Evaluation of in-vehicle technologies to prevent unlicensed driving in Queensland and Victoria

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ABSTRACT

Unlicensed driving is a serious problem in many Australian states, with unlicensed driving-related crashes (UDC) costing up to $304 million per year in Queensland, and $176 million in Victoria. In this paper, we present a Benefit-Cost Ratio (BCR) analysis of a set of Intelligent Transportation Systems technologies aimed at preventing unlicensed driving by verifying the driver's identity through biometric technology, as well as the validity of their licence. Utilised together, the technology would essentially take the form of a licence interlock. The goal of this program of research (from which this paper stems) was to provide preliminary recommendations as to which technology is the most beneficial and should be implemented as part of a government-led program increasing the functionalities of electronic driving licences (EDL). The corresponding BCR analysis revealed that fingerprints and finger vascular patterns recognition technologies were found to systematically have the best BCRs. In regard to the most effective manner to implement the technology, a corresponding investigation with five scenarios revealed that the greatest benefits would be achieved with: *(a)* a mandatory system for all banned drivers (e.g., suspensions & disqualifications), and *(b)* a mandatory system for banned drivers under the age of 21 only. Scenario *(b)* performs extremely well, with returns of up to 16 times the investment with a simple fingerprint-based interlock. Although often more modest, all systems were found to have BCRs above 1 in all of the implementation scenarios except one. This paper further outlines the findings in regard to addressing the significant problem of unlicensed driving via emerging technologies.

1. Introduction

Unlicensed driving is a serious and multi-faceted problem in Australia, as people who illegally operate motor vehicles on the roads pose a greater risk to other legitimate drivers due to a higher crash rate (Baldock et al., 2013). More specifically, unlicensed drivers are also overrepresented in severe crashes (Lahausse and Fildes, 2019), single vehicle crashes and those that involve non-traffic control (Wilmink et al., 2008). Previous research has also linked unlicensed driving with recreational road use and drink-driving (Fildes, 2003). Data sourced from the Queensland Department of Transport and Main Roads (TMR) suggests that unlicensed drivers were involved in 6.61% of all crashes from 2005 to 2013. If considering fatal crashes only, this figure increases to 12.05%. A similar pattern of risk exists in Victoria, as for data for 2003-07 indicates comparable crash outcomes of 5.9% for fatal crashes (Catchpole, 2014). Using TMR and VicRoads data we estimated the social cost associated with those crashes to be approximately $304 million per annum in Queensland and $176 million per annum in Victoria. With the ongoing deployment and improvement of modern technologies in cars, technological advances may offer a solution to the unlicensed driving issue. Arguably, licensing technology that links drivers to vehicles holds significant potential to reduce unlicensed driving as well as corresponding crash involvement by preventing unlicensed drivers from operating vehicles (in a similar manner to that of an alcohol ignition interlock). However, it should be noted that not all unlicensed drivers (ULD) are similar. For example, while many have had their licence suspended or cancelled, or have been disqualified, due to a past driving offence, others may be driving with expired licences that they simply forgot to renew or have the incorrect licence class for the vehicle they are operating. Interventions that target ULD can either be focused at the whole group of ULD or at any subgroup e.g., disqualified drivers only.

Automatic Number Plate Recognition (ANPR) has been flagged as one approach to detect ULD and had shown some preliminary deterrent effects (Wilmink et al., 2008). However, ANPR can only help stop ULD once they are on the road and operating with ANPR still requires significant policing resources. A more efficient approach may be to completely stop an ULD from being able to start their vehicle. In this regard,

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a previous study by AARB (Baldock et al., 2013) concluded that the most effective tool to prevent unlicensed driving would be an electronic driving licence (EDL) interlock (EDLI). Preliminary trials were undertaken in Sweden in the mid-1990s (Goldberg, 1995, 1997; Myhrberg, 1997), the most concrete research so far in this domain, but seemingly never led to any implementation among the general public. The main limitation of an EDL-based system as the one tested in Sweden is that it only verifies that the presented EDL is valid: it does not verify the identity of the person presenting this licence. So, it could be relatively easy for a disqualified or suspended driver to use the licence of a friend or partner, increasing the possibility of circumvention. To solve this problem, the EDLI can be combined with biometrics, which offer a wide potential to verify the identity of the driver. Since the 1990s, improvements in biometrics have led to several EDLI systems being proposed (Ashwin et al., 2013; Divya and Padmasarath, 2013).

Following the conclusions of Baldock et al. (2013). (Catchpole (2014)), it is necessary to start quantifying the exact benefits expected from the implementation of an EDLI, as well as quantifying the costs associated with different implementation approaches to estimate their exact social benefit. Presently, there is little peer-reviewed research regarding EDLIs. Scientific evidence does not permit informed judgment on: *(1)* the most appropriate technologies, *(2)* the best implementation approaches, and *(3)* current barriers and, conversely, *(4)* potential facilitators to widespread deployment. This paper proposes to perform such an analysis and computes the BCRs for different types of EDLI based on biometric technology.

The aim of this paper is to identify technologies and implementation scenarios (e.g. which population should be targeted for deployment) to maximise benefits for two states of Australia (Queensland and Victoria) that have quantified the costs of unlicensed driving. Preliminary recommendations can then be made for the benefit of road safety stakeholders and help direct future research toward the most promising technologies. The results presented in this paper are based exclusively on mathematical modelling derived from data provided by state governments and from the literature; no new data was collected.

2. Method

2.1. Overall methodology

The methodology used in this paper is divided into four parts:

- First, the social cost of ULD-related crashes will be estimated based on data provided by TMR for the 2005–2013 period and VicRoads for the 2009–2013 period. The aim is to extract the cost of crashes involving ULD, both multiple and single vehicle crashes, and calculate the cost per annum and per driver.
- The second task is to generate a number of possible implementation scenarios. Those scenarios will control for exposure to the EDLI, allowing for estimations of the benefits expected from the different systems and technologies when implemented in the real world.
- Thirdly, a review of existing biometric technologies that are applicable to create an EDLI will be undertaken to obtain critical information such as the efficiency of the technology and the cost of such devices. Different EDLIs based on different technologies will be considered. This part is crucial to support subsequent calculations in the fourth task.
- Finally, in a fourth part we will compute the BCR for the different EDLIs in the proposed implementation scenarios. The discussion of the BCR results will permit the identification of observable trends and conclude which scenarios and technologies that are most beneficial to prevent ULD-related crashes and, thus, should be considered for future more in-depth research and implementation.

Table 1
Social costs per crash.

Type of injury	Cost per person (VIC, 2014 $)	Cost per person (QLD, 2014 $)
Fatality	$2,271,132	$3,290,808
Serious injury	$511,415	$328,530
Other injuries	$19,575	$18,204

2.2. Social costs of ULD-related crashes

The cost of crashes is estimated by government agencies in term of community or social costs, using the HARM reduction method developed by the Monash University Accident Research Centre (Vulcan et al., 1992). The dollar value of costs per person for Queensland and Victoria for fatalities, serious injuries, and other less serious injuries were provided by TMR and VicRoads, respectively. We converted them to 2014 Australian Dollars (Table 1) to be used in our calculations. For this study, we assume that there the average cost per person sourced from TMR and VicRoads is representative of the costs of ULD-related crashes.

