Characteristics of fatal road crashes involving unlicensed drivers or riders: Implications for countermeasures

Abstract

Drivers or riders without a valid license are involved in 10% of fatal road crashes in Norway. This was shown by an analysis of data from all fatal crashes in the period 2005-2014. A literature review shows that unlicensed drivers have a considerably increased crash risk. Such crashes could be prevented by electronic driver authentication, i.e., a technical system for checking that a driver or rider has legal access to a vehicle before driving is permitted. This can be done by requiring the driver/rider to identify themselves with a national identity number and a unique code or biometric information before driving may commence. The vehicle thereafter verifies license availability and vehicle access by communication with a central register. In more than 80% of fatal crashes with unlicensed drivers/riders, speeding and/or drug influence contributed to the crash. This means that a majority of crashes with unlicensed drivers alternatively could be prevented by already available systems, such as alcolock and speed limit dependent speed adapters. These systems will have a wider influence, by preventing crashes also among licensed drivers. Mandatory implementation of alcolock, speed limiter, and electronic driver authentication in all motorized vehicles is estimated to prevent up to 28% of fatal road crashes, depending on effectiveness of the systems.

Keywords: driver authentication; alcolock; intelligent speed adaptation; unlicensed driving; fatal road crashes

1 Introduction

Studies from several countries indicate that a considerable share of road crashes are caused by drivers or riders without a valid license. Most estimates from Australia and USA indicate that unlicensed drivers/riders are involved in between 10% and 20% of fatal crashes (Watson, 2003; 2004; Watson & Steinhardt, 2007; AAA, 2011; Baldock et al., 2013). In Europe, there is a lack of studies on unlicensed drivers/riders and crash involvement. The only results we have found come from a study of Belgian police reports from fatal crashes on Belgian motorways (Slotmans & DeSchrijver, 2015), showing that 2.9% of involved drivers were unlicensed. This is clearly lower than the estimates from Australia and USA, even if we take into consideration that it is based on number of involved drivers rather than number of crashes. Since we have found no other European studies, and the only study includes only motorway crashes, there is clearly a need for more studies of unlicensed driving and serious crashes in Europe.

It should be noted that the problem of using a motorized vehicle without a valid license also concerns riders of powered two-wheelers, in addition to drivers. Therefore, for simplicity we use the term ‘unlicensed drivers/driving’ here to refer to both these vehicle categories.

Unlicensed driving is a traffic safety issue only to the extent that unlicensed drivers are at a higher risk than other drivers; in other words, if the share of unlicensed drivers is higher in crashes than in driving generally. Unfortunately, data on unlicensed driving in general are scarce. According to Sweedler and Stewart (2007), a report from the UK Department of Transport (Knox et al., 2003) found that unlicensed drivers account for less than one percent of total hours driven. If this figure is generally valid, the share of unlicensed drivers in crashes is several times higher than their share in traffic, showing that their crash risk is clearly elevated. This conclusion is also supported by several estimates of relative risk based on case-control studies (de Young et al., 1997; Watson, 2004; Blows et al., 2005; Brar, 2012). Further evidence for unlicensed drivers' crash risk comes from the finding that odds ratios tend to increase with crash severity (Watson, 2004). In a study from Canada, Suggett (2007) found that there was a higher share of fatalities in crashes among unlicensed (3%) compared to licensed (1.4%) drivers.

It should be noted that investigating prevalence of unlicensed driving as well as estimating the associated crash risk is methodologically challenging. For drivers involved in crashes, such data are rather easily available, since license status ordinarily will be registered by police or other authority bodies investigating crashes. However, estimating crash risk requires exposure data as well, which means that one should know the proportion of driving taking place with unlicensed drivers or riders, and ideally the distribution of unlicensed driving in space and time. One way of circumventing the lack of exposure data is using the quasi-induced exposure case-control method, which compares the prevalence of a risk factor (unlicensed driving in this case) between at-fault and not-at-fault drivers, assuming that the proportion of not-at-fault drivers with the risk factor present represents the prevalence among drivers in general, at the times and places were accidents have occurred. This approach was used in the study by de Young et al. (1997) of crash risk among unlicensed drivers in California. There are, however, some limitations of this method, related e.g. to the allocation of fault to the parties involved in a crash. This may result in biased risk estimates; for example, ascribing fault to only one party in a two-vehicle crash is sometimes an over-simplification, since even not-at-fault drivers may have a higher risk of being involved in crash compared to an average driver. This bias will result in too low risk estimates, whereas a possible tendency to ascribe fault to the unlicensed driver just because this is something illegal will attenuate risk estimates. De Young et al. (1997) conclude that despite these limitations, "estimates yielded by the induced-exposure method are reasonable approximations that provide a better indication of the risks posed by ... unlicensed drivers than would otherwise be available" (Young et al., 1997, p.22). The same method was used also in the studies in Queensland, Australia, by Watson (2004) and in California by Brar et al. (2012), yielding similar results. A somewhat different approach was used in the case-control study by Blows et al. (2005) in New Zealand. The cases in this study were 615 killed or hospitalized drivers, whereas the controls were identified by randomly sampling of a comparable number of drivers at representative road sites. This study yielded odds ratios for unlicensed driving between cases and controls in the same order of magnitude as the relative risks from the other mentioned studies.

