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Segment characteristics and severity of head-on crashes on two-lane rural highways in Maine

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Abstract

More than two out of three of all fatal crashes in Maine occur on rural, two-lane collector or arterial roads. Head-on crashes on these roads account for less than 5% of the crashes, but they are responsible for almost half of all fatalities. Data analyzed in this study was provided by Maine Department of Transportation and covers all head-on crashes for 2000–2002 during which period there were 3136 head-on crashes reported. Out of these, 127 were fatal crashes and 235 produced incapacitating but not fatal injuries. These two categories made up over 75% of the crash cost. A clear majority of head-on crashes on two-lane, rural roads in Maine were caused by drivers making errors or misjudging situations. Illegal/unsafe speed was a factor in 32% of the crashes while driver inattention/distraction was a primary factor in 28%. Fatigue was responsible for around one in 40 crashes and one in 12 fatal crashes. Alcohol or drugs was a factor in one in 12 crashes and one in nine fatal head-on crashes. Less than 8% of fatalities involved someone overtaking another vehicle, and only around 14% involved a driver intentionally crossing the centerline. Two in three fatal head-on crashes occurred on straight segments and 67% of these happened on dry pavement. There is a clear trend towards higher speed limits leading to a higher percentage of crashes becoming fatal or having incapacitating injuries. There is also a clear trend – if one keeps speeds constant and AADT within a certain range – that wider shoulders give higher crash severities. Also, for higher-speed roads, more travel lanes (than two) increase crash severity. In summary, there seems to be two major reasons why people get across the centerline and have head-on collisions: (a) people are going too fast for the roadway conditions; or (b) people are inattentive and get across the centerline more or less without noticing it. The latter category of crashes could probably be reduced if centerline rumble-strips were installed. More or less all head-on collisions could be eliminated if median barriers were installed. In-vehicle technology could also be used to significantly reduce the incidence of lane departures. Furthermore, today's speed limits should be better enforced since a high percentage of serious crashes involve illegal speeding. This should be combined with lowered speed limits for targeted high-crash segments.

Keywords: Head-on; Collisions; Crashes; Severity; Speed; Shoulder width

1. Introduction

1.1. Rural crash types

About 60% of all fatal crashes in OECD Member countries happen on rural roads (OECD, 1999) and as much as 80% of these crashes fall into three categories: single vehicle crashes (35%), head-on collisions (25%), and collisions at intersections (20%) (Wegman, 2003).

Two-lane rural highways make up a substantial proportion of the highway network in northeastern United States as in most of the world. In the state of Maine, roughly 95% of all rural highway miles are only two lanes wide. Furthermore, as the population continues to spread outside established urbanized areas as a result of population sprawl, traffic volumes on these facilities are increasing. This is expected to lead to an increased number of crashes involving vehicles traveling in opposite directions. A disturbing finding since Fig. 1 shows that head-on crashes in the late 1990s already accounted for almost half of all traffic fatalities on non-interstate rural roads in Maine even though less than 5% of all crashes there were of head-on type.

1.2. Overview of fatal crashes in Maine

Fatal crashes will be a focus of this paper since they are responsible for about half of the crash costs when it comes to head-on collisions—as shown later in this paper. Therefore, an analysis of a small number of crashes illuminates the causation

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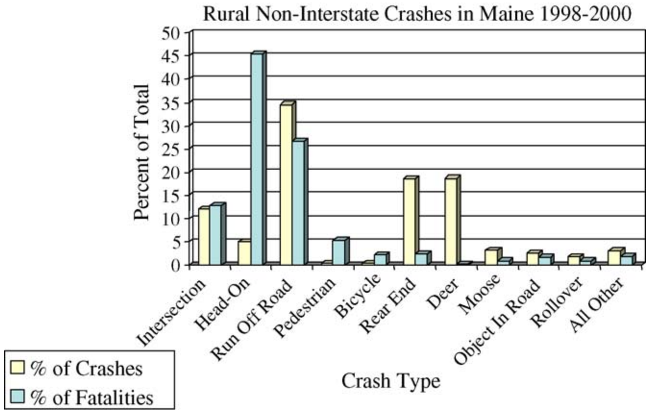

Fig. 1. Crash and fatality proportions by crash type on rural non-interstate highways.

of roughly half the crash cost. Also, fatal crashes are reported to a higher degree than other ones, are the ones that are the most thoroughly investigated with respect to cause, have the most reliable data, and are the ones that easiest can be found in data banks.