2.3. Implementation scenarios

Five different EDLI exposure (e.g., implementation) scenarios are considered, shown in Table 2. A total of five technologies (described in Section 3) will be compared with those scenarios.

Those scenarios are designed to propose different strategies to implement EDLI and identify the best returns. Those scenarios have been laid out based on existing practice for alcohol interlocks and suggestions made by previous research from ARRB (Catchpole, 2014); we do not claim to be providing an exhaustive list of possible scenarios. There are two types of scenario: targeted and untargeted.

(Catchpole (2014)), in particular drivers under 21. Young drivers are known to be over-represented in fatal unlicensed driving-related crashes (UDC) (Hanna et al., 2006) Catchpole (2014) that suggests 18.9% of banned drivers have a previous unlicensed driving related ban on their records. This should not be confused with the recidivism rate during the ban period. Indeed, the previous ban could be many years before the latest offence. All the targeted scenarios have a duration (or lifespan) of five years, during which an equivalent number of drivers n_d is equipped with the EDLI each year. As detailed in Section 2.4.4., we assume drivers have the EDLI for a duration of no more than one year.

The first scenario differs from the others as it considers an untargeted progressive fleet-wide implementation (achieved through legislative requirements in all new vehicles), over a duration of 10 years. This is not necessarily a realistic option for an EDLI system due to its blanket nature, but it is useful to include in the analysis to compare with targeted approaches, and also account for similar proposals for alcohol interlock systems.

2.4. Benefit-cost ratios

2.4.1. BCR calculation

The BCR evaluation method used on this study is similar to the one found in papers like (Lahausse and Fildes, 2019; Wilmink et al., 2008; Fildes, 2003; Paine, 2002), and build up on the utilisation of the HARM estimates. The HARM method is particularly useful for assessing the injury mitigation effect of countermeasures installed in vehicles (Lahausse and Fildes, 2019). The BCR evaluation takes the annual HARM reduction that one can expect from implementing an EDLI and spread it over a certain period of time, then compare it to the costs associated with implementing such system. A discounting procedure is also necessary to discount future benefits to the present for an accurate comparison with the initial investment costs. Overall, the BCR (for a 5-year scenario) for a given EDLI can be computed with Eq. (1).

Table 2
Details of the implementation scenarios.

Scenario	Nb. of vehicles equipped yearly (n_d)		Duration (years)	
	QLD	VIC		
1: Fleet-wide implementation, all new registered vehicles	90,512	100,824	10	
2: Mandatory implementation for all banned drivers	202,769	100,401		5
3: Mandatory implementation for all banned drivers under the age of 21	26,484	16,175		
4: Mandatory implementation for all banned drivers with any previous bans, i.e. recidivists	38,323	18,976		
5: Mandatory implementation for all banned drivers with any previous bans, i.e. recidivists, and under the age of 21	5,005	3,057		

$$BCR = \frac{1}{C_{tpv}} \left[\frac{H_0}{V_0} + \frac{H_1}{V_1(1+d)} + \frac{H_2}{V_2(1+d)^2} + \frac{H_3}{V_3(1+d)^3} + \frac{H_4}{V_4(1+d)^4} \right] \quad (1)$$

Where C_{tpv} is the total system cost per vehicle (see Section 2.4.3 for the computation of this value); H_i is the expected benefit (in dollars) in year i (see Section 2.4.2); V_i is the number of equipped vehicle in year ; and d is the discount rate in percent (see Section 2.4.3). If V_i and H_i are the same every year, then we can simplify Eq. (1) to:

$$BCR = \frac{H}{C_{tpv}V} \left[1 + \frac{1}{(1+d)} + \frac{1}{(1+d)^2} + \frac{1}{(1+d)^3} + \frac{1}{(1+d)^4} \right] \quad (2)$$

Equivalent to:

$$BCR = \frac{H}{C_{tpv}V} \sum_{n=0}^{5} \frac{1}{(1+d)^n} \quad (3)$$

2.4.2. Expected benefits

The expected benefits (i.e. the HARM reduction) of an EDLI was calculated based on the assumed number of crashes that could be prevented by implementing this system, depending on several parameters: efficiency, non-circumvention rate, and penetration ratio (exposure). If it were possible to prevent all the crashes related to unlicensed driving, the maximum benefit would be equal to $344.7 million per annum (both states combined). However, the actual number of UDC prevented by any system will be smaller.

$$H = K e_T r \frac{n_d}{n_{UDC}} \quad (4)$$

Eq. (4) describes how to calculate the expected savings H for an EDLI for any given year; K is the yearly social cost for the all the UDC in the selected state, e_T is the EDLI's biometric technology efficiency (see Table 5 in Section 3), r is the non-circumvention rate (see Table 4), n_d is the number of drivers equipped with the EDLI in the selected scenario (see Table 2) and n_{UDC} is the number of UDC in the selected state.

There were $n_{UDC} = 1061$ on average in Queensland between 2005 and 2013 with 513 involving banned drivers, so an exposure scenario as defined for scenario 2 in Table 2 with $n_d = 513$ would have a maximum impact on 513/1061 = 48.31% of the crashes. With an efficiency of 100% ($e_T = 1$) and a non-circumvention rate of 100% ($r = 1$), this would result in a best-case saving of H= $128.5 million per annum. Actual savings will be governed by the values of r and e_T.

Efficiency rates are given in Section 3. The non-circumvention rate represents the system's ability to prevent fraud, spoofing[1], or general circumvention (avoidance) by users. Previous research on alcohol interlock programs suggest that such rates vary from 3 to 6% (Hanna et al., 2006; Watson, 1998). Watson (2003) have found that 62.5% of drivers apprehended driving without a licence were using their own

vehicle. An EDL interlock would be circumventable notably by using someone else's licence. Such an interlock combined with any biometric technology would be much harder to circumvent, depending on the nature of the biometric technology used. The following best non-circumvention rate will be used in this study: EDL interlock 70%; fingerprints 95%; finger vascular patterns 97.3%; speech recognition 80%; face recognition 85%; iris scan 97.3% (more details in Table 4). The 97.3% value stems from a 3% offence rate recidivism, where 90% are driving a different vehicle as mentioned previously (Hanna et al., 2006; Watson, 1998).

2.4.3. System costs

The costs for an EDLI program include capital costs and operational costs. Operational costs, which include maintenance/servicing and removal of the devices, are not included in this analysis. Indeed, the maintenance cost of most systems is likely to be low or null from the road authorities' point of view as compared to the capital costs; furthermore, operational costs would generally be covered by drivers through the system's leasing. For the rest of this study we will focus primarily on the costs accrued by the state governments instead of the costs in-cured by the users. The total cost per vehicle C_{tpv} is computed as follows in Eq. (5):

$$C_{tpv} = C_d + \frac{C_p}{V} \quad (5)$$

Where C_d is the device cost; C_p is the program cost incurred by the state government for the EDLI program; and V is the number of vehicles involved in the selected scenario. Costs accrued over the program's lifespan are discounted back to the first year using a discount rate d (Eqs. (1)–(3)) of 4%–7% (different rates are accounted for as government agencies or states use different values (Lahausse and Fildes, 2019).

