SNOWMOBILE, MOTORCYCLE AND MOOSE-CAR ACCIDENTS
Aspects on Injury Control

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SNOWMOBILE, MOTORCYCLE AND MOOSE-CAR ACCIDENTS
Aspects on Injury Control

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ABSTRACT

Injuries related to snowmobiles, motorcycles and moose-car collisions have increased. The aim of the present thesis was to analyse mechanisms and consequences in fatal and non-fatal accidents of these types, and to penetrate possible preventive measures.

Snowmobiles

The median age of the injured was 30 and of the killed 32, males predominating. A majority of the accidents occurred during weekends, and especially the fatal accidents occurred after dark. The extremities were the most commonly injured parts of the body, however, drowning, crushed chest and cranial injuries caused most of the fatalities. Among the fatalities, four out of five were under the influence of alcohol. The present Swedish laws regarding snowmobiles seem well motivated. "Built-in" safety measures in the construction of the snowmobiles, properly designed snowmobile tracks and functional search and rescue systems could reduce the injuries.

Motorcycles

The median age was 19 years for both the traffic injured and the killed. Half of the traffic accidents were collisions with other motor vehicles. In the fatally injured group, also collisions with fixed roadside objects were common. Of the fatally injured, more than every fifth person died in an accident where alcohol was an influential factor. In the injured group, lower extremity injuries (especially in off-road riding) were common and among the fatalities most riders died from injuries to the head or chest. Out of one thousand motorcycle riders interviewed, 45% reported wobbling experiences (8% reported severe wobbling). Possible injury reducing measures include increasing the licensing age, more discriminating driving test, "built-in" restriction of the motorcycle's top speed, elimination of motorcycles prone to wobbling, and a more intensive traffic supervision (speeding, alcohol).

Moose-car collisions

The median age of the drivers was 38 years. Most collisions happened at dusk or when dark (3/4). The median collision speed was 70 km/h. The damage to the car was typical, the roof and the windshield pillars were deformed downwards and backwards. The broken windshield was often pressed into the passenger compartment. Most of the injured car occupants suffered cuts predominantly to the head and upper extremities. Nearly all the fatally injured died of head and neck injuries. The injuries may be reduced by strengthening the roof and the windshield pillars, and by introducing antilacerative windshields.

Key words: Injury, accident, prevention, snowmobile, motorcycle, moose-car collision
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by

ULF BJÖRNSTIG

Umeå 1985
To my children

Johanna and Mattias
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Key words: Injury, accident, prevention, snowmobile, motorcycle, moose-car collision
This thesis is based on the following publications, which will be referred to by their Roman numerals:

SNOWMOBILE RELATED INJURIES

I  Björnstig U, Eriksson A, Mellbring G. 
Snowmobiling injuries: types and consequences. 

II  Eriksson A, Björnstig U. 
Fatal snowmobile accidents in northern Sweden. 

MOTORCYCLE RELATED INJURIES

III  Björnstig U, Bylund P-O. 
Motorcycling injuries in northern Sweden. On-road and off-road riding. 

IV  Björnstig U, Bylund P-O, Lekander T, Brorson B. 
Motorcycle fatalities in Sweden. 

V  Björnstig U, Bylund P-O. 
Wobbling motorcycles cause serious injuries and fatalities. 

VI  Brorsson B, Ifver J, Björnstig U. 
Wobbling in modern motorcycles. 

INJURIES RELATED TO MOOSE-CAR COLLISIONS

VII  Björnstig U, Bylund P-O, Eriksson A, Thorson J. 

VIII  Eriksson A, Björnstig U, Thorson J. 
Collisions between cars and mooses. An analysis of collisions with fatal personal injuries. 
Travel Medicine International 1985;3:130-137.
INTRODUCTION

Traffic injuries have during the last decades received increasing attention from researchers. Despite an increase in traffic activity, the total number of people killed in traffic has decreased during the seventies in Sweden (Fig. 1). A similar trend has also been observed in other countries, e.g. in the USA where the fatality rate has decreased as illustrated in Fig. 2.

Fig. 1.
Road traffic accidents reported by the police and total traffic activity, 1970-1982. Non built-up areas. Index 1970 = 100. t = traffic activity, i = accidents with personal injury, f = fatal accidents (1).

Fig. 2.
US traffic fatality rate \( (n) \) per year and 100 million of vehicle miles traveled (2).

Factors influencing this positive trend are reduced speed limits, seat belts and helmets and increasing demands on the cars, where the US standard (FMVSS = Federal Motor Vehicle Safety Standards) in many cases have been a guideline for other countries. The intention of these standards is to reduce the frequency of accidents (e.g. standards for mirrors, lights and tyres) and the likelihood of injuries sustained (e.g. standards for windshields and steering assembly). The extent of damage
beeings exaggerated by e.g. a postcrash fire should also be reduced by those standards. In the USA it is estimated that vehicle standards introduced have saved more than 25 000 lives between 1966 - 1974 (3).

However, injuries caused by certain accidents such as accidents involving snowmobiles and motorcycles have shown a tendency to increase, as have collisions between cars and animals (Fig. 3), mostly moose (4-6). Several factors may have contributed to this trend: technical development and fashion trends have made snowmobiles and motorcycles more popular with a consequent increase in the number of these vehicles. Further, the number of moose increased during the seventies in Sweden, also increasing the risk of collisions with moose.

Fig. 3.
Number of road traffic accidents between motor vehicles and animals in Sweden. Accidents involving injury to person (6). About 90% of these accidents involved a moose or a roe-deer.

INJURY CONTROL AND HADDON'S MATRIX (7, 8)

The word "injury" (in + jus, "not right") means harm, hurt, loss or wrong. The term usually refers to damage resulting from acute exposure to physical or chemical agents. In the present thesis, the most important etiological agent is mechanical energy, carried by a vehicle (e.g. snowmobile, motorcycle or car). The injuries are caused by unwanted energy transfer to the human body.

The fundamental tasks in injury control are to:
- prevent the agents (here mechanical energy) from reaching people in amounts that exceed injury thresholds,
- minimize the consequences of injuries when inevitable.
Injury control could be aimed at the agent, at reducing exposure or human susceptibility.

Haddon's matrix (Table I) was considered a suitable method for the analysis of the events that the present thesis deals with. Haddon's analytic framework (7, 8) divides the sequence of events into three phases: pre-crash, crash and post-crash. In each of these phases human, vehicle and environmental factors operate and determine the outcome. The end result is damage to people, vehicle, equipment, physical environment and society. The aim is to manipulate these factors in such a way that human injury is avoided, minimized or successfully treated.

The first (pre-crash) phase includes all factors that influence upon the likelihood of an accident taking place. In the second (crash-phase), counter-measures attempt to prevent harmful interaction of the etiological agent (here mechanical energy) with the host. Even if the crash is not prevented, the variety and effectiveness of the counter-measures at this level determine whether the injuries to the human can be avoided or minimized. The third (post-crash) phase refers to maximizing salvage, once damage has been done, keeping death and disability to a minimum.

Approaches to the injury problem are not limited to primary prevention of the initial event, but involve any stage of the injury-producing process that can be effectively changed. Priority should be given to measures that will most effectively reduce injury and the choice should not be determined by the relative importance of causal or contributing factors only, or by their order in the sequence of events. As a result of failure to understand this point, emphasis on "human error" as the cause of most injuries, has resulted in undue emphasis on changing behaviour, rather than on using more effective measures to reduce injuries. A mixed strategy should usually be employed, incorporating countermeasures addressed to the three phases: pre-crash, crash and post-crash. Preference should, if possible, be given to "passive" or "automatic" measures, i.e. those that protect the individual automatically without any action on his part (9, 10). The aim should be that neither mechanical failure, nor human action should result in personal injury.
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AIMS OF THE THESIS

The aim of the present thesis was to analyse snowmobile, motorcycle and moose-car accidents and:

- to describe injury mechanisms and consequences in non-fatal and fatal accidents,
- to analyse the wobbling experience of owners of modern motorcycles,
- to suggest possible injury-preventive measures.
Fig. 4. Swedish law stipulates that a snowmobile must be registered and insured. A snowmobile may not be driven along public roads, within certain recreational areas, densely built-up areas or within nature reserves. The Traffic Temperance Law applies to drivers of these vehicles and the driver must be at least 16 years old. Further, by voluntary agreement, organized import is restricted to snowmobiles with a maximum effect of 60 hp,* however these can reach top speeds of 160 - 180 km/h.

MATERIAL AND METHODS

Paper I
People injured in snowmobile accidents during the winter (Nov.-May) 1979-1980, (n = 137), were interviewed when seeking medical attention at hospitals or district medical officers in the county of Västerbotten. A total of 137 injured snowmobilers were registered (Series I). The doctors were requested in repeated personal communications to pay special attention to any involvement of alcohol in the accidents. Case records and Social Security Office documents were analysed.

* 1 horsepower (hp) = 0.74 kW
According to the Swedish Meteorological and Hydrological Institute (11), the first snow came in the inland parts of the area in late October. No injuries were reported until November when snow was also present in the coastal areas.

The best available estimation of the speed at the moment of the accident was the statements of the speed given by the injured persons themselves in the interviews.

