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Assessing the Safety Outcomes of Selected HVNL Programs in Australia

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Abstract

It is well-established that there is a close correlation between traffic volumes and the number of crashes. It is also recognised that environmental factors such as landscape and weather affect crash rates. Using a spatial econometric analysis, this paper explores deterrence as an additional factor. In particular, deterrence as a result of heavy vehicle regulation. Our research focusses on the effectiveness of three key regulatory programs operating in NSW under the Heavy Vehicle National Law (HVNL): On Road Enforcement (ORE), Safe-T-Cam (STC) and the Intelligent Access Program (IAP).

The developed econometric model finds relationships between each program and the crash rate, providing an indication of their deterrence impact. Under the modelling assumptions presented in this paper, major reductions in NSW of these HVNL program activities could result in an additional 22 crashes per year.

The model results suggest that:

- ORE activity is proactive, where an increase in intercepts could lead to decreases in the crash rate
- There tend to be fewer crashes in regions where there is an STC
- Operators' perception of being observed in the IAP could, marginally reduce the crash rate. It is important to emphasise that the impact of IAP on safety outcomes is much lower than the other two programs as its principle focus is on asset protection.

The results suggest that those programs with a higher chance of notices being issued (ORE and STC) are more effective in deterring non-compliant behaviour and improving safety outcomes.

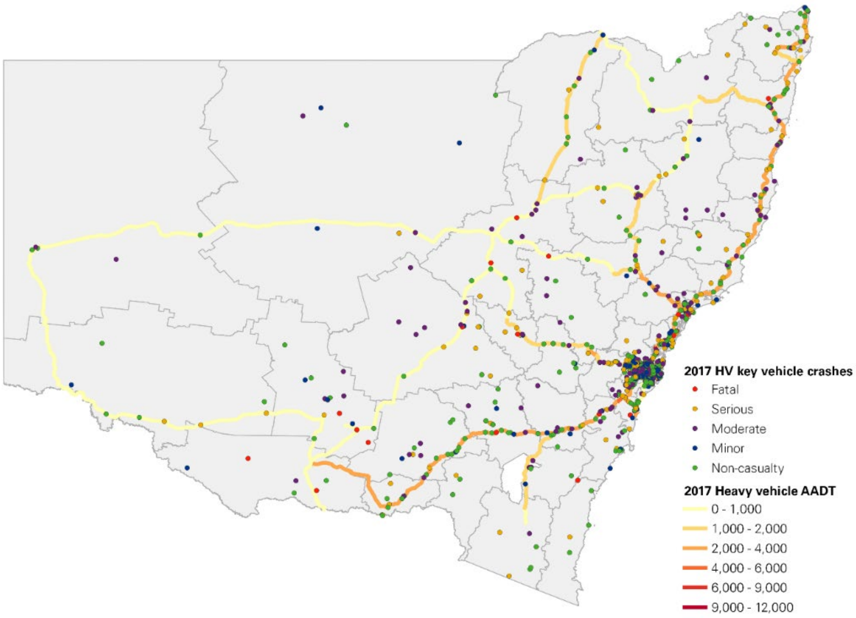
The research is novel as it uses quantitative economic modelling to determine the safety benefit in terms of potential crashes avoided. This has traditionally been difficult for the studied long-established programs due to the inability to perform a before and after comparison.

1. Introduction

It is well-established that there is a close correlation between traffic volumes and the number of crashes. It is also recognised that environmental factors such as landscape and weather affect crash rates. Using a spatial econometric analysis, this paper explores deterrence as an additional factor, in particular, deterrence as a result of heavy vehicle regulation.

Figure 1 illustrates heavy vehicle traffic volumes and crash locations by severity for 2017. While it is clear that there is a higher number of crashes on roads with higher heavy vehicle traffic, there are some regions where volumes are substantially lower, but crashes remain substantial. We posit that this variation in heavy vehicle crash rates can be linked directly back to heavy vehicle regulatory activity and monitoring. This is an important finding as heavy vehicles are overrepresented in crashes more broadly.

