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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

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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).

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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

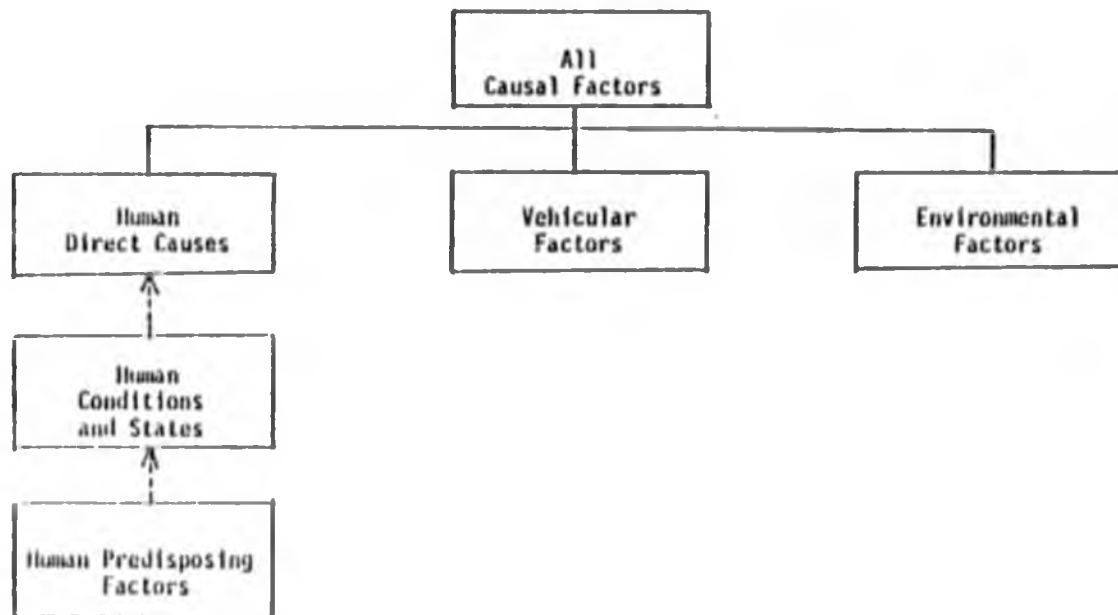


Figure 2.1 Major Categories of Causal Factors in Motor-vehicle Collisions

Source: Institute for Research in Public Safety (1975)

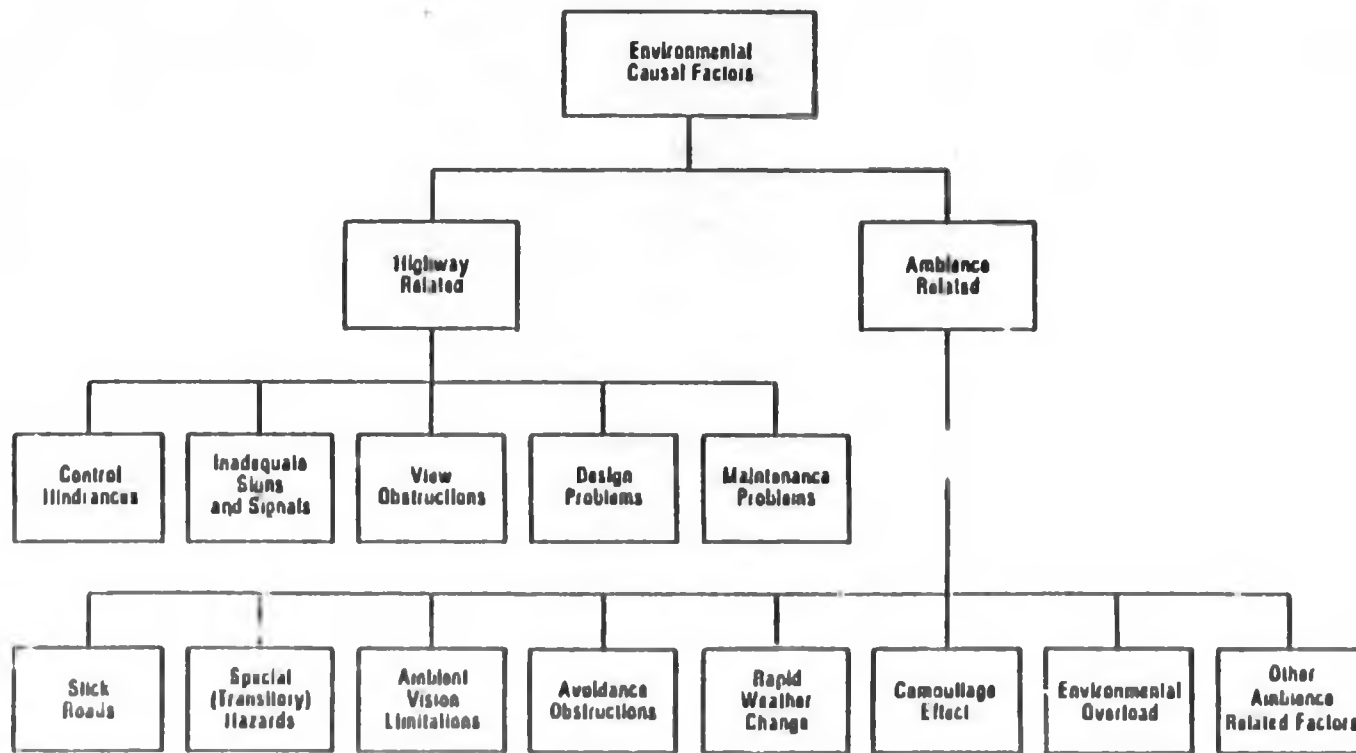


Figure 2.2 Environmental Causal Factors in Motor-vehicle Collisions

Source: Institute for Research in Public Safety (1975)