The injuries were graded according to the Abbreviated Injury Scale (AIS) where MAIS denotes Maximum AIS (12). AIS = 1 is a minor injury; AIS = 2 is a moderate injury as e.g. a concussion or an uncomplicated fracture; AIS = 6 is an instant fatal injury. The mean MAIS-value was calculated in some cases, this simply denotes the mean value of the different MAIS-values in the group and should not be regarded as the severity of a “mean injury”.

Paper II
All fatalities (n = 36) in the four most northern counties in Sweden during eight seasons (1973-07-01 -- 1981-07-01) were analysed (Series II). This area is half the total area of Sweden and in this area there was one snowmobile in traffic per 15 inhabitants in 1980. Registration of snowmobiles has been compulsory in Sweden since 1974.

RESULTS

The results are presented in detail in Papers I and II. A summary of the results and some additional results are presented here.

Injury incidence and fatality rate
The number of snowmobiles in traffic in the county of Västerbotten was 15 000 or 24% of the total number of all registered snowmobiles in Sweden (1980-01-01). There were 230 000 inhabitants in the county, i.e. there was 1 registered snowmobile per 15 inhabitants.

The injury incidence was 9 per 1 000 snowmobiles and the fatality rate about 1 per 10 000 snowmobiles. Assuming an annual driving distance per
vehicle of about 1 000 km (cf 13, I) this gives 100 injured and 1 killed per 10 million kilometres.

Age, sex and driving experience
Men between 20-39 years (median age 30 and 32, respectively) were injured most frequently in both series I and II and constituted 44% and 53% (n = 19), respectively. Drivers were injured and killed more frequently (67%; I and 83% (n = 30); II), than passengers. Of 117 drivers with a known annual driving distance in series I, 21% stated that they were beginners (i.e. with a total driving distance <100 km). Among the fatally injured drivers 10% (n = 3) were considered to be beginners according to the police investigations.

Time of accident
During the months of March and April, 45% (I) were injured and 42% (n = 15) (II) were killed. During November and December, when the ice is usually thin, 33% (n = 12) were killed (9 drownings) compared with only 18% injured in series I. Most people were injured during weekends and holidays in both series, 65% (I) and 56% (n = 20) (II). In series I only 18% of the riders were injured between 06.00 p.m. - 06.00 a.m., but 69% (n = 25) of the fatalities were injured during these darker hours.

The accident
The most frequent mechanism of injury (50% in series I) were: a sudden stop due to a collision with a fixed object, driving into a ditch and the like, or falling off the machine for other reasons. Six of the ten who were injured at high speed (≥80 km/h) (I) had fallen off the machine because of high speed on uneven terrain. Among the fatalities, driving through thin ice was the most frequent accident mechanism which caused 42% (n = 15) of the fatalities. A sudden stop was the cause in 33% (n = 12) of the fatalities and three had collided with a moving car. It was obvious from the police investigations that the speed had been high in these latter accidents. Two riders had been strangled when parts of clothing had got caught in the rotating parts of the motor and one person had been killed when his snowmobile overturned and fell on top of him. These two latter types of accidents were not represented in
series I. In series I, 6% were injured because of other mechanical faults such as a jammed throttle, broken suspension or disintegration of the running board or wheel.

The injuries and helmet usage
In series I almost half of the injured suffered MAIS ≥ 2 injuries. Three out of the ten persons injured at a speed stated to be 80 km/h or higher, had serious injuries (MAIS ≥ 3) and the mean MAIS-value was 2.1 for this group compared with 1.6 for those injured at lower speeds. In series I, the lower extremities were most commonly injured (35%) followed by the upper extremities (25%) and head and neck (17%). Among the fatalities, drowning was the most frequent cause of death, 39% (n = 14). Crushed chest caused the death in 31% (n = 11) of the cases and intracranial injuries in 17% (n = 6). Suffocation and intraabdominal injuries caused the remaining fatalities.

Helmets were worn by 50% of the riders in series I. Helmet usage was only 16% (3 of 19) in the age groups over 50. Of the fatalities 31% (n = 11) were helmeted.

Treatment and sickness benefit
A total of 28% of the injured in series I were treated as in-patients for a total of 411 days, i.e. on average 11 days per person. The age group 30-39 had the highest number of in-patient treatment days or 170 days which was 41% of all in-patient treatment days (Fig. 5, Paper I). Among the fatalities 89% (n = 32) died before arrival at the hospital and the remaining four persons lived 1-3 days after the accident.

Sickness insurance benefit was paid to 64% of the injured for an average of 48 days (mean SEK 5 800/entitled person). The total "cost" of treatment and sickness allowance was SEK 1.1 million in 1979 years monetary value or SEK 8 200 per injured. For the whole country this would be around SEK 4 - 5 million annually (I).

Alcohol
Among the injured (I) 6 out of 80 (8%) seeking medical attention within 24 hours, were obviously (or stated by themselves) under the influence of alcohol. All 6 were men between 20-49 years of age, 3 collided with
an obstacle and 2 had fallen off the vehicle when driving. Three of those received in-patient treatment for 32 days, which on average is the same treatment time as for the other in-patients treated. However, these 6 were on sick leave for a total of 576 days or 96 days per person, which is twice as long as the average leave (45 days) of the other injured persons. The mean cost per injured for these six was SEK 28 000 compared with SEK 7 300 for the other group.

Among the fatalities, post-mortems were carried out in all 36 cases. Drunken driving could be excluded in only 17% (n = 6) of the cases and the mean blood alcohol level was 1.6 g/l in 23 cases who died immediately and in which postmortem alcohol analyses was performed. Fourteen of 20 microscopic analysed livers exhibited liver steatosis and/or cirrhosis consistent with alcohol abuse.

DISCUSSION

The discussion is systematized according to Haddon's matrix. The factors discussed are summarized in Table II (p. 26). Each cell is discussed separately.

Pre-crash-human cell

Against the background of the enormous speed potential of the fastest snowmobiles (180 km/h) the Swedish age limit of 16 years can be conceived to be too low. In the present study, there were, however, no fatalities among drivers below 20 years of age and neither were the frequency of injuries especially high, the average in-patient treatment time was not significantly longer either. These findings therefore do not indicate that the 16-year age limit is too low from the injury point of view. However, the exposure may be small among the youngest drivers.

Every fifth person injured (I) and every tenth person deceased (II) had only minor driving experience. Perhaps a better and more extensive training could have prevented some of these injuries. Today only voluntary training in snowmobile clubs is available and the educational
value is difficult to assess (cf 14). However, this training is probably better than no training at all and an important educational goal for the clubs should be to discourage dangerous driving. Licensing as a prerequisite to register a person as owner of a snowmobile could be discussed.

Among the fatalities, drunken driving was an important factor and the figures of blood alcohol levels were disturbingly high. In series I only about 8% were considered as obviously being under the influence of alcohol. The fatalities often happened after dark on a weekend; this being consistent with what is known from other vehicle accidents with fatal outcome (15-17). However, the percentage of intoxicated snowmobilers (83%) seems higher than corresponding figures for other vehicles. In a study of fatal single car accidents also from the northern part of Sweden, 56% of the drivers were reported to have been driving under the influence of alcohol (18) and in another study from the southern part of Sweden Krantz found this to be the case in 50% (17). In our study on motorcycle fatalities (IV) alcohol was an influential factor in 23% of the fatalities. Perhaps the risks involved in driving a snowmobile when drunk are underestimated and the fact that the Traffic Temperance Law also applies to snowmobilers is a fact that is not common knowledge. It is obvious that the ability to drive a snowmobile is impaired when inebriated. If other solutions to the transportation problem of inebriated persons are possible, e.g. by organized group transports from parties, or by help from a friend or other person, this would be beneficial from the injury point of view.

Despite the relatively low age of the deceased, more than 1 out of 5 were known alcohol abusers and many of the microscopically examined livers exhibited steatosis and/or cirrhosis consistent with alcohol abuse. At least three of the fatally injured drivers had earlier lost their car driving licence and one person had lost his fire arm licence because of alcohol abuse (II). This indicates that at least among the deceased a deviant personality may be overrepresented. Krantz (17) found that more than 50% of car drivers involved in fatal single vehicle accidents were known to the authorities (registered in criminal or social records). Waller and Lamborn (19) characterized injured snowmobilers as either young inexperienced drivers, or older, aggressive
men who had a high alcohol intake and with more snowmobile accidents and traffic violations than other drivers. They also found that in most cases where the speed at the time of the accident was over 50 km/h the snowmobile driver was intoxicated.

Crash-human cell
The way bodies move in a crash can be an important factor, e.g. a child sitting in front of an adult could be crushed by the forward movement of the latter, especially if colliding with a road barrier or other immovable object. It would be wise to place children behind the driver. Perhaps a rider can minimize the impact forces in certain situations if he can jump off the machine prior to impact. The older victims had a longer mean stay in hospital and more days off work than the younger ones (I); this being typical for the elderly who are well known to display greater vulnerability and have a slower recovery. Thus, elderly persons ought to temper their snowmobiling activities as they do with other potentially dangerous sports.