Figure 1 Heavy vehicle volumes and heavy vehicle key vehicle crashes



Source: KPMG map from TfNSW Centre for Road safety data and TfNSW traffic volume data

This research focusses on the effectiveness of three key regulatory programs operating in NSW under the Heavy Vehicle National Law (HVNL), specifically:

- **Intelligent Access Program (IAP)**, which is a regulatory telematics system that monitors the speed and location of heavy vehicles to ensure they comply with road access rules
- **On road enforcement (ORE)**, which is made up primarily of on road intercepts of heavy vehicles
- **Safe-T-Cam (STC)**, which is an automated monitoring system that uses digital cameras to read heavy vehicle number plates to monitor fatigue-related offences, and feeds into other compliance activities (e.g. ORE).

2. Literature Review

The basis for our model is in deterrence theory, where deterrence is ‘the prevention of criminal behaviour through the use of, or by the threat of, legal sanctions’ (Tay, 2005). In the context of heavy vehicles, this means that compliance rates would increase if the would-be offenders refrain from committing an offence because of the perceived risk of being punished. This would in turn lead to improved road safety. It therefore is a preventative measure for the bulk of heavy vehicles.

While there has been no similar research specifically on the impact of heavy vehicle regulatory activities on road safety, our research is not without precedent: there is a substantial body of literature linking deterrence-based programs to road safety outcomes. Tay (2005) found that the introduction of random breath testing (RBT) in Queensland reduced the number of alcohol-related fatal crashes by 28.5 per cent. The research highlighted the importance of the visibility of the RBT program, which resulted in increasing the perceived risk of being caught, even though only a relatively low number of drivers were stopped or apprehended. This example is particularly relevant for the ORE program, where a relatively small proportion of trucks are stopped. However, we would expect that the existence of the ORE program and the risk of being caught does have some level of deterrence for heavy vehicle operators and drivers given the direct financial implications of compliance actions on the livelihood of operators and drivers. Thus, it is expected that our model would find a similar negative correlation between crash rates and ORE, as found by Tay with the RBT program.

Mobile speed cameras have been found to have a similar effect. As with RBT and ORE programs, mobile speed cameras introduce the effect of the 'anywhere, anytime' to speed monitoring, something that fixed speed cameras do not have. Christie et al. found that mobile speed cameras reduced the number of injurious crashes by up to 45 per cent on routes where the camera was used (Christie, Lyons, et al, 2003). In Queensland, mobile speed cameras are associated with a 13 per cent reduction in the risk of a crash, and 15 per cent for serious injury crashes (Newstead, Budd, et al., 2018).

For STC, fixed speed cameras are the most relevant example in the literature. The impact of fixed speed cameras varies across studies but can be as large as a 55 per cent reduction in crashes at treated sites (Graham, Naik, et al., 2019). Average speed cameras have a comparable effect, with one study finding a reduction in injury crashes by 16 per cent in the UK (Owen, Ursachi, et al., 2016). For fatal and serious injury crashes, the decrease was higher, at 36 per cent. In NSW, the Centre for Road Safety (2011) found that fixed speed cameras resulted in a 26 per cent reduction in both total crashes and number of casualties. In Queensland, fixed speed cameras were found to have a seven per cent reduction in the risk of a crash (Newstead, Budd, et al., 2018). We expect to find a similar negative correlation between STCs and heavy vehicle crashes in this assessment.

For IAP, Transport for NSW (TfNSW) receives information on all possible breaches to access conditions but does not have the capacity to review all of them to confirm non-compliance. This means that the likelihood for most vehicles in the IAP is that they will not be penalised for non-compliance. Thus, the most relevant deterrence literature relates to the impacts of being observed. Research shows that 'perceptions of detection have stronger effects than punishment severity' for deterring crime (Rauhut, 2015). The fact that IAP operators know that they are being monitored could have a deterrent effect and we could find a negative correlation between IAP activity and heavy vehicle crashes. However, given the very low rate of non-compliance notices issued for vehicles operating in the IAP, this effect is likely to be small and may reduce the longer a vehicle is enrolled in IAP as operators realise this. As a result, we would expect that the program's effect on road safety is substantially lower than that of the other two programs.

3. Overview of data

A common way to measure safety outcomes is by crash rates, such as the number of crashes per vehicle kilometres travelled, or per net tonne kilometres travelled. It is possible to quantitatively model the link between the HVNL programs and crashes using an econometric (regression) model.