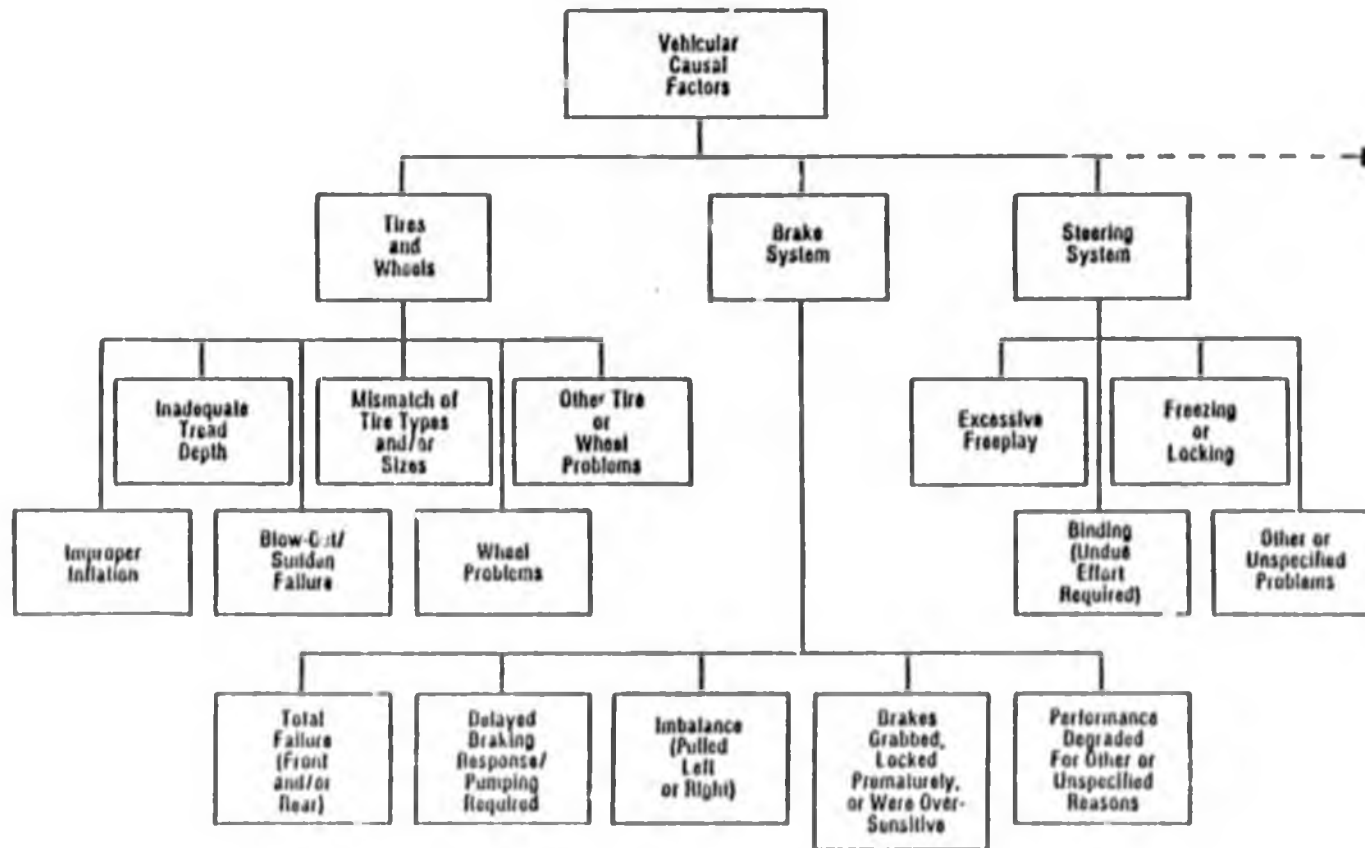


Figure 2.3 Vehicular Causal Factors in Motor-vehicle Collisions

Source: Institute for Research in Public Safety (1975)