Postcrash-human cell
Knowledge of first aid among snowmobile riders and other persons involved in a crash can determine the outcome. By using snowmobile tracks and by avoiding to drive alone, the chances of being helped quickly are increased. The importance of these factors may be illustrated by two of the fatalities: one person got caught under his overturned snowmobile and died of suffocation by immobilization of the chest, another person, unconscious but not lethally injured, drowned in 15 cm deep water. It is essential that rescue activities are triggered as soon as possible. The risk of making the injuries even worse, and to receive additional frost or hypothermic injuries, increases if the weather is windy and cold (20). Food, warm drinks and warm and dry clothes would keep the injured warm. Influence of alcohol can also be a postcrash problem and in this situation make the injured more prone to misjudge the injuries and the proper handling of them.

Precrash-vehicle and equipment cell
Faults with the snowmobile itself were seldom the cause of the accidents (I, II). Of course, all rotating engine parts should be effectively covered to prevent getting parts of clothing caught in e.g. the
fly wheel (21, 22, II). It is more difficult to eliminate the risk of getting parts of clothing caught in the running board. After the completion of paper II one person was killed when his anorak got caught in the running board when he tried to lift a stuck snowmobile. A "dead mans grip" and information about these risks would be beneficial.

Deficient handling of snowmobiles has not been claimed as an accident cause. Perhaps a further improvement of the steering skis and suspension would decrease the risk of a sudden stop and of receiving injuries to the spine when driving on rough terrain. It could also be questioned if the snowmobile lighting had been satisfactory in some cases as the rider collided with a road barrier in the dark.

The statements of the speed at the accidents are of limited accuracy, however, it was obvious that some of the accidents had happened at high speed (I, II). It could be questioned whether a snowmobile should have such an impressive speed potential as is the case at present. A limitation of the engine size or power output could be discussed, like an automatic limitation of the maximum number of revolutions. The disadvantage of some of these limitations is that it is relatively easy to override them.

**Crash-vehicle and equipment cell**

In a crash the riders could be injured by sharp, hard and prominent parts of the snowmobile or get their feet and lower legs caught and twisted between the snowmobile and the ground. The construction of modern snowmobiles seems, however, often to be quite good from this point of view. This opinion is supported by our results: in our series (I) 35% of the injuries were lower extremity injuries which could be compared with corresponding figures (45-56%) reported in several studies from the USA and Canada a decade ago (22-26). Three persons were injured when their chin hit the area around the centre of the handlebar when the snowmobile suddenly stopped. Padding (softening) of the parts most likely to be hit by the rider would reduce the risk of injury.

Further, a strengthening of the construction of the frontal part and windshield of the snowmobile could influence the severity of injuries caused by collisions with e.g. road barriers (3 fatalities (II)) or un-
observed wires in the terrain. Persons were also injured when run down by a snowmobile (3 were killed (II)). A smooth injury minimizing design of the frontal part of the snowmobile and especially of the skis could be discussed.

Wearing of helmets, protective clothing and boots will probably have an injury reducing effect. The snowmobile-overalls are, however, primarily designed to keep the rider at a comfortable temperature when riding in winter and the energy attenuating characteristics are not as optimal as in e.g. motorcycle-suits. The quality of the overall with respect to exposure to cold water and the risk of drowning should be considered. Improvements could also be done in the design of the snowmobiler's boots. The lower extremities were the most often injured parts of the body (I) and the injury-reducing potential to this part of the body merits further interest.

Postcrash-vehicle and equipment cell
A jammed throttle can be both a precrash and a postcrash problem. This is illustrated by one case where the throttle jammed, the snowmobile drove at high speed up against a tree and then landed on the riders back and buttocks with the engine running at full speed. This illustrates that a smooth working throttle that works well at all temperatures, is essential. A "dead mans grip", which stops the engine when the rider looses his grip of the handlebar is a necessity. Skis for use in an emergency situation when the snowmobile cannot be driven could also be beneficial.

Precordash-physical environment cell
An essential goal should be to prevent snowmobiling on thin ice; as this was the most common cause responsible for most of the fatalities (II). Warning signs ("thin ice") could of course be used but the goal is very difficult to achieve. Information about this risk will hardly influence the main risk group made up of intoxicated riders. Hopefully, some discerning person in the environment of the risk taking rider will stop the ride.

Separation from road traffic seems essential. Negri (26) reported from the USA that the most serious risk in snowmobiling arose on roads where
collisions with other vehicles caused the most severe injuries. In view of this, the prohibition of snowmobiling on public roads in Sweden (other than perpendicular crossings) is sensible.

Preparing snowmobiling tracks free from ditches, ravines, fixed objects, risky water passings and rough terrain would contribute to reduction of injuries. Also, a separation from skiers and from other recreational winter activities is important. Road barriers and wires in the terrain should be clearly visible and consequently marked with warning signs. If possible, wires should be placed at such a level that snowmobilers would not get them in their faces or around their necks. Driving in bad and cold weather should be avoided.

Crash-physical environment cell
In both series collisions with a fixed object were frequent. It is fundamental to prevent abrupt deceleration of crashing vehicles and persons. Snowmobile tracks should be free from trees and other fixed objects near or in the track. The riders should avoid to drive on rough, unknown terrain. Road barriers, if at all necessary, would be made so that they give way gently on impact. Other, less injurious solutions could be sought.

Postcrash-physical environment cell
The terrain along the snowmobile tracks should allow easy transportation of the injured by rescue patrols. Further, warming-up houses in the terrain along the tracks would be beneficial as a first station at which the injured person can be cared for while waiting for rescue personnel.

Precrash-socioeconomic environment cell
When viewed against the background of our results current Swedish snowmobile laws seem well advised. An effective restriction of the top speed of the snowmobiles could be discussed. Injuries caused by accidents at high speeds (≥80 km/h) seemed to be more severe than injuries caused at lower speeds but, on the other hand, less than every tenth person stated that they were injured at high speed (I). Every fifth injured and every tenth deceased were stated to be beginners. Thus, training and licensing should be discussed. At present, the best training is probably given in snowmobile clubs. The most important task
for them must be to influence the attitudes against careless driving and driving under the influence of alcohol and to inform about the Temperance Laws.

Among the fatalities, several persons were known to the authorities to be alcoholics. It seems inconsistent to allow these persons to register and drive snowmobiles.

The current age limit of 16 years seems reasonable from the injury point of view and has the prerequisite to be relatively well accepted. A higher age limit, if respected, should lessen the exposure and in this way reduce the total number injured, but at present it may be difficult to gather common support for this idea.

In conclusion it can be stated that legal limitations are difficult to control "in the terrain". Requirements of the vehicle construction and of the owners background are somewhat easier to control at the time of registration.

Crash-socioeconomic environment cell

The injury reducing effect of motorcycle helmet law is well documented (27, 28). The majority of the snowmobile drivers, especially the younger ones, had used a helmet (I). The effect of a helmet law for snowmobiles is difficult to assess because effective control of the law seems impossible. Against the background of these factors the injury-reducing effect of a helmet law will probably be marginal but not worthless. Vehicle construction standards which specify sufficient protection of rotating parts, lower extremities, and padding will also contribute to reducing injuries.

Postcrash-socioeconomic environment cell

Search and rescue activities (police, rescue patrols, helicopters and other emergency medical systems) should be quickly and adequately triggered. A system which makes it possible for snowmobilers to file a route-plan should ensure that rescue activities are triggered as soon as possible. It should also be of value if the snowmobile clubs taught snowmobilers first aid in order to be able to help injured colleagues. Further, the rescue resources must be adequate in the areas permitted for snowmobiling.
<table>
<thead>
<tr>
<th>Pre-crash phase</th>
<th>Human factors</th>
<th>Vehicle and equipment factors</th>
<th>Physical environment factors</th>
<th>Socio-economic environment factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age and sex, Training, Drunken driving, Personal character</td>
<td>Vehicle faults and handling</td>
<td>Thickness of ice, Separation from road traffic, Track design, Separation from other recreational activities, Marking of road barriers and wires</td>
<td>Speed restrictions, Education and training, Licensing, Temperence Law, Registration of vehicles, Legal age limit</td>
</tr>
<tr>
<td>Crash phase</td>
<td>Drivers and passengers position on the snowmobile and movement in a crash, Susceptibility of the body to injury</td>
<td>Crash-worthiness of the snowmobile, Softening/padding, Protective clothing</td>
<td>The area in and near the track free from fixed objects, Road barriers which give way gently</td>
<td>Helmet law, Standards of vehicle safety</td>
</tr>
<tr>
<td>Post-crash phase</td>
<td>First aid, The ability of persons to withstand low temperature (clothing, food)</td>
<td>&quot;Dead mans grip&quot;, First aid and rescue equipment (skis)</td>
<td>Access to the accident site</td>
<td>Search and rescue organization (snowmobile patrols, helicopters)</td>
</tr>
</tbody>
</table>
DEFINITIONS

- A light motorcycle has a cylinder volume of \( \leq 125 \text{ cm}^3 \) and the legal licence holding age is 16 years. Only a single person is allowed to ride on a light motorcycle if the driver is younger than 18 years.
- A heavy motorcycle has a cylinder volume \( > 125 \text{ cm}^3 \) and the age limit for this size of motorcycle is 18 years.
- When a motorcycle is taxed and insured it is classified as "in traffic" in the vehicle register. Many motorcycles not in use are registered but not in traffic.
- Off-road riding means cross-country riding which most often took the form of moto-cross (III).
- Wobbling refers to a condition when a motorcycle starts to oscillate and becomes difficult or impossible to steer. Wobbling denotes two types of oscillatory movements: front wheel flutter and high speed weave.