Rural, non-interstate crashes, the ones presented in Fig. 1, make up a clear majority of the fatal crashes in the state of Maine. The Fatality Analysis Reporting System (FARS) web-based encyclopedia (NCSA & NHTSA, 2005) shows that there in 2002 were 186 fatal crashes in Maine involving 272 vehicles. Fourteen (8%) of the fatal crashes occurred on rural interstate highways, 58 (31%) on other rural arterials, 55 (30%) on rural collector roads, 38 (20%) on rural local roads, and 4 on rural roads with unknown classification. There were two crashes with unknown urban/rural designation. This means that over 90% (169–171 out of 186) of the fatal crashes in the state were rural and less than 10% (15–17) occurred in urban compact areas. The fact that more than two out of three (127–133 out of 186) of all fatal crashes in Maine occurred on rural collectors/arterials means that this is where a considerable part of the safety improvement efforts ought to be concentrated. And, head-on collisions are the ones taking roughly half of all lives on these roads. Clearly, something should be done to reduce the number of head-on collisions. An obvious first step is to identify what is causing these head-on crashes – especially the fatal ones – and do whatever is necessary to reduce their occurrence, or at least their severity.

1.3. Review of literature

Research into what factors are correlated with head-on-crash occurrence indicates that the frequency of head-on crashes decreases with increased lane width (Al-Senan and Wright, 1987; Zegeer et al., 1981) and that most fatal head-on crashes take place on roadways with high posted speed limits (Al-Senan and Wright, 1987; Leisch, 1971) and at passing zones (Agent and Deen, 1975). Also, the vehicle crash severity is affected by speed limit (Renski et al., 1999), road width (Huang et al., 2002), and segment curvatures (Abdel-Aty, 2003). A study from New Zealand (Clissold, 1976) found that head-on collisions were over-represented in wet weather on both urban and rural roads. An analysis of 505 fatal head-on crashes in Minnesota (Minnesota Department of Transportation, 2004) shows that almost 50% (243 of 505) of the crashes were attributed to “driving left of roadway center—not passing,” which typically would indicate inattention, while 109 (22%) were classified as “illegal or unsafe speed,” 95 (19%) as “other human contributing factor,” 90 (18%) as “driver inattention or distraction,” and 73 (14%) as “improper or unsafe lane use.” Only 59 (12%) were classified as skidding and 57 (11%) as weather related in spite of Minnesota’s northerly climate with long, snowy winters.

A comprehensive overview using national data on head-on collisions is provided by NCHRP (2003). Results from that study is presented later in this paper as comparison material to Maine results.

2. Data and methodology

The primary data analyzed in this study was provided by Maine Department of Transportation with listings of all the state’s head-on crashes for 2000–2002. These files integrate characteristics of each crash and the roadway on which it happened; including the variables shown in Table 1. Data provided by FARS (NCSA & NHTSA, 2005) has also been used in the study.

A majority of the results presented below have been derived through comparison of crash numbers and crash severities for different roadway layouts and environmental conditions. By keeping ‘all’ other variables constant, the influence of individual variables are isolated.

An ordered probit model was also used for looking at the simultaneous influence of different variables on the crash severity. Independent variables for this modeling were roadway-surface conditions (dry-road or not), daylight conditions (dark and no artificial illumination or not), night-time (between 10 p.m. and 6 a.m. or not), evening (between 3 p.m. and 10 p.m. or not), heavy-vehicle involvement, paved shoulder width (in feet), and speed limit (in mph). The advantage of using a probit analysis rather than keeping all other variables constant is that one gets a lot more data on the influence of each variable.

Table 1
Crash data variables

Crash data variables provided by Maine Department of Transportation
Jurisdiction, town name
Route name, street name, estimated mile point, link node identification, segment identification
Crash date, hour of day, day of week
Weather condition, road surface condition, light condition
Number of fatalities, number of incapacitating injuries, number of evident injuries, number of possible
injuries, estimated economic impact
Federal functional class jurisdiction, factored AADT, speed limit (mph)
Average median width (ft), shoulder width left (ft), shoulder type left, shoulder width right (ft), shoulder
Type right, number of lanes
Apparent contributing crash factors, pre-crash actions
Driver ages, driver physical conditions, and driver license types, vehicle types

For example, if we want to study shoulder width and we keep speed limit constant at 55 mph, we get fewer segments with a specific shoulder width than if we look at the influence of shoulder width for all speed limits combined. On the other hand, a probit analysis may give biased results if we assume that the effect of a specific variable is constant and the effects of different variables are multiplicative. And this bias can occur even if there is no co-variance between the independent variables. For example, if (we assume that) wider shoulders give less serious crashes when speeds are 55 mph but that wider shoulders give more serious crashes when speeds are 35 mph, then we would need a variable for shoulder width on 35 mph-roads and another variable for shoulder width on 55 mph-roads—and the purpose with a multiplicative model would be lost. The results of the probit analysis of Maine data indicate that such biases may have occurred at least with respect to analysis of shoulder width, and results from the probit analysis is therefore not presented in this paper but can be obtained through a separate report (Deng, 2006).

For a head-on crash to occur, one vehicle must cross the centerline of the road. The reasons drivers cross the centerline can be divided into intentional and unintentional ones even if there are situations where it is difficult to tell what the intent of the driver was. The standard legal definition of intent is used, that is “intent indicates the state of mind accompanying the act” rather than whether or not a person steered the vehicle across the centerline. Examples of *intentional* reasons are:

- overtaking slower vehicle;
- turning left;
- making a shortcut through a left-hand curve;
- intent to commit suicide (not included in these crash statistics).

