENCE

DIFFERENCING:	0	VARIABLE:	15
SEASONAL DIFFERENCING:	1	LABEL:	
SEASONAL SPAN:	12	CASES:	1- 84
TRANSFORMATIONS:	NONE	ADJUSTED SSQ:	0.46058E+05

PARAMETER NUMBER	PARAMETER TYPE	ORDER	BEGINNING VALUE	ESTIMATED VALUE	95 PER CENT LOWER LIMIT	95 PER CENT UPPER LIMIT
1	AR	1	0.40000E+00	0.23972E+00	0.12306E-02	0.47822E+00
2	AR	2	0.20000E+00	0.24718E+00	0.92580E-03	0.49344E+00
3	ARS	1	-.46000E+00	-.50152E+00	-.73021E+00	-.27284E+00

RESIDUAL AUTOCORRELATIONS:

CASES	DF	Q	SIG
13- 84	17	0.64431E+01	.9897

1- 10	-0.06	-0.02	0.09	-0.04	-0.05	0.07	-0.00	-0.02	-0.05	0.00
ST.E.	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
11- 20	-0.00	-0.09	0.08	-0.05	0.06	-0.05	0.10	-0.12	-0.06	0.14
ST.E.	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13

PARAMETER CORRELATION MATRIX

	1	2	3
1	1.0000		
2	-0.2668	1.0000	
3	0.1551	-0.1275	1.0000

Table A.9 ARIMA Model Estimation Results for the Frequency of Had-been-drinking Crash Involvement Among 25 - 45 Year Old Drivers in Michigan

ESTIMATION SUMMARY — TERMINATION:SSQ CONVERGENCE

DIFFERENCING: 0	VARIABLE: 13
SEASONAL DIFFERENCING: 0	LABEL:
SEASONAL SPAN: 12	CASES: 1- 84
TRANSFORMATIONS: NONE	ADJUSTED SSQ: 0.13607E+06

PARAMETER NUMBER	PARAMETER TYPE	PARAMETER ORDER	BEGINNING VALUE	ESTIMATED VALUE	95 PER CENT LOWER LIMIT	95 PER CENT UPPER LIMIT
1	DELTA		0.15000E+03	0.70258E+02	0.21346E+02	0.11917E+03
2	AR	1	0.24000E+00	0.29701E+00	0.62508E-01	0.53152E+00
3	ARS	1	0.56000E+00	0.73547E+00	0.56430E+00	0.90664E+00

RESIDUAL AUTOCORRELATIONS:

CASES	DF	Q	SIG
1- 84	17	0.15027E+02	.5935

1- 10	-0.02	-0.08	0.25	-0.04	0.06	0.11	0.03	-0.01	0.12	0.18
ST.E.	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12
11- 20	-0.05	-0.13	0.03	0.13	-0.05	-0.04	0.03	-0.06	-0.02	0.06
ST.E.	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13