MATERIAL AND METHODS

Paper III

The study is based on 156 causalties which during the three years 1979, 1981 and 1982 were treated at the regional hospital in Umeå after a motorcycle accident (Series III). Within the hospital's primary admission area (100,000 inhabitants) there were 1,350 motorcycles in traffic and three active moto-cross clubs with altogether nearly 100 riders (52 with a competition licence) in 1982. In the moto-cross clubs; 1,200 man-riding hours practice and 1,000 man-hours competition were reported during the three years in question. The number of motorcycles in traffic and the number of licensed motocross riders in the area corresponded approximately to average levels for the whole country.

The injured persons were interviewed during or soon after their hospital visit (139 cases). In 17 cases it was not possible because of serious injuries (7 cases) or other reasons (10 cases). Information about these accidents was thus limited to police reports, hospital records and the register of vehicles and licences.
The treatment costs were calculated from the hospital's balance sheet (1982) and information on the length of sick leave and gross sickness benefit was obtained from the Social Security Office. The assessment of treatment and sickness benefit was restricted to one year after the accident. The injuries were graded according to the Abbreviated Injury Scale (12).

**Paper IV**
The material comprised a total of 129 deceased motorcycle riders (125 accidents) who were brought to the notice of the Swedish Road Safety Office during the period 1979 - 1981 (Series IV). Police investigations and autopsy reports were examined, however, in one case only the death certificate was available.

**Paper V**
This paper (Series V) describes in detail six non-fatal wobbling accidents and six fatal accidents from series III and IV. The survivors were interviewed, the police investigations studied and in some cases witnesses were also interviewed to obtain supplementary information to verify the course of events at the scene of the accident.

**Paper VI**
A random sample of motorcycle owners was drawn from the Swedish Central Vehicle Register. Information concerning the vehicles and owners was also collected from the register. To limit the study to active riders with their own motorcycles, the following criteria were established for the sample:

- The owners should not be older than 30 years. This restriction was introduced to avoid the inclusion of parents who were registered as owners in order to avoid high insurance premiums although they did not ride the motorcycle.
- The motorcycle had to be a 1978-82 model.
- The motorcycle had to have a cylinder volume of at least 239 cm³.
- The motorcycle had to have been in traffic for at least three months during 1982.

A questionnaire was sent to the sample of 1,043 motorcycle owners obtained by a selection fraction of 1/30. Fifty-three (5%) did not answer
the questionnaire and 56 were excluded for not having ridden the motor-
cycle listed during 1982 or for having ridden only cross-country or on
circuit-tracks. After these exclusions, the sample included 934 owners
who anonymously responded to the survey (Series VI).

RESULTS

The results are presented in detail in Papers III-VI. A summary of the
results and some additional results are presented here.

Traffic injured and killed (III, IV)

Ninety-two (59%) of the total 156 injured riders in series III were in-
jured in 85 traffic accidents. Among the fatalities, all were regarded
as traffic accidents because this is the reporting criteria in the
official statistics. The traffic injury incidence in series III was
25/1 000 motorcycles in traffic or about 31-35 per 10 million km and
the fatality rate was 0.8/1 000 motorcycles or 1 per 10 million km
(IV), assuming an annual driving distance of 7 000 - 8 000 km (cf VI).

The age distribution of the traffic injured riders in series III and
IV is presented in Fig. 5. The median age was 19 years in both groups
compared with a median age of 24 years for the owners of motorcycles in
traffic (1981-07-01).

Fig. 5.

Age distribution of traffic in-
jured riders in series III and
IV.
On light motorcycles in traffic, 33% in series III and 30% in series IV were injured. The percentage of motorcycles in traffic of different sizes and the percentage killed is shown in Table III.

Table III. Percentage of motorcycles and killed in different cylinder volume classes.

<table>
<thead>
<tr>
<th>Cylinder volume (cm$^3$)</th>
<th>≤125</th>
<th>126-400</th>
<th>401-600</th>
<th>601-900</th>
<th>901-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorcycles in traffic (%)</td>
<td>31</td>
<td>17</td>
<td>16</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>Riders killed (%)</td>
<td>30</td>
<td>11</td>
<td>15</td>
<td>31</td>
<td>13</td>
</tr>
</tbody>
</table>

At weekends 24% in series III were injured and 43% (IV) were killed. During the hours of darkness 21% were injured in series III and 31% were fatally injured (IV). In both groups, half of the persons were injured within urban areas and half outside urban areas.

Collision with other vehicles (52%) and fixed objects (33%)* caused altogether 85% of the fatalities. The corresponding figures in series III were 50%, (40% and 10%, respectively). In 46% (III) and 26% (IV) of the accidents, involving a collision with another vehicle, the motorcycle had come from behind when colliding with the other vehicle.

Collisions with moose caused 7 fatalities and all these riders died of head and neck injuries. In series III only one person was injured in a moose collision; the injuries in this case were only minor because he slid, together with the motorcycle, underneath the moose. It can be assumed that had it not been for his protective leather clothing (which was extensively damaged) the injuries would have been more severe.

Wobbling was reported by six of the injured in series III and in six fatal accidents witnesses confirmed that the motorcycle had wobbled before the crash. Since there were witnesses in only 47% of all fatal

* 38% including the six wobbling cases
single accidents, this figure should be regarded as a minimum (IV). All of these six deceased died after a final collision with a fixed object such as a lamp post, tree or road barrier.

In series III the mean value of the assessed speed at the moment of injury was about 50 km/h (range 10-100 km/h, median 50 km/h). Among the fatalities an estimation of the speed was available from witnesses in 67% (n = 86) of the cases. In 62% of these 86 cases the speed was reported to have been higher or much higher than permitted. Notable was that most fatalities (77%) happened on a road with a speed limit of 70 km/h or lower (IV).

Off-road riding and the group "others" (III)
Fifty-two riders were injured in off-road riding activities and 12 persons during other activities such as e.g. road-racing, run or kick-starting the motorcycle and so on. The median age in the off-road riding group was 18 years (range 12-39 years). In this group 85% (n = 44) were injured when riding on motocross-tracks and 15% (n = 8) were injured in other off-road activities. The accident mechanism in the off-road riding group was mostly stated to be too high speed in combination with uneven surface and poor visibility. Eleven riders (21%) were injured when jumping with the motorcycle.

Injuries and treatment (III, IV)
The fatal injuries (IV) were most often localized to the head and neck, chest and abdomen (Fig. 6). In the traffic injured group in series III the dominant injury most often occurred in the lower (36%) and upper (30%) extremities (Fig 6). Among persons injured in off-road riding the tendency towards extremity injuries was even more prominent, the corresponding figures were 26% and 53% in this group. The distribution of all injuries in series III is shown in Table IV. The mean number of injuries was 1.8 for the traffic injured and 1.1 for riders injured in off-road riding.

In off-road riding, injuries with MAIS = 3 were the most serious. Five motocross riders suffered rupture of the cruciate ligaments of the knee. These riders had got their knee pressed and twisted under an overturned motorcycle.
Table IV. Series III. Distribution of injuries in the groups: Traffic injured (T), Off-road injured (OR) and "Others" (0). Total 234 injuries in 156 persons.

<table>
<thead>
<tr>
<th></th>
<th>Wound superficial contusion, distortion</th>
<th>Total ligament rupture or joint dislocation</th>
<th>Fracture</th>
<th>Cerebral concussion, contusion, intracranial hemorrhage</th>
<th>Miscellaneous</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head T</td>
<td>6</td>
<td>7</td>
<td>30</td>
<td>3</td>
<td></td>
<td>46</td>
</tr>
<tr>
<td>and OR neck</td>
<td>-</td>
<td>1</td>
<td>5</td>
<td>-</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Trunk T</td>
<td>3</td>
<td>11</td>
<td>11</td>
<td>9</td>
<td></td>
<td>23</td>
</tr>
<tr>
<td>OR</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>0</td>
<td>4</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Upper T extr</td>
<td>14</td>
<td>3</td>
<td>28</td>
<td>16</td>
<td></td>
<td>45</td>
</tr>
<tr>
<td>OR</td>
<td>3</td>
<td>1</td>
<td>12</td>
<td>-</td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Lower T extr</td>
<td>25</td>
<td>2</td>
<td>24</td>
<td>1</td>
<td></td>
<td>52</td>
</tr>
<tr>
<td>OR</td>
<td>12</td>
<td>9</td>
<td>8</td>
<td>-</td>
<td></td>
<td>29</td>
</tr>
<tr>
<td>0</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Total T OR</td>
<td>48</td>
<td>5</td>
<td>70</td>
<td>30</td>
<td>13</td>
<td>166</td>
</tr>
<tr>
<td>0</td>
<td>16</td>
<td>10</td>
<td>24</td>
<td>5</td>
<td>1</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>-</td>
<td>4</td>
<td>1</td>
<td>-</td>
<td>12</td>
</tr>
</tbody>
</table>
Of the fatally injured riders (IV) a further analysis of the injuries was possible in 126 cases. Most of these (87%) suffered multiple serious (AIS ≥ 3) injuries. Most common were serious head injuries (79% of the injured), chest injuries (63%), and internal abdominal injuries (46%). Twentyone percent had serious spinal injuries.

