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# Should we pass on minimum passing distance laws for cyclists? Using signal detection theory to model tactical enforcement options.

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## Abstract

Minimum legal distances for motorists passing cyclists is seen by advocates as a straightforward way to bring about increases in perceived safety and remove a prominent barrier to greater uptake of cycling. The evidence, however, is not as clear. The alternative to compliance-based enforcement via Minimum Passing Distance Laws (MPDLs) is performance-based enforcement as recently implemented by UK Police forces under the banner 'Operation Close Pass'. This relies on roadside driver education and a much greater role for police officer judgement and discretion. For a MPDL to be introduced it has to show an improvement by enforcing more manoeuvres that make cyclists feel unsafe, whilst at the same time not penalising drivers for manoeuvres which are benign. The study used Signal Detection Theory to show that on almost every measure performance-based enforcement is preferable. Officer discretion is aligned more closely to cyclists' real-world perceptions of risk than an objective compliance-based MPDL. Any level of enforcement harshness can be achieved equally well, if not better, through officer discretion than through a fixed passing distance law, with the former being significantly easier to adjust if needed. Passing distance laws also run the risk of a net loss to the effectiveness of cyclist safety because it is more difficult to

prosecute and enforce manoeuvres which make cyclists feel unsafe than the performance-based alternative.

## Keywords

Cycling, Cycling Safety, Road Safety Measures, Vulnerable Road Users.

## Introduction

In the majority of locations cycle pathways are limited or absent meaning bicycles have to share the road with motor vehicles. In these situations motor vehicles, as the faster moving road user, are required to safely navigate around cyclists. Safety is critical, especially in situations involving high speeds or restricted space. Due to the perceived danger several governments around the world have recently passed Minimum Passing Distance Laws (MPDLs). These enable police forces to prosecute drivers who overtake cyclists too closely based on a fixed distance criterion. MPDLs are one of several measures available for removing a key barrier - perceptions of risk - preventing people from switching transport modes from motorised vehicles to bikes (Scottish Government, 2010). MPDL advocates call for a quick introduction as they maintain that such a law must improve safety (UK Government and Parliament, 2016). Unfortunately, despite the intuitive appeal of ‘black and white’ laws there is little evidence to show MPDLs consistently achieve their intended results (RSA, 2018, Schramm et al., 2016). The United Kingdom (UK), like many nations, does not have a specific compliance-based MPDL. Rather, it relies on enforcement of a more general, performance-based nature based on the 1988 Road Traffic Act and the associated Highway Code (Rule 163 and 212) (UK Department of Transportation, 2015; UK Legislation, 1988). Performance-based enforcement relies on police officer discretion, with the written law providing road users with subjective performance targets to meet via their driving behaviour. The specific performance target in this case is Highway Code Rules 163 and 212 which state that "plenty of room" is given when passing a cyclists, “at least as much room as you would when overtaking a car”. This should ensure that “careless, or inconsiderate driving” (UK Legislation, 1988) is avoided. Many in the UK and elsewhere want this to change.

In 2016, an online petition to have a MPDL considered in the UK Parliament was signed by over 23,000 people (UK Government and Parliament, 2016). The petition referred to the recent uptake of MPDLs in other countries and argued that such a law in the UK would reduce bicycle fatalities and accident rates, a claim that has yet to be proven (Schramm, Haworth, Heesch, Watson, & Debnath, 2016). This petition was heard in October 2016 but was rejected by the Department of Transport on the Government's behalf. The reasoning was that: "This type of legislation would be too difficult to enforce and the Government does not believe it would add to the existing rules and guidance" (UK Government and Parliament, 2016). A note of interest and continued review was included in the parliamentary response, leaving room for MPDL to be reconsidered given "time to understand the benefits and impacts of this legislation on cyclists and other road users.". This present study aims to provide much needed understanding of an often hotly contested issue.