As heavy vehicle volumes, crashes and HVNL activity vary across regions, we commenced with a spatial assessment of the HVNL programs, traffic volumes, and the safety outcomes. This provided an understanding on which to structure our regression model. The regions used were Australian Bureau of Statistics (ABS) statistical level 3 (SA3) for regional areas, and SA4s for metropolitan areas in Sydney, Newcastle, and Wollongong. To these, we were able to link the traffic volume data, HVNL program data, and crash data. The outcome of this process is a panel dataset for the regions, consisting of all the datasets aggregated to the regional level from 2015 to 2017. This was the input into the regression analysis. Table 1 provides data summary statistics.

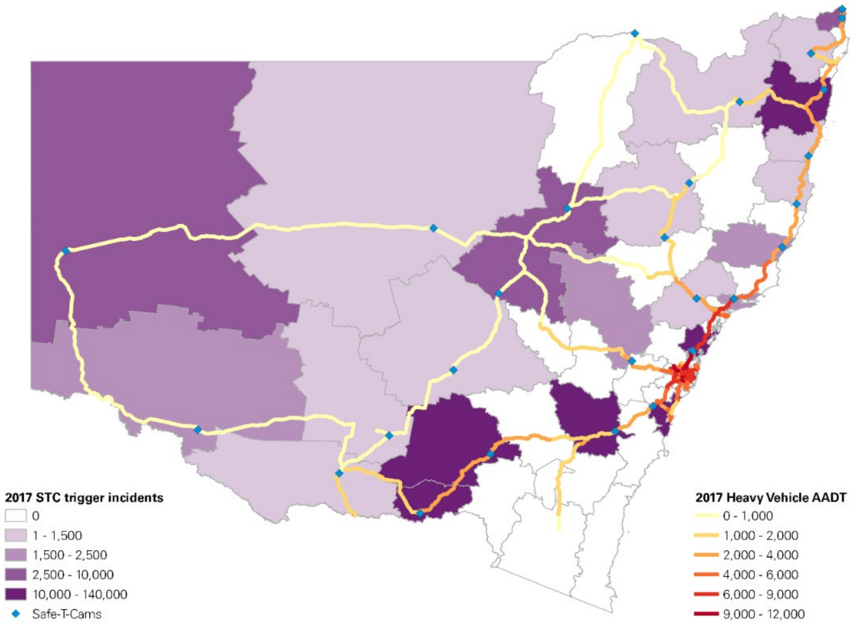
Figure 2 provides an example of the program data used (in this case, STC), where specific incidents or reports are aggregated up each region.

Table 1 Data summary statistics

Dataset	Years available	Number of observations	Period	Categories
Traffic volumes	2015	210	Annual	Two directional traffic flows for: • light vehicles • heavy vehicles • all vehicles.
	2016	208		
	2017	250		
IAP	2015	632,356	Individual non-compliance reports (NCR) reviewed aggregated to annual data	• Scheme of enrolment • Category of NCR • Location (latitude and longitude) • Type of vehicle • Date and time of infringement
	2016	479,960		
	2017	455,840		
STC	2015	249,665	Individual trigger events aggregated to annual data	• All trigger events • Trigger event by category type • Location (latitude and longitude) • The STC that recorded the trigger event • Vehicle type
	2016	327,099		
	2017	372,514		
ORE	2015	330,492	Individual intercepts aggregated to annual data	• Number of intercepts • Intercept location (latitude and longitudes • Date and time of intercept • Number of notices issued (total) • Notices issued by category • Vehicle type • State of registration of vehicle
	2016	344,046		
	2017	333,871		
Safety outcomes (crashes)	2015	1,235	Individual crashes aggregated to annual data	• Key vehicle (heavy vehicle only) • Date and time of crash • Location of crash (latitude and longitude) • Vehicle type and state of registration • Contributing factors • Number of and type vehicles involved • Severity of crash • Primary features of crash location • Speed limit • Road classification • Classification of first impact
	2016	1,194		
	2017	1,200		
Spatial areas (regions)	N/A	59	N/A	• SA3s used for regional areas • SA4s used for Sydney metro areas

Source: TfNSW Compliance and Regulatory Services data, TfNSW Traffic Volume Viewer and TfNSW Centre for Road Safety

Figure 2 Safe-T-Cam locations and number of trigger events



Source: KPMG map from TfNSW Compliance and Regulatory Services data

4. Model

If the programs improve road safety, that is if they reduce the number of crashes, then the coefficients in a mathematical model on the STC location, ORE intercepts, and IAP reviews would be negative. As discussed above, the model focusses on the deterrence effect of the programs which is why it is not necessary to consider compliance outcomes or specific notice types in the model. Further, for all three programs, activity and compliance indicators are highly correlated which means including compliance outcomes in the model would not add any explanatory power.