Examples of *unintentional* crossovers are:

- inattentiveness, distraction;
- having fallen asleep;
- inability to see centerline, e.g. when roadway is covered by snow;
- losing control because of speeding, especially in right-hand curves;
- over-correction after running off the right edge of the pavement.

3. Results: crash numbers

3.1. Number of head-on crashes by severity

In total, 3136 head-on crashes were reported in the state of Maine for the years 2000–2002. Out of these, 127 were fatal crashes and 235 produced incapacitating but not fatal injuries. There were 142 fatalities, 403 incapacitating injuries, 968 evident injuries and 1024 possible injuries during these 3 years.

If we use costs per injury type as recommended by FHWA (2002) with a fatal injury valued at $3,000,000, an incapacitating injury at $565,000, an evident injury at $175,000, a possible injury at $45,000 and a damaged vehicle at $2300, then the fatalities themselves had a cost of $426 million out of a total cost of $876 million for all the head-on crashes. This means that fatal crashes made up roughly half of the total costs. Fatal and incapacitating crashes together made up more than 75% of the total cost of all head-on crashes.

Eighty-one of the 3136 crashes occurred on multilane interstates (motorways) and have been omitted from most of the analyses below. Of the remaining crashes, 1426 occurred on state highways, 689 on state-aid roads, 930 on town roads, and the remaining 10 on other roads.

3.2. Risk factors in fatal crashes

Below follows an analysis of factors behind fatal crashes as construed from the crash reports. The association between design characteristics and non-fatal crash numbers is discussed in Section 3.3.

Based on the police reports, the primary cause of the 124 fatal head-on crashes that occurred away from the Interstate System in 2000–2002 has been assessed by the author of this paper. It should be noted that it is the primary cause of the crash, not the primary cause of the fatality that is listed. For example, a crash would be listed as sleep related when a driver crosses the centerline after falling asleep even if it may be high speed of the oncoming vehicle that made the crash fatal. Many crashes are difficult to attribute to only one factor and multiple risk-factors are sometimes listed.

Intentional crossovers:

- overtaking vehicles, while sober: seven crashes;
- overtaking vehicles, while under the influence of alcohol/drinking: three crashes;
- avoiding vehicle changing lanes, while under the influence of alcohol/drinking: one crash;
- driving left of center, not passing, while avoiding someone changing lanes: three crashes;
- driving left of center, not passing, while avoiding someone slowing: one crash;
- driving left of center, not passing, while avoiding vehicle, object, ped, or animal in road: two crashes;
- turning left, while under the influence of alcohol/drinking: one crash.

In total, there were 18 crashes that most likely were caused by an intentional crossover (across the centerline). A few of these may have been ‘necessary’ for avoiding another crash, e.g. rear-ending another vehicle or hitting a pedestrian, but most of the crossovers probably had improved mobility as the driver’s primary objective.

Probably unintentional crossovers:

The crashes listed in this subgroup cannot easily be classified into intentional versus unintentional crossovers. For example, a person being under the influence of alcohol – as well as a sober person – may be making intentional shortcuts through left-hand curves. But, probably, only a small fraction of the crashes listed here should be considered intentional:

- driving left of center, not passing, while sober, awake and not distracted: 18 crashes;
- driving left of center, not passing, while under the influence of alcohol/drinking: 12 crashes;
- driving left of center, not passing, while illegally speeding: 9 crashes;
- driving left of center, not passing, while using drugs: 2 crashes.

In total, there were 41 crashes that probably were caused by unintentional crossover of the centerline but where intention cannot be ruled out.

Unintentional crossovers:

A small percentage of the crashes listed below may also be intentional but the chances that these are intentional are assessed by the author as minimal. This does not mean that a different behavior by the driver would not have eliminated the crash from happening:

- driving left of center, not passing, while inattentive/distracted: 16 crashes;
- driving left of center, not passing, or wrong way after having fallen asleep/fatigued: 11 crashes;
- skidding across, while snow and illegal speed and sober: 13 crashes;
- skidding across when dry road; illegal speed: 8 crashes;
- skidding across when dry road; no other apparent factor: 7 crashes;
- skidding across, while snow but not illegal speed: 6 crashes;
- skidding across, while under the influence of alcohol/drinking: 2 crashes;
- skidding across, while ill: 1 crash;
- skidding across after tire failure: 1 crash.

In total, there were 65 crashes that almost certainly were caused by an unintentional crossover.