**Compliance-Based MPDL**

The MPDLs currently deployed in other countries fall into the compliance-based enforcement category. Objective values, such as passing distance, are prescribed which define the boundaries of acceptable driving behaviour. If the passing distance is greater than that mandated by the law, no offence has been committed (and presumably the cyclist feels safe). If the passing distance is less than that mandated by the law, an offence *has* been committed (and presumably the cyclist feels unsafe). The 2016 UK MPDL petition based many of its claims on examples of MPDL enforcement in other countries (UK Government and Parliament, 2016). Table 1 shows the large range of MPDLs considered in the current study.

*Table 1 – Currently Enforced MPDLs from around the World, showing Compliance Requirements and Area of Jurisdiction*

| MPDL Abbreviation | Compliance Requirements | Area of Jurisdiction |
|---|---|---|
| 2F | 2 Foot (61cm) | North Carolina, USA |
| 3F | 3 Foot (~ 1m) | Majority USA States |
| 4F | 4 Foot (122cm) | Pennsylvania, USA |
| 1.5m | 1.5m | France, Spain, Germany, Belgium, and Portugal |
| TX Law | 1m for cars | Austin, Texas, USA |
| Reduced (Red) TX-Law | 2m for HGV | |
| Q-Law | 1m under 60kmph, 1.5m above 60kmph | Queensland and New South Wales, Australia |
| I-Law | 1m under 50kmph | Ireland* |
| Reduced (Red) TX-Law | 1.5m above 50kmph | |

* Proposed but subsequently (2019) rejected.

France, Spain, Germany, Belgium, and Portugal all have 1.5m MPDL (Clune, 2017; Road Safety GB, 2016; Schramm, Haworth, Heesch, Watson, & Debnath, 2016). Ireland's proposed (but recently rejected) MPDL differs from European norms, varying the distance required with speed as in Queensland (Fine Gael Press Office, 2017). There appears to be little discussion about how effective the mainland European MPDLs are, or even how (or indeed if) they are enforced. In the US, twenty-nine states have MPDLs with the majority opting for a three foot (91cm) passing requirement. Two exceptions are North Carolina, which implemented a two foot (61cm) passing distance, and Pennsylvania, with four feet (1.22m) (National Conference of State Legislature, 2016). The oldest implementation is Wyoming, enacted in 1973, with most other State MPDLs put into force within the last five years. The Austin law requires that "passenger cars or light trucks" give vulnerable road users a minimum three feet of clearance and that larger vehicles give at least six feet (1.82m) (City of Austin, Texas, 2017; austintexasgov, 2013). Enforcement in this case is often based on 'sting operations' conducted by the police (LeBlanc, 2013).

Queensland is the first Australian state to trial, and permanently implement, a MPDL (ABC News, 2016; Schramm, Haworth, Heesch, Watson, & Debnath, 2016). In 2014, Queensland began a two year trial period which mandated vehicles maintain a one metre passing distance when overtaking cyclists in a 60km/h or less speed limit zones (37mph) and maintain a one-and-a-half metre passing distance in areas with a greater than 60km/h speed limit. Research (Schramm, Haworth, Heesch, Watson, & Debnath, 2016) was commissioned to evaluate the effectiveness of the law during this trial period, the main results of which were:

- "the MPD rule has been difficult for police to enforce" (p. 71)
- "drivers have expressed concern about the ease of compliance on narrow and windy roads and where there is adjacent or oncoming traffic" (p. 71)
- "Most riders and drivers surveyed had observed motorists giving bicycle riders more room when overtaking than they used to." (p. 71)
- "The level of observed compliance with the new rule was relatively good" with less than a fifth of drivers purportedly breaking this rule. (p. 71)