PARAMETER CORRELATION MATRIX

	1	2	3
1	1.0000		
2	-0.4140	1.0000	
3	-0.8691	-0.0714	1.0000

Table A.10 ARIMA Model Estimation Results for the Frequency of Had-not-been-drinking Crash Involvement Among 21 - 24 Year Old Drivers in Michigan

```
ESTIMATION SUMMARY                                        TERMINATION:SSQ CONVERGENCE
*****************************************************************************
                                                                VARIABLE:  18
DIFFERENCING:           Ø                                          LABEL:
SEASONAL DIFFERENCING: Ø                                           CASES:   1-  84
SEASONAL SPAN:         12                                  ADJUSTED SSQ:Ø.19648E+Ø7
TRANSFORMATIONS:        NONE
*****************************************************************************
PARAMETER   PARAMETER      BEGINNING      ESTIMATED           95 PER CENT
 NUMBER     TYPE  ORDER      VALUE          VALUE        LOWER LIMIT   UPPER LIMIT
-----------------------------------------------------------------------------
    1       DELTA          Ø.3ØØØØE+Ø3   Ø.2167ØE+Ø3   Ø.8Ø11ØE+Ø2   Ø.35329E+Ø3
    2       AR       1     Ø.59ØØØE+ØØ   Ø.453Ø9E+ØØ   Ø.25Ø95E+ØØ   Ø.65522E+ØØ
    3       ARS      1     Ø.62ØØØE+ØØ   Ø.673Ø1E+ØØ   Ø.49428E+ØØ   Ø.85173E+ØØ
*****************************************************************************
RESIDUAL AUTOCORRELATIONS:   CASES           DF             Q             SIG
                             1-  84          17        Ø.13722E+Ø2       .6867
-----------------------------------------------------------------------------
 1- 1Ø     -Ø.ØØ  -Ø.Ø7   Ø.Ø8   Ø.Ø6  -Ø.Ø2  -Ø.Ø1   Ø.Ø6  -Ø.Ø8   Ø.Ø3   Ø.Ø4
 ST.E.      Ø.11   Ø.11   Ø.11   Ø.11   Ø.11   Ø.11   Ø.11   Ø.11   Ø.11   Ø.11

11- 2Ø      Ø.18  -Ø.Ø7   Ø.29   Ø.Ø7  -Ø.12  -Ø.Ø3  -Ø.ØØ  -Ø.Ø4   Ø.Ø1  -Ø.Ø3
 ST.E.      Ø.11   Ø.12   Ø.12   Ø.12   Ø.12   Ø.13   Ø.13   Ø.13   Ø.13   Ø.13
*****************************************************************************
PARAMETER CORRELATION MATRIX
-----------------------------------------------------------------------------
        1         2         3
 1   1.ØØØØ
 2  -Ø.5Ø83   1.ØØØØ
 3  -Ø.79Ø7  -Ø.Ø91Ø   1.ØØØØ
*****************************************************************************
```

Table A.11 ARIMA Model Estimation Results for the Frequency of Had-not-been-drinking Crash Involvement Among 25 - 45 Year Old Drivers in Michigan

ESTIMATION SUMMARY TERMINATION:SSQ CONVERGENCE

		VARIABLE:	19
DIFFERENCING:	0	LABEL:	
SEASONAL DIFFERENCING:	0	CASES:	1- 84
SEASONAL SPAN:	12	ADJUSTED SSQ:	0.12356E+08
TRANSFORMATIONS:	NONE		

PARAMETER NUMBER	PARAMETER TYPE	ORDER	BEGINNING VALUE	ESTIMATED VALUE	95 PER CENT LOWER LIMIT	95 PER CENT UPPER LIMIT
1	DELTA		0.75000E+03	0.51644E+03	0.19635E+03	0.83654E+03
2	AR	1	0.64000E+00	0.47842E+00	0.27736E+00	0.67949E+00
3	ARS	1	0.63000E+00	0.66412E+00	0.47846E+00	0.84977E+00

RESIDUAL AUTOCORRELATIONS:	CASES	DF	Q	SIG
	1- 84	17	0.18607E+02	.3516

1- 10	-0.03	-0.02	0.06	0.07	-0.04	-0.01	0.00	-0.07	0.05	-0.01
ST.E.	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
11- 20	0.27	-0.11	0.30	0.12	-0.09	-0.09	0.00	-0.07	-0.01	-0.00
ST.E.	0.11	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13

PARAMETER CORRELATION MATRIX

	1	2	3
1	1.0000		
2	-0.4920	1.0000	
3	-0.7639	-0.1491	1.0000

APPENDIX B

DESIGN VALIDITY

DESIGN VALIDITY

There are numerous potential threats to the validity of the conclusions reached in the present investigation. These potential threats to the validity of conclusions can be categorized in a number of ways, the most popular 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: (A) statistical conclusion validity, (B) internal validity, (C) construct validity, and (D) external validity. Each of these types of validity is discussed below.

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 true 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 points was used in estimating the statistical relationships. Power is also increased by refraining from the use of very low levels of Type I error as the criterion for a statistically significant relationship, since power is directly related to the level of Type I error chosen.

Statistical conclusion validity was strengthened by the use of the most powerful 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 all systematic components of the total variance in the dependent measures, and thus reduce the error variance. As is discussed in Section 3.4 on the data analysis methods, extensive effort was expended to identify all of the systematic components of the total variance in each dependent time-series prior to an assessment of the statistical significance or magnitude of the drinking age effects.

A second threat to statistical conclusion validity is the violation of the assumptions of the procedures used. This threat to validity was minimized by explicitly noting the assumptions accompanying the statistical procedures used, the robustness of the procedure to a violation of those assumptions, and an assessment of the extent to which the assumptions were 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 3.4.