In the listings above, only the most important reasons for a crash were included. In some instances, there were also secondary or tertiary 'causes' (contributing factors, physical conditions, and pre-crash actions) indicated in the police report. In total, 271 drivers were involved in the 124 fatal crashes analyzed. Table 2 shows apparent contributing factors (a maximum of two per driver), physical conditions, and pre-crash actions as they were reported—for a maximum of four factors per driver. In summary, it can be concluded that human factors are the most common risk factors in head-on crashes. However, roadway characteristics and vehicle design can certainly influence the outcome of a crash as well as the likelihood that there will be a crash since both the risk of making a human error and the risk that making that error will lead to a collision can be influenced by external factors.

The alignment of the roadway was not captured in the data file provided by Maine DOT. Therefore, the analysis of alignment is based on a FARS web-query. In total, there were 93 fatal head-on crashes on two-lane segments for the 3-year period 2000–2002. Out of these, 61 (66%) occurred on straight segments and 32 (34%) on curves. (This can be compared to national data showing that in 1999, 75% of non-passing vehicles were "going straight" and 25% were "negotiating a curve" (NCHRP, 2003).) Of the (Maine) crashes along straight segments, 41 (67%) happened on dry pavement, 6 (10%) on wet pavement, and 14 (23%) on snow covered or icy roadways. Among crashes on curves, 26 (81%) happened on dry pavements, 3 (9%) on wet pavements, and 3 (9%) on snow covered or icy roadways. Thus, there is a tendency towards curves having a lower percentage of crashes occurring during inclement roadway conditions but the difference is not statistically ensured. It may seem surprising that ice and snow is more of a factor on straight segments than at curves. Whether this is typical or not has not been confirmed. The overall percentage of head-on collisions happening during snowy or icy conditions is however low in other northern states as well. An analysis of 505 fatal head-on crashes in Minnesota (Minnesota Department of Transportation, 2004) shows that only 59 (12%) were classified as skidding and 57 (11%) as weather related in spite of Minnesota's northerly climate with long, snowy winters.

Table 2
Summary of primary contributing factors for fatal crashes

Contributing factors/driver conditions/pre-crash actions	Number
Human factors	
Illegal/unsafe speed	41
Driver inattention, distraction	36
Avoiding vehicle, etc.	34
Drinking/OUI	14
Asleep/fatigued	11
Driver inexperience	10
Passing	9
Physical impairment	8
Ill	3
Using drugs	2
Other improper maneuver	28
Sum human factors	196
Vehicle factors	
Defective tire	1
Other vehicle defect	1
Sum vehicle factors	2
Environmental factors	
Skidding on snow or ice	19
Skidding on dry or wet road	19
Vision obscured by sun or object	2
Sum environmental factors	40
Total all factors	238

3.3. Cause of non-fatal crashes

The 3136 head-on crashes of all severity levels involved 6830 vehicles. Each driver/vehicle has been attributed two or fewer apparent contributing factors. The numbers presented in Table 3 are the raw numbers from the police reports without any further analysis to differentiate between actual causation or not.

Vehicle defects were a contributing factor, according to the police reports, in about 5% of the head-on collisions, as shown in Table 3. Vision obscurement, even when it is the windshield that is the problem, is typically not a vehicle defect—at least not when the windshield is covered by ice or snow. Vision obscurement is typically an environmental factor but if the crash is

Table 3
Summary of primary contributing factors for head-on crashes

Contributing factors/driver conditions/pre-crash actions	Number
Human factors	
Impairment	
Drinking/OUI	144
Using drugs	16
Asleep/fatigued	87
Physical impairment	182
Ill	35
Maneuver	
Illegal/unsafe speeds	896
Improper overtaking/passing	167
Improper turn	189
Avoiding vehicle, etc.	311
Other improper maneuver/violation	2104
Behavioral	
Driver inattention/distraction	1747
Driver inexperience	376
Driving left of center—not passing	818
Sum human factors	7072
Vehicle factors	
Defective tire	40
Defective brakes	15
Defective steering	11
Defective lights	1
Other vehicle defect	88
Sum vehicle factors	155
Environmental factors	
Skidding	627
Vision interfered by sun or light	134
Other vision obscurment	294
Sum environmental factors	1055
Total all factors	8282

occurring when a driver is passing someone where there is insufficient passing-sight distance, one should blame the driver rather than the roadway alignment—so some of the environmental factors in Table 3 ought to have been listed as human factors. It can be seen that a vast majority of the crashes were caused by human error and that is not surprising. For example, Australian research has shown that roughly 95% of all crashes involve human error (Roads and Traffic Authority of NSW, 1996). In this Maine study, human error has been divided into impairment crashes and behavioral ones. Around 12% of all crashes had a driver with some type of clear impairment. More or less every crash involves some type of behavioral human error and many crashes have more than one human error listed as a contributing factor. Illegal/unsafe speed was a factor in 28.6% of the crashes and driver inattention/distraction in 55.7%.