This extensive study provides some evidence that MPDLs can be successful, and indeed advocates of MPDL in other regions point to Queensland as "the best and most up to date [..] evidence that MPDL works". (Safe Cycling Ireland, 2017). The evaluation report does, however, state that "it is premature to draw conclusions regarding the road safety benefits of the road rule at this stage." (Schramm, Haworth, Heesch, Watson, & Debnath, 2016). This is because hospital injury statistics had not been released at the time of publication, rendering a direct comparison with pre-MPDL incident rates impossible. Fatality statistics and the preliminary police data also both proved statistically insignificant, but “nevertheless encouraging” (Schramm, Haworth, Heesch, Watson, & Debnath, 2016). Adding to the mixed picture are the sheer number of mandated safe passing distances, from as little as 2 feet (61cm) in North Carolina all the way out to 2m (200cm) in Austin, Texas. Clearly there is no consensus about what an objectively or subjectively safe passing distance is, or even what factors should be considered by the law. A 61cm law is presumably easy to enforce as anything less clearly represents a close pass. A 2m law is certainly generous for cyclists, yet may result in enforcement action being taken on motorists whose manoeuvre was not felt to be subjectively dangerous by the cyclist being passed. Clearly it is a trade-off.

The academic literature reveals cyclist perceptions of passing manoeuvre safety are indeed affected by the objective measurements included in compliance-based MPDL. Speed, lateral passing distance, and the size of the overtaking vehicle, which one paper condensed into an ‘aerodynamic force’ (Carlos Llorca, 2017), are all factors in perceived risk. Cyclists state they consider vehicle speed, type (e.g., trucks or cars), road width and surface condition when making decisions about route choice. These factors influence their perception of a route’s safety and are weighted against distance and time improvement factors when making this choice (Manton, Rau, Fahy, Sheahan, & Clifford, 2016). The factors which MPDLs depend on, therefore, are supported by research to be amongst the most vital in cyclist risk perceptions, but they are not the only ones.

Other factors not considered by MPDLs also play a role. One study found that, ironically, cyclist facilities at junctions increased their perceived dangerousness. The infrastructure itself signalled that an area was dangerous and required intervention (Parkin, Wardman, & Matthew, 2007). It has also been found that increased use of safety equipment such as high-visibility clothing and helmets had a negative effect on perceived safety (Lawson, Pakrashi, Ghosh, & Szeto, 2013) and that changes in cyclist appearance and behaviour, such as helmet wearing or apparent gender, influences how much lateral passing distance drivers gave when overtaking (Walker, Garrard, & Jowitt,, 2014; Walker I. , 2007). The safer the cyclist appeared, the more dangerously motorists drove around them. Findings such as these may suggest that the introduction of a MPDL is recognition of widespread dangerous driving behaviour and a signal to potential cyclists that a higher level of danger is present than is actually the case. This, in turn, could *discourage* mode shift, the reverse of the intended effect (Stanton, et al., 2013). An MPDL may also relax drivers into thinking that the ‘minimum’ passing distance is always appropriate and thus encourage them to pass closer to cyclists than they would without the law. More broadly, with the prospect of punitive enforcement motorists may feel the need to lobby for their own measures, such as enforced use of cycle paths where they exist, tax or registration for bicycles, mandatory helmet use etc. These counterintuitive effects demonstrate that even ‘black and white’ laws bring with them significant grey areas. Under these conditions the role of police officer discretion in a performance-based enforcement paradigm becomes attractive.

**Performance-Based Minimum Passing Distance Laws (MPDLs)**

Performance-based enforcement requires drivers to satisfy safety objectives with a degree of flexibility in how they achieve it. In the UK they must avoid “careless, and inconsiderate, driving” under the Road Traffic Act 1988, c.52, Section 3 (UK Legislation, 1988). As these safety objectives are subjective goals, such as “give cyclists ‘at least as much room as you would when overtaking a car’” (UK Government and Parliament, 2016) disagreement can occur between the driver, the police officer, and importantly the cyclist being overtaken, as all may have different subjective perceptions of risk. This means performance-based laws embody an inherent subjectivity, with disagreement potentially undermining the purpose of the law. The advantage is that many more factors apart from passing distance can be considered, and there is flexibility in how the law is interpreted depending on the context. While undeniably subjective, it does allow some of the disadvantages associated with MPDLs to be surmounted.