The relative risk estimates or odds ratios for crash involvement of unlicensed drivers are clearly significant in all these studies and vary between 2.6 and 11.1, which clearly demonstrates the overinvolvement of this group of drivers in crashes.

Unlicensed drivers have been found to be more frequently reported for other traffic violations as well. For example, speeding, drunk or drugged driving, and other negligence are clearly more frequent among unlicensed drivers (Watson and Steinhardt, 2007), a finding that explains much of their added crash risk.

Since the evidence of increased crash risk among unlicensed drivers is so strong, there is a need to get more detailed knowledge both about the prevalence of unlicensed driver crash involvement and about characteristics of those drivers and the crashes they are involved in.

The main purpose of the present study is to present an analysis of the prevalence of unlicensed driving among at-fault drivers for fatal crashes in Norway during the ten-year period 2005-2014, based on reports from in-depth investigations of all fatal road crashes. In addition, we investigate the prevalence of additional risk factors present among the unlicensed drivers, primarily alcohol influence and speeding. We will not attempt to estimate crash risk, since Norwegian data on unlicensed driving in general are not available.

Various ideas have been suggested regarding development of technical systems for preventing unlicensed driving, and thereby reduce the number of crashes. In discussing our results, we include a short overview of research regarding possible technological solutions to this problem. More specifically, we will estimate potential effects of a system for electronic driver authentication and make comparisons with expected effects of alternative or complementary measures like alcolock and intelligent speed adaptation.

2 Method

Our estimations of the share of crashes with unlicensed drivers are based on data from the accident investigation boards (UAG, "UlykkesAnalyseGruppe") of the Norwegian Public Roads Administration. The UAGs carry out in-depth investigations of all fatal crashes in Norway and write a comprehensive and detailed report from each investigated crash, based on on-the-scene observations, interviews with witnesses, police reports, vehicle and license register data, vehicle inspections, and in some cases computer-based crash reconstruction in order to estimate pre-crash trajectory and speed. The work of the UAGs is carried out in parallel with and independently of investigations by the police.

For the years 2005-2014 reports from 1850 fatal crashes were available, which include all fatal road crashes in that period. Key information from each crash investigation is recorded by the UAG in a database. The researchers in the present project had access to both the database and the detailed reports from each crash.

In Norway, a fatal crash is defined as a crash resulting in the death of a road user within 30 days after the crash. All crashes on public roads, as well as crashes involving motorized vehicles outside public roads are included. Crashes with clear indications of suicide are not included in the UAG database, nor are crashes where a driver dies before the crash because of a medical condition.

There is a code in the UAG database for "invalid license"; however, it turned out that license status data were incomplete for drivers who were obviously not at fault for the crash. Consequently, we have complete data on license status only for at-fault drivers, and there were no crashes where "invalid license" was registered for an innocent driver. Data from the database were supplemented with screening of individual reports from all crashes. This screening revealed some instances of "invalid license" for at-fault drivers which were missing in the database.

Unlicensed drivers include both persons who have had their license revoked or suspended, either due to traffic violations, health problems or other reasons, as well as persons who had never held a license. Drivers holding a license that is valid for a different vehicle category, but not for the vehicle they used in the crash, are also counted as unlicensed. The UAG database does not contain information about the different reasons for being unlicensed; all the mentioned reasons are coded as "unlicensed".

Information about stolen vehicles involved in fatal crashes was also available in crash reports, and this information was noted in the screening process in addition to license status.