The device cost C_d includes the device itself (e.g., electronics, sensors) and the labour cost for the installation in the vehicle (based upon costs for alcohol interlock programs in Victoria and Queensland). Again, some of this cost could be assumed by the drivers themselves, such as in the existing alcohol interlock programs.

A further "program cost" C_p must be included to represent the capital investments necessary to either adapt the Queensland EDL program so it can support the EDLI (e.g. including the necessary information on the licence chip, installing the infrastructure to update cards in TMR public locations, etc.), or either implement an EDL program in Victoria. The program cost for Queensland is estimated to be $15 million for the present analysis, about half the cost of the original program. Compared to Queensland, which moved from pure pen-and-paper licences to a full EDL-capable system, Victoria already operates part of the necessary infrastructure to establish an EDL program. As such, the program cost for the state (EDL + EDLI) is estimated to be $30 million for the present analysis. Program costs are reported on the drivers using an EDLI, as shown in Table 3 (the technologies combinations listed in the table are described in Section 3, Table 5).

2.4.4. Assumptions

We took the following assumptions to reduce the complexity of the

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[1] Spoofing is defined as presenting a fake biometric record to the system, such a fake fingerprint made of resin for a fingerprint sensor or holding a picture of a different person in front of the camera for a face recognition based system.

Table 3
Candidate technologies costs.

		EDL Interlock	EDL + fingerprints	EDL + finger veins	EDL + speech	EDL + face	EDL + Iris
Device cost per vehicle		$200	$220	$300	$205	$220	$1,000
Including program (scenario 1)	QLD	$366	$386	$466	$371	$386	$1,166
	VIC	$498	$518	$598	$503	$518	$1,298
Including program (scenario 4)	QLD	$591	$611	$691	$594	$611	$1,391
	VIC	$1781	$1801	$1881	$1786	$1801	$2,581

Table 4
Non-circumvention rates.

	Best	−10%	−20%
EDL interlock	70%	60%	50%
fingerprints	95%	85%	75%
finger veins	97.3%	87.3%	77.3%
speech	80%	70%	60%
face	85%	75%	65%
iris	97.3%	87.3%	77.3%

BCR analysis: *(i)* only single and double vehicles UDC are preventable; *(ii)* costs are mostly capital cost; *(iii)* program cost is identical for all EDLI type; *(iv)* EDLI are installed in only one vehicle per driver; *(v)* the minimum circumvention rate is 3%; *(vi)* that disqualified drivers are disqualified for, on average, 1 year at maximum; and *(vii)* the proportion of ULD driving a new vehicle is the same as the general population.

For *(i)*, the assumption is based on the difficulty of assigning fault in multi-vehicles crashes; the data used in this study did not allow to determine precisely the nature of involvement of ULDs in such crashes. However, it can be reasonably argued that in the case of a two or single vehicle crash if the ULD was not on the road that day, regardless of fault, the crash would not have happened. Hence, we assume that these crashes are preventable by the EDLI. Assumptions *(ii)* and *(iii)* are covered in Section 2.4. Assumption *(iv)* is based on the established practice of alcohol interlocks, Further discussion on the limits of this assumption-ns is given in Sections 2.3 and 2.4.2. Assumption *(v)* is covered in Section 2.3; the non-circumvention rate is based on the assumption that EDLI circumvention will be similar to that of alcohol interlocks because they are similar kind of technologies. Assumption *(vi)* is based on an average duration of disqualification periods. Disqualification and suspension periods can vary a lot. First offenders, e.g. for drink driving, are likely to receive a three to six months disqualification- period. Cumulative disqualifications may have much larger periods spaning several years. Suspension period are generally shorter than a year, also in the three to six months range for suspensions incurred by speeding or demerit points. Penalties for unlicensed driving are longer (two to five years in Queensland in case of driving while disqualified). We thus assume that one year is the maximum length of EDLI installation for drivers mandated to use one. For assumption *(vii)* there is no reason to expect a priori that ULD are more likely to drive new vehicles than the rest of the general population.

2.4.5. Sensitivity analysis

Sensitivity analysis is required when preforming a BCR analysis. Indeed, a lot of variables could not be easily quantified. For example, it is difficult to assign numbers for notions such as the likelihood that a banned driver would use a vehicle owned by a friend or relative (i.e. the non-circumvention rate defined in Section 2.3). To compensate for such limitations, sensitivity analysis was used to reflect different scenarios and provide a better understanding on how each specific variable affects the expected benefits. Previous research using similar methods (Lahausse and Fildes, 2019; Fildes, 2003) recommended performing an analysis for the discount rate (4, 5, and 7%), principally because different government agencies use different rates (Lahausse and Fildes, 2019). The other variable applied to sensitivity analysis was the non-

circumvention rate (best, best minus 10%, and best minus 20%, see Table 4), which is the variable where it is the most uncertain that the assumption taken for this BCR analysis will hold, given the difficulty to quantify such rate. This approach allowed to reduce a potential optimistic bias in the BCR results, especially in the "best minus 20%" rate, which considers a scenario where the system is particularly easy to circumvent, with e.g. only one in two simple EDL interlock non-circumvented in this particular scenario.

3. Unlicensed driving prevention technologies

A review of the literature identified five well established biometric technologies to be paired with an Electronic Driver Licence (EDL), which would facilitate verification of the person presenting the EDL. Those five technologies are:

1. **Fingerprint**s – this technology uses the patterns of the user's fingerprints to provide unique identification, usually measured today with a optical or electronic sensor.
2. **Finger vascular patterns** – this technology detects the subcutaneous pattern of veins in the user finger with an optical sensor (infrared) to provide identification.
3. **Speech recognition** – this technology records acoustic patterns unique to each person's voice to provide identification (strictly speaking it is "*speaker* recognition" because it does not attempt to understand the spoken words, just find who said them).
4. **Face recognition** – this technology extracts patterns from the user's face and their relative distances to create a map unique to each user.
5. **Iris recognition** – this technology captures a near-infrared image of the iris to analyse unique patterns (rings, freckles, etc.) found in each eye.

A standalone EDL interlock without biometric verification is also discussed. Although not entirely necessary, the ability to verify the identity of the driver is desirable for any EDLI in order to limit fraud. The advantages and disadvantages of those technologies are presented in Table 5. A system's efficiency is calculated by taking the inverse of the identity verification error's rate; error rates are sourced from the technical literature for each technology.

4. Results

4.1. Social costs of unlicensed driver crashes

The cost of unlicensed driving-related crashes (UDC) in Queensland is estimated to be $303.09 million per annum on average over the years 2005 to 2013; the total cost over this period was $2.5 billion. For the years 2009 to 2013, the cost of UDC in Victoria was estimated to have been $175.8 million per annum, for a total cost of $879 million (see Table 1 for the social costs per injury categories, sourced from VicRoads for Victoria, and TMR for Queensland). These estimates include all crashes that involved at least one unlicensed driver. However, it can be argued that not all these crashes are caused by unlicensed driving. Indeed, in a crash with more than 2 vehicles, the data used to compute this estimate do no identify which party is at fault. Therefore, we were not able to determine precisely the nature of involvement of unlicensed

Table 5
Summary of the literature review for EDL interlock and biometrics.