An interesting example of performance-based enforcement is ‘Operation Close Pass’ being trialled by UK police forces in the West Midlands and Scotland. This operation uses a plain clothes police cyclist who rides along notoriously cyclist-unfriendly roads in their jurisdiction, and who is then responsible for identifying motor vehicles which have driven dangerous or negligently close to them. In distance terms this is generally stated by police to be less than 1.5m. When subject to one of these manoeuvres the plain clothes officer will radio to their colleagues to pull the offending vehicle over. Once stopped drivers are offered “road-side education” as an alternative to being charged under a specific MPDL. After a year of operation, the first area to trial this operation reported a 20% reduction in serious cyclist collisions. In fact, almost 200 offenders were pulled over, and a further 15 prosecuted (West Midlands Police, 2017).

These findings propelled Operation Close Pass to local and national press attention (BBC News, 2017; Stacey, 2017; Walker P. , 2017). It also offers an interesting point of comparison. Does a subjective performance-based enforcement approach such as Operation Close Pass lead to better outcomes than the application of a fixed rule under a MPDL? In other words, which approach leads to the greatest proportion of manoeuvres which cyclists themselves perceive as unsafe, also being categorized by police as illegal. The problem is fundamentally one of decision-making under uncertainty. Passing distance is very difficult to measure objectively, and in all current cases relies on police officer judgement; cyclist's perception of risk is also highly subjective; and the context, too, introduces another level of uncertainty. Which strategy provides the right balance of enforcement under these conditions? This study sets forth to find out using a novel Signal Detection Theory (SDT) paradigm.

# Method

### Design

The study will achieve its aim of assessing the efficacy of compliance and performance-based passing distance enforcement using Signal Detection Theory (SDT) (Green & Swets, 1966). Subjective perceptions of risk, gathered from members of the public viewing on-bike video clips of passing manoeuvres, form the input. Police officer enforcement decisions, based on the same video clips, form the response. A passing manoeuvre which is judged to be unsafe by cyclists and illegal by police officers is categorised as a Hit (H). An unsafe manoeuvre judged by police officers to be legal but unsafe by cyclists would be a Miss (M). A manoeuvre judged by cyclists to be safe and legal on the part of police officers, is categorised as a Correct Rejection (CR). A safe manoeuvre judged by police officers to be illegal but safe by the cyclists would be a False Alarm (FA). An effective MPDL is one that can discriminate between manoeuvres cyclists judge to be safe (Noise) and unsafe (Signal); a MPDL which maximises Hits and Correct Rejections and minimises False Alarms and Misses.

| | | | |
|---|---|---|---|
| Response | Illegal | False Alarm (FA) | Hit (H) |
| | Legal | Correct Rejection (CR) | Miss (M) |
| | | Safe | Unsafe |
| | | Input | |

*Figure 1 – Signal Detection Theory (SDT) taxonomy applied to the Minimum Passing Distance Law (MPDL) problem. Public perceptions of risk form the input. Police enforcement decisions form the response.*

## Participants

Eighty-three participants provided data for the risk perception-based SDT input. Sixty-five of them were affiliated with the host institution (Heriot-Watt) which is a campus-based university with a large population of regular commuters. They comprised 51 people who identified as male and 14 who identified as female. The over-representation of males to females mirrors national trends, which see men making nearly three times as many cycle trips as women (Cycling UK, 2019). Nineteen (29.2%) participants reported they were regular cyclists. Sixty-one were aged 18 – 25, four were aged between 26 – 34, and one was aged between 35 – 65 (Table 2). The sample is a little younger than the cycling population at large, yet prominently features one of the groups who cycle the most (21-29 year olds) (Cycling UK, 2019). A further eighteen self-selecting participants (not included in Table 2) responded anonymously to an online passing distance consensus survey. These participants also reported they were experienced road users. The study was performed under the ethical scrutiny of Heriot-Watt University with informed consent provided.