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. (1) This threat to validity can be avoided either by explicitly making adjustments in the critical significance levels (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.

A low level of reliability in the measures used 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 used. 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 minimized when the data were aggregated at the state level. The result of the statewide aggregation was the canceling out of numerous random measurement errors occurring at the local level; consequently, the sytematic patterns in the series were more easily discernable in the aggregated data.

Low reliability in the implementation of the intervention is a fifth potential threat to statistical conclusion validity. If the intervention is not implemented in a uniform fashion, with a high degree of random error in the manner in which it is implemented from month to month, one is less likely to observe the true covariation that may be present between the intervention and the dependent series. Implementation unreliability was minimized as a threat to the validity of the present study because the interventions of interest, namely changes in the legal drinking age, were simply and clearly defined interventions. The major source of intervention implementation unreliability was the differential levels of enforcement of the drinking age across local jurisdictions and over time. Since adequate information on the nature of enforcement efforts was not available, variations in the level of enforcement could not be explicitly incorporated into the analyses. As a result, inconsistencies in enforcement efforts reduced the power of this investigation to detect effects of the drinking age changes.

The sixth threat to statistical conclusion validity is identified by Cook and Campbell (1979:44) as "random irrelevancies in the experimental setting." It 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. It should be noted that a large number of these other causes of crash frequency, although not explicitly identified, were controlled in the analyses by the specification of systematic trend, seasonal, and other autocorrelation components present in the dependent variables. In addition to these systematic trend, seasonal, and autocorrelation components of the series that reflect causal influences, there was a random component in each series due to other omitted causal influences on the series. (2) The differential operation of these other factors across jurisidictions was controlled 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 and sampling error, provided the basis for an assessment of the statistical significance of the effects of the legal interventions.

The final threat to statistical conclusion validity identified by Cook and Campbell (1979:44) is "random heterogeneity of respondents," or, in other words, the random error associated with the sampling of subjects from the population of interest. Since the present research did not use a sample of fatal accidents, but rather a census of fatal collisions for the entire state, sampling error was not a threat to statistical conclusion validity in the analyses of the fatality variables.(3) Sampling error was present in the measures of traffic crash frequencies, which were based on a 20 percent random sample of all reported crashes. In the analyses of these variables, the sampling error was part of the total residual error used to assess the statistical signficance of intervention effects.

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 sucessive 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 for the observed relationships between the measure of beverge alcohol availability (i.e. the legal drinking age) and measures of motor vehicle accidents as possible were analyzed and dismissed as implausible explanations for the observed covariation.

The first 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 rahter 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 the legal drinking age precede the measures of accidents, the argument that the causal relationship is reversed was discarded.

The second major threat to internal validity is history, a comtemporaneous event that may be the true cause of the observed effect. For example, one might argue that any downward shifts in accidents among Michigan youth after the raise in the legal drinking age in 1978 were due to the moderate gasoline shortage (and increased gasoline prices) of 1979, and the resultant drop in miles driven. Similarly, one might argue that a reduction in alcohol-related traffic accidents was due to reduced consumption of alcohol after Michigan's ban on non-returnable beverage containers caused a significant increase in the price of packaged beer.(4) Such explanations of observed shifts in the dependent series were ruled out by specific features in the research design. The use of quasi-control groups, consisting of the affected age group's older peers not affected by the drinking age interventions, permits an assessment of the validity of alternative explanations, of which the gasoline shortage and beverage price increases are two examples. Such contemporaneous historical events would most likely affect all age groups, not just the 18-20 year olds, and would therefore be seen in the accident measures for the comparison age groups.

Alternative historical events were also ruled out as explanations of a covariation between the interventions and the dependent variables by the fact that two interventions were examined, one of which was the reverse of the other. In such a situation any contemporaneous historical event that is suggested as an explanation of observed shifts must operate in opposite directions at different times, or two historical events must be postulated which operate in opposite directions. Since such multiple historical confounds were unlikely, the research design as here formulated was robust against contemporaneous history as a threat to internal validity. Moreover, the major event with known effects on crash frequency, the fuel shortage and related factors of early 1974, was explicitly controlled in the data analyses.