For each crash with more than one motorized vehicle involved, different criteria were used for identifying the at-fault driver. A crash-involved driver violating a priority regulation was always defined to be at fault. For other crashes, the driver at-fault was defined by identifying the earliest instance of loss of control that contributed to the crash. The at-fault driver was identified as the driver of the vehicle losing control. This judgment was based solely on information about course of the crash, irrespective of legal considerations. This implies that an at-fault driver had not necessarily violated a traffic rule, and a traffic rule violation did not imply fault for the crash unless judged as a contributing factor. Drivers in single-vehicle crashes were always considered to be at fault.

We used the UAG database also to register speeding and alcohol influence among both licensed and unlicensed drivers involved in crashes. The crash investigation teams had coded speeding in two different ways. After estimating the likely pre-crash speed, based on braking or skid marks on the road surface, vehicle deformations, witness testimony, or computer-based crash reconstruction, they first judged whether the speed was too high for the driving conditions (road, weather, traffic, etc.) irrespective of speed limit. Second, they determined whether the estimated speed was above the limit for license revocation. Both judgments were coded in the database.

UAG data on alcohol influence is partly based on autopsies of killed drivers. For surviving drivers, data are based on breath or blood tests. Cases with values above the legal limit of 0.2% BAC (which is the same for full-license and probationary-license drivers) were coded as influenced by alcohol. It should be noted that there may be some underreporting of alcohol influence, because drivers are not tested unless the police officer suspects influence.

In addition to the analysis of crash data, a literature search was carried out to find publications on prevalence or risk regarding unlicensed driving, as well as on possible technological countermeasures

3 Results

3.1 Prevalence of unlicensed driving in crashes

Out of the 1850 fatal crashes analysed, the at-fault driver was unlicensed in 188 crashes, i.e. 10.1%. The frequency distribution of vehicle categories with unlicensed drivers or riders is shown in Table 1. The 'Other' category includes two snowmobiles and one tractor.

In addition, there is an unknown number of crashes with unlicensed drivers who were involved in crashes as innocent party. Unfortunately, license status is not routinely registered in crash reports for drivers who are obviously not at fault for the crash.

We see that a far larger share of motorcycle, moped and ATV riders involved in fatal crashes are unlicensed, compared to car drivers. In fact, as many as one out of three moped riders involved in a fatal crash is riding without a valid license.

Table 1. Unlicensed drivers or riders at involved in fatal crashes 2005-2014, by vehicle category and crash culpability.

		Fatal crashes with unlicensed driver/rider	
Vehicle category	Total no. of fatal crashes	Number	Percent of all fatal crashes
Car	1255	115	9.2
Motorcycle	182	49	26.9
Moped	21	7	33.3
ATV, snowmobile, tractor	47	9	19,1
Truck, bus	200	7	3.5
Other	42	1	2.4
Not reported*	103	0	0
Total no.	1850	188	10.1

* For 103 crashes, data on type of the at-fault vehicle were not available in the database.

3.2 Additional risk factors and crash characteristics

We investigated the prevalence of additional risk factors among the unlicensed drivers, compared to other drivers involved in fatal crashes. Table 2 shows the prevalence of alcohol or drug influence, speeding, and stolen vehicles among both unlicensed and licensed at-fault drivers involved in fatal crashes. Influence of alcohol or drugs was found among 70% of drivers and 50% of riders without a valid license, compared to 17% of licensed drivers/riders. Both speeding (considerably above the speed limit, and/or clearly inappropriate to traffic and driving conditions) and using a stolen vehicle were also much more prevalent among unlicensed drivers.

Among unlicensed drivers there was a higher proportion of persons younger than 25 years, especially for motorcycle and moped riders. A higher share of unlicensed drivers were previously registered in police records, and as many as 29 out of the 188 drivers had stolen the involved vehicle. In comparison, there were six crashes with stolen vehicles with a licensed driver (out of 1662 crashes).

Table 2. Fatal crashes involving an at-fault driver/rider either influenced by drugs or alcohol, speeding, or using a stolen vehicle, by license status (valid vs. not valid) and vehicle category (cars and heavy vehicles vs. other motorized vehicles). Percent.