*Table 2 – Participants who took part in the passing distance risk perception activity.*

| | Frequency (n=) | Sample proportion (%) |
|---|---|---|
| **Sex** | | |
| Male | 51 | 77.3 |
| Female | 14 | 21.2 |
| **Age stratum (years)** | | |
| 18-25 | 61 | 92.4 |

| | | |
|---|---|---|
| 26-34 | 4 | 6.0 |
| 35-36 | 1 | 0.0 |
| **Cycling habits** | | |
| Regular | 19 | 28.8 |
| Non-regular/none | 46 | 69.7 |

Ten participants provided data for the enforcement-based SDT response. The participants were Police Scotland traffic officers who were all familiar with the trial of Operation Close Pass and the MPDL debate. The sample consisted of two regular cyclists, and one who had performed the duties of the 'undercover cyclist' in Operation Close Pass.

## Materials

*Video Clips of Passing Manoeuvres*

The SDT risk perception survey was completed in person by 66 of the 83 road users, with a further 18 completing the exercise anonymously on-line. Likewise, the enforcement decisions provided by the police were completed in person at the Police Scotland Training College and based on the same 36 video clips.

The footage for the video clips was filmed from a rear facing miniature HD video camera attached to the seat-post of a Peugeot ANC Halfords team replica road bike with a 62cm Reynolds 753r steel frame. This provided a camera height from the ground of 94cm, a vertical field of view (FOV) of 94.4$^{o}$ and a horizontal FOV of 122.6$^{o}$). The bike was ridden a total of just under 600 miles on public roads in traffic, experiencing several thousand passing manoeuvres over the course of approximately 40 hours of riding time. The material includes manoeuvres captured on roads in Queensland, Australia (where a MPDL is active) and Scotland, UK (where – at the time of writing - it is not). Both countries drive on the left and both cycling locations were coastal towns of similar population. All the footage shown occurred in similar dry weather conditions during daylight hours, with the camera equipment mounted at the same height on the same bicycle with the same (male) rider wearing the same cycle clothing (yellow and black cycle club livery). Cycling attire like this is associated with closer passes and was used deliberately in order to experience a range of passing manoeuvres. The police participants commented that the cyclist's riding behaviour was consistently within Police cyclist policy in terms of road position, speed, and apparent proficiency. In all clips they agreed that any incident would likely have been the motorists fault given this limited footage.

Thirty six video clips were selected from the approx. 40 hours of footage to represent an even spread of vehicle sizes, road speeds, and passing distances. These variables were chosen because vehicle size, road speed and passing distance are the ones considered by various MPDLs. These variables were determined as follows:

- **Vehicle size** was determined with reference to the Austin MPDL. Large vehicles include heavy goods vehicles and buses over 7.5 tons; medium vehicles include commercial vans, light trucks, and large passenger vehicles with a trailer or caravan under 7.5 tons; small vehicles include passenger cars. For the clips chosen these categories are unambiguous and do not require further in-depth verification.
- **Permitted road speed** was determined using GPS data attached to the video files. This was used to pinpoint the precise location of the passing manoeuvre, with Google Maps then used to identify road speed signs in the vicinity. Again, for the clips chosen this factor was unambiguous and did not require further in-depth verification.
- **Passing distance** was determined visually as it would be in practice when enforcing MPDLs. This is potentially ambiguous and *does* require further in-depth verification. The first step was to initially determine passing distance using objects in the footage of approximately known size (e.g. drain covers, kerb stones, lane markings etc) to then estimate passing distance to approximately 25cm increments. This initial estimation was used to select the clips used in the study, which in turn were further checked via an on-line distance consensus survey administered to the Police participants. The mean distance estimations provided by the online and Police participants were within 20%/20cm of the initial estimate.

The 36 video clips break down into the following vehicle size, road speed and passing distance categories as shown in Table 1. One clip of a Category 9 passing manoeuvre was used twice in the presentation (clip numbers 11 and 32). This was to provide an internal check on intra-respondent reliability. The 36 clips were also preceded by five practice clips in order to acquaint respondents with the task and stabilise the responses prior to the data collection phase proper.