The third threat to internal validity is maturation, gradual devlopmental changes in the dependent variables simply due to the passage of time. The time-series design ruled out this threat by providing 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; in any case, observed trends in the dependent variable series were explicitly taken into account in the data analyses.

The testing threat to internal validity refers to the impact repeated testing may have on the system under investigation, and the possibility that testing effects may be the true cause of an observed relationship. This threat was eliminated in the present design by the unobtrusive nature of the measurement process. This is, the measurement process was an institutionalized feature of the social system, rather than an artifact of the experimental situation. Secondly, this potential threat was minimized in the time-series design by the long pre-intervention series which made it highly improbable that a testing effect would suddenly emerge at the point of the intervention.

The fifth 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 were measured may have changed at the same time point as the legal changes in the drinking age, and may account for any observed shifts in the series at the point of the legal changes. This argument was not a plausible alternative explanation of the proposed causal relationship for several reasons. First, the presence of comparision groups that would also have experienced basic changes in the measurement process ruled out instrumentation as a validity threat. Such changes in the measurement process cannot be used to explain the differential shifts in the frequency of accidents for the 18-20 age group as compared to the aged groups presumably unaffected by the legal drinking age changes. This threat to validity was also minimized by the analysis of two interventions, one the reversal of the other, since two instrumentation changes, causing opposite shifts in the dependent series, must be postulated. Finally, the threat was reduced simply by the time-series nature of the design. With a large number of observations over an extended period of time prior to the intervention, a substantial instrumentaion change exactly at the point of the intervention became less plausible. (5)

Statistical regression or regression to the mean is another often mentioned threat to internal validity. Regression to the maean occurs 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 observation 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 the 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 was not a threat to the interval validity of the present design for several reasons. First, a long series of obsevations was available prior to the interventions, facilitating the determination of the atypicality 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 the observations immediately prior to and immediately after the interventions. Furthermore, the analysis methods took 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 seventh and eighth potential threats to internal validtiy 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 study results. One type of selection threat occurrs 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 were assessed by examining shifts within each of the series, selection and mortality may have threatened internal validity if the composition of the experimental group changed substantially at the points at which the interventions were 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 individuals who attain the age of 18 and dropping out of individuals who attain the age of 21. This change in the 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 the composition of the experimental groups were primarily due to a stable aging process that cannot be influenced by the intervention or extraneous factors. Thus, it was highly implausible that the changes in the composition of experimental groups accounted for observed shifts in the dependent variables.

There are three threats to internal validity which involve the 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 in the present design 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 took 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 was possible that each of the experimental groups experienced a different "local" history, and this differentially experienced contemporaneous event was actually the cause of the shifts observed in the series concomitant with the drinking age interventions. For example, two contemporaneous events, the moderate gasoline shortage and price increases of 1979 and the ban on non-returnable beverage containers (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 that was not true for adults. Since youth may have less discretionary disposable income available, and since these contemporaneous events increased the cost of both driving and of 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 data analyses presented in Chapter 4.0 reveal that the 1974 fuel shortage/price increases did not affect young drivers more than older drivers. This finding reduced the plausibility of the argument that the increased fuel prices of 1979 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 the reporting of alcohol-related accidents occurred only for accidents involving youth. The instrumentaion change could then account for the 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 the three factor surrogate measure of alcohol-related crashes as discussed in Section 3.2. 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 the 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 18-20 age group indirectly changes the level of alcohol availability for the 16-17 age group, as discussed in Chapter 2.0. As a result, the interventions may have an impact on the 16-17 year old cohort as well as the focal 18-20 age group. The diffusion of the intervention to 16-17 year olds was no threat to the present investigation since other comparison groups (aged 21-24 and 25-45), whose levels of alcohol availability were not affected by the interventions, were included in the design. The effects of the drinking age changes on the 16-17 age group were directly assessed along with the impact upon 18-20 year olds.

The last three threats to internal validity are potential "reactive effects" of experimentation. The first reactive effect Cook and Campbell (1979:54) discuss is "compensatory equalization of treatments," which occurs when the providers of the treatment recognize that the control groups not receiving the treatment may feel discriminated against; as a result, the providers work to obtain a portion of the treatment for the control groups. In the present investigation, the older age cohort control groups were not affected by changes in the legal drinking age; regardless of whether the legal age was 18 or 21, those over 21 had alcoholic beverages legally available to them.