Environmental factors with respect to roadway conditions are seldom listed as a contributing factor. However, every crash has roadway conditions and weather listed in the report and every driver has a pre-crash action listed—even if that entry often just states "following roadway." The roadway was dry in 1759 crashes (56.1%), wet in 407 cases (13.0%), snow or ice covered

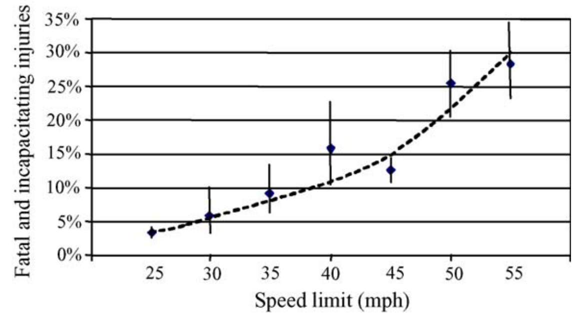

Fig. 2. Likelihood of incapacitating or fatal injury.

and not sanded in 523 crashes (16.7%), sanded in 404 (12.9%), and had other or unknown conditions in the remaining 44 cases (1.4%).

The pre-crash action shows that 654 drivers were making a left turn (20.9% of all crashes), 106 were making a right turn, and 34 were making a U-turn. This may have contributed to the driver of the other vehicle not anticipating the arrival of this vehicle.

4. Results: severity causation

4.1. Speed limit

Fig. 2 shows the percentage of crashes that, at a given speed limit, lead to fatal or incapacitating injuries whereas Fig. 3 shows the percentage causing fatalities. Confidence intervals assume that the recorded numbers vary around expected numbers according to a random process (Poisson distribution). There is a 2.5% probability that the 'true' percentage is above the shown bar and a 2.5% probability that it is below.

Overall in the United States, about 0.61% of all crashes are fatal (38,309 fatal crashes among 6,316,000 crashes according to NHTSA, 2004). As seen in Fig. 3, head-on collisions at any speed limit above 25 mph are on average more severe than the typical roadway crash. And, overall, head-on collisions produce fatalities more than six times as frequently as other types of crashes.

Figs. 2 and 3 have dashed lines illustrating how the relationships between speed and severity seem to vary. However, it is quite clear that collisions on 40-mph roads seem to be more serious than 'expected' whereas 45-mph roads have less serious

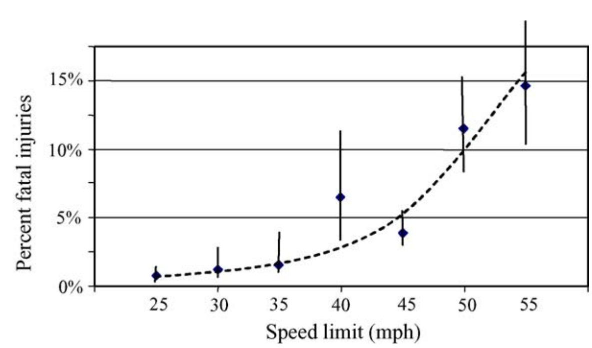

Fig. 3. Likelihood of fatal injury in head-on collision.

Table 4
Roadway class and severity of head-on crashes, Maine 2000–2002

Federal classification	Total number of crashes	Fatal and incapacitating crashes		Fatal crashes	
		Number	Percentage of total for that class (%)	Number	Percentage of total for that class (%)
Local	793	46	5.8	12	1.5
Minor collector	186	27	14.5	8	4.3
Major collector	711	97	13.6	30	4.2
Minor arterial	678	88	13.0	36	5.3
Other principal arterial	687	101	14.7	39	5.7
Interstate	81	3	3.7	2	2.5
Sum	3136	362	11.5	127	4.0

crashes than what one might expect. A reason for this may be that 45 mph is the default rural speed limit in the state of Maine. Therefore, minor roads with "no speed limit" are categorized as 45-mph roads even if travel speeds may be lower. On the other hand, some high-standard arterials have 35 or 40-mph speed limits when going through rural hamlets even though they invite higher speeds than many 45-mph roads with no posted speed limits.

4.2. Roadway class

The share of head-on crashes resulting in serious injuries for different roadway classes is shown in Table 4. The share of crashes leading to fatal or incapacitating injuries is clearly lower for local roads than for other types. Speed may be the reason for this. If we look at the absolute number of head-on crashes, major collectors, minor arterials and principal arterials have safety concerns that are almost identical (23%, 22%, and 22%, respectively)—while they carry around 24%, 19%, and 18%, respectively of the rural VMT of the state of Maine (FHWA, 1996). It is probably on these three roadway classes that safety measures for reducing head-on crashes primarily should be considered.

4.3. Shoulder width and AADT

It is obvious that speed influences the severity of crashes. By keeping the speed limit constant, we can see how other variables vary with safety. Forty five miles per hour sections has the highest number of serious injury crashes and an analysis of two-lane 45-mph roads are shown in Table 5. On average, 12.1% of these crashes result in fatal or incapacitating injuries. If we disregard AADT, roads with no shoulders (or one-ft shoulders) have a lower percentage of crashes resulting in serious injuries than other roads ($p = 0.055$). The 2–4 ft category has a risk of serious injuries very similar to the average whereas all categories of roads with shoulders wider than 5 ft have higher risk (than average) of serious injury ($p = 0.003$ for the combined shoulder widths 5–10 ft).