*Table 3 - Breakdown of Clips by Variables included in the Video Surveys*

| Category | No. of clips |
|---|---|
| Practice | 5 |

| Category | Vehicle Size | | Road Speed | | Passing Distance | |
|---|---|---|---|---|---|---|
| | | No. of clips | | No. of clips | | No. of clips |
| 1 | Small | 12 | Under 60km/h | 6 | Under 1m | 3 |
| 2 | | | | | Over 1m | 3 |
| 3 | | | Over 60km/h | 6 | Under 1m | 1 |
| 4 | | | | | Over 1m | 5 |
| 5 | Medium | 12 | Under 60km/h | 5 | Under 1m | 3 |
| 6 | | | | | Over 1m | 2 |
| 7 | | | Over 60km/h | 7 | Under 1m | 1 |
| 8 | | | | | Over 1m | 6 |
| 9 | Large | 12 | Under 60km/h | 5 | Under 1m | 2 |
| 10 | | | | | Over 1m | 3 |
| 11 | | | Over 60km/h | 7 | Under 1m | 4 |
| 12 | | | | | Over 1m | 3 |


*Figure 2 – Top image shows an example of a category 1 passing manoeuvre clip (small vehicle, under 60kmph, under 1m). Bottom image shows an example of a category 12 passing manoeuvre clip (large vehicle, over 60kmph, over 1m)*

The video showing the five practice clips and 36 experimental clips lasted, in total, nine minutes. It was presented to participants on a central shared screen and the running order was as follows: instructions (30 seconds), five practice clips (1 minute), then 36 experimental clips (7.5 minutes). Each clip was approximately six seconds long. A five second black pause screen was inserted in between each clip, during which participants were expected to complete the risk perception survey. The speed of the clip presentation was a deliberate step designed to induce an initial, intuitive reaction from participants.

*Risk Perception Survey*

The 66 road users providing a risk perception input into the SDT method were provided with an eight-page survey booklet. This contained instructions, five unmarked scales for rating the five practise clips, 36 unmarked scales corresponding to the 36 experimental video clips, and a post-survey demographics questionnaire covering gender, age, cycling habits, and opinions about MPDL. The unmarked scales had 'low risk' on the left and 'high risk' on the right, with participants instructed to place a clear line anywhere on the scale. A ruler template was used to translate the participant ratings into a position, measured in millimetres, along the unmarked scale. As stated above, two identical clips were shown twice as an intra-respondent reliability check. The mean difference in risk ratings between the two identical clips was 9.5 out of 71 (13.2%) with a standard deviation of 10 (14%). A Wilcoxon Signed Ranks test revealed the median ranks of the identical clips to not be significantly different (Z = -0.13, p = ns) with a correspondingly weak effect size (r = 0.01). The hypothesis that rankings of identical clips differed significantly, and are therefore unreliable, is rejected.

*Distance Consensus Survey*

The 18 on-line participants providing distance estimates did so using the same 36 clips, in the same order, as above. This time, however, the respondents were able to view the passing manoeuvre clip as many times as they required, and even pause at the exact moment of passing to allow for better distance estimation. They then responded to each clip with an answer from 0.25m out to 2.5m, in 0.25m increments. A multiple choice drop down menu was used. The mean difference in distance estimations between the two identical clips was 0.4 metres (16%) with a standard deviation of 0.5 metres (20.3%). Six out of the 18 on-line participants rated the same clip identically (33%). Whilst there is an expected degree of ambiguity and variability in the ratings, a Wilcoxon Signed-Ranks Test indicated that the median ranks for the duplicate clips were not significantly different (W = 32.5, p = ns) with a correspondingly weak effect size (r = 0.156). The hypothesis that rankings of identical clips differed significantly, and are therefore unreliable, is rejected.

*Police Survey*

The