Technology	Efficiency[2]	Costs[3]	Advantages	Limitations	Practicality	References
EDL interlock	99.9%	$200	High reliability; good user acceptance; EDL already implemented in QLD; low cost	Easily circumvented	Technology already trialled (Sweden) and proven to be well accepted by drivers but has not been pushed to any deployment. Would form the necessary basis for any EDLI. QLD licences could easily be converted	(Baldock et al., 2013; Goldberg, 1995, 1997; Myhrberg, 1997; Goldberg, 1999; Young et al., 2003) (Department of Transport and Main Roads, 2015)
EDLI & fingerprints	99%	$220	Low costs; high reliability; ease of use; current public acceptance; ICAO compliant	Fraud is possible; scaling up issue with existing EDLI systems	Widely available technology; already exist for fleet operators. Steering wheel sensors may be a practical way to verify driver's identity over time,	(Ashwin et al., 2013; Maio et al., 2002; Jain et al., 2007; Champagne et al., 2008; Maltoni et al., 2009; Rubella et al., 2012; Tashk et al., 2012; Cuddihy et al., 2014; Ramkumar, 2014)
EDLI & finger vascular patterns	98%	$300	Low costs; high reliability; fraud-resistant; ease of use	Not ICAO-compliant, acceptance issues, limited research on efficiency	Available commercially and can be combined with fingerprints for improved reliability	(Jain et al., 2007; Liu et al., 2010; Damavandinejadmonfared et al., 2012)
EDLI & speech recognition	80%	$205	Low costs; ease of use; simple hardware;	Low efficiency; vulnerable to environmental conditions; not fraud-resistant; privacy issues	Natural to use and not complex to install, but have lower performance than other technologies and could be rejected by public	(Jain et al., 2007; Reynolds, 1995; Ariyaeeinia and Sivakumaran, 1997; Giarimi and Magnusson, 2002; Delac and Grgic, 2004; Kinnunen et al., 2006; Beigi, 2011; Krupp et al., 2013)
EDLI & face recognition	85%	$220	Ease of use; continuous verification easy; good public acceptance (less invasive); already in use in QLD, VIC, NSW for licence applicants; ICAO compliant	Low efficiency; capture time is long; vulnerable to environmental conditions; not fraud-resistant privacy issues	Some alcohol interlock already use face pictures, and the technology is viewed as less invasive than other biometrics, but performance is major issue	(Jain et al., 2007; Delac and Grgic, 2004; German Federal Government, 2004; Hashimoto, 2006; Abate et al., 2007; Jafri and Arabnia, 2009; Smart Start Interlocks, 2014)
EDLI & iris recognition	99%	$1,000	Very high reliability; fraud-resistant; ICAO compliant	High cost; difficult to use; bulky sensors; privacy issues; high false negative rate	Widely available technology but that has practicality issues for implementation in vehicles (e.g. the "stop and stare" interface), as well as a much higher cost than any other	(Jain et al., 2007; International Biometric Group, 2005; Bowyer et al., 2008)

[2] For systems using the EDL interlock and a biometric technology, the efficiency is a combination of the two systems' rates.
[3] Estimated cost per vehicle per system.

Table 6
UDC costs per age groups (QLD, 2005-13).

	Age group	Total cost	Cost per annum	Unlicensed driver involved	Cost per driver
All crashes	Less than 21	$628,091,167	$76,191,369	2443	$257,098.31
1 vehicle		$355,751,245	$43,154,841	1362	$261,197.68
2 vehicles		$272,339,923	$33,036,528	1081	$251,933.32
All crashes	21-25	$378,042,365	$45,858,892	1630	$231,927.83
1 vehicle		$195,146,593	$23,672,497	733	$266,230.00
2 vehicles		$182,895,771	$22,186,396	897	$203,897.18
All crashes	26-39	$912,553,776	$110,698,454	3323	$274,617.45
1 vehicle		$490,162,766	$59,459,795	1413	$346,895.09
2 vehicles		$422,391,010	$51,238,659	1910	$221,147.13
All crashes	40-59	$265,097,591	$32,157,988	1152	$230,119.44
1 vehicle		$117,594,489	$14,264,944	401	$293,253.09
2 vehicles		$147,503,102	$17,893,045	751	$196,408.92
All crashes	60 +	$53,818,024	$6,528,461	189	$284,751.45
1 vehicle		$10,773,766	$1,306,925	40	$269,344.15
2 vehicles		$43,044,258	$5,221,536	149	$288,887.64

drivers in those crashes. Despite this, for crashes that include one or two vehicles it can be reasonably argued that this crash would not have happened if the ULD was not on the road that day regardless of fault. Indeed, even if the ULD was not at fault, they were illegally present on the road; removing them from the road may have been sufficient to prevent the subsequent crash. Henceforth we are assuming that only such crashes are preventable by an unlicensed driving prevention system (EDLI) and present data relating to those only; they represent more than 70% of the total cost.

Combining both states, the cost of single and double vehicles crashes involving an ULD was calculated to be $344.74 million per annum for 2009–2013. In total, 5234 ULD were involved in those crashes, meaning the average cost per driver was $329,328. More specifically, the cost per ULD was $377,300 in Queensland and $299,371 in Victoria.

The offenders are largely male; the proportion is the same in both states (77%). Costs per age groups are listed in Tables 6 and 7. The distribution of UDC per age group is shown in Fig. 1. One can note how the less than 21 category is over-represented in Queensland.

Offence categories are listed in Tables 8 and 9 for Queensland and Victoria respectively. The distribution of offenders in both states is also shown in Fig. 2. Those are the most relevant categories in terms of preventing unlicensed driving. The most notable difference between the two states is in the "never held a licence" category: only 1.2% in Victoria versus 13.6% in Queensland. Costs per offenders are generally higher in Victoria, except for the inappropriate class group from Queensland which has the highest value overall ($438k). In this group, the offending driver was usually driving a motorcycle without the proper permit, and as a result, crashes involve a significant proportion
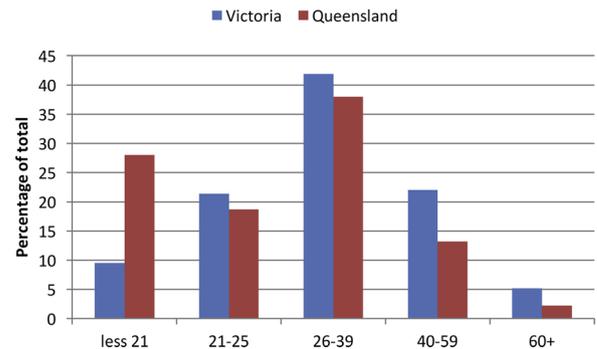

Fig. 1. Distribution of crashes per driver's age groups.

of hospitalisations. In Victoria, this category is less prevalent in the data and has the lowest overall cost per driver (not if counting single vehicle crashes). In both states, people that drove with an expired licence, possibly unknowingly, are among the safest categories. "Banned" drivers, for example cancellations and disqualifications, are the most common type of recorded offenders. In Queensland, 4225 such drivers were involved in crashes between 2005 and 2013 that comprised approximately 2% of the drivers banned during this period. This value can be compared to estimated recidivism rates during the ban period of 3–6% of alcohol interlocks (Hanna et al., 2006; Watson, 1998), suggesting the rate of drivers on the road while banned is higher.