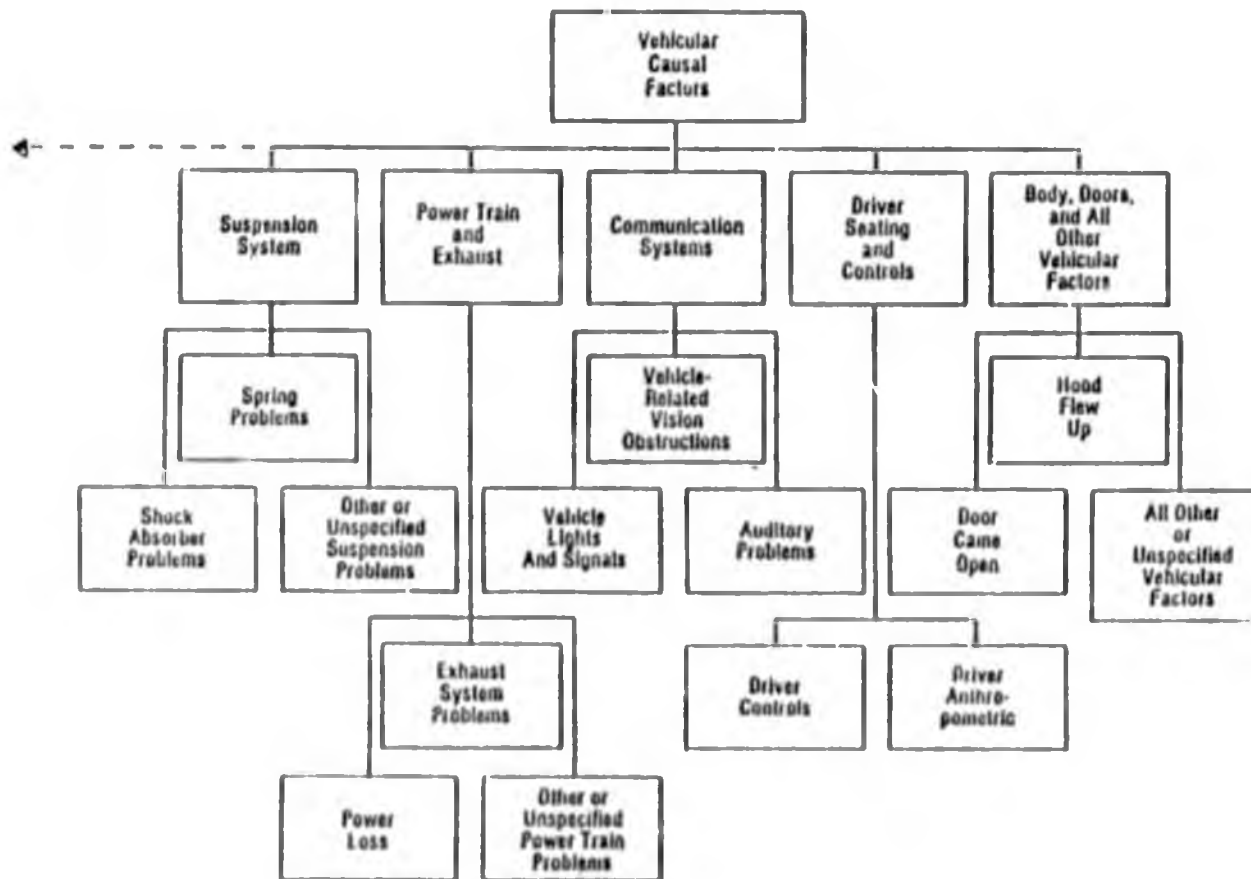


Figure 2.3(continued) Vehicular Causal Factors in Motor-vehicle Collisions

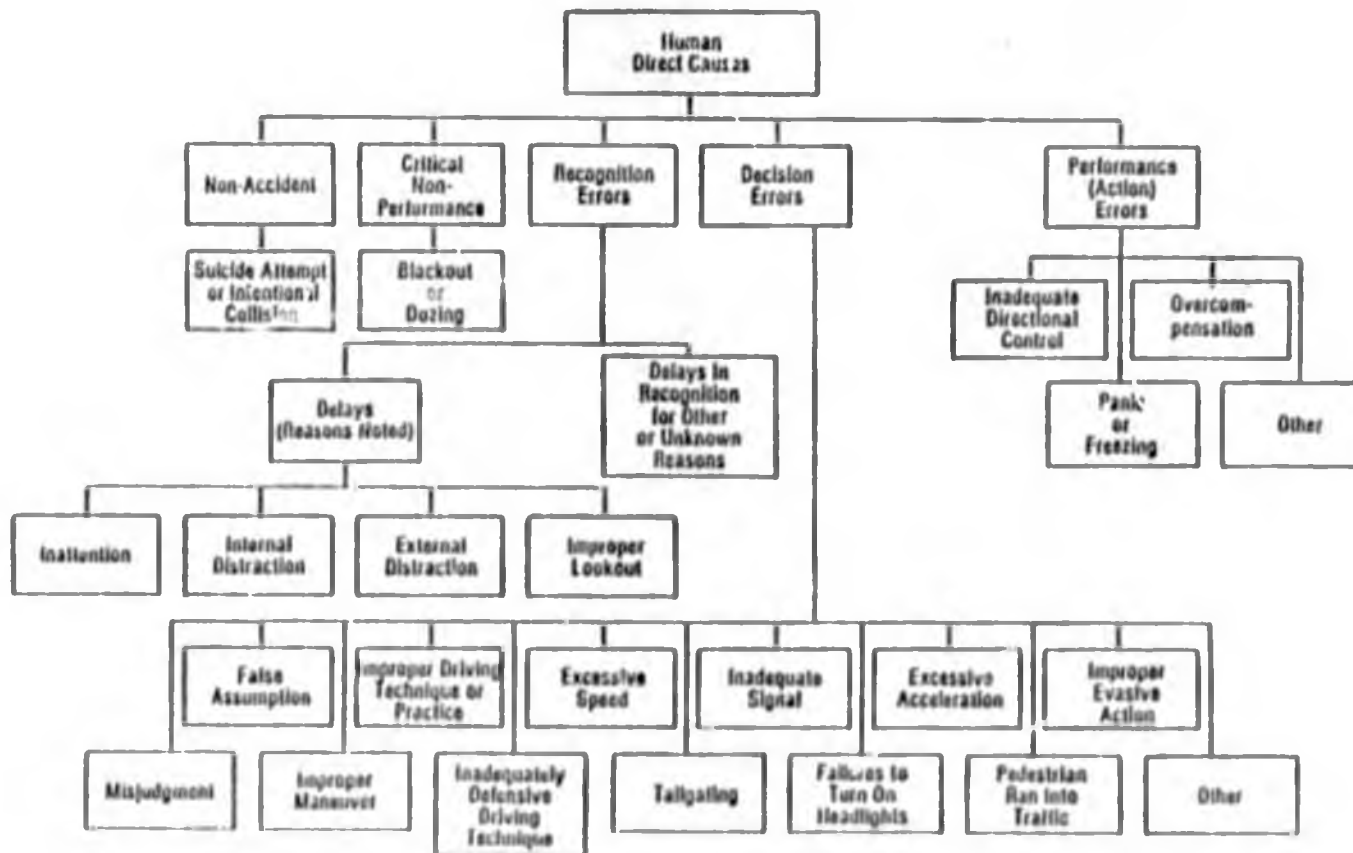


Figure 2.4 Human Direct Causes in Motor-vehicle Collisions

Source: Institute for Research in Public Safety (1975)

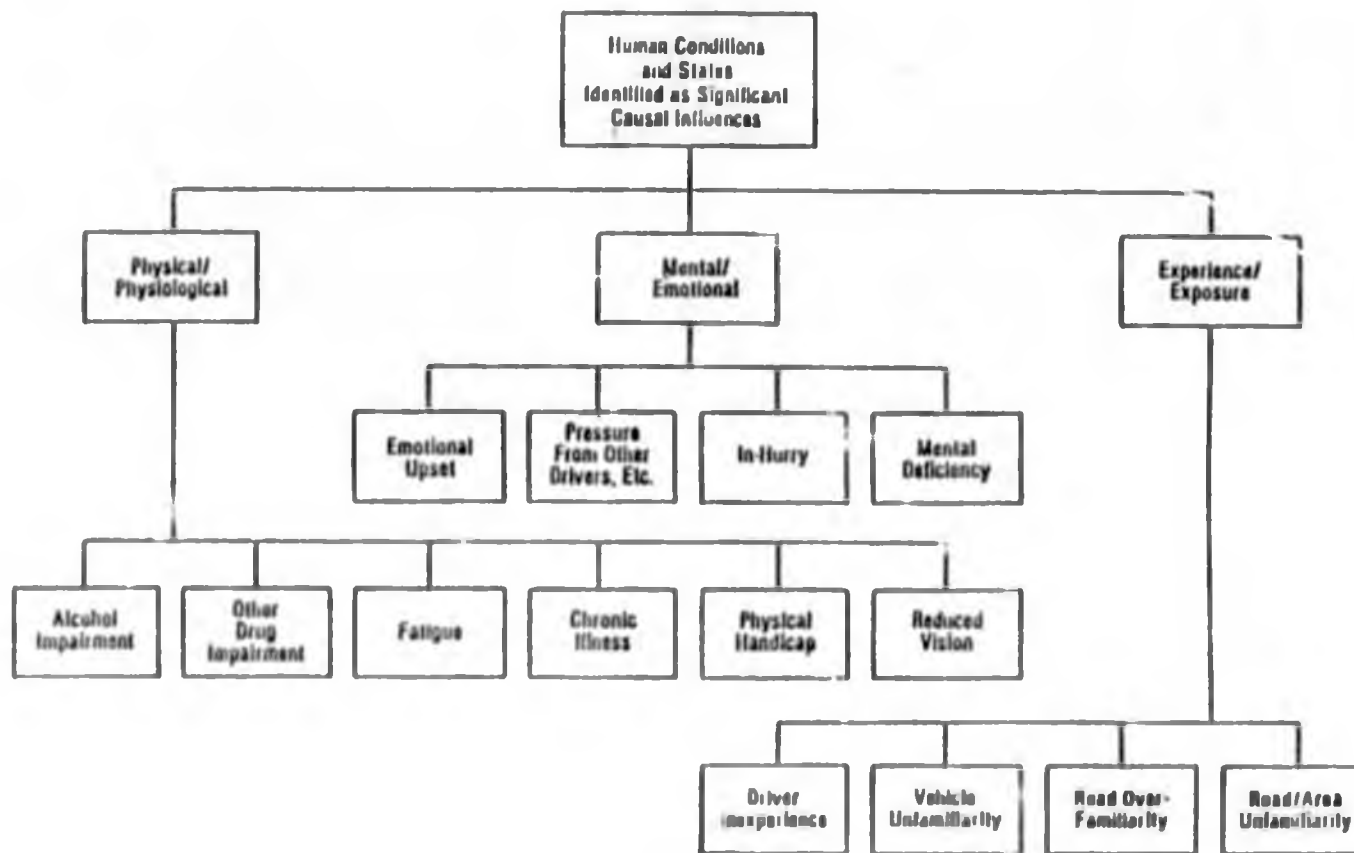


Figure 2.5 Human Conditions and States Identified as Causal Influences in Motor-vehicle Collisions

Source: Institute for Research in Public Safety (1975)