If we instead look at the influence of AADT, without considering shoulder width, we find that the three categories with the lowest volumes – below 2000 vehicles per day – have lower than average risk of serious injury ($p = 0.052$). All of the categories with higher AADT have higher percentages of the crashes leading to serious injuries. (Combining them into one category, with AADT = 2001 or more, gives a statistically significant difference from the average, $p = 0.02$.)

If we keep the AADT category constant in Table 5, then none of the cells (with that AADT) turn out to be statistically significantly high or low. The same is true if we keep shoulder width constant. In other words, for a given shoulder width, AADT does not significantly influence the risk of serious injuries; and for a given AADT, shoulder width does not play a significant role. Still, combined, it is clear that high-volume roads with wide shoulders are the most dangerous ones (per crash) whereas low-volume, narrow roads are the ones with the least severe crashes.

If we combine the three highest volume categories – AADT above 4000 – there is a clear tendency that narrower shoulders give a lower percentage serious injuries and wider shoulders (7 ft or wider) give a higher chance of fatalities and incapacitating injuries ($p = 0.08$). If combining the three lower volume

Table 5
Two-lane, 45-mph roads and portion fatal or incapacitating injuries vs. shoulder width and AADT

Average shoulder width/AADT	0–1 ft	2–4 ft	5–6 ft	7–8 ft	9–10 ft	Sum
0–200	16/148	3/41	0/0	0/0	–	19/189
201–500	5/66	7/72	0/2	0/0	–	12/140
501–2000	7/79	28/261	1/9	0/1	1/1	37/351
2001–4000	1/21	14/99	2/15	1/4	0/0	18/139
4001–8000	0/9	7/43	2/8	4/20	0/1	13/81
8001–15000	1/6	1/9	3/16	7/17	4/12	16/60
15001–30000	0/0	2/6	0/9	2/8	0/3	4/26
Sum	30/329	62/531	8/59	14/50	5/17	119/986

Table 6
Shoulder width and crash numbers by severity for two-lane, 50-mph roads

Shoulder width	0–2 ft	3–6 ft	7–10 ft	Sum
Crash severity fatal and incapacitating	0	23	18	41
All other crashes	5	98	60	163
Sum	5	121	78	204

categories (AADT below 2000) there is also a tendency that no shoulders give fewer serious injuries than (wider) shoulders.

A similar analysis was done for two-lane roads with AADT above 4000 vehicles per day and a speed limit of 50 mph. This is the speed limit with the second highest number of serious crashes, and excluding low-volume roads should minimize the influence of traffic volume. The summary results of this analysis are shown in Table 6. Again, there is a tendency that wider shoulders have a higher percentage of crashes produce serious injuries (23% for roads with shoulders at least 7 ft wide compared to 18% for roads with narrower shoulders) even if there are no statistically significant differences.

When combining the above analysis of the 45 and 50-mph roads, it is clear from the comparisons that there is a correlation between wider shoulders and more serious injuries. However, the relationship may not be causal. Roads with wider shoulders may, in general, also have 'better' vertical and/or horizontal alignment and it may be this that contributes the more serious injuries (through higher speeds even though the speed limit is kept constant in this analysis). Still, it is not unlikely that the wider shoulders themselves also lead to higher speeds and therefore that there is a causal relationship between wider shoulders and more serious injuries per reported crash. Note that the number of crashes per mile driven has not been addressed in this section.

4.4. Number of lanes

An analysis of all roadways, rural as well as urban, shows that roads with more than two lanes on average have a lower percentage of crashes producing serious injuries than two-lane roads do. This may, however, be caused by the fact that most four-lane, non-interstate roads in Maine are in urban, low-speed environments. An analysis of 45/50/55-mph rural roads give results as presented in Table 7. When excluding urban roads and roads with speed limits of 40 mph or lower, 1.3% of all head-on crashes occur on roads with more than two lanes while 2.6% of incapacitating, and 4.0% of fatal crashes occur on these wider roads. In other words, there is no indication whatsoever that more lanes lead to less serious injuries when we analyze rural roads separately.

Table 7
Number of lanes and crash numbers by severity for rural roads with speed limits 45–55 mph

Number of lanes	Fatal	Fatal and incapacitating	All other crashes	Sum
1	0	0	0	0
2	95	228	1103	1331
3	3	5	9	14
4	1	1	3	4
5–7	0	0	0	0
Sum	99	234	1115	1349

5. Conclusions and discussion

A clear majority of head-on crashes on two-lane, rural roads in Maine are caused by drivers making errors or misjudging situations. It is a well-known fact that fatigue – and actually falling asleep – is a major contributor to fatal crashes on Maine's Interstates (Gårder and Alexander, 1994). But on two-lane roads, fatigue is responsible for only around one in 40 head-on crashes and one in 12 fatal head-on crashes. Alcohol or drugs is a factor in one in 12 crashes and one in nine fatal head-on crashes. Only a small minority of head-on crashes occur because someone is trying to pass another vehicle (one in 19 crashes and one in 14 fatal crashes). Illegal or unsafe speed is a common factor contributing to almost every third crash whereas inattention/distraction is a factor in at least every second crash. Almost a third of head-on crashes occur on wintry roads.