Table 7
UDC costs per age groups (VIC, 2009-13).

	Age group	Total cost	Cost per annum	Unlicensed driver involved	Cost per driver
All crashes	Less than 21	$107,446,692	$21,489,338	228	$471,257.42
1 vehicle		$67,499,056	$13,499,811	113	$597,336.78
2 vehicles		$39,947,636	$7,989,527	115	$347,370.75
All crashes	21-25	$207,112,001	$41,422,400	513	$403,727.10
1 vehicle		$107,080,724	$21,416,145	225	$475,914.33
2 vehicles		$100,031,277	$20,006,255	288	$347,330.82
All crashes	26-39	$416,452,184	$83,290,437	1005	$414,380.28
1 vehicle		$202,518,510	$40,503,702	402	$503,777.39
2 vehicles		$213,933,674	$42,786,735	603	$354,782.21
All crashes	40-59	$174,030,118	$34,806,024	528	$329,602.50
1 vehicle		$72,047,585	$14,409,517	193	$373,303.55
2 vehicles		$101,982,533	$20,396,507	335	$304,425.47
All crashes	60 +	$47,323,490	$9,464,698	125	$378,587.92
1 vehicle		$14,877,867	$2,975,573	37	$402,104.51
2 vehicles		$32,445,623	$6,489,125	88	$368,700.26

Table 8
UDC costs per offence category (QLD, 2005-13).

	Offence	Total cost	Cost per annum	Unlicensed driver involved	Cost per driver
All crashes	Cancelled Disqualified	$1,059,167,351	$128,482,522	4225	$250,690
1 vehicle		$542,007,129	$65,748,291	1781	$304,327
2 vehicles		$517,160,222	$62,734,232	2444	$211,604
All crashes	Unlicensed[4]	$532,821,206	$64,633,991	2070	$257,402
1 vehicle		$275,314,498	$33,397,084	952	$289,196
2 vehicles		$257,506,708	$31,236,906	1118	$230,328
All crashes	Never held license	$305,283,989	$37,032,540	1191	$256,326
1 vehicle		$190,628,921	$23,124,282	735	$259,359
2 vehicles		$114,655,068	$13,908,258	456	$251,437
All crashes	Expired	$155,863,590	$18,907,066	836	$186,440
1 vehicle		$60,618,034	$7,353,284	260	$233,146
2 vehicles		$95,245,556	$11,553,783	576	$165,357
All crashes	Inappropriate	$185,561,898	$22,509,626	423	$438,681
1 vehicle		$101,188,807	$12,274,730	222	$455,805
2 vehicles		$84,373,091	$10,234,896	201	$419,767

[4] Includes drivers that have served their disqualifications period and never re-applied, interstate drivers, and possibly some never licensed drivers.

4.2. Benefit-cost ratios

Results for the BCRs are shown in Tables 10–19. BCR-related literature suggests the following interpretation: a BCR above 3 corresponds to excellent returns, whereas BCR between 1 and 3 are described as acceptable (e.g., still good but not as desirable as a value over 3). Those returns groups are colour-coded in Table 7 to 16 for easier parsing of the results with the following key:

BCR	Returns	Colour
More than 6	Excellent	
3-6		
2-3	Acceptable	
1-2		
Less than 1	Unacceptable	

Scenario 1 – progressive fleet-wide implementation to all newly registered vehicles

Scenario 2 – Mandatory interlock for all banned drivers

Scenario 3 – Mandatory interlock for all banned drivers under the age of 21

Scenario 4 – Mandatory interlock for all banned recidivists

Scenario 5 – Mandatory interlock for all banned recidivists under the age of 21

4.3. Technologies

Almost all technologies yield BCRs above one, showing that because of the cost associated with unlicensed driving, any program preventing
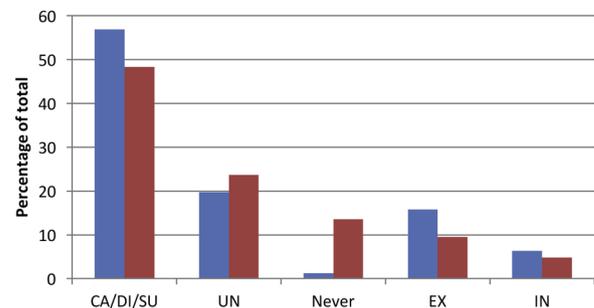

Fig. 2. Distribution of crashes per offence category.

ULD from being on the road will have positive benefits. The sensitivity analysis varying the non-circumvention rates shows that all the technologies continue to yield similar positive BCRs; it is possible to explain some of this robustness by the EDLI exposure models chosen in the scenarios (specifically, a single prevented fatality in Queensland yields the same monetary saving as the costs of equipping 5568 vehicles with a simple EDLI). Regardless of scenarios, the combination of EDLI plus fingerprint biometrics is systematically the best performing technology, followed closely by the standalone EDL and vascular patterns biometrics one. This can be explained by the relatively high success rate of those technologies and their limited capital costs. From an implementation perspective vascular pattern biometrics also provides the advantage of a very high non-circumvention rate as it requires a living

Table 9
UDC costs per offence category (VIC, 2009-13).

	Offence	Total cost	Cost per annum	Unlicensed driver involved	Cost per driver
All crashes	Cancelled Disqualified Suspended	$551,873,188	$110,374,638	1367	$403,711
1 vehicle		$262,904,273	$52,580,855	559	$470,312
2 vehicles		$288,968,915	$57,793,783	808	$357,635
All crashes	Unlicensed4	$199,968,854	$39,993,771	473	$422,767
1 vehicle		$109,523,274	$21,904,655	210	$521,539
2 vehicles		$90,445,580	$18,089,116	263	$343,900
All crashes	Never held license	$10,392,793	$2,078,559	30	$346,426
1 vehicle		$8,112,186	$1,622,437	19	$426,957
2 vehicles		$2,280,607	$456,121	11	$207,328
All crashes	Expired	$136,866,069	$27,373,214	379	$361,124
1 vehicle		$58,104,246	$11,620,849	128	$453,939
2 vehicles		$78,761,823	$15,752,365	251	$313,792
All crashes	Inappropriate	$53,322,062	$10,664,412	152	$350,803
1 vehicle		$25,389,130	$5,077,826	54	$470,169
2 vehicles		$27,932,932	$5,586,586	98	$285,030

Table 10
Scenario 1 QLD: 10 years, program cost $15 million.