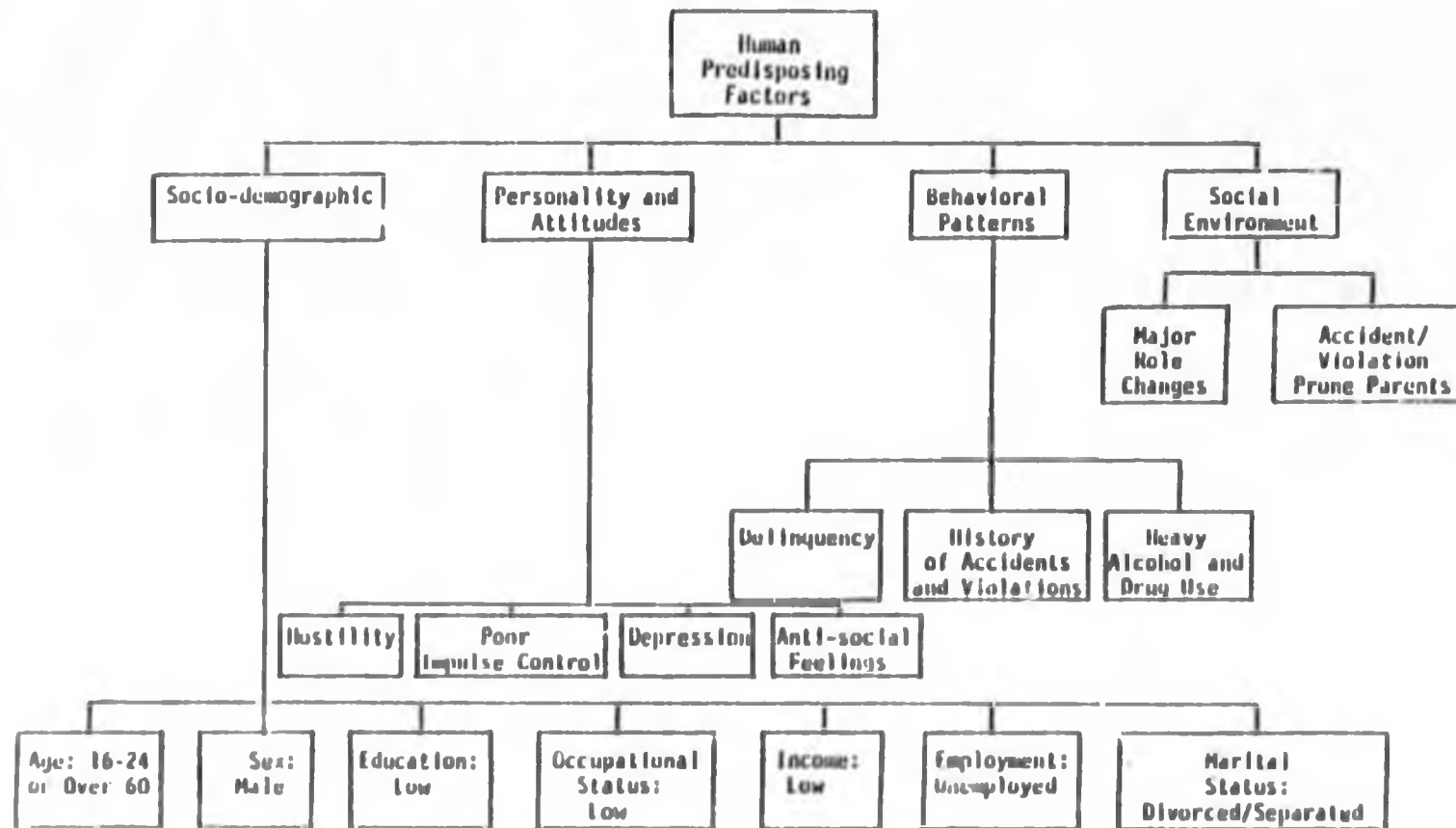


Figure 2.6 Human Predisposing Factors for Motor-vehicle Collision Involvement

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., 1979). (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 (Pruyser 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; Zylmar, 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; Felz 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

Douglas 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 1924.

Douglass and Freedman (1977) replicated some of the earlier analyses, using four years of observations after the legal change. According to the authors, the results demonstrated that the increase in alcohol-related crash involvement among Michigan youth, identified in the 1974 research, persisted over the four years after the reduced drinking age took effect (i.e. 1972 through 1975). 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 (1975, 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 based on police reports) have been observed using alternative measures of alcohol-involvement not influenced by police reporting practices, such as analyses of single-vehicle, nighttime, and weekend crashes.

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) DUIIL 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 DUIIL 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 distribution 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

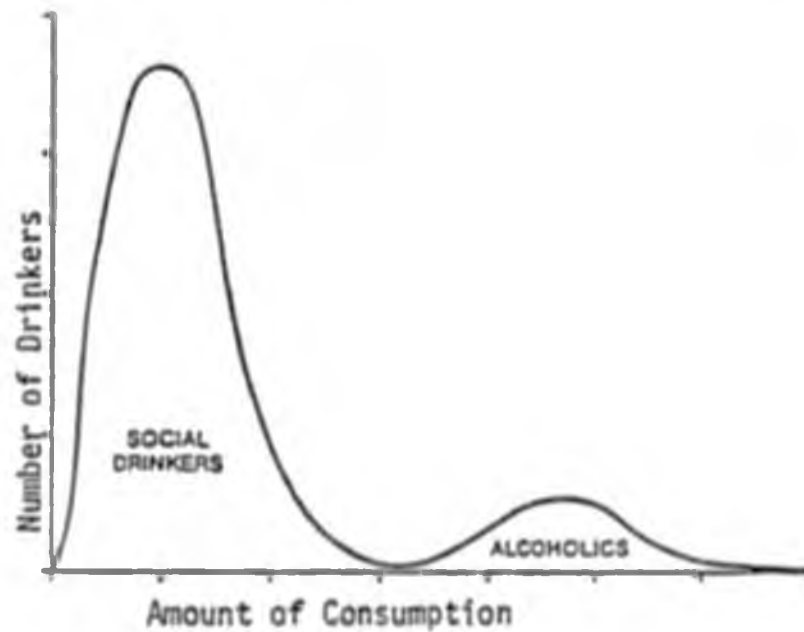


Figure 2.7 The Bimodal Model of Alcohol Consumption

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 2.5) 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, 1979).