License status	Vehicle category	Drugs or alcohol	Speeding	Stolen vehicle	Neither drugs, alcohol, speeding, nor stolen vehicle	N
Unlicensed driver/rider	Cars and heavy vehicles	70,2	58.1	18.5	12.2	124
	Other vehicles	50.0	68.8	9.4	19.0	64
	All	63.3	61.7	15.4	14.4	188
Driver/rider with valid license	All vehicles	17.0	44.6	0.4	48.9	1662
All drivers/riders	All vehicles	21.7	46.3	1.9	45.4	1850

The differences in proportions between licensed and unlicensed drivers were tested by a chi-square test, and the differences were significant for drug/alcohol influence (χ^2=195.2; df=1; p<0.00001), speeding (χ^2=16.6; df=1; p=0.00005), age younger than 25 years (χ^2=11.1; df=1; p<0.0009), and being registered in police records (χ^2=26.6; df=1; p<0.00001). For driving a stolen vehicle, the prevalence among licensed drivers is too low for the chi-square test (one cell with expected frequency less than five), but the difference between 0.4% for licensed drivers and 15.4% for unlicensed drivers is undoubtedly significant by any appropriate test. The sum of percentages for each row in Table 2 largely exceeds 100%, which is explained by an extensive overlap between the additional risk factors.

We also found that unlicensed drivers are overrepresented in running-off-the-road crashes and in crashes during weekend nights. Fifty-six percent of unlicensed driver crashes were off-road crashes, compared to 31% of crashes among licensed drivers. As much as 42 % of crashes among unlicensed drivers are weekend-night crashes, compared to 15% for licensed drivers.

Looking at alcohol/drugs and speeding together, it appears that one or both of these factors were present among 86% of drivers and 79% of motorcycle and moped riders without valid licenses.

4 Possible technological solutions

4.1 Electronic driver authentication

The high share of unlicensed driving in fatal crashes implies that there is a large potential for crash reduction by technical systems making it impossible to use a motor vehicle without documenting the possession of a valid license for the vehicle type in question as well as a permission to use the actual vehicle. In the 1990's a so-called "electronic driving license" system was developed in Sweden, consisting of a smartcard with license information and a card reader in the vehicle (Goldberg, 1995; 1999). The system was trialled in a field study with 15 cars, with largely positive results regarding user acceptance and satisfaction (Myhrberg, 1997). The evaluation study concludes that the users had no problems getting used to the system and most of the users thought the system could have a great effect on preventing theft and unauthorized driving. The tested system also included an option for remote stopping of vehicles by the police, and high-speed trials of steering and braking after the ignition had been cut indicated no major safety problems. It is however pointed out that many practical issues must be solved before such a system can be introduced on a larger scale, and that it will have little effect until all vehicles are equipped. It is also problematic to require such a system in one European country only, due to EU regulations regarding trade barriers. Therefore, large-scale introduction needs to be decided for all EU.

We are not aware of other examples of similar systems that have been tested in practice, even though further development of such systems has been pointed out in several articles and reports as a potentially effective safety measure (Watson, 2003; SIKA, 2005; SOU, 2005; Baldock et al., 2013; Hållström, 2015; Makwana et al., 2016).

With today's technology, it is probably feasible to develop systems for electronic driver authentication that are both cheaper and more effective than what was possible in the 1990's. In this article, we describe certain prerequisites for a driver authentication system to function as intended. The system has to be user friendly, so that starting a vehicle will not be more complicated than it is today. For the system to be effective, we assume that the driver/rider has to identify themselves before each trip, e.g. by entering a national identity number combined with registering biometric information (e.g. fingerprint) and/or entering a PIN code, and that the vehicle sends a verification request to a central register of licenses and vehicle access information. If the verification is positive, driving can proceed as normal. If not, the driver receives a request to stop as soon as possible and a warning that the engine will be turned off.

The system must handle several scenarios regarding authentication in different contexts of using a vehicle, including borrowing a vehicle, driving a rental vehicle, temporary access by service and repair personnel etc., driving in emergency situations, and vehicle fleets where drivers have access to several vehicles. Conceivably, it could be possible to drive in emergency situations without a valid authentication, provided a message about the driving is automatically sent to a surveillance centre. On the basis of discussions in the research literature as well as our own considerations, we have sketched a few principles for managing all the mentioned challenges.

A simple and effective system for electronic driver authentication will require the following components:

- A central register of licenses and vehicle access information, with connection to all registered vehicles.
- An authentication unit in the vehicle, for receiving input from the driver, communicating with the central register, and providing feedback to the driver.
- A surveillance centre for handling cases of illegal driving, with possibility of remote control of vehicles.