There seems to be two major reasons why people get across the centerline and have head-on collisions: (a) people are going too fast for the roadway conditions; or (b) people are inattentive and get across the centerline more or less without noticing it. The number of the latter category of crashes could possibly be reduced significantly if centerline rumble-strips were installed.

An analysis from the mid 1980's of all fatal head-on collisions in North Carolina (Gårder, 1990) shows that roughly 50% were caused by inattentive or sleepy drivers crossing the centerline by mistake. Drivers losing control of their vehicles caused almost all of the remaining fatal head-on crashes. According to the crash reports in that study, drivers most commonly lost control of their vehicles by entering right-hand curves at too high speeds, which is likely to be influenced by the radius of the curve, the distance from the previous curve, and the roadway width. Other risk factors for unintended centerline crossings included over-correction after running off the right edge of the pavement. Just like in the current analysis of Maine crashes, only a small percentage of the North Carolina crashes involved drivers intentionally crossing the centerline because of overtaking slower vehicles. National data confirm that passing slower vehicles is not a big safety problem. "...in nearly all cases, fatal head-on crashes occur in non-passing situations. Of 7430 vehicles involved in head-on crashes on two-lane, undivided roadway segments, only 4.2% involved a vehicle 'passing or overtaking another vehicle' (1999 data)" (NCHRP, 2003).

Overall, the findings suggest that efforts to reduce the incidence of head-on crashes should be aimed at reducing unintentional crossings of the centerline, rather than improving information given to drivers about when it is safe to intentionally cross the centerline. In other words, improving passing sight distance and no-passing zone signage and pavement markings would not appear to have much potential for reducing the frequency of fatal head-on collisions. On the other hand, in-vehicle technologies and treatments such as installing centerline rumble strips or addition of a flush or raised median through horizontal curves could reduce these crashes.

In the longer term, in-vehicle technologies keeping vehicles in their lanes could be the ultimate way of eliminating head-on crashes. Already today, there are in-vehicle technologies such as electronic stability control (ESC) which helps improve cornering and control by monitoring the grip at the wheels as well as the driver's steering and braking inputs. ESC can sense differences between the driver's intentions and the vehicle's direction in turns. A comparison between models equipped with ESC as standard and the previous year's 'identical model' except for that model not having ESC showed that fatal run-off-road crashes were reduced by about 56% when ESC was installed. The fatality risk reduction for crashes involving two or more vehicles was smaller (17%) and not statistically significant but head-on collisions were not evaluated separately in that study (IIHS, 2005). Also, lane departure warning and lane keeping assistance systems have great potentials for reducing both head-on and run-off-road crashes. There are already commercial camera-based systems available as optional equipment on some 2005-model vehicles, but no independent safety evaluation seems to be undertaken. However, this and other studies show that high speeds contribute to serious injuries. Illegal and excessive speeds can be considerably reduced by in-vehicle speed alert or control systems, also known as Intelligent Speed Adaptation (Carsten and Tate, 2005). Finally, alcohol-related crashes can be reduced by the Alcohol Interlock Systems preventing drivers under the influence of alcohol from driving. A study of their efficiency was conducted on multiple alcohol offenders in Maryland. Drivers were randomly assigned to either ignition interlocks or standard treatment regimens. Only 2.4% of the 698 people assigned to use the interlocks were re-arrested for alcohol violations during the first year the devices were required. This compared with 6.7% of the 689 who received the standard treatment (IIHS, 2000).

In the shorter term, the most effective treatment of two-lane roads may be to install a continuous barrier along the centerline, and to widen the road up with an extra passing lane where appropriate. Adding an extra passing lane by itself, as illustrated in Fig. 4 (courtesy of the Swedish Road Administration), did not have much of a safety effect in Sweden—though it provided substantial mobility benefits at times. And the potential safety benefits in Maine would likely also be small even though the strategy "use alternating passing lanes or four-lane sections at key locations" has been reported by NCHRP (2003) to reduce fatal and injury crashes by 30 to 40% and property-damage crashes only slightly less. NCHRP still cautions against using three-lane sections since drivers tend to use the middle lane for passing also in the direction were this is prohibited by the use of double-yellow striping. 2 + 1-lane roads have also been built in Germany but typically without any center barriers. Still, these reconstructions have been reported to improve the safety compared to earlier layouts with one lane in each direction (Palm and Schmidt, 1999).

Fig. 5. Median barrier application in Massachusetts (exhibit V-9 in NCHRP, 2003).

Fig. 4. 2 + 1-lane road.