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

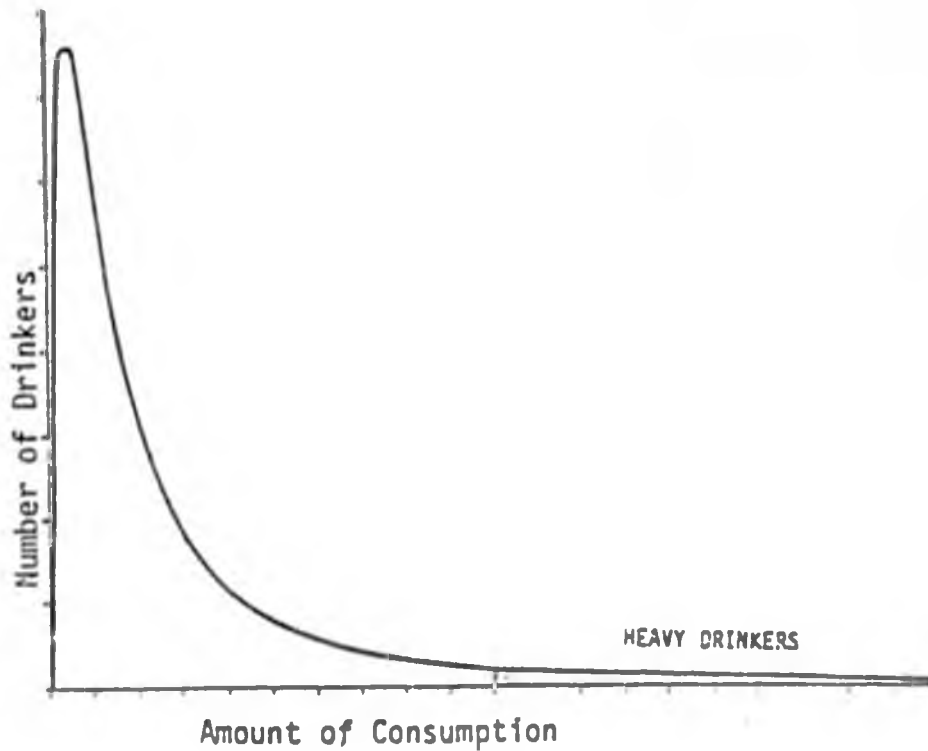


Figure 2.8 The Single Distribution Model of Alcohol Consumption

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

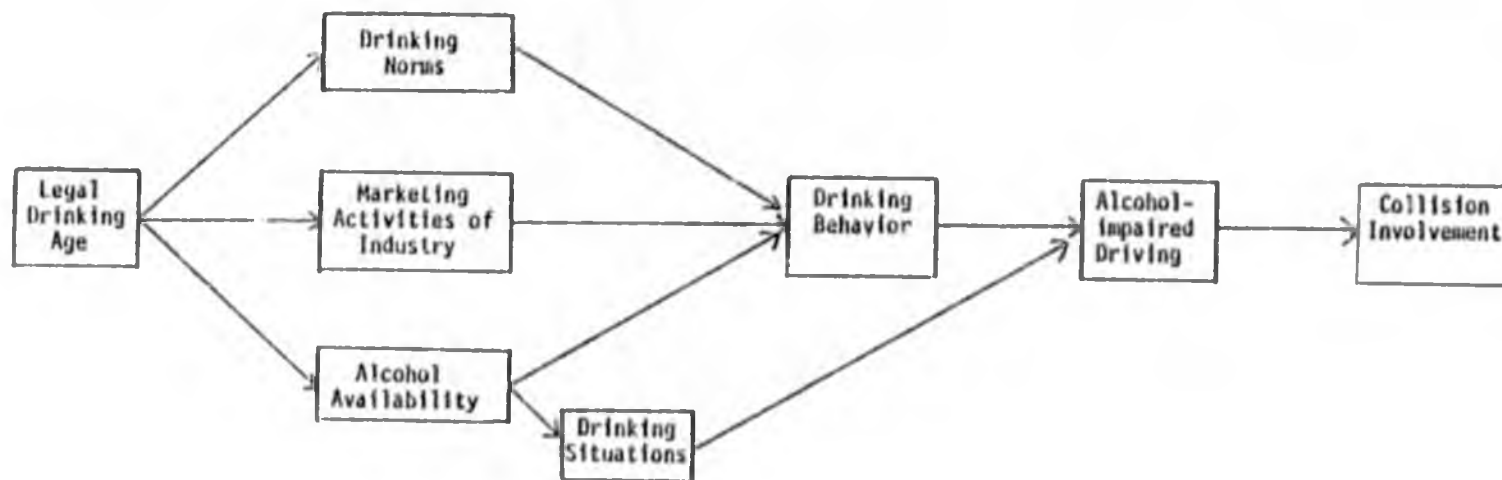


Figure 2.9 Conceptual Model of the Impact of Changes in the Legal Drinking Age on Motor-vehicle Crash Involvement

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 involvement 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 DWIL arrests in February 1979 versus the number of DWIL 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:

$$\begin{array}{ccccc}
 O_1 O_2 O_3 \dots O_{n_1} & I_1 & O_{n_1+1} O_{n_1+2} O_{n_1+3} \dots O_{n_1+n_2} & I_2 & O_{n_1+n_2+1} O_{n_1+n_2+2} \dots O_{n_1+n_2+n_3} \\
 O_1 O_2 O_3 \dots O_{n_1} & & O_{n_1+1} O_{n_1+2} O_{n_1+3} \dots O_{n_1+n_2} & & O_{n_1+n_2+1} O_{n_1+n_2+2} \dots O_{n_1+n_2+n_3}
 \end{array}$$

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 1973, and  $n_3$  is the number of monthly observations after the drinking age was raised. The second row in the design diagram represents a comparison time-series, not influenced by the 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	
	IINBD	HBD	3FS	TOTAL	3FS
<u>Experimental</u>					
18-20 years old					
16-17 years old					
<u>Comparison</u>					
21-24 years old					
25-45 years old					

- \*NOTES: 1. HBD refers to Had Been Drinking according to police reports.  
 2. IINBD 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 4BD 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 final 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 (Douglas 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 53 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

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

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,  $\Gamma_1$  to  $\Gamma_p$  are the seasonal auto-regressive parameters,  $\phi_1$  to  $\phi_p$  are the regular auto-regressive parameters,  $\Delta_1$  to  $\Delta_Q$  are the seasonal moving-average parameters,  $\theta_1$  to  $\theta_q$  are the regular moving-average parameters,  $u_t$  is the random (white noise) error component, a is a constant, and B is the backshift operator such that  $E(z_t)$  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 unidentifiable) 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, 1973:20-33). 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  $\epsilon_t$

in equation 1) are independently drawn from the same distribution over time and thus are characterized by constant variance, and that the autocorrelations 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

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

where  $\omega_0$  to  $\omega_s$  and  $\delta_1$  to  $\delta_r$  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  $B(I_t)$  equals  $I_{t-1}$ .  $I_t$  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; Burnett et al., 1975; Carpenter, 1974, 1975; Chu and Kunn, 1976; Dart, 1977; Kahane, 1975; Klein et al., 1976; O'Day et al., 1975; Sosis et al., 1977; Tofany, 1975; United States Department of Transportation, 1978; Wierkowski and MacLard, 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 ( $w/(1-Bd)^r$  with  $I_c$  defined as a step function), and an abrupt permanent impact model ( $wI_c$  with  $I_c$  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 fatality reduction was evident (O'Day et al., 1978; Seila et al., 1977; United

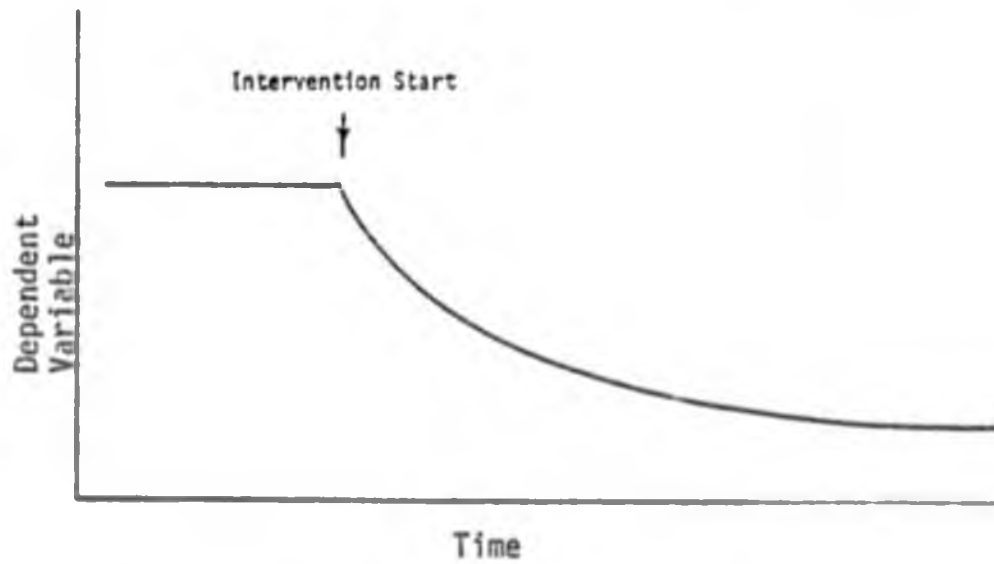


Figure 3.1 Negative Impact Pattern Estimated by the  $rsb(1,0,0)$  Transfer Function Model with a Step Function Input