Population is included to capture key relevant regional characteristics relating to road safety but independent of the three programs. It is expected to have a positive coefficient, as the probability of a crash would increase as population increases.

There are many other factors that contribute to crashes and crash rates apart from regulatory activity. These can include road conditions, weather, time of day, level of traffic, just to name a few. To capture these other variables in the model, the number of crashes per million heavy vehicle kilometres travelled (HVKT) lagged by one year was included as an explanatory variable. Including the lag means that data for the other variables for 2015 could not be included and thus the modelling timeframe spans two years (2016 and 2017).

The preferred regression model illustrates the impact of each program on the number of heavy vehicle crashes at a given time in a given region in a log-linear form.

The preferred model is:

$$crashH_{t,r} = e^{\beta_o + \beta_1 \log pop_{t,r} + \beta_2 stcsD_r + \beta_3 int_{t,r} + \beta_4 + iapt_{t,r} + \beta_5 \log crashH_{t-1,r}}$$

The variables are defined in Table 2.

Table 2 Variable definitions

Description	Variable name
Crashes per million HVKT in region *r* and year *t*	$crashH_{t,r}$
Population per million vehicle kilometres in region *r* and year *t*	$pop_{t,r}$
STC locations per road kilometre in region *r*	$stcsD_r$
ORE intercepts per million vehicle kilometres in region *r* and year *t*	$int_{t,r}$
IAP NCRs reviewed per million vehicle kilometres in region *r* and year *t*	$iapt_{t,r}$

5. Results

Coefficient estimates and key test statistics are presented in Table 3 and their implications will be discussed in turn. For ORE intercepts and IAP NCRs, we accept a slightly higher p-value for the coefficient estimate. This is because we identified some issues with the granularity of the geographic location of some data points for ORE, which would impact its correlation with crash locations. For IAP, only a relatively small sample of NCRs received (an average of five per cent of the total) was used. This is because most NCRs received are not reviewed and therefore do not have an outcome of either compliant or non-compliant. As the inclusion of both variables still improve the model's overall explanatory power, the model provides the first evidence that ORE and IAP reduce crash rates.

Table 3 Model results

Coefficient	Coefficient estimate
Constant	-3.216177***
Log of crashes per million HVKT in region *r* and year *t*	0.501649***
Log of population per million vehicle kilometres in region *r* and year *t*	0.486475***
STC locations per road kilometre in region *r*	-16.272641**
ORE intercepts per million HVKT in region *r* and year *t*	-0.021675*
IAP NCRs reviewed million vehicle kilometres in region *r* and year *t*	-0.012164*
Significance codes: 0 '***'; 0.05 '**'; 0.2 '*' Residual standard error: 0.4289 on 90 degrees of freedom Multiple R-squared: 0.882, Adjusted R-squared: 0.8755 F-statistic: 134.6 on 5 and 90 DF, p-value: < 2.2e-16	

The model has an adjusted R^2 of 0.8755 which is a high value and suggests that it reproduces the variance in the data well. For example, the model predicted 6.8 crashes in 2016 in Bourke-Cobar-Coonamble SA3, compared to seven actual crashes. Similarly, for Moree-Narrabri SA3, the model predicted 9.1 crashes in 2016, where nine crashes occurred. The coefficient estimates can be interpreted as follows:

- **Constant**
  Since a certain amount of crashes will be random events, one would expect a positive intercept. If all other values are zero, the constant translates to a crash rate of 0.04 ($e^{-3.216177}$) crashes per million HVKT, which, being larger than 0, aligns with expectations.
- **Crashes per million HVKT lagged by one year**
  The coefficient estimates suggest that a certain share of crashes is a result of factors that cannot be influenced by the three programs as they are most likely a result of non-random region-specific factors. Again, the positive coefficient estimate aligns with expectations.
- **Population per million vehicle kilometres**

This variable indicates the traffic density. It can be interpreted in a similar way as the intercept but adds more region-specific information. The positive coefficient estimate suggests a higher risk of a crash in areas with denser traffic, all else equal. This is in line with expectations as the risk and consequence of crashes increases with the number of vehicles on the road.