The second reactive effect potentially threatening internal validity is "compensatory rivalry by respondents receiving less desirable treatments" (Cook and Campbell, 1979:54), and refers to action taken by control group subjects to obtain a portion of the treatments (which are perceived as being desirable). The third reactive threat is "resentful demoralization of respondents receiving less desirable treatments" (Cook and Campbell, 1979:54). This threat to internal validity occurs if the treatments are perceived as desirable and the no treatment control groups retaliate by lowering productivity or efforts, or otherwise distort the differences between treatment and control groups. These two effects were not threats to the internal validity of this investigation because the present study examined natural experiments that occurred as part of normal on-going policy-making processes in the State of Michigan, and thus were not subject to the reactive effects that are often present in artifically contrived experimentation, which is an atypical presence in the social system under investigation.

In summary, the goal in designing this research was to obtain valid conclusions as to whether changes in the availability of beverage alcohol, as represented by changes in the drinking age, caused substantial changes in alcohol-related accident frequencies. 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 used 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.

Construct Validity. Construct validity answers the question, given the established causal relationship between the operationalization 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, as is found in Chapter 2.0, is an important aid for obtaining measures that are appropriate to the concepts under study.

The 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 not a threat in the present design because multiple indicators of each concept were used. As discussed in Section 3.2, the traffic crash dependent variable measures include the frequency of police reported "had not been drinking" crash-involved drivers, the frequency of police reported accident-involved drivers where the driver "had been drinking," and an empirically derived three factor surrogate measure of alcohol-related accidents. Furthermore, two categories of crash involvement were examined, the total frequency of crash involvement and the frequency of fatal crash involvement. The use of such multiple indicators of traffic accidents and alcohol-related traffic accidents permitted an assessment of convergent validity. The measure of the 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, obviating the need for multiple indicators.

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 was based on the judgements of the investigating police officer, while the three factor surrogate was empirically constructed on the basis of objective information concerning the driver and circumstances surrounding the collision.

There are three theats to construct validity that are potential reactive effects of the experimental situation. The first threat occurs if the subjects within the various experimental conditions guess what the researcher's hypothesis is and act in such a manner to confirm (or disconfirm) that hyothesis. 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 expectations 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. All three of these potential threats to construct validity, resulting from reactive effects, were eliminated in the present investigation by the unobtrusive nature of the experiment. The experiment 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 the expectations of police offficers, who are responsible for the collection of data on traffic accidents, influenced the reported frequencies of crashes. This threat was minimized by the use of measures that the police had little control over and thus were unlikely to be distorted by such subjective factors. The three factor surrogate measure of traffic fatalities, in particular, was virtually impossible to distort by police accident investigators.

Another threat to construct validity was 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 the 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 were administered, or only a portion of the potential range of the outcome variables were measured. This potential source of invalidity was minimized in the present design because the measurement of the outcome variables was continuous and because 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, however, that the concept of alcohol availability is continuous and the present design only examined 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 were at widely divergent points of the availability continuum. Although a detailed examination of the pattern of impact of marginal changes in the 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 achieved.

The interaction of various interventions also could reduce construct validity. Since this study evaluated the impact of two interventions, any impact observed for the second intervention may only obtain when the second intervention is preceded by the first intervention. Thus one could argue that the effect of the second intervention, raising the drinking age, only occurs if raising the drinking age follows, by seven years, a drop in the legal drinking age. The threat that the two interventions may interact to produce the observed effects was avoided by the nature of the two interventions, one being the reverse of the other. Obviously, one expects a law establishing the legal drinking age at a particular age to have an effect of shifting the level of accident time-series only if the drinking age was something other than that age prior to the new law. The interaction of different drinking age interventions, therefore, did not reduce construct validity because the two interventions were, in a sense, only one treatment, with the 1978 drinking age change simply the reversal of the 1972 intervention, restoring the drinking age to its pre-1972 level.

One type of interaction effect that cannot be controlled by the design is the interaction of the focal intervention, i.e. drinking age changes, with other planned or unplanned "interventions," such as changing economic conditions or the implementation of a ban on non-returnable beverage containers. Such factors may have interacted with the drinking age changes to produce shifts in crash frequency among youth and the only way to avoid invalid inference is cognizance of such confounding "interventions" when interpreting the results of the data analyses.