Technology / Discount rate	EDL interlock	fingerprints	finger veins	speech	face	iris
Best non-circumvention						
4%	5.10	6.51	5.46	4.61	5.00	2.20
5%	4.84	6.17	5.18	4.37	4.74	2.09
7%	4.36	5.56	4.67	3.94	4.27	1.88
Best non-circumvention-10%						
4%	4.37	5.82	4.90	4.03	4.41	1.98
5%	4.15	5.52	4.65	3.82	4.18	1.88
7%	3.74	4.97	4.19	3.44	3.77	1.69
Best non-circumvention-20%						
4%	3.64	5.14	4.34	3.45	3.82	1.75
5%	3.45	4.87	4.11	3.27	3.62	1.66
7%	3.11	4.39	3.71	2.95	3.27	1.50

hand, unlike fingerprint sensors that can be circumvented by fake fingers made of plastics.

4.4. Scenarios

The absolute best BCRs are found in scenario 4 for Queensland (mandatory EDLI for all recidivists, Tables 16 and 17): EDLI plus fingerprints reaches returns of 9.54 times the investment. However, scenario 4 is not the best overall because the BCRs for Victoria are lower in this instance than compared to scenario 2 (all banned drivers, Tables 12 and 13). Overall the best scenario for both states is scenario 2, where all banned drivers are issued with a mandatory EDLI system. In this scenario, the best performing technology (e.g., fingerprints) has BCRs in the 7–9 to 1 range in Queensland and 4–6 to 1 range in Victoria. This scenario is designed to maximise exposure to the system; although the upfront costs for issuing large number of EDLI systems may be higher, a larger number of crashes can be prevented.

Catchpole (2014), the scenarios that focused on those drivers were scenario 3 and 5. Our results show a sharp contrast in terms of outcome between those two scenarios. One would expect that returns would be high because although drivers under the age of 21 represent 28.34% of the per annum cost of UDC, they only account for 13.06% of all the driving bans in Queensland every year. As a result, they have a rather high per driver cost ($258k), the third highest among age groups. Scenario 3 mandates the EDLI for all banned drivers under 21 and performs reasonably well in Queensland (best BCRs 3–5 to 1) but less so in Victoria with returns on average close to 1.5 to 1 (best is 2.75 to 1). On the other hand, scenario 5, mandating the EDLI for all banned recidivists under 21 is the worst performer for both states and the only scenario to have mostly negative returns. Although this category of offenders has been shown to generate some of the highest costs, BCRs are the lowest of all scenarios because the exposure is fairly limited e.g., only about 5000 drivers every year in Queensland and 3000 in Victoria.

This means that the expected UDC preventable in this scenario go as low as 10 per annum in Victoria, 27 times less than for scenario 2.

The fleet-wide mandatory implementation (scenario 1, Tables 10 and 11) was not found to be a cost-effective strategy compared to the other approaches, except for scenario 5 (recidivists less than 21 years of age, Tables 18 and 19).

5. Discussion

This study is a Benefit-Cost Ratio (BCR) analysis of ITS technologies to prevent unlicensed driving by verifying the driver's identity through biometric technology. The overall goal was to identify the most efficient, cost-wise, combination of EDL interlock technology and deployment scenario in order to inform future research (and possibly implementation). The study was part of a larger project aimed at identifying the public's appetite for ITS products in Australia. Given the scant research on the topic and the direct links with alcohol ignition interlock technology, the latter technology will be utilised to inform the proceeding discussion.

Taken together, the current results can be considered to be very positive regarding the expected benefits of EDLI. Most of the proposed scenarios yield good results with BCRs above 1 for many technologies and scenarios, except for recidivists under the age of 21 (scenario 5). BCRs were always higher in Queensland than Victoria for the same technology/scenario combination. This is easily explained by two factors: *(1)* the program cost in Queensland is half that of Victoria since Queensland already has deployed EDL, and *(2)* Catchpole (2014) to target young drivers are not found to be substantiated by our study.

Regarding alcohol interlocks, early research on their BCR also showed very high potential benefits. For example, in 1991 (Torpey et al., 1991), the BCR for alcohol interlocks was 13 to 1 (for recidivists caught with a BAC over 0.05). After many years of experience in the implementation of alcohol interlocks, studies (Catchpole, 2014; Hanna

Table 11
Scenario 1 VIC: 10 years, program cost $30 million.

Technology / Discount rate	EDL interlock	fingerprints	finger veins	speech	face	iris
Best non-circumvention						
4%	1.84	2.37	2.09	1.66	1.82	0.97
5%	1.74	2.25	1.98	1.58	1.73	0.92
7%	1.57	2.03	1.78	1.42	1.56	0.83
Best non-circumvention-10%						
4%	1.57	2.12	1.87	1.46	1.61	0.87
5%	1.49	2.01	1.77	1.38	1.53	0.82
7%	1.34	1.82	1.60	1.24	1.38	0.74
Best non-circumvention-20%						
4%	1.78	2.32	2.04	1.62	1.78	0.95
5%	1.69	2.20	1.94	1.54	1.69	0.90
7%	1.52	1.99	1.74	1.39	1.52	0.81

Table 12
Scenario 2 QLD: 5 years, program cost $15 million.

Technology	EDL interlock	fingerprints	finger veins	speech	face	iris
Discount rate						
Best non-circumvention						
4%	7.49	9.39	7.48	6.73	7.21	2.63
5%	7.35	9.22	7.34	6.61	7.08	2.58
7%	7.10	8.89	7.09	6.38	6.83	2.49
Best non-circumvention-10%						
4%	6.42	8.40	6.71	5.89	6.36	2.36
5%	6.30	8.25	6.59	5.78	6.25	2.32
7%	6.08	7.96	6.36	5.58	6.03	2.24
Best non-circumvention-20%						
4%	5.35	7.41	5.94	5.05	5.51	2.09
5%	5.25	7.28	5.83	4.96	5.41	2.05
7%	5.07	7.02	5.63	4.78	5.22	1.98

et al., 2006; Paine, 2002; Watson, 1998) have shown that the early BCR studies were a fair representation of the actual benefits that would be gained by implementing such programs. More recently, a study suggested a positive BCR for a fleet-wide implementation of interlocks to all new vehicles in Australia (Lahausse and Fildes, 2019). This is encouraging and lead credence to the results from the current study. However, it should be noted that experience has shown that alcohol interlock programs still have some limitations. There is limited evidence supporting that the interlock's effect continue after it is removed (McCartt et al., 2010; Horberry et al., 2014), which is likely to apply to EDLI too. Some of these limitations can be explained by a low deployment rate in some jurisdiction (Katteler, 2005). Finally, alcohol interlocks are usually evaluated in terms of reduction in DUI recidivism instead of crash reduction. In the present paper, we use the reduction of crashes, and associated social costs, as our main metric.

5.1. Implications for practice

This study shows that the best approach to prevent UDC via in-vehicle technological intervention, is to install EDLI (for a year period) in combination with fingerprints or finger vascular patterns biometrics in all banned drivers regardless of recidivism (scenario 2). The best performance is achieved with fingerprint sensors, and in the long terms finger vascular pattern could perform even better as the technology matures. If total program costs, or limiting the individual costs to targeted drivers, is the stakeholders' main concern, then a simple EDLI without biometric would still be generating positive returns.