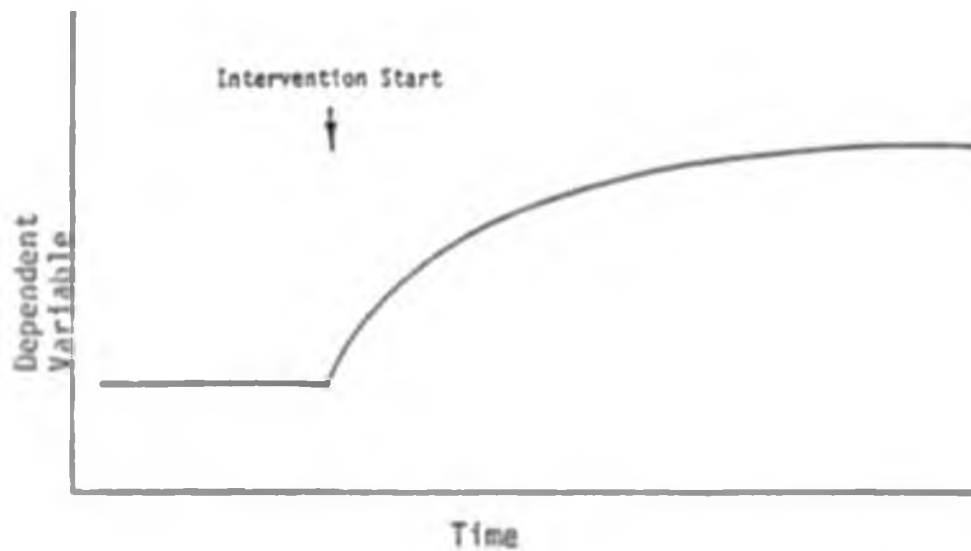


Figure 3.2 Positive Impact Pattern Estimated by the  $rsb(1,0,0)$  Transfer Function Model with a Step Function Input

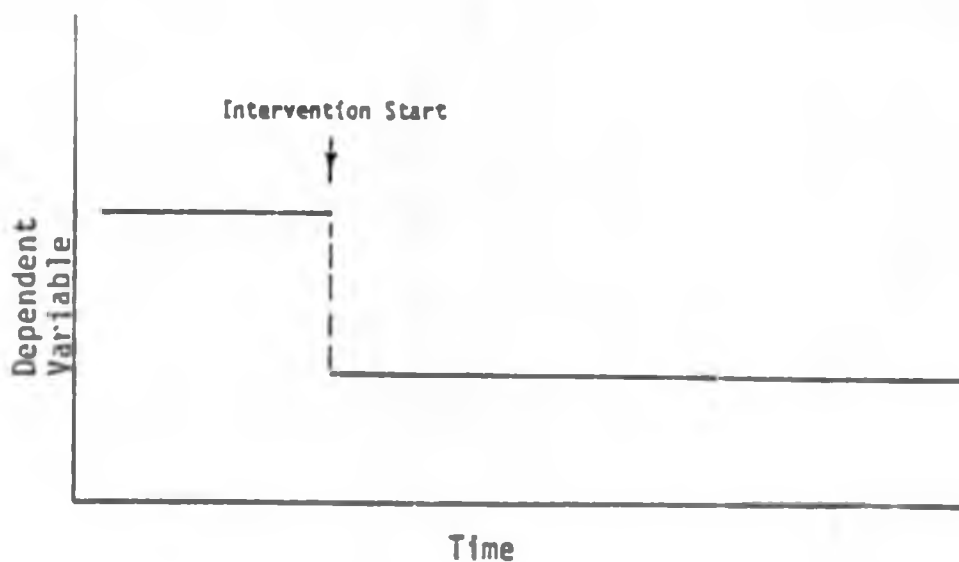


Figure 3.3 Negative Impact Pattern Estimated by the  $rsb(0,0,0)$  Transfer Function Model with a Step Function Input

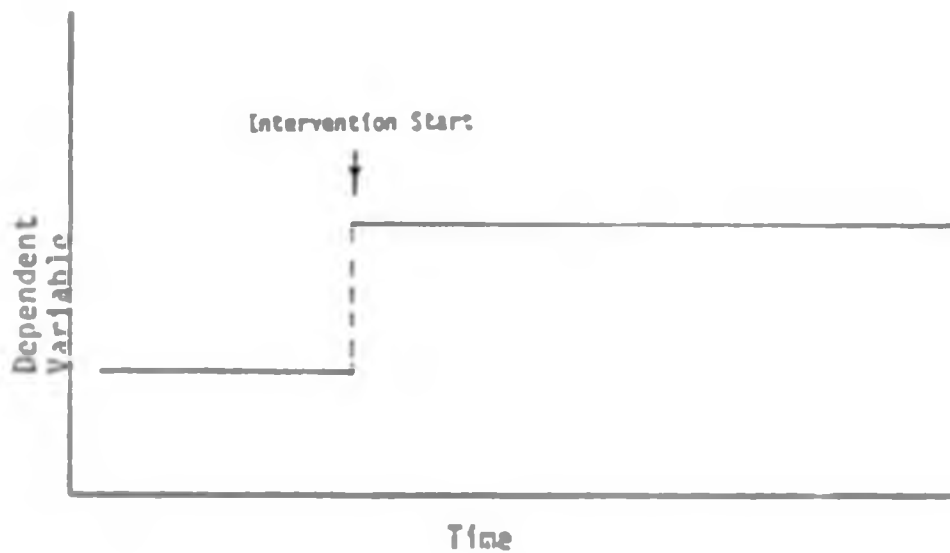


Figure 3.4 Positive Impact Pattern Estimated by the  $rsb(0,0,0)$  Transfer Function Model with a Step Function Input

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

$$(3) \quad y_t = \frac{\text{Noise (ARIMA) model}}{\left[ \frac{(1 - \alpha_1 B^d - \dots - \alpha_p B^{pd})(1 - \beta_1 B - \dots - \beta_q B^q)u_t + v_t}{(1 - \gamma_1 B^d - \dots - \gamma_r B^{rd})(1 - \delta_1 B - \dots - \delta_s B^s)(1 - \theta^d)(1 - \theta)^d} \right]} \cdot \frac{\text{Intervention (transfer function) model}}{\left[ \frac{(w_0 - w_1 B - \dots - w_r B^r)}{(1 - \delta_1 B - \dots - \delta_r B^r)} (1_{t, \dots}) \right]}$$

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  $\delta$  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

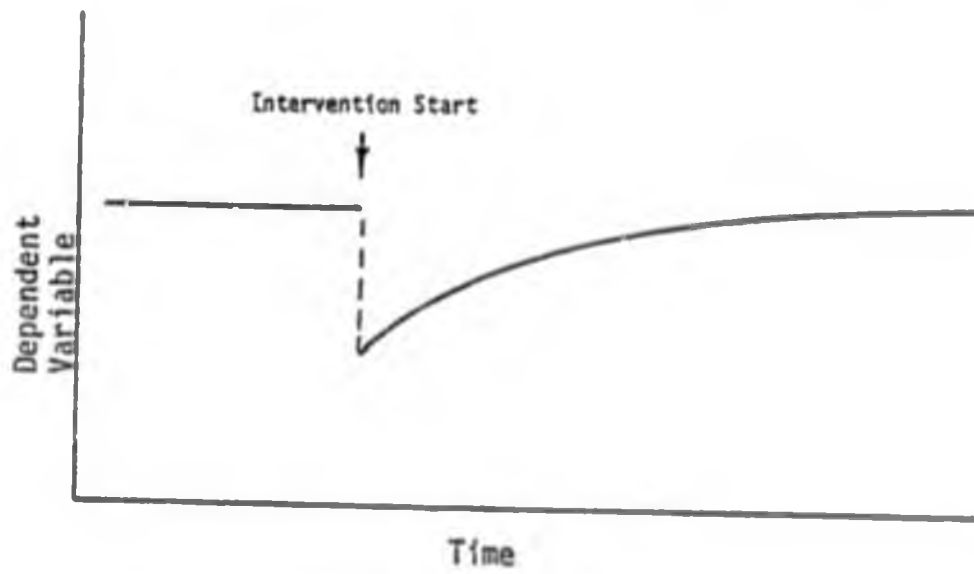


Figure 3.5 Negative Impact Pattern Estimated by the  $rsb(1,0,0)$  Transfer Function Model with a Pulse Function Input