Among the traffic injured in series III, injuries with MAIS ≥ 3 were more frequent than in off-road riding (see Fig. 1, Paper III). Also inpatient treatment, days on sickness benefit and "costs" were higher in the traffic injured group (Table V). All three fatalities in series III happened in traffic. The serious (AIS ≥ 3) intracranial injuries took up most of the care period (1 038 days (43%)) and those of the vertebrae and spinal cord took up to 490 days (20%); all these injuries occurring in traffic. The mean cost of treatment and sickness benefit reached SEK 53 000 in the traffic injured group and SEK 5 000 in the off-road riding group. This calculation is limited to one year after the accident and should be regarded as a minimum. Since all six disabled cases (head and spinal cord injuries) were injured in traffic and required medical care temporarily (4 cases) or constantly (2 cases)
Tabell V. In- and out-patient care and sickness benefit in the groups: traffic, off-road and "others" in series III.

<table>
<thead>
<tr>
<th></th>
<th>TRAFFIC</th>
<th></th>
<th>OFF-ROAD</th>
<th>OTHERS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary seeking</td>
<td>Referred patients</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>RiUm (n=79)</td>
<td></td>
<td>RiUm + local hospital (n=13)</td>
<td>RiUm (n=52)</td>
<td>RiUm (n=12)</td>
</tr>
<tr>
<td>Out-patient care</td>
<td>No of visits/n = mv</td>
<td>204/79 = 2.6</td>
<td>207/92 = 2.3</td>
<td>108/52 = 2.1</td>
</tr>
<tr>
<td></td>
<td>Σcost/n = mv (kkr)</td>
<td>124/79 = 1.6</td>
<td>128/92 = 1.4</td>
<td>62/52 = 1.2</td>
</tr>
<tr>
<td>In-patient care</td>
<td>No of days/n = mv</td>
<td>508/31 = 16</td>
<td>2337/44 = 53</td>
<td>94/16 = 6</td>
</tr>
<tr>
<td></td>
<td>Σcost/n = mv (kkr)</td>
<td>879/31 = 28</td>
<td>4150/44 = 94</td>
<td>139/16 = 9</td>
</tr>
<tr>
<td>Sickness benefit</td>
<td>No of days/n = mv</td>
<td>3308/33 = 100</td>
<td>3805/35 = 109</td>
<td>341/10 = 34</td>
</tr>
<tr>
<td></td>
<td>Σcost/n = mv (kkr)</td>
<td>509/33 = 15</td>
<td>579/35 = 17</td>
<td>49/10 = 5</td>
</tr>
<tr>
<td>Total</td>
<td>Σcost/n = mv (kkr)</td>
<td>1512/79 = 19</td>
<td>4857/92 = 53</td>
<td>250/52 = 5</td>
</tr>
</tbody>
</table>

RiUm = regional hospital in Umeå
n = number of injured in the group
mv = mean value
kkr = 1,000 Swedish crowns (SEK)
Σ = total
for more than one year after the accident, the difference between the two groups will be still greater in the long run.

A closer risk comparison between the traffic injured group and the off-road riding group in series III is difficult to make due to difficulties to find relevant exposition data.

Alcohol

Blood alcohol analysis was done in all autopsy cases but not in cases treated at the hospital. There was no note in the case record suggesting drunken driving among the riders in series III, except in one case where postmortem analysis later demonstrated presence of ethanol in the blood. In series IV, 27 (21%) of the fatally injured motorcycle-riders (7 passengers) had been riding under the influence of alcohol. Of these riders, 16 had collided with a post, tree or other immovable object and 10 had collided with another vehicle. Further two sober motorcyclists were killed in two separate accidents when an oncoming intoxicated car driver had come over on the wrong side of the road. Another sober motorcyclist collided at a road junction with an intoxicated car driver who should have given way. In 18 cases, the riders survived for more than six hours after the injury and blood alcohol analysis was not carried out initially. This, together with massive blood transfusions, made the negative postmortem analysis inconclusive. These victims were not suspected of being under the influence of alcohol according to the police investigations.

Wobbling in modern motorcycles (VI)

Altogether 45% of the interviewed motorcycle owners reported that they had experienced wobbling tendencies or severe wobbling at least once during 1982 (8% reported severe wobbling). This indicates that about 5 000 - 8 000 riders in Sweden during 1982 may have encountered severe wobbling. The frequency of reported wobbling increased:
- as the annual riding distance increased,
- as the cylinder volume of the motorcycle increased,
- with the riders increasing use of the motorcycles power and speed resources, especially prominent concerning severe wobbling,
- in inverse proportion with the age of the rider.
There was no statistical difference in the incidence of wobbling:
- between motorcycles of different years of manufacture,
- in relation to the riders experience of riding motorcycles.

There were indications of a difference in the incidence of reported wobbling between motorcycles with a cylinder volume greater than 750 cm$^3$. An analysis of matched pairs in this group resulted in a statistically significant difference ($X^2$ (McNemar) = 9.48; p < 0.01) between the groups Japanese and Non-japanese makes in favour of the Non-japanese group.

The exactness of the reported wobbling speed is for natural reasons limited. However the average reported wobbling speed was about 60 km/h in the front wheel flutter range and about 145 km/h in the high speed weave range.

DISCUSSION

Percrash human cell
Young male riders were the most frequently injured and killed. The median age for riders in traffic was 19 years in both series III and IV, which should be compared with the median age of the owners of motorcycles in traffic which was 24 years. This favours the hypothesis that the youngest riders belong to an accident prone group. Other motorcycle studies have demonstrated similar results (29, 30) and the same tendency is also present in other types of unintentional injuries (5, 15, 31). Probably, the injury frequency is more dependent on low age than on training (32). Consequently, it seems logical to raise the age limit for motorcycle driving.

The driver training in Sweden has been constituted of about 10 hours driving practice on motorcycle and about 10 hours of theoretical education. The training has until now not included much practice in handling severe or critical situations. In 1985 the requirements in the driving test have increased and now include an emergency stop test from 90 km/h.
It should be noted that 110 km/h is the highest permissible speed on Swedish roads. Of course, it could be argued that the driving test should go a little beyond what ordinary driving requires as in pilot training, where no one passes the test without being able to handle emergency situations apart from normal flying conditions. Should the motorcycle rider brake for the first time at 110 km/h in a critical situation on a highway? On the basis of this, it seems that the requirements in the driving test need to be reassessed once more. Furthermore, if the motorcycle rider is taught to stoop over the tank in case the motorcycle starts to wobble, he can bring the oscillation to a stop.

The attitudes of young motorcyclists to risk taking activities are often tough and probably they underestimate or do not understand the risk of injury and the possible consequences. At least 21% of the fatally injured motorcycle riders were riding under the influence of alcohol, every fifth one lacked a valid driving licence and many were driving faster than the actual speed allowed (IV). An interesting question is whether it is possible from prior convictions, to point out a rider, who is at a high risk of being involved in an accident. Nordic research in this area should be stimulated. In a study from the USA (33), it was shown that vehicle drivers with one or more conviction had a fatality rate of 3-7 times the fatality rate of drivers without prior convictions. This was especially true concerning young violators and it was concluded that actions probably should be taken immediately after the first conviction.

The high percentage of fatally injured riders who were under the influence of alcohol underlines the well-known fact that alcohol and fatal accidents are strongly correlated. It is probably a difficult task to get this group of riders to understand and react to the fact that alcoholic beverages should not be consumed prior to motorcycle riding. They must probably be stopped by a discerning friend, other person or a policeman.

Crash human cell
How the movement of the riders body in a crash can be modified is discussed in the crash-vehicle cell.
Postcrash-human cell
Adequate handling of the ventilation problem in full-face helmets, prevention of aspiration and a correct handling of vertebral injuries is essential for the outcome. The ventilation problem is further discussed in the postcrash-equipment cell.

Precrash-vehicle and equipment cell
The stability of a motorcycle should, of course, be adequate within its whole speed range and not dependent of the riders weight. The fact that this is not always the case is shown in series III-VI, where injuries and fatalities were caused by motorcycles which started to wobble, often at high speed. The result of the interview study VI verified that severe wobbling was not infrequent. During one year about 5 000 - 8 000 riders in Sweden are estimated to have experienced severe wobbling. In the Swedish vehicle publication (SFS 1972: 592, § 7) it is stated that "a vehicle should be reliable from the traffic point of view". When referring to wobblingprone motorcycles one can strongly question whether they are in compliance with this paragraph. It is obvious that wobblingprone motorcycles should not be allowed on the market and the responsibility for this rests largely on the manufacturers, the motorcycle dealers and on the authorities.