- **ORE intercepts per million vehicle kilometres**

  ORE intercepts aim to ensure compliance across all aspects of heavy vehicle regulation, although compliance outcomes reflect a strong focus on vehicle road worthiness. Thus, this variable can be interpreted as the effect compliant vehicles have on road safety. The negative coefficient indicates proactive ORE activity where an increase in intercepts sees a decrease in the crash rate.

  This result demonstrates a clear relationship between heavy vehicle compliance and safety outcomes given the close correlation between notices issued and intercepts. As over 60 per cent of notices issued in ORE are defect (about 55 per cent) or mass related (about 10 per cent), this illustrates the importance of monitoring these two categories for non-compliance.
- **STC locations per road kilometre**

  STCs are designed to deter heavy vehicle drivers from driving tired and, to a lesser extent, speeding. The negative coefficient estimate indicates that there are fewer crashes in regions with higher STC densities.

  This finding links the effect of fatigue monitoring on safety outcomes. Over 90 per cent of STC trigger incidents are due to fatigue, indicating that the STC system is fulfilling its role in monitoring fatigue in heavy vehicles.
- **IAP non-compliance reports (NCR) reviewed per million vehicle kilometres**[1]

  The negative coefficient in the model indicates a relationship between IAP and safety outcomes, where increasing the number of NCRs reviewed is correlated with a decrease in the crash rate. The IAP tracks location information on every journey of every vehicle in which the telematics device is installed. This could give drivers the perception that they are continuously observed, and the perceptions of detection would apply even though the likelihood of sanction is very low.

Figure 3 In-sample predictions – Preferred model

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[1] Readers should note that IAP differs from the other two programs in its main objective. While STC and ORE are principally focused on improving safety outcomes, IAP is firstly an asset protection program. Compliance activity in the IAP have focussed on special purpose vehicles (i.e. mobile cranes), as self-declaration requirements make it challenging to sanction freight carrying vehicles. The limited ability to prosecute freight-carrying vehicles under the IAP could limit its deterrence impact. The independent variable used for IAP in this paper is the number of NCRs reviewed. However, this makes up an average of just 12 per cent of 'reviewable' NCRs (i.e. those NCRs where a possible breach has occurred). The balance of NCRs thus goes unreviewed and any breaches unsanctioned.

Testing the residuals confirmed that the model is unbiased in both years and both region types and thus coefficient estimates can be used with confidence.

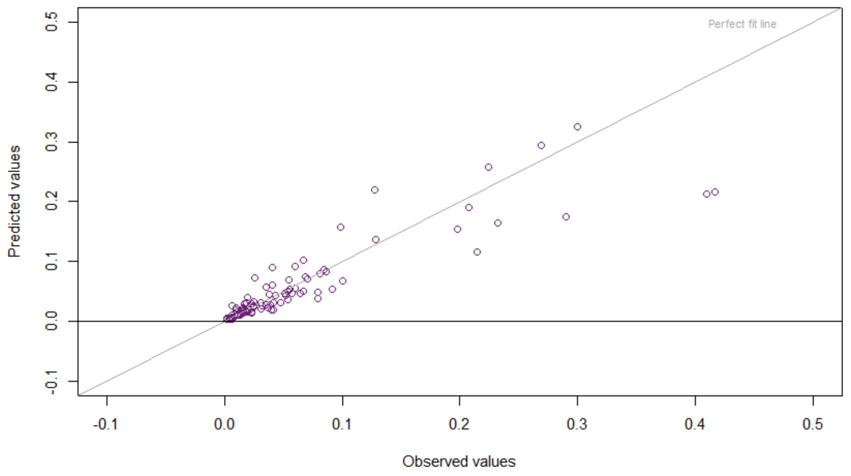


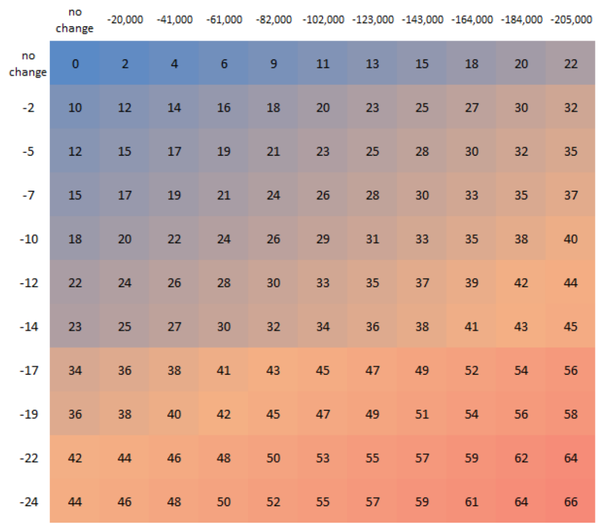
Figure 2 plots the observed data points (x-values) against those predicted by the model (y-values). The clustering of points along the 45-degree line shows that the model reproduces the data accurately.