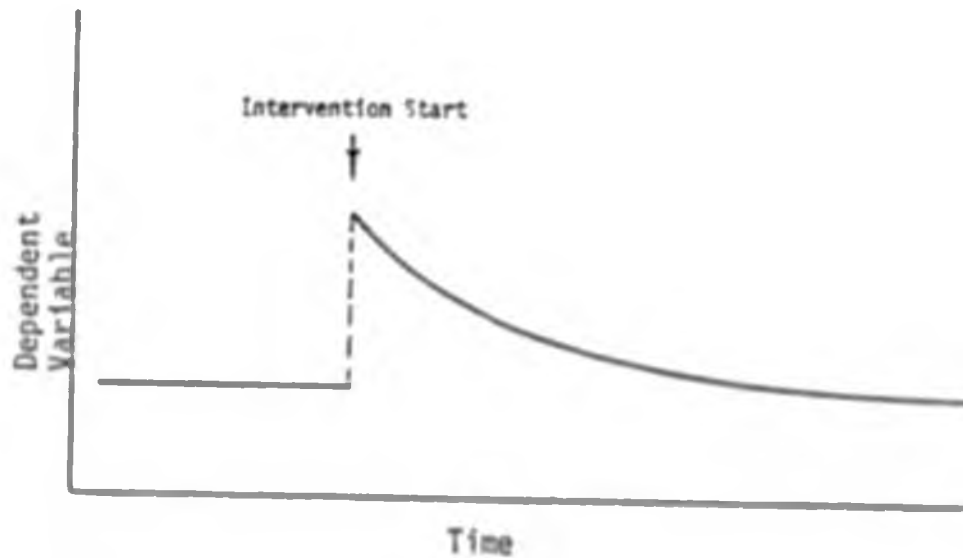


Figure 3.6 Positive Impact Pattern Estimated by the  $rsb(1,0,0)$  Transfer Function Model with a Pulse Function Input

estimate of  $\delta_1$  should not be negative, indicating an oscillating impact pattern. The estimate of  $\delta_1$  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 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 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 difference 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 identification procedures could not be used. Instead, transfer function models were specified a priori on the basis of theoretical expectations, and assessed within an hypothesis testing framework.

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

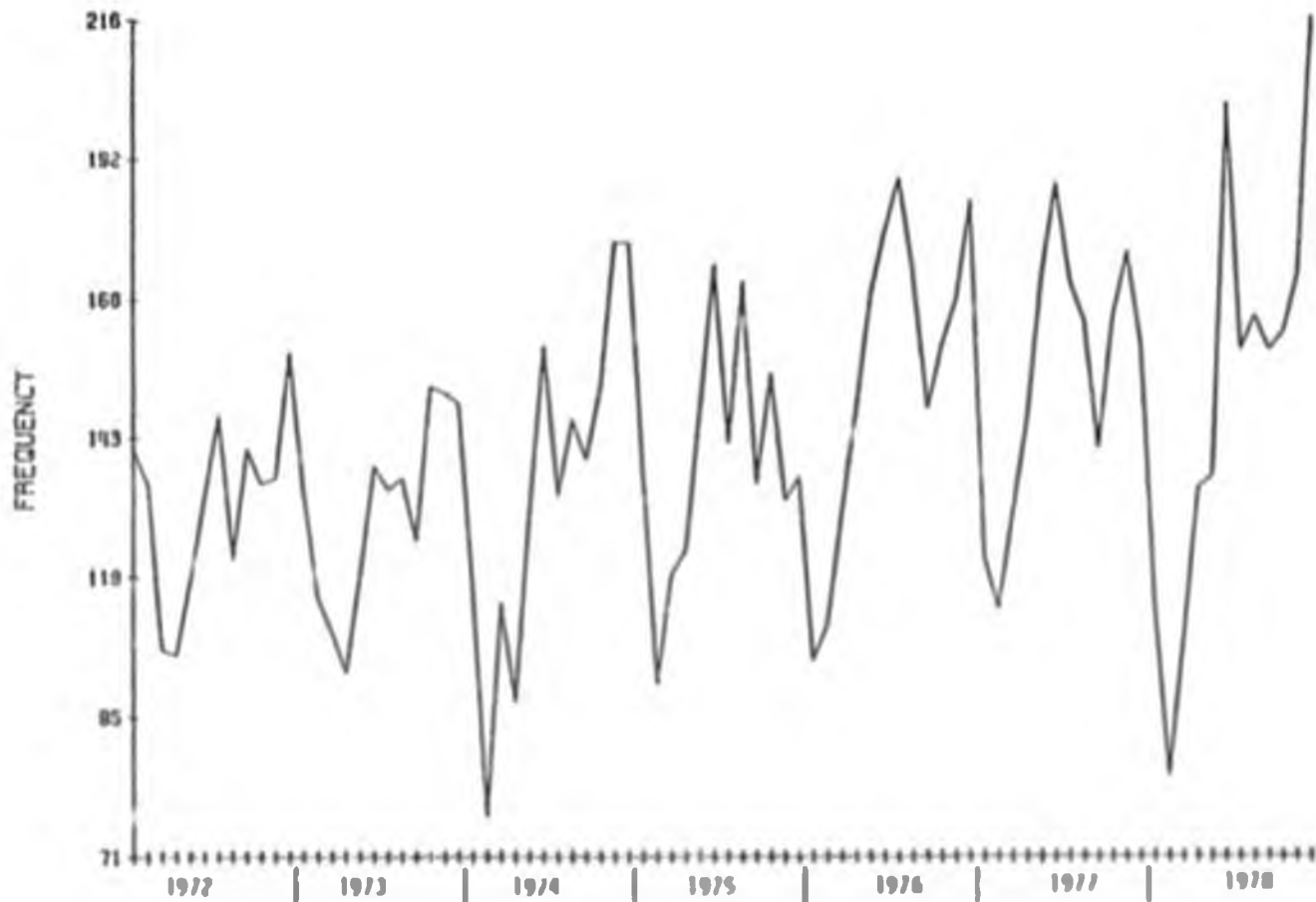


Figure 4.1 Frequency of Three-factor-surrogate Crash Involvement Among 18 - 20 Year Old Drivers in Michigan, 1972 - 1978

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)<sub>12</sub> 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)<sub>12</sub> model.

AUTOCORRELATIONS

.....  
DIFFERENCING: 3 VARIABLE: 9  
SEASONAL DIFFERENCING: 0 LABEL: F3510.C  
SEASONAL SPAN: 0 CASES: 1- 84  
.....