Four riders were injured in crashes caused by aqua-planing (III). Worn tyres should not be used as they render the motorcycle more liable to aqua-planing and probably also to wobbling. Moreover, they reduce the braking efficiency. Other functional shortcomings of the vehicles were seldom stated to play a part in the accident (III). The compulsory annual vehicle inspection could probably help to keep the vehicles in traffic up to standard.

Speed restriction "built in" in motorcycles should theoretically be possible by means of a mechanical or electrical regulator which rerestricts the number of revolutions of the engine. Such regulators are currently in use, however, the intention is to prevent damage to the engine (and not to the riders). Other technical measures with the intention of restricting the top speed of the motorcycle could also be discussed. It would appear to be illogical that most motorcycles purchased have speed resources far beyond (sometimes twice) the maximum permitted speed on Swedish roads.
One driver in series III felt so dizzy because of inadequate ventilation in a fullface helmet that he drove into a ditch together with his passenger. The problem with retention of carbon dioxide in fullface helmets has been analysed experimentally by Aldman et al. (34). The riders could be instructed not to wear tightfitting clothing against the helmet and they could also be recommended to open the visor when driving slowly.

**Crash-vehicle equipment cell**

The most important factors determining the crashworthiness of a motorcycle are the ability to protect the riders legs and feet in a collision and the freedom of hard and prominent parts which could catch the rider or cause injuries. The movement of the riders body determines the outcome in many crashes. Among the fatalities (IV), 52% died in collisions with other motor vehicles. Probably, the deceleration of the rider will, at least in some cases, be less severe if the rider slides upwards and forwards from the motorcycle and over the other vehicle. A construction which will let this happen is presented in Fig. 7.

Fig. 7.

An example of the construction of the fairing in a modern motorcycle. In the event of a collision the rider can slide upwards and forward without being caught in parts of the motorcycle.
"Packaging" of the riders body in a helmet, leather suit, boots and gloves should contribute to minimizing injury. The effect of helmets is well documented (27, 28) and most riders in both series III and IV had used helmets. Despite this, more than half of the fatally injured died of head injuries, indicating heavy head impact. The helmet weight has been claimed to cause injuries to the cervical spine (35, 36) but the overall injury reducing effect of helmets is undoubtedly favourable (27, 28, IV). It may, however, still be possible to improve protecting characteristics of the helmets.

Open fractures occurred only in those riders who were riding without a leather suit (III). An injury reducing effect of leather suits, especially concerning soft tissue injuries, has been reported previously (37, 38). To stimulate the use of approved suits (Fig. 8), the insurance premiums are at present lower for riders using these suits. Lower extremity injuries constituted one third of all injuries in series III and were most often injuries of the ankle. There may still be room for improvements of motorcycle riders' boots.

Fig. 8
A motorcycle rider with full-face helmet (1), leather-suit with paddings (2), and reinforced boots (3).
Fatal injuries to the trunk caused 40% of the deaths (VI). A protective shield like the chest shield used by motocross riders (Fig. 9) would reduce injuries to the chest, upper abdomen and upper extremities.

Fig. 9.
A protective shield for the trunk and arms often used in off-road riding.

Postcrash-vehicle and equipment cell
The use of fullface helmets (Fig. 8) has introduced a risk of worsening brain injuries by rebreathing expired air behind the visor (34). This causes retention of carbon dioxide in the blood which in turn may lead to a worsening of a concussion edema of the brain. It is consequently most important to have the visor opened as soon as possible after a head injury, especially if the rider is unconscious. It is, thus, essential that the first person on the accident scene has this knowledge and understands how to open the helmet, which sometimes can be very tricky.

After a crash the throttle should automatically take the idle position to minimize the risk of injuries due to a running transmission and rear wheel. Modern moto-cross cycles have a closed throttle-wire-system which minimizes the possibility of accidental throttling in a crash situation. The risk of fuel being spilt on hot parts in a crash (risk of fire) should also be minimized, as should the risk for the riders of undesirable contact with exhaust pipes or other hot parts.
Precrash-physical environment cell
The road was wet or slippery in nearly every tenth fatal accident (IV) and in series III about every tenth victim blamed potholes, gravel on asphalt or slippery road markings as factors contributing to the accident. Although road factors had only been blamed as the cause of a minor part of the injuries, a good maintenance of roads and elimination of elevated road markings may contribute to the reduction of injuries. Good construction of roads and road crossings should do so as well. Collisions with oncoming vehicles caused one fourth of the fatalities and a separation from oncoming traffic, eventually by e.g. guard rails would be beneficial.

Game collisions, mostly with moose, seem to have a high risk of fatal outcome. Seven riders in series IV died in moose collisions because of injuries to the head and neck. Information to the riders would be justified. In addition, game fences may reduce the risk of game collisions according to some studies (39, 40). However, Lehtimäki did not find that fences reduced the total number of game accidents (41).

Crash-physical environment cell
The fundamental problem is the prevention of abrupt deceleration of the riders in collisions with other vehicles or immovable roadside objects like lampposts and trees. Collision with a fixed object caused every third fatality (IV) while only every tenth in series III had collided with a fixed object. It is obvious that fixed, non-yielding lampposts should not be placed near the roadside, trees and other immovable hazards should be removed from possible running-off areas. These measures are also strongly motivated in other types of vehicle crashes. E.g. in a study from the USA (42) it was found that half of all fixed objects in fatal vehicle crashes were within four meters from the roadside.

Postcrash-physical environment cell
In our series III and IV we could not find that the physical environment had contributed to a worsening of the injuries after the crash. Nor was the access to crash sites a problem for rescue personnel.

Precrash-socioeconomic cell
Against the background of the high number of young persons injured in motorcycle accidents, one of the most effective injury reducing mea-
sures would be to increase the legal driving age to at least 18 years (as in Denmark). The intensive technical development of motorcycle engines during the last decade has resulted in power outputs of 25-30 hp in light motorcycles and up to 100 hp in heavy motorcycles. This is a fivefold increase in motorcycle engine power during the last 30-40 years and today's motorcycles are quite a different vehicle compared with those used when the 16 year age limit was introduced in the fifties (43). At that time a light motorcycle had a top speed of about 60-70 km/h (43). In Norway, the engine power of a light motorcycle is restricted to 7 hp and the cylinder volume to ≤100 cm³. One can question if it is consistent of the Swedish society to allow 16-year olds to ride such a lethal vehicle as a motorcycle, when the same society requires a minimum age of 20 to buy alcoholic beverages.

The requirements in the driving test need to be dramatically increased. In this test, the driver should prove that he can handle the machine also in critical situations at high speed. One emergency stop at 90 km/h is not enough (a new requirement in 1985) as the driver is allowed to drive at 110 km/h on some Swedish roads. Is it too dangerous to practice braking at this higher speed? If so, motorcycles should consequently not be constructed for a higher speed than 90 km/h. A better and more extensive training with competent teachers should increase the possibility of picking out unfit riders.

Alcohol was an influential factor in 23% of the fatalities. This is, however, a lower figure than the 35-66% which is reported from other countries (44-47). Lereim in Norway (48) found, in a hospital based series, that 10 out of 72 injured motorcyclists had been driving under the influence of alcohol. Corresponding figures as far as fatal single car accidents are concerned are also quite high in Sweden (50-56%) (17, 18). These figures should be correlated to the incidence of alcohol influenced motorists in routinely performed roadside surveys: the incidence is about 1 per 1,000 checked (49). The corresponding figure for motorcycle riders alone is lacking. It is a public belief that the Swedish Temperance Law is effective, but the opposite opinion has also been put forward (50). Perhaps a very intensive traffic supervision, especially during nights and weekends, would have some deterrent effect. Another approach is to forbid motorcycle riding during these
hours (cf 51). The traffic Temperance Law ought to be changed so the demand for sobriety also applies to the motorcycle passengers. Still another approach is to influence the widespread weekend activities in motorcycle clubs, so the activities are planned in such a way that the riders are sober when driving home.

Illegal and reckless driving was frequent among the fatally injured persons (IV). The fact that motorcycle riders often exceed the speed limit has been shown in a recent Swedish study (52). On roads with a speed limit of 70 km/h, 43% drove faster than 90 km/h; on roads with a 90 km/h limit, 31% drove faster than 110 km/h; and on roads with 110 km/h limit, 12% drove faster than 130 km/h. A more intensive traffic supervision could have a preventive effect also on speeding and other forms of illegal driving. In the fatal collisions which occurred at road or street junctions (28% of all collisions with other vehicles) the motorcycle, in almost half the cases, should have had right of way. A contributory factor to this not happening can be that the motorcycle was difficult to detect because of its small frontal area and high speed. In Sweden, since 1977, even motorcyclists are required by law to have dipped headlights on during daylight hours. If motorcycle headlights are automatically turned on by the ignition key, the risk of forgetting the light is minimized. Perhaps a 3-point light or a marking with red fluorescent warning tape should help to make motorcycles even more conspicuous.

Crash-socioeconomic cell
The helmet law seems to be accepted and well advised. The helmet standards need to be raised and further improvements to be initiated. Standards for safety suits and other protective clothing would be beneficial. The lower insurance premiums when safety suits are used would inevitably encourage riders to use them. A standard for the "crash-worthiness" of motorcycles can also be discussed. Traffic planners should not allow fixed objects, such as light poles to be placed near the roadside.