The last threat to the construct validity of the present investigation is the interaction of testing and the interventions, that is, the possibility that the intervention effects observed may only occur if there is pre-testing. The measurement of the outcome variables prior to the intervention implementation did not reduce design validity because the pre-testing utilized here was a continuous, institutionalized data collection system, rather than an artifact of the experimental situation.

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 extend 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 sample analyzed.

The selection of a target population of all accident involved youth in Michigan, with the analysis of a census of fatalities and a random sample of reported crashes, reduced this constraint on generalizability.

There are two major limitations on the populations to which the findings could safely be generalized. First, since the analyses were limited to the aggregate of all reported crash involved youth in Michigan, no generalizations could be made to particular subpopulations of Michigan youth. For example, without specific analyses of particular subgrous based on sociodemographic or social-psychological variables, one could not determine the differential impact of the changes in the 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 population of youth. Second, because the analyses were based solely on the Michigan population, the generalizability of the results was, strictly speaking, limited to the State of Michigan. It must be recognized that generalizing to other states is based on one's judgement as to the similarities betweeen those states and Michigan, rather then based on explicit features of the research design. (6)

The interaction of setting and treatment is the second basic threat to external validity. This limitation on generalizability occurs when the intervention effects observed are due to the implementation of the interventions in a particular socio-cultural setting. Since the present investigation assessed the effects of changing the legal drining age in only one socio-cultural setting, one cannotgeneralize 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.

The 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 implemented, the generalizability of the findings are severely limited. The analysis of two interventions changing the legal availability of beverage alcohol at different time points, substantially reduced this threat to external validity. Since impact of a change in the drinking age in 1972 and the impact of another change in 1978 was examined, the plausibility of the argument that particular historical circumstances interacted with the intervention both in 1972 and 1978, 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 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 the 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. 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 (A) the appropriate use of powerful statistical procedures, (B) the use of long series of observations for multiple measures, (C) the analysis of multiple comparison groups, and (D) the examination of two policy interventions, one the reverse of the other, function to provide conclusions of high validity concerning the impact of changing the legal minimum drinking age on measures of motor vehicle accidents. The establishment of such causal relationships is among the most important goals of theory-oriented hypothesis-testing research and policy-oriented evaluation research. Identifying causal relationships allows one to move on to an assessment of the generalizability of the causal conclusion to broader concepts. 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 and fatalities. The levels of design validity for construct and (especially) external validity are somewhat lower, however, and broad generalizations to related concepts and other populations and settings should be made with care. It should be noted that, as Cook and Campbell (1979) pointed out, construct and external validity are, in the final analysis, matters of replication. Therefore, the replication of the present investigation in other states, using various measures of the concepts and using the powerful 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 accidents.

Notes to Appendix B

1. 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.

2. The major exogenous factor with a known impact on the frequency of crashes was the fuel shortage and national maximum legal speed limit reduction of early 1974. The effects of the fuel shortage/speed limit reduction were explicitly controlled in the data analyses assessing the effect of the drinking age changes.

3. Some may argue that without probability sampling from a defined population, any use of statistical testing is inappropriate. However, the model of statistical inference used here is an econometric or time-series model where the statistical significance of an intervention parameter was assessed by comparing its size with the size of the total random component in the dependent variable. The purpose of statistical inference in this investigation was to separate the systematic effects from the random component, not generalizations to specified population. For additional discussion of this issue see Berk and Brewer (1978).

4. The proposed ban on non-returanable soft drink and beer containers was submitted to and approved by the people of the State of Michigan at the general election held on November 2, 1976, and took effect on December 3, 1978 (Michigan Compiled Laws of 1970, Sections 445.571 through 445.576, as amended by Initiated Law of 1976, Section 2, and Public Acts of 1977, Number 270). Available evidence indicates that, after the effects of inflation were controlled, packaged beer prices increased by about 10 percent in the first year after the law took effect (Michigan State Legislature, 1979).

5. As was discussed in Section 3.2, variables characterized by major instrumentation changes (such as the had been drinking/had not been drinking measure in the late 1960s and early 1970s) were excluded from the analyses.

6. One important difference between states, potentially limiting generalizability, identified in previous research (Douglass, 1974), 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 the 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.

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