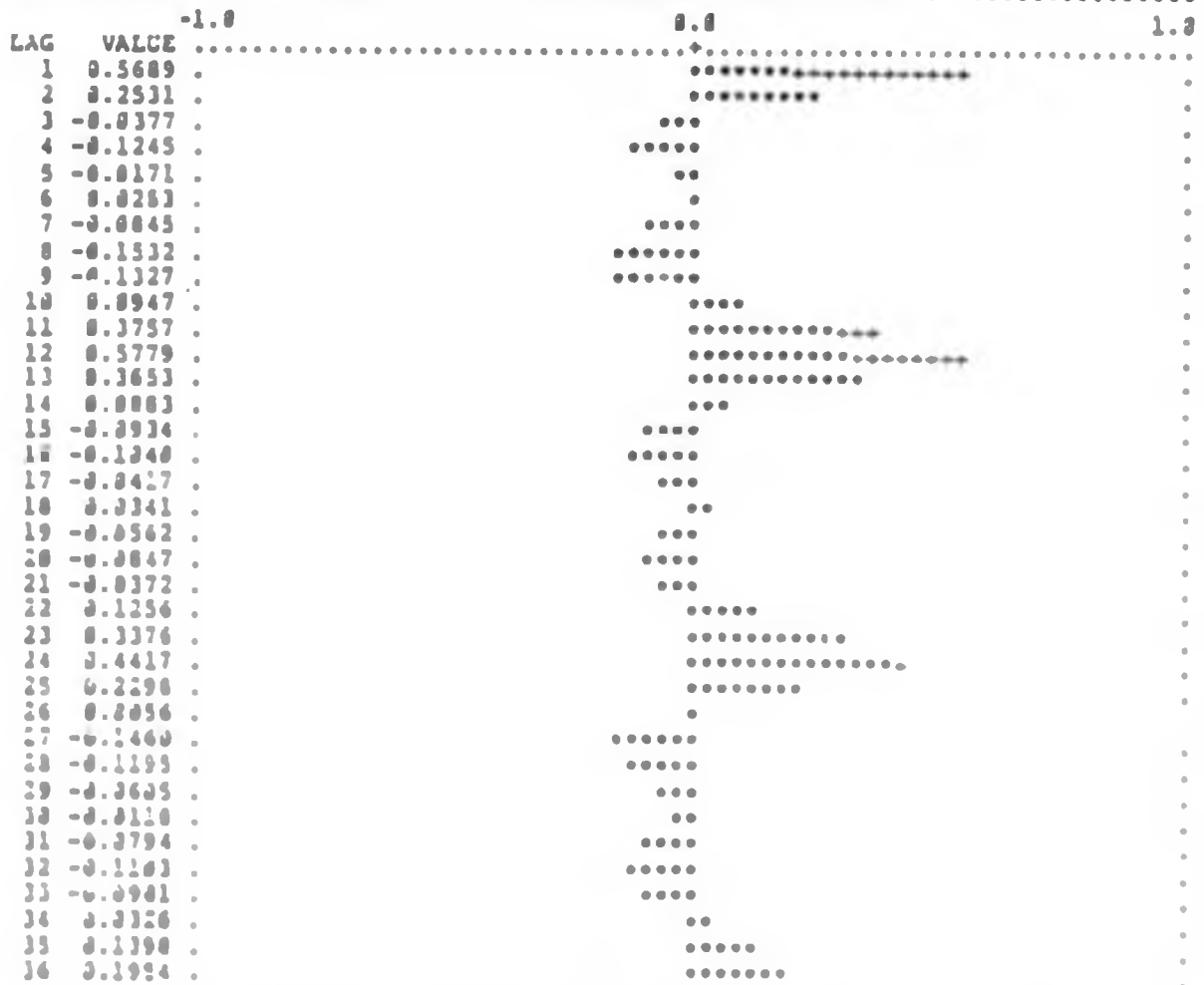


Figure 4.2 Autocorrelation Function of the Frequency of Three-factor-surrogate Crash Involvement Among 18 - 20 Year Old Drivers

PARTIAL AUTOCORRELATIONS

DIFFERENCING: 0 VARIABLE: 9  
 SEASONAL DIFFERENCING: 0 LABEL: P3629.C  
 SEASONAL SPAN: 0 CASES: 1- 84

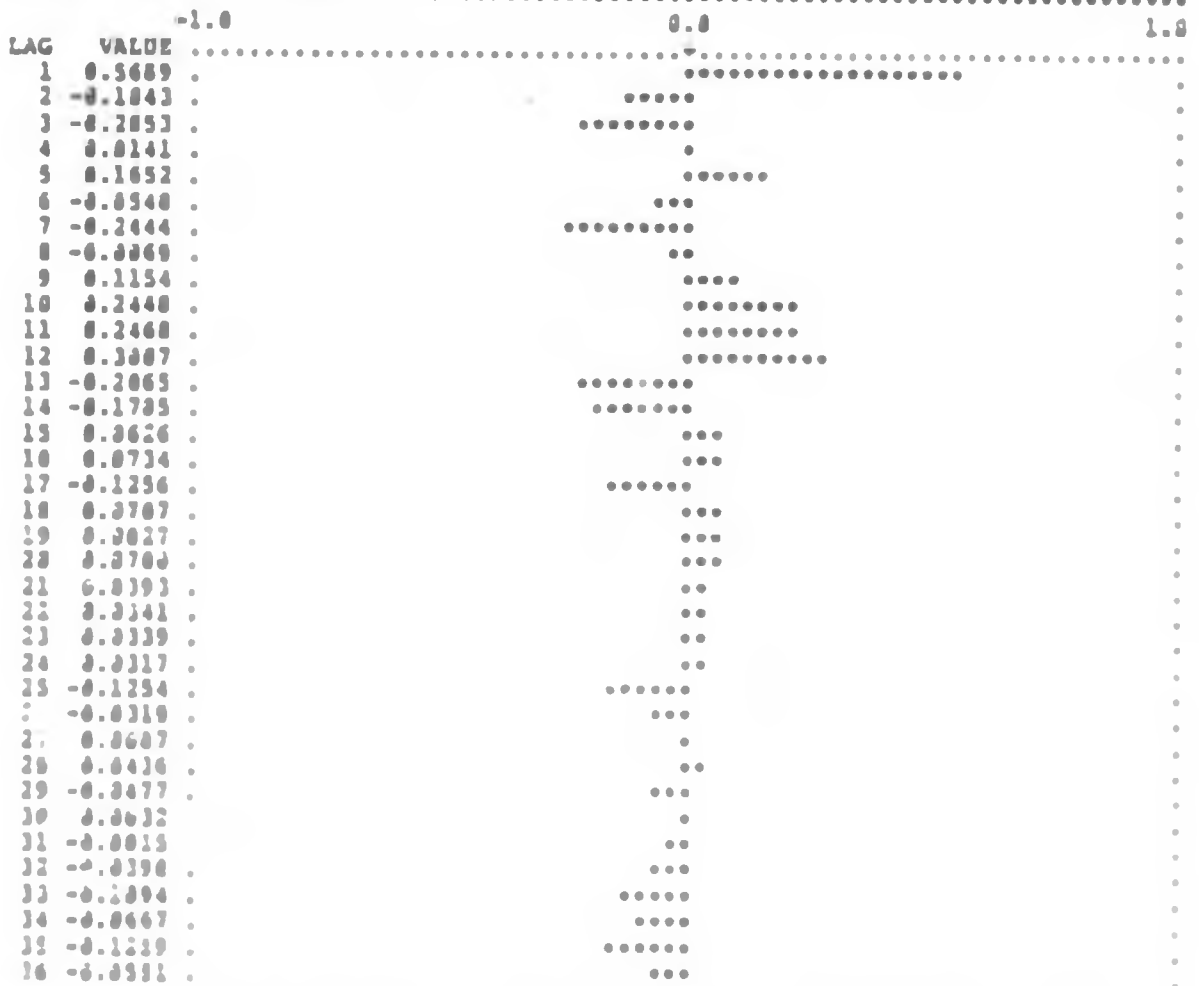


Figure 4.3 Partial Autocorrelation Function of the Frequency of Three-factor-surrogate Crash Involvement Among 18 - 20 Year Old Drivers

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-significant 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