Postcrash-socioeconomic cell
It would be beneficial if motorcycle riders, police and ambulance personnel were given adequate instruction in first aid, with special reference to the problems concerning fullface helmets and neck injuries.
The chance of injuries being complicated by delay and improper handling would be reduced if effective ambulance transport facilities are available at all times of the day, like trained ambulance and hospital personnel. However, concerning fatally injured persons, Krantz and Löwenhielm reported that improvement in the emergency care could hardly cause a considerable reduction in the number of deaths (53).

During motocross competitions medical personnel are always present. During training there are no such requirement but there is always one other person present who is responsible for safety.
Table VI. Haddon's matrix. Factors influencing motorcycling injuries

<table>
<thead>
<tr>
<th>Human factors</th>
<th>Vehicle and equipment factors</th>
<th>Physical environment factors</th>
<th>Socioeconomic environment factors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-crash phase</strong></td>
<td><strong>Age and sex</strong>&lt;br&gt; Training&lt;br&gt; Risk-taking attitude&lt;br&gt; Drunken driving</td>
<td>Stability of the motorcycle&lt;br&gt; Tyres&lt;br&gt; Speed limiting device&lt;br&gt; Ventilation in fullface helmets</td>
<td>Road condition and construction&lt;br&gt; Meeting traffic&lt;br&gt; Game-fences</td>
</tr>
<tr>
<td></td>
<td><strong>Crash phase</strong>&lt;br&gt; The body's movement in a crash</td>
<td>Crash-worthiness of the motorcycle&lt;br&gt; Protective clothing</td>
<td>Roadside hazards (fixed objects)</td>
</tr>
<tr>
<td><strong>Post-crash phase</strong></td>
<td><strong>First aid</strong>&lt;br&gt;</td>
<td>Ventilation in fullface helmets&lt;br&gt; Throttle construction which prevents unintentional throttling after a crash</td>
<td>Access to the accident site</td>
</tr>
</tbody>
</table>
INJURIES RELATED TO MOOSE-CAR COLLISIONS (VII, VIII).

DEFINITIONS

"Severe personal injury" according to the official statistics follow the ECE-definition (Economic Commission for Europe; i.e. injuries which could be expected to require in-patient treatment) (1). Fatal injury means that the injured died within 30 days from the accident (1).

When analysing the severity of the personal injuries the AIS scale was used, where MAIS denotes maximum AIS (12).

The size of the moose is given as calf (less than one year old) or adult animal. A Scandinavian moose calf usually weighs less than 200 kg, a moose cow weighs about 250-400 kg and a bull 250-600 kg.

The car sizes have been classified according to weight: small (<1100 kg), medium sized (1100-1450 kg) and large cars (>1450 kg).

MATERIAL AND METHODS

Paper VII

The selection of moose-car collisions included in this study was made from the official statistics of "Road traffic accidents between motor vehicles and game with personal injuries". A total of 900 such accidents were reported during 1979 and 1980 (6, 54). Moose were involved in 85% of them. Only direct moose-car collisions were analysed. Collisions with other animals and collisions involving secondary collisions with other vehicles or fixed objects were thus excluded. The selection procedure is described in Fig. 10.

Police reports and hospital records were examined and one person per car, in most cases the driver, was interviewed by telephone. In two accidents (0.7%), there were no police reports available apart from the report to the National Central Bureau of Statistics. All medical records needed were available but in 7% there was no interview information from the car occupants. The follow-up period for treatment and sickness benefit was limited to two years after the accident.
Information about damage to the windshield pillars (A-pillars) and car roof was received through interviews and from 15% of the accidents photographs verified that the answers given in the interviews were plausible.

All data presented have been corrected with regard to the selection fraction (1:3 of slightly injured) to the total material of 650 direct collisions, involving 1309 car occupants of whom 989 were injured (Series VII). The exact sampling uncertainty $p < 0.95$ is presented for some variables. It should further be noted that the accuracy of some interview data (e.g. speed at the collision, deformation) for obvious reasons is uncertain and perhaps inferior to the sampling precision. An approximation of the sampling precision can thus be used as in Table I, Paper VII.

![Diagram](image)

**Fig. 10. Selection procedure.** Every third collision with slight personal injuries was randomly selected. $n =$ number of accidents, $n_i =$ number of injured and $n_o =$ number of car occupants.
Paper VIII

Information on traffic fatalities caused by collisions with animals during the period 1976-1981 was obtained from the National Central Bureau of Statistics. From this material, all collisions involving vehicles and cloven hoofed animals were selected. The material included 72 collisions (of which 9 were motorcycle collisions) with 83 fatalities in all (series VIII).

Police and autopsy reports, including the results from analyses of alcohol and drugs, were analysed for all these 72 collisions. Photographic documentation of the car involved in the accident was obtained in 21 of the 63 car accidents.

In order not to blur the injury panorama and physical damage to passengers and vehicles, only the 55 direct collisions between cars and moose with together 63 fatalities were further analysed. I.e. cases involving secondary collisions with other cars or fixed objects, and motorcycle collisions, were not included.

RESULTS

A summary of the results in Paper VII and VIII is presented below.

Drivers aged between 20 - 39 had the highest accident frequency which decreased at higher ages in both series VII and VIII. The annual mean distance driven by the drivers was 25 000 km (VII). The accident frequency was highest in the autumn. There was also a peak tendency in June, which is the time of the year when the moose cows part from their calves. Most accidents occurred during dusk and dark in both series. Friday and Sunday had the highest frequency of the weekdays with together 38% (VII) and 47% (VIII) of the accidents. Nine percent of the accidents (VII) occurred in occupational traveling and 23% during commuting to and from work, i.e. 32% were considered as occupational accidents according to Swedish law. The size of the car involved in the accidents is presented in Table VII.
Table VII. The size of the cars involved in the collisions and the distribution of cars in traffic in Sweden (1980-01-01) (55).

<table>
<thead>
<tr>
<th>Car size</th>
<th>Series VII n = 650</th>
<th>Series VIII n = 55</th>
<th>In traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>38%</td>
<td>38%</td>
<td>42%</td>
</tr>
<tr>
<td>Medium</td>
<td>53%</td>
<td>60%</td>
<td>51%</td>
</tr>
<tr>
<td>Large</td>
<td>10%</td>
<td>2%</td>
<td>7%</td>
</tr>
</tbody>
</table>

The reported median speed at the time of the collision was 70 km/h (VII) and 90-100 km/h (VIII). Three out of five drivers reported that they first saw the moose so late that they didn't have a chance to use the brakes before the collision (VII). Collisions with an adult moose were most common (66%) (VII) and this tendency was still more pronounced in the fatally injured group (VIII) in which collision with an adult moose were reported in 89% of the 21 collisions where the size of the moose was described. The impact was square on, with the centre of the car hitting the moose in the middle of its trunk, in 48 ± 5% of the collisions. In 21% of the collisions one of the A-pillars took the main impact. In the rest of the collisions, impact was against either, the front or rear end of the moose. Details were missing in 7% of the cases (VII).

Damage to the cars

The damage was typical for these collisions; the A-pillars were bent backwards and downwards, the roof was in most cases pressed backwards and down while the front and hood were only slightly damaged. The degree of damage was proportional to the speed and to the size of the moose and was most severe in the smallest cars (see Figs 3-5 in Paper VII). In the fatal collisions the damage to the cars seemed to be even more pronounced, and the roof was often torn far back and sometimes totally ripped off (see Fig. 11). In a large car no belted person suffered serious injuries (MAIS ≥ 3) (VII) and only one person was fatally injured in a large car (VIII).
Fig. 11. A medium sized taxi car which collided with a moose. One person died. (An illustration also of the occupational risk for taxi drivers).

Injuries and treatment
The correlation between roof deformation and MAIS in belted front seat occupants is presented in Fig. 6, paper VII. In series VII 80% of the injured had injuries with MAIS = 1; 16%, MAIS = 2, and 4% suffered more serious injuries. The head and neck (54%) and upper extremities (38%) were the parts of the body most often injured. All nine fractures of the thoracic and lumbar spine as well as 12 out of 18 fractures of the cervical spine occurred in front seat occupants of small cars. In the fatally injured group at least 95% died of head injuries. The most common type of injury was cuts and contusions mostly from the broken windshield and 93% of the injured suffered such injuries, 6% got glass pieces in their eyes (VII). In the group of injured seeking medical attention (n = 728) 25% were hospitalized for an average of 19 days (median 3 days) (VII). Half of these 728 received sickness benefit for an average of 33 days per person (median 7 days).
DISCUSSION

Precrash-human cell
Typical characteristics for the accidents were: a sober driver between 20-39 years with a long annual driving distance. Most accidents occurred during dusk or dark and most collisions were with an adult moose which appeared so surprisingly that the driver did not manage to brake before the collision. The high frequency of accidents among drivers in the age group of 18-24 years which is a feature of other car collisions (1, 5, 6) was thus missing in our study. Only one fatally injured driver had alcohol present in his blood (0.75 g/l). It thus seems that this type of collisions is not so age- and alcoholdependent as traffic accidents in general.