When compared to current practice with alcohol interlocks, our results suggest that targeting repeat offenders would not be the most efficient approach. Given that unlicensed driving is not focalised on a smaller sub-component of the driving population, a comparison between the two technologies for recidivist offenders is less warranted. Nevertheless, the "incapacitatory" effects of interlocks have been

repeatedly demonstrated (Morse and Elliott, 1990), and thus EDLI have the potential to create such an effect across a larger proportion of the motoring population. The number of crashes saved may be increased by combining the EDLI with an Catchpole (2014) showed that drivers banned for an alcohol offence were more likely to be affected by alcohol when involved in an UDC than other unlicensed drivers. The most recent ban (the one current at the time of the UDC) was caused by alcohol-related offences in 41.2% of banned drivers.

A number of challenges remain for deploying EDLI on our roads. Government support and political will for tackling this issue appear to have fluctuated over time. After some initial activity in the 1990s (Goldberg, 1995, 1997; Myhrberg, 1997) EDLI had seemingly fallen by the wayside. Even a state like Queensland which already have electronic licences (the only one in the country so far) has not supported any work in this direction when previous research (Baldock et al., 2013; Lahausse and Fildes, 2019; Catchpole, 2014; Watson, 2003) and our figures show that UDC are a significant and costly problem there. The Victorian government initiative that supported our original research shows that road safety authorities are now again taking an increasing interest in this matter, which is salutary given the large benefits that could possibly be obtained from such technology. This growing support may have been influenced by the general success of alcohol interlocks, including both in terms of preventing DUI recidivism and public reception. In this regards it is notable that mandatory fleet-wide implementation of alcohol interlocks to all new vehicles has been recently proposed (Lahausse and Fildes, 2019). An additional challenge will be to obtain public acceptance and support for EDLI itself. Research has suggested that acceptance of vehicle technology systems is firstly dependent upon the driver's awareness of the problem the system is aimed at addressing (Horberry et al., 2014; Katteler, 2005). There is no research surveying the public's awareness about the issue of unlicensed driving. Public support of alcohol interlock is substantial (McCartt et al., 2010), but may not be translated to EDLI because *(1)* the public

Table 13
Scenario 2 VIC: 5 years, program cost $30 million.

Technology	EDL interlock	fingerprints	finger veins	speech	face	iris
Discount rate						
Best non-circumvention						
4%	5.15	6.66	5.85	4.67	5.12	2.72
5%	5.06	6.54	5.74	4.58	5.02	2.67
7%	4.88	6.31	5.54	4.42	4.85	2.58
Best non-circumvention-10%						
4%	4.41	5.96	5.25	4.08	4.51	2.44
5%	4.33	5.85	5.15	4.01	4.43	2.40
7%	4.18	5.65	4.97	3.87	4.28	2.31
4%						
4%	3.68	5.26	4.65	3.50	3.91	2.16
5%	3.61	5.16	4.56	3.44	3.84	2.12
7%	3.49	4.98	4.40	3.32	3.71	2.05

Table 14

Scenario 3 QLD: 5 years, program cost $15 million.

Technology Discount rate	EDL interlock	fingerprints	finger veins	speech	face	iris
Best non-circumvention						
4%	3.83	5.02	4.62	3.49	3.86	2.58
5%	3.76	4.93	4.54	3.42	3.79	2.54
7%	3.63	4.76	4.38	3.30	3.66	2.45
Best non-circumvention-10%						
4%	3.29	4.50	4.15	3.05	3.41	2.32
5%	3.23	4.41	4.07	2.99	3.34	2.28
7%	3.11	4.26	3.93	2.89	3.23	2.20
Best non-circumvention-20%						
4%	2.74	3.97	3.67	2.61	2.95	2.05
5%	2.69	3.90	3.61	2.57	2.90	2.02
7%	2.59	3.76	3.48	2.48	2.80	1.95

may not consider unlicensed driving to be as problematic as drink driving, and *(2)* alcohol interlocks do not involve verification of the driver's identity, hence not resulting in any privacy concerns.

5.2. Limitations

As with any benefit-cost analysis this study has several limitations. BCR calculations imply a range of assumptions (e.g. simplifications) with regards to some variables that are not easily expressed in mathematical form. For example, it is difficult to quantify notions such as the likelihood that a banned driver would use a vehicle owned by a friend or relative. In short, we assumed that *(i)* only single and double vehicles UDC are preventable; *(ii)* costs are mostly capital cost; *(iii)* the program cost is identical for all EDLI type; *(iv)* EDLI are installed in only one vehicle per driver; *(v)* the minimum circumvention rate is 3%; *(vi)* drivers are banned for, on average, 1 year at maximum; *(vii)* the proportion of ULD driving a new vehicle is the same as the general population. Any significant change to those assumptions may change the BCR results and this study's conclusions. For example, multiple vehicles ownership may affect the cost per user (at least for a portion of ULD) and number of EDLI systems deployed.

Calculating costs also has associated limitations, as noted research that compared the observed efficiency and benefits of alcohol interlocks to its predicted benefits (Bruner and Kumar, 2005). In this paper, the program cost is assumed to be the same for all technologies. It could be reasonably argued that only implementing an EDLI would cost less than adding any biometric sensing because the relevant state authority would not have to invest in those sensors and ensure that the licences' chip contains this data. We also ignored operational costs on the basis that they are likely to be much smaller than capital costs required to set up the EDLI program. This assumption is made from the point of view of the state authorities; for targeted drivers, the EDLI would incur a non-negligible cost, like existing alcohol interlock programs. For example, in New South Wales, the yearly cost for the user is $2200 but this include some of the capital costs associated with the purchase and installation. In Queensland, the yearly cost would be approximately $1900. A future analysis will need to account for these costs to users too. Furthermore, we note that our results are highly dependent on the reliable estimate of the social cost of ULD-related crashes by TMR and VicRoads; underestimation of those figures would yield better BCRs, but overestimation may make EDLI non-cost-effective.

With regards to the scenarios considered in this study, a major limitation is that the exact numbers for targeting specific classes of licences was unknown. If learner and probationary permit holders were much more likely to be committing unlicensed driving offences, a targeted program like the Victorian alcohol interlock may still be more appropriate. This is relevant to the fact that our results did not substantiate the suggestion that young drivers should be targeted (Catchpole, 2014).

Finally, our study only looked at combining the EDLI with one biometric technology. Strong suggestion can be found in the literature (Ross and Jain, 2004; Snelick et al., 2005) that combining multiple biometric technologies would improve the overall system performance. Combined systems are recommended in the literature for official identification purpose, and a combination of cheaper and less reliable technologies may yield similar performance than more expensive single technologies.

5.3. Future research

In our results, some BCRs reach high values, up to 9 to 1; this may seem to be too optimistic but is not necessarily the case. Future research should refine these results by incrementally addressing the limitations of the present study. For example, a more detailed study of fault (e.g., culpability) may reveal how many multi-vehicles crashes involving an unlicensed driver were caused by this driver. We ignored those crashes

Table 15

Scenario 3 VIC: 5 years, program cost $30 million.