6. Implications

By comparing model estimates accounting for reduced activity levels with the values predicted by the model, we can estimate the impact these reductions could have on road safety in NSW and derive indicative economic cost or benefit. For each program, activity levels were reduced to zero. Figure 3 presents the estimated number of additional crashes that the model predicts to occur for the simulated activity reductions. The values were derived as the average of the predictions made under 2016 and 2017 traffic conditions. The figure shows that relatively small reductions in activity levels could reduce road safety. The figure shows three panels. The top two show the combined impact of a range of activity levels reductions for two of the three programs. The top row and left column of these panels show the effect of the reduction of the respective program in isolation. The bottom panel shows the combined effect of a reduction in ORE by 100 per cent and the reduction ranges shown for the other two programs. The bottom right square in this panel shows the number of crashes the maximum combined reduction in activity is expected to have. The key observation is that the model predicts 85 additional crashes per year when the activity of all three programs is reduced to zero.

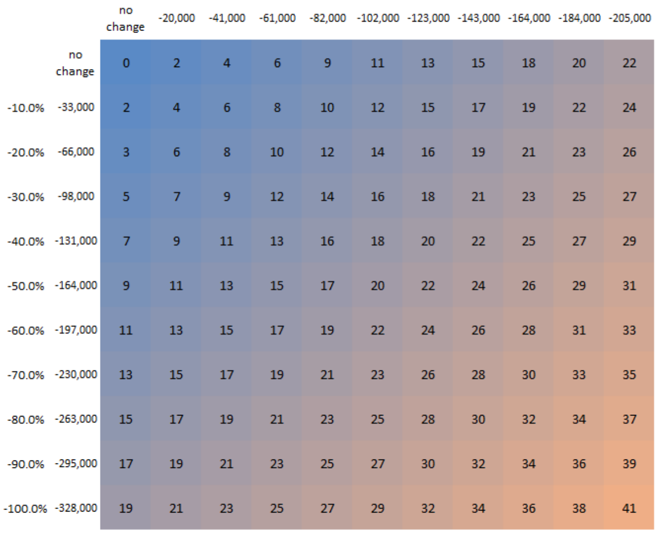
Figure 4 Avoided crash estimates by program

ORE (columns) and STC (rows)



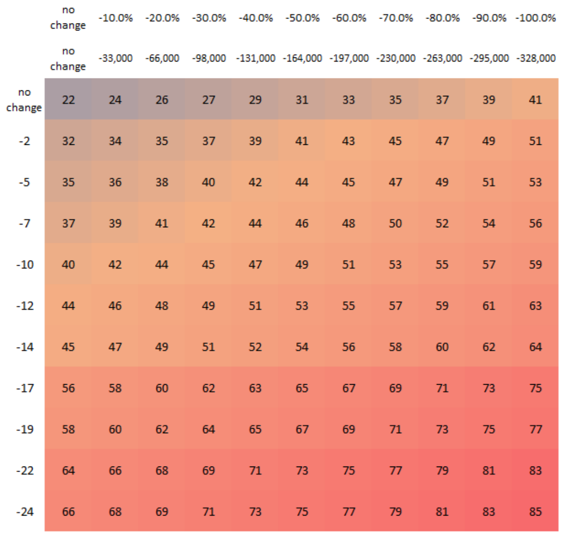
	no change	-20,000	-41,000	-61,000	-82,000	-102,000	-123,000	-143,000	-164,000	-184,000	-205,000
no change	0	2	4	6	9	11	13	15	18	20	22
-2	10	12	14	16	18	20	23	25	27	30	32
-5	12	15	17	19	21	23	25	28	30	32	35
-7	15	17	19	21	24	26	28	30	33	35	37
-10	18	20	22	24	26	29	31	33	35	38	40
-12	22	24	26	28	30	33	35	37	39	42	44
-14	23	25	27	30	32	34	36	38	41	43	45
-17	34	36	38	41	43	45	47	49	52	54	56
-19	36	38	40	42	45	47	49	51	54	56	58
-22	42	44	46	48	50	53	55	57	59	62	64
-24	44	46	48	50	52	55	57	59	61	64	66