The primary advantage of a system based on central license verification compared to license information stored in a smartcard chip is that the license information will be updated continuously. A system based on a physical driver's license card will allow more opportunities for using false cards, e.g. a card where a recent license withdrawal is not registered.

For an electronic driver authentication system to be effective, it has to be implemented on a mandatory basis; i.e., it must include all vehicles of the categories for which it is developed. This also implies that implementation in any European country has to be organized at the EU level and that necessary changes in legislation for licensing and vehicles are also implemented.

An alternative solution could be a digital tachograph like the system already used in heavy vehicles. A tachograph will enable authorities to verify in retrospect whether the vehicle has been driven by a driver with a valid license, and otherwise in accordance with laws and regulations. The main advantage of using a tachograph-based system is that the technology is already available and has been tried out. However, the tachograph alone will not prevent illegal driving, and it allows more possibility for cheating, for example by using another driver's tachograph card. To achieve the largest possible reduction in crash rates, further development and field studies of a system for electronic driver authentication as described here is therefore clearly recommended.

It should be noted, though, that a system for unique driver identification may raise some privacy protection issues, which need to be solved before mandatory implementation is feasible. For example, identification by a means of a national identity number may be problematic in some countries. On the other hand, safe and simple identification systems have been developed for other applications, like for example online banking services, and development of a safe, simple, and socially acceptable system for driver identification may possibly build on experiences from such applications.

4.2 Comparing expected effects of driver authentication with alcolock and speed limiter

Since alcohol influence and/or speeding occur in more than 80% of crashes among unlicensed drivers, one should consider carefully whether mandatory implementation of existing systems like alcolock and intelligent speed limiters (ISA) would be more cost-effective solutions than a system for electronic driver authentication. When we refer to ISA in this article, we consider only mandatory (intervening) ISA, which prevents vehicles from exceeding the speed limit.

As a basis for evaluating possible effects of different systems, we counted the proportion of all fatal crashes for each combination of the risk factors 1) unlicensed driving, 2) alcohol influence, and 3) speeding well above the speed limit (above the normal limit for license withdrawal) for the at-fault driver. Note that in this analysis we have excluded crashes where speeding is judged to be "too high for the conditions", because this does not necessarily mean above the speed limit; therefore, some crashes involve speeding below the influence area of a speed limiter. Table 3 shows percentage of crashes for all combinations of the three risk factors, separately for cars and heavy vehicles on one hand and powered two-wheelers and ATVs on the other hand. Figure 1 shows a Venn diagram with percentages of crashes for all combinations of the three risk factors for the total number of crashes.

On the background of the fatal crash analysis, the crash reduction potential of an electronic driver authentication system alone for all motorized vehicles is estimated at 10.1% percent of fatal crashes.

However, assuming alcolock and ISA are 100% effective in preventing crashes related to alcohol influence and speeding over the limit for license withdrawal respectively, each of those two measures will prevent a larger share of crashes than electronic driver authentication. For alcolock, the estimated reduction is 14.2%, and for ISA 13.7%. Due to the overlap between unlicensed driving, speeding, and driving under the influence of alcohol, the total effect of the three measures will be less than the sum of each single effect. Implementing all three measures in all motorized vehicles is estimated to prevent at least 27.6% of fatal crashes; i.e., the sum of all percentages inside the three circles in Figure 1.

Table 3. Fatal road crashes 2005-2014, by vehicle category and involvement of all possible combinations of alcohol influence, speeding and unlicensed driving. Speeding is defined as speed above the limit for immediate license withdrawal, which is considerably higher than the speed limit. Percent of all crashes in category.

	Vehicle category				
	Cars and heavy vehicles (n=1478)		Motorcycles, mopeds, and ATVs (n=231)		All categories (n=1850)*
Risk factor	% of crashes in category	% of all crashes	% of crashes in category	% of all crashes	
Alcohol only	6.6	5.3	7.4	0.9	6.2
Speeding only	7.3	5.8	11.3	1.4	7.2
Unlicensed only	3.5	2.8	16.5	2.1	4.9
Alcohol + speeding	4.7	3.8	1.3	0.2	3.9
Alcohol + unlicensed	2.7	2.2	3.9	0.5	2.6
Speeding + unlicensed	0.7	0.6	4.3	0.5	1.1
All three factors	1.4	1.1	3.0	0.4	1.5
Any combination	27.1	21.6	47.6	5.9	27.6

* The total number is higher than the sum of the two vehicle categories, because there were 141 crashes where at-fault vehicle category was not specified. None of the three risk factors were present in any of these crashes.