Technology Discount rate	EDL interlock	fingerprints	finger veins	speech	face	iris
Best non-circumvention						
4%	2.07	2.75	2.69	1.89	2.12	2.05
5%	2.03	2.70	2.64	1.85	2.08	2.01
7%	1.96	2.61	2.55	1.79	2.01	1.94
Best non-circumvention-10%						
4%	1.77	2.46	2.41	1.65	1.87	1.84
5%	1.74	2.42	2.37	1.62	1.83	1.81
7%	1.68	2.34	2.29	1.57	1.77	1.74
Best non-circumvention-20%						
4%	1.48	2.17	2.14	1.42	1.62	1.63
5%	1.45	2.14	2.10	1.39	1.59	1.60
7%	1.40	2.06	2.02	1.34	1.53	1.54

Table 16

Scenario 4 QLD: 5 years, program cost $15 million.

Technology / Discount rate	EDL interlock	fingerprints	finger veins	speech	face	iris
Best non-circumvention						
4%	7.33	9.54	8.55	6.65	7.33	4.29
5%	7.20	9.37	8.40	6.53	7.19	4.21
7%	6.95	9.04	8.10	6.31	6.94	4.07
Best non-circumvention-10%						
4%	6.28	8.53	7.67	5.82	6.47	3.85
5%	6.17	8.38	7.53	5.72	6.35	3.78
7%	5.96	8.09	7.27	5.52	6.13	3.65
Best non-circumvention-20%						
4%	5.24	7.53	6.79	4.99	5.60	3.41
5%	5.14	7.39	6.67	4.90	5.50	3.35
7%	4.96	7.14	6.44	4.73	5.31	3.23

Table 17

Scenario 4 VIC: 5 years, program cost $30 million.

Technology / Discount rate	EDL interlock	fingerprints	finger veins	speech	face	iris
Best non-circumvention						
4%	2.68	3.57	3.46	2.45	2.74	2.55
5%	2.63	3.50	3.40	2.40	2.69	2.50
7%	2.54	3.38	3.28	2.32	2.60	2.42
Best non-circumvention-10%						
4%	2.30	3.19	3.11	2.14	2.42	2.29
5%	2.26	3.13	3.05	2.10	2.37	2.25
7%	2.18	3.02	2.94	2.03	2.29	2.17
Best non-circumvention-20%						
4%	1.92	2.82	2.75	1.84	2.10	2.03
5%	1.88	2.77	2.70	1.80	2.06	1.99
7%	1.82	2.67	2.61	1.74	1.99	1.92

Table 18

Scenario 5 QLD: 5 years, program cost $15 million.

Technology / Discount rate	EDL interlock	fingerprints	finger veins	speech	face	iris
Best non-circumvention						
4%	0.92	1.23	1.21	0.84	0.94	1.01
5%	0.90	1.20	1.19	0.82	0.93	0.99
7%	0.87	1.16	1.15	0.79	0.89	0.96
Best non-circumvention-10%						
4%	0.79	1.10	1.09	0.73	0.83	0.91
5%	0.77	1.08	1.07	0.72	0.82	0.89
7%	0.75	1.04	1.03	0.70	0.79	0.86
Best non-circumvention-20%						
4%	0.66	0.97	0.96	0.63	0.72	0.80
5%	0.64	0.95	0.95	0.62	0.71	0.79
7%	0.62	0.92	0.91	0.60	0.68	0.76

Table 19

Scenario 5 VIC: 5 years, program cost $30 million.

Technology / Discount rate	EDL interlock	fingerprints	finger veins	speech	face	iris
Best non-circumvention						
4%	0.42	0.57	0.57	0.39	0.44	0.54
5%	0.42	0.56	0.56	0.38	0.43	0.53
7%	0.40	0.54	0.54	0.37	0.41	0.51
Best non-circumvention-10%						
4%	0.36	0.51	0.51	0.34	0.39	0.49
5%	0.36	0.50	0.51	0.33	0.38	0.48
7%	0.34	0.48	0.49	0.32	0.37	0.46
Best non-circumvention-20%						
4%	0.30	0.45	0.46	0.29	0.33	0.43
5%	0.30	0.44	0.45	0.29	0.33	0.42
7%	0.29	0.43	0.43	0.28	0.32	0.41

because fault was not available in our data, thus some UDC costs have been not accounted. On the other hand, the circumvention rate may have been underestimated. The correct a priori assessment of the program's costs is a crucial factor as well (Bruner and Kumar, 2005); any future research will have to include the EDLI operation costs, especially those incurred by state governments.

Another important aspect of future research will be to combine multiple technologies; as mentioned in Section 5.2, using only single biometric technologies was a major limitation of the present study. For example, a combination of fingerprints and face recognition may be a cheaper and more efficiently performing approach than the best single-biometric EDLI we studied (i.e. finger vascular patterns recognition). This type of combination is currently used in smart-gates at immigration checkpoints in airports in multiple countries, where the identity verification requirements are high.

Finally, future research should improve the EDLI implementation scenarios by looking at the how different licence classes are more, or less, likely to be committing unlicensed driving offences. The data to achieve this refinement is available from previous studies and state governments but need to be translated to the context of BCR studies.

6. Conclusion

Previous research has shown that unlicensed drivers represent a danger to legitimate drivers due to a higher crash risk, and their over-representation in severe crashes. In Queensland 12% of fatal crashes involved an unlicensed driver (2005-13). In this paper, we conducted a cost-benefit analysis of EDLI and associated biometric technologies to quantify the expect benefits and costs of such systems in two Australian states (Queensland and Victoria). The goal of this analysis was to determine the best EDLI system and to provide recommendation for future research and implementation. The cost-benefit analysis has shown that EDLI combined with fingerprints recognition is the best performing unlicensed driving prevention technology that was under consideration in this paper. Fingerprints recognition is a mature technology, already well received by the public, that could be deployed very quickly on the market. Our paper also suggests that for some small cost increase vascular pattern recognition could improve on some of the fingerprint recognition's limitations without sacrificing the expected returns; the principal limitation of this technology is that it does not have the same level of maturity as fingerprints. Future research is required to identify the benefits of combining multiple biometric technologies in a single system, as recommended by the literature to improve efficiency. In terms of deploying the EDLI on the roads, our paper has shown that the best overall scenario in both states of Queensland and Victoria is a mandatory installation of the EDLI for all banned drivers. Future research is needed in this area to refine this finding by looking at the relative risks of different license classes and type of bans (e.g. suspension vs. disqualifications) which were bundled together in our analysis. Furthermore, the public and government support for such systems remains unknown or ill-defined. Public acceptance has been shown to be tied to the awareness of the problem that the system is supposed to tackle; currently, there is no research surveying the public's awareness about the issue of unlicensed driving. Government support appears to be picking up, but examples of previous research projects in countries like Sweden show that this could falter and lead to little outcome. An EDLI is also dependent upon an electronic driver licence program, which only exists in Queensland at the time of writing. However, given the personal and economic costs of crashes caused by unlicensed driving, which are growing as the motor vehicle fleet expends nationally by about 2% per annum, further focus on this issue is clearly warranted.

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