ORE (columns) and IAP (rows)



		no change	-20,000	-41,000	-61,000	-82,000	-102,000	-123,000	-143,000	-164,000	-184,000	-205,000
	no change	0	2	4	6	9	11	13	15	18	20	22
-10.0%	-33,000	2	4	6	8	10	12	15	17	19	22	24
-20.0%	-66,000	3	6	8	10	12	14	16	19	21	23	26
-30.0%	-98,000	5	7	9	12	14	16	18	21	23	25	27
-40.0%	-131,000	7	9	11	13	16	18	20	22	25	27	29
-50.0%	-164,000	9	11	13	15	17	20	22	24	26	29	31
-60.0%	-197,000	11	13	15	17	19	22	24	26	28	31	33
-70.0%	-230,000	13	15	17	19	21	23	26	28	30	33	35
-80.0%	-263,000	15	17	19	21	23	25	28	30	32	34	37
-90.0%	-295,000	17	19	21	23	25	27	30	32	34	36	39
-100.0%	-328,000	19	21	23	25	27	29	32	34	36	38	41

IAP (columns) and STC (rows) + 80,000 ORE intercepts less



	no change	-10.0%	-20.0%	-30.0%	-40.0%	-50.0%	-60.0%	-70.0%	-80.0%	-90.0%	-100.0%
	no change	-33,000	-66,000	-98,000	-131,000	-164,000	-197,000	-230,000	-263,000	-295,000	-328,000
no change	22	24	26	27	29	31	33	35	37	39	41
-2	32	34	35	37	39	41	43	45	47	49	51
-5	35	36	38	40	42	44	45	47	49	51	53
-7	37	39	41	42	44	46	48	50	52	54	56
-10	40	42	44	45	47	49	51	53	55	57	59
-12	44	46	48	49	51	53	55	57	59	61	63
-14	45	47	49	51	52	54	56	58	60	62	64
-17	56	58	60	62	63	65	67	69	71	73	75
-19	58	60	62	64	65	67	69	71	73	75	77
-22	64	66	68	69	71	73	75	77	79	81	83
-24	66	68	69	71	73	75	77	79	81	83	85

Crash severity: Share (five-year average) and economic cost

Severity	**Rate**	**Cost per crash**
Crashes Minor/Other injury	15%	$89,314
Serious injury	17%	$574,265
Moderate injury	23%	$97,512
Non-casualty	43%	$10,338
Fatal	2%	$8,586,767
Expected cost		**$316,588**

Source: TfNSW, Centre for Road Safety

Source: KPMG analysis

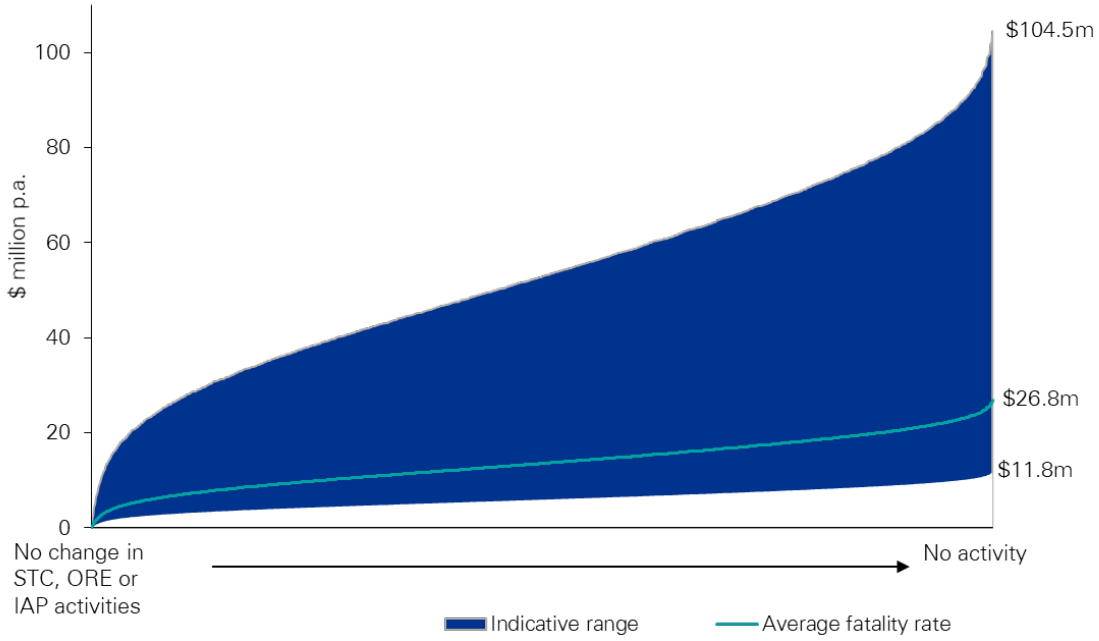
Applying the typical severity split derived from Centre for Road Safety data and the cost per crash published in TfNSW's Economic Parameter Values (2019) presented above we can now estimate the annual value at risk for a given activity reduction. The table shows that the cost of a fatal crash substantially exceeds that of all other severity categories as well as the expected cost across categories. As fatal crashes are also rare and their frequency differs substantially from region to region and year to year, the expected cost alone might not accurately reflect the societal cost of the crashes that the model predicts to occur under lower activity levels.