Åberg (56) has studied how car drivers react on game-warning signs and how they detect moose dummies in the terrain. He found that only 40% had noticed the warning signs, and these drivers did not slow down to any greater extent. Further he concluded that it was difficult to change drivers' normal visual search of the roadside.

To decrease the risk of these collisions it would be wise to drive slower (<70 km/h) especially during darkness. It is, however, not realistic to expect that people voluntarily will lower their travelling speed so much. Of course, a lower speed limit during hours of darkness could be discussed but at present it does not seem to be realistic. Another way to avoid these collisions is of course to use a non-road transport.

Crash-human cell
The movement of car occupants in a moose collision is dependent on the use of seatbelts, both among the front and rear seat passengers. The design of the present study VII did not allow assessment of the injury reducing effect of seatbelts in this type of collision. It is unlikely that injuries would be worsened by the use of seatbelts, which at least would prevent the occupants from being ejected out of the car. This must be especially true as far as the rear seat passengers are concerned; the injury risk seems low if they are retained in the rear seat.
Postcrash-human cell
Adequate first aid handling with special attention to spinal injuries is essential. The fact that this is not always the case is illustrated by the following tragicomical story: one driver, hanging half unconscious in his car, which had gone down a small ravine, heard people coming down to help him. They pulled at the jammed doors, looked into the car and said: "He is dead, let us go and take care of the moose".

Precrash-vehicle and equipment cell
The use of extra headlights on the car could make it easier to see a moose on the roadside. When meeting traffic this is not possible, the asymmetric dipped headlight is probably the best achievable light at present. Recently, a game whistle has come on the market, the ultrasound from the whistle is supposed to frighten the moose. However, if a moose is not frightened by the loud noise of a car at high speed, it would be strange if an ultrasound should have any effect.

Crash-vehicle and equipment cell

Because of its long legs the body of the moose, in the collision, smashed against the windshield, A-pillars and front roof, which gave way backwards and downwards. The deformation seemed to increase, with increasing speed of the car and size of the moose, and with decreasing size of the car. The moose had in most cases pressed the broken windshield into the passenger compartment and most car occupants suffered
cutting injuries. In some cases the steering wheel was deformed backwards, indicating that the moose had reached deep into the passenger compartment (Fig. 12). Our deformation data was based on interview information and therefore the results must be carefully interpreted even if they seem logical. It would therefore be of great value to verify our findings in comparative, standardized crash tests.

The peak forces in a collision with an adult moose at a speed of 75-80 km/h can be calculated to be in the order of 100 kN (= 10 000 kp). However, at present cars are not designed to withstand this stress. Most of today's cars are designed to fulfil the US FMVSS 216 "Roof Crash Resistance Standard", which states that the front roof/ A-pillar should not be deformed more than 127 mm (5"") when a force of 1.5 x the kerb-weight of the car is applied. This is equivalent with a stress of 15-20 kN (1500-2000 kp) for a typical Swedish medium sized car, i.e. a much lower stress than in a moose collision.

Two of the most effective injury reducing measures must be to strengthen weak structures (roof and A-pillars) and to use an antilacerative windshield to protect the car occupants from cutting injuries (Fig. 7, paper VII).

A softening and padding of the interior parts most likely to hit the occupants would also be of value. The available compartment space is an important factor. From this point of view the tendency towards smaller cars with an aerodynamic and light weight construction is not beneficial. With a large windshield inclined at a sharp angle the front part of the roof will be dangerously close to the heads of the front seat occupants. Large spaces of glass probably also increase the risk of getting the moose pressed into the car. Weight reducing measures might in many cases mean weaker constructions, which further increase the risk of personal injury. Probably also the side windows in the front doors are important in determining the size of load the roof can stand (57). The currently practiced weight reducing measure to decrease the thickness of the sidewindows is not at all beneficial in view of the above mentioned discussion.
On the basis of our results it could be recommended that persons, who drive a lot in moose-rich areas, should use a large and well constructed car and keep the speed low, until the car manufacturers have improved the strength of the roof and A-pillars and put in an antilacerative windshield.

**Postcrash-vehicle and equipment cell**
Jammed car doors could after a crash delay the caretaking of the occupants, the frequency of such problems was beyond the scope of our Papers VII-VIII. However, a strengthening of the structures discussed above will probably lessen the risk of car door jamming.

**Precrash-environment cell**
Several measures aimed at preventing the contact between the car and moose have had none or little success according to a number of Nordic studies (40, 41, 56, 58). These measures include for instance clearing the area along roads to improve visibility and the use of game mirrors which reflect headlights and in this way are supposed to frighten the moose. Furthermore, game warning signs have had very little effect on the speeds of cars (56). The game fences, which in later years, have been set up along roads with heavy traffic in moose dense areas, will probably have some effect (40). However, Lehtimäki (41) found that the reduction of game collisions within road sections covered by fences were compensated by an increase of collisions at the ends of the fences. This applied to fences shorter than 2 km. In the light of this and because three out of five moose collisions with personal injuries occurred on spots where no game risk was noted (game warning signs were missing), the total injury reducing effect of fences will probably be marginal. The annual investment cost for fences is at present about SEK 40 million or equivalent to SEK 200 per new car sold in Sweden.

The size of the moose population influences the likelihood of collisions, especially if large populations live near and/or migrate across roads with heavy traffic. If it was possible to reduce the number of moose near roads with heavy traffic, this would be beneficial from the injury point of view.
Crash- and postcrash-environment cell
The individual size of the moose involved in a crash, partly determines the damages and injuries. If possible a reduction of, especially, the number of big moose would be beneficial from the injury point of view. To reduce the risk of secondary collisions with fixed road side objects and meeting traffic the road side should have a driving-off area free from fixed objects and the lanes should be separated from oncoming lanes.

Precrash-socioeconomic cell
Is a major reduction in the moose population politically possible? The current population during the later years has been 300 000 - 500 000 moose of which about 150 000 are shot annually during the hunting season in the autumn. Moose hunting is a popular recreational and economic business in Sweden. Against this background it may be difficult to achieve a wide support for a major reduction in the moose population.

In some Swedish counties, a reconnaissance is made from aircraft in order to warn road users by radio about road sections which have a high risk of moose collisions.

Information and education of car drivers like warning signs along the roads, should not be expected to have any greater injury reducing effect according to Åberg (56).

Most accidents happened at dusk or during darkness. It is, however, difficult for travellers driving to and from work to change their time of travelling. (Every fourth moose collision happened when driving to or from workplaces). Dusk and dark travelling can, however, be decreased by introducing "summertime", i.e. turning the clock one hour forwards. In 1980, "summertime" was introduced in Sweden and a study comparing game accidents 1979 with 1980 found a reduction in the number of these accidents because more travelling occurred during the light half of the day (59).

Crash-socioeconomic cell
The Swedish car market is a small part of the whole world market. It seems impossible to demand special Swedish standards on A-pillars,
windshields and front roofs. A more fruitful way could be to have the insurance premiums based also on the cost of personal injuries, which is presently not the case. This would lower the premiums on the safest cars and people, organizations and companies running big car fleets would then be more prone to choose the safest cars. Furthermore, against the background that 8% of the collisions happened during occupational work, the Swedish Board of Occupational Health Safety can be motivated to require that cars used in occupations must meet certain standards of safety. The use of antilacerative windshields should strongly reduce the number of cutting injuries from the glass and should be supported from authorities and insurance companies.

Postcrash-socioeconomic cell
Efficiently functionating emergency services with sufficient equipment to open a crashed car and safely take care of the occupants should also be available in sparsely populated areas, where this type of accident often occurs.
<table>
<thead>
<tr>
<th>Haddon's matrix. Factors influencing the outcome of moose-car collisions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Human factors</strong></td>
</tr>
<tr>
<td>Pre-crash phase</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Crash phase</td>
</tr>
<tr>
<td>Post-crash phase</td>
</tr>
</tbody>
</table>
FINAL CONCLUSIONS

From the injury point of view, Swedish snowmobile laws seem well advised. Further, laws which require supervision "in the terrain" are probably bound to fail (e.g. helmet law). Easier to control are measures aimed at the construction and performance of the snowmobile (i.e. "built-in" speed limitation) or to the owners (e.g. licensing and making alcohol abuse disqualifying for ownership). Stimulation of voluntary training and education in snowmobile clubs is probably the best achievable today. Suitable snowmobile tracks and qualified emergency service would be beneficial.

To reduce the motorcycle injuries the age limit could be increased to at least 18 years; the demands in the driving test could be increased, a more intensive traffic supervision aimed at preventing speeding and driving under the influence of alcohol would also be beneficial. A limitation of the speed resources ("built in" in the motorcycle) and improvements of helmets and protective clothing would also reduce injuries. Wobbling prone motorcycles should be eliminated from traffic, and information to motorcycle owners of the risk of moose collisions should be given.

Currently measures aimed to prevent collision between moose and cars have had little injury reducing effect. A more fruitful way would be to strengthen the front roof and windshield pillars of the cars and use an antilacerative windshield, i.e. a windshield with an inner plastic layer preventing cutting injuries.
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