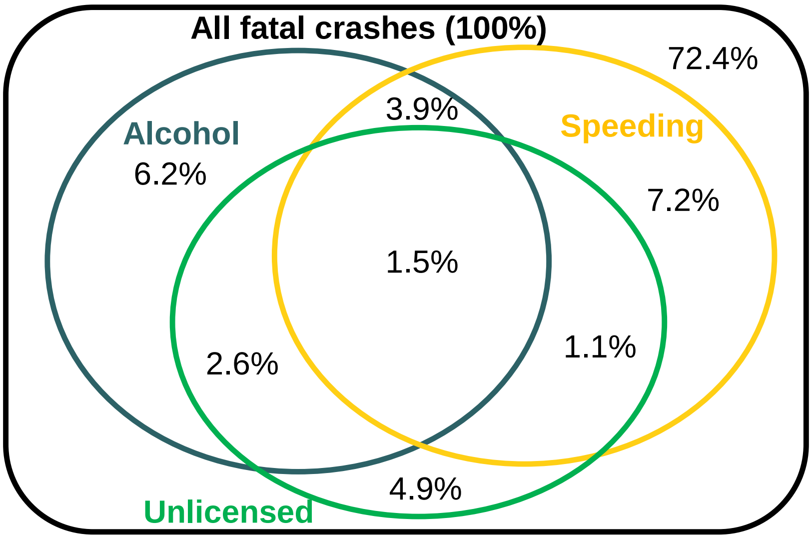

Figure 1. Fatal road crashes 2005-2014, by contribution of alcohol influence, speeding, and/or unlicensed driving. Percent. Speeding is defined as speed above the limit for immediate license withdrawal, which is considerably higher than the speed limit.

4.3 Considerations of countermeasure effectiveness

The estimates of crash reduction given above are based on the assumption that all three countermeasures are 100% effective in preventing crashes related to the respective risk factors, i.e., unlicensed driving, drunk driving, and speeding above the criterion for license withdrawal. This assumption is probably too optimistic, and we have consequently made an additional and more conservative estimate for comparison. If we assume that all three measures are only 50% effective, which we believe is a very conservative assumption, the total reduction in fatal crashes will decrease from 27.6% (Table 3 and Figure 1) to 17.2%. The relatively moderate reduction in total effectiveness resulting from a substantial decrease in effectiveness of each single countermeasure is explained by the large overlap between the three risk factors. Since several risk factors are present in the same crash, any of the three countermeasures could have prevented the crash. For example, if only 50% of speed-related crashes are prevented by ISA, a large proportion of the remaining crashes will be prevented by alcolock and/or driver authentication, and vice versa.

5 Discussion

The results from our analyses of unlicensed driving in fatal crashes show prevalence rates in the same order of magnitude as studies from other countries, e.g. Australia (Watson & Steinhardt, 2007; Baldock et al., 2013) and USA (AAA Foundation for Traffic Safety, 2011). Thus, unlicensed driving seems to be a widespread problem. Our finding of overrepresentation of speeding and drunk driving among unlicensed drivers is also consistent with previous research (Watson and Steinhardt, 2007). An interesting difference from other research results is the high proportion of unlicensed moped and motorcycle riders in fatal crashes in our study, with a prevalence about three times higher than for car drivers. In comparison, results from USA (AAA Foundation for Traffic Safety, 2011) show very similar prevalence for those two vehicle categories.

Several alternative countermeasures against unlicensed riding and driving have been discussed in previous studies, e.g., Knox et al. (2003) and Baldock et al. (2013). The most highly recommended approaches seem to be improved detection methods and more effective sanctions. One possibility for more effective detection of unlicensed driving is the use of cameras for automatic number plate recognition (ANPR), connected to a vehicle and license database. A possible sanction is vehicle impoundment. Legal measures like prohibiting unlicensed persons from purchasing a motorized vehicle have also been discussed. However, most alternative countermeasures have serious shortcomings, as pointed out in the mentioned studies. For example, ANPR cameras will fail do detect an unlicensed driver who is not the owner of the vehicle, nor is vehicle impoundment a feasible sanction against those drivers. Furthermore, unless risk of detection is increased considerably above present levels, stronger sanctions will probably not contribute much to preventing unlicensed driving in the first place. Although these alternative measures might possibly be implemented more easily in Norway than the restrictive systems discussed here, they are likely to be far less effective in preventing unlicensed driving and riding.