We therefore estimate the range of values between:

- No fatal crashes which brings down the expected cost per crash to $139,047.
- A fatal crash rate of 13 per cent, representing the upper bound of a 95 per cent confidence interval around the five-year average crash rate presented above, increasing the expected cost per crash to $1,235,180.

Figure 4 shows this range and the expected cost for the combinations of reduction in activity presented in Figure 3 above. Under the average fatality rate, the maximum economic cost of the maximum modelled activity reduction would amount to $26.8 million. If there were no fatalities this figure would amount to $11.8 million. If the fatality rate was at the upper bound of the recent observations, this value could be nine times as high at $104.5 million.

Figure 5 Avoided crash costs range ($2019)



Source: KPMG analysis

7. Conclusion

The econometric model estimated for this study found relationships between each program and the crash rate, providing an indication of their deterrence impact. Under the modelling assumptions presented in this study, major reductions in NSW of these HVNL program activities could result in an additional 22 crashes per year.

The model results suggest that:

- ORE activity is proactive, where an increase in intercepts could lead to decreases in the crash rate
- There tend to be fewer crashes in regions where there is an STC
- The perception of being observed in the IAP could marginally reduce the crash rate. While the IAP is principally focused on asset protection, the program was included in the econometric model to assess its potential to generate indirect safety benefits.

The results suggest that those programs with a higher chance of notices being issued (ORE and STC) are more effective in deterring non-compliant behaviour and improving safety outcomes. The IAP's effect on safety outcomes is significantly smaller which is to be expected.

Under the modelling assumptions presented in this study, the elimination of these HVNL program activities in NSW could result in an additional 85 crashes per year. Based on the average fatality rate over the last five years, reducing the activity of all three programs to zero would amount to a risk of $26.8 million in increased crash costs to the NSW community. If there were no fatalities, this figure would amount to $11.8 million. If the fatality rate was at the

95 per cent confidence level of the recent observations, this would result in an additional 11 fatal crashes, with a cost as high as $104.5 million. The correlation between HVNL regulatory programs and crashes was high overall, but weak for fatal crashes due to their low frequency. This means that upper limit cost estimates should be considered as indicative only.

8. Limitations and future work

The model is subject to the following limitations:

- The model focusses on the deterrence that is created by monitoring and the resulting changes in behaviour. While there is broad consensus in the literature that this effect exists, there is a debate about the impact of the severity and swiftness of sanctions associated with the monitoring outcomes (Davey & Freeman, 2010).
- The road network developed as the common denominator only captures a sample of the roads. It could further enhance the robustness of the model to use detailed traffic data which could be derived from a traffic model. In this case, program activities and crashes could be mapped to specific roads.
- As all three programs have been in place for longer than the modelling timeframe, we were not able to specify the model with data spanning a period without programs. The model could be improved by expanding the time period.
- The safety effect of IAP might be overestimated by the model because it only uses a small sample (an average of five per cent) of the total number of NCRs received. To improve the robustness of these estimates, all of the IAP activities could be included and the distinction made between special purpose vehicles (mobile cranes) and freight-carrying vehicles . The latter is particularly relevant as sanctions have so far focussed on mobile cranes.

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