The strategy "install median barriers for narrow-width medians on multilane roads" was given "moderate 'relative cost to implement and operate'." This strategy is illustrated as applicable also for one-lane-per-direction highways as shown in Fig. 5, courtesy of NCHRP (2003). A comprehensive safety evaluation is not provided, rather NCHRP states: "The statistics listed above highlight a few types of median barriers but do not give insight regarding the safety of a roadway with and without a median barrier. Statistically sound studies are still needed to produce effectiveness measures and to consider this strategy a proven strategy. However, this strategy was tried and accepted in a number of applications. Additionally, there have been no significant findings that the effects of striking the barrier will have a worse result than the head-on collision it is designed to prevent." (NCHRP, 2003). The only empirical evidence that seems to be available is that from Sweden as presented below.

By more or less eliminating the shoulders, the pavement width of a three-lane road with a central barrier can be kept at 13.5 m (44 ft—the width of a roadway with two 12-ft lanes and two 10-ft shoulders) as shown in Fig. 6. Such roads – where the passing lane alternates between the two travel directions – have been constructed in Sweden since 1998. There were about 1000 km (620 miles) of such 2 + 1-lane roads opened to traffic in the summer of 2004. They all have cable barriers. Solid concrete barriers of New Jersey style could be an alternative where speeds are below 70 km/h (44 mph) whereas cable barriers should be used at higher speeds since cable barriers minimize the risk of injuries to the occupants of the vehicle. Traditional steel guardrails are said to have properties in between cable barriers and concrete barriers (Carlsson and Bergh, 2004). A safety analysis of these Swedish reconstructions shows that the number of injured people on these segments has been reduced by

Fig. 6. 2 + 1-lane road with barrier.

around 55% and fatalities have been reduced by 85% compared to the before situation with two 12-ft lanes and 10-ft shoulders. The total number of property-damage-only crashes has increased somewhat. There is a slight (non-significant) increase in rear-end crashes and a large number of guardrail collisions in the after situation. The average frequency of center barrier collisions is around 0.40 collisions per million vehicle-kilometers (0.64 per million vehicle-miles) on 90-km/h (56-mph) roads and 0.56 collisions per million vehicle-kilometers (1.03 per million vehicle-miles) on 110-km/h (68-mph) roads. The cost of repairing the damages from approximately 3000 barrier collisions has been substantial – not least from a worker-safety perspective – but at this point, no serious injuries have occurred during these repairs while more than 40 fatalities in head-on collisions have been avoided. The average repair costs are around 70,000 SEK per year and kilometer, or $14,000 per mile and year. Also, plowing and snow-removal costs have increased by around 7000 SEK per year and kilometer, or $1400 per mile and year. Finally, when the first segment was built, less than 1% of Swedish drivers liked the design idea. But within one year, 40% of users supported the design concept and now a majority likes these roads (Carlsson and Bergh, 2004).

To get a large number of center barriers installed in Maine is probably unrealistic no matter how effective they may be. As noted above, Maine has 5544 miles of numbered routes and if installing centerline barriers costs $68,000 per mile (Washington State Department of Transportation News, 2002), 5544 miles of roadway installations would cost around $377 million which can be compared to Maine Department of Transportation overall budget of $483 million for the entire program area highways and bridges for the fiscal biennium 2004–2005 (Maine Department of Transportation, 2003). However, to have centerline barriers installed along some high-crash sections may be a realistic goal. Other sections could have continuous centerline rumble strips installed. For mobility reasons, two-lane roads with center barriers need passing lanes at regular intervals. An alternating passing lane and cable barriers can be provided within the footprint of a two-lane road with 10-ft wide shoulders if the shoulders are narrowed to about 1 ft each. However, bicyclists and other slow-moving traffic will frequently need wider shoulders to travel safely and 4-ft shoulders should still be provided if there aren't alternative routes for bicyclists. Also, if former shoulders are to be used as travel lanes, their bearing capacity must be upgraded to carry trucks.

The Maine data analyzed here shows that widening two-lane roads and providing extra travel lanes without providing center barriers influence the crash severity negatively. And, if we keep AADT and speeds constant, there is a clear tendency that roads with no shoulders or narrow shoulders have crashes producing few serious injuries while roads with wider shoulders (7 ft or wider) have a higher risk of crashes producing fatalities and incapacitating injuries. If we cannot put in center barriers to 'eliminate' crossovers or install centerline rumble strips to reduce involuntary crossovers caused by driver inattention, the most effective way of reducing crash severity, according to the data presented here, is to reduce speeds. However, it would be difficult to get acceptance among drivers for reducing speed limits across the board. And since two-thirds of all fatalities occur on straight segments, it would not be very effective to reduce speed at sharp curves only. Rather, speed limits should be better enforced – or enforced through photo enforcement and/or in-vehicle technology – since a high percentage of serious crashes involve illegal speeding. This could be combined with lower speed limits for a few targeted high-crash segments.

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