The relatively high prevalence of unlicensed driving, speeding, and alcohol influence among at-fault drivers in fatal crashes clearly indicates that restrictive in-vehicle technical systems have a large potential for increased safety. Alcolock and speed limiting systems are probably the two most effective measures in terms of the share of fatalities they can prevent. On the other hand, a considerable number of crashes among unlicensed drivers are not related to speeding or alcohol influence, and consequently cannot be prevented by alcolock or speed limiters. Assuming mandatory implementation of both alcolock and ISA (preventing driving above current speed limit), the additional effect of driver authentication was estimated at 4.9% of fatal crashes. Without implementation of alcolock or ISA 10.1% is a more realistic estimate for the effect of driver authentication alone. These estimates may, however, be too modest, considering the unknown number of crashes where a not-at-fault driver is unlicensed, some of which can also possibly be prevented by driver authentication.

Thus, the lack of license status data for not-at-fault drivers is a serious limitation of the prevalence estimates in our study, since there are certainly some crashes where the not-at-fault driver is unlicensed. Consequently, the proportion of fatal crashes involving an unlicensed driver is somewhat underestimated. This implies that the potential preventative effect of a system for driver authentication is underestimated as well.

The extensive overlap between unlicensed driving one hand and both speeding and alcohol influence on the other hand indicates that the majority of crashes among unlicensed drivers can possibly be prevented by installing alcolocks and speed limiters on all motorized vehicles. Electronic driver authentication will, however, have a significant additional effect.

The effect of speed limiters may also be underestimated in this study, because the estimated effect is based only on the share of crashes with speeds much higher than the speed limit. A larger share of crashes was judged to be related to too high speed for the conditions, and we can assume that a significant proportion of those crashes also involved speeding above the speed limit, but below the limit for license withdrawal. However, we do not know the number of such crashes, and therefore they are not included in our estimates. On the other hand, some of the crashes involving extreme speeding may conceivably have been fatal even if the speed had been below the limit. It is therefore difficult to estimate the exact proportion of crashes related to speeding that can be prevented by a mandatory ISA system. Our estimate of a total reduction of fatal crashes by 13.7 % is slightly lower than some previous estimates; e.g. Carsten and Tate (2005) estimated that 37% of fatal accidents could be saved by a mandatory system making it impossible for vehicles to exceed the speed limit.

Concerning alcolocks, a less than 100% effectiveness would imply that the estimated effect is too high. The same would be true also for electronic driver authentication. However, due to the large overlap between the three risk factors unlicensed driving, speeding and drunk driving, a less than 100% effectiveness of each single measure will result in a relatively modest reduction of the combined effect of ISA, alcolock and driver authentication. Even with an effectiveness of each countermeasure as low as 50%, the estimated reduction in fatal crashes is as high as 17.6%. System effectiveness is anyway important for obtaining the largest possible reduction in crashes. It is therefore a challenge for both system developers and authorities to take care that mandatory systems are effective and reliable, and difficult or impossible to tamper with.

Although all three systems are technologically feasible, it will necessarily take several years before the maximum potential effects estimated here are reached, assuming implementation in all new vehicles from a certain date. Furthermore, implementation in practice will depend on several political, administrative and legal considerations. Alcolocks and ISA represent more mature technologies and probably require less communication infrastructure than a driver authentication system. Chances for implementation within a short time horizon may therefore be better for these systems. On the other hand, documentation of crash reduction potential may be an additional factor influencing future decisions regarding implementation of such systems. And if one succeeds in eliminating speeding and driving under influence of drugs and alcohol as crash causation factors, the possible contribution of driver authentication may become more salient. More precise estimates of the potential effects of such in-vehicle systems will hopefully contribute to well-informed political and administrative decisions regarding system implementation.

A future possibility is that the transition into a fleet of fully autonomous vehicles will solve the problem of unlicensed driving by eliminating the driver completely from the loop. However, we believe this scenario is so far into the future that every possible effort should be considered in the meantime to take care that persons who are not fit for driving are prevented from using a motorized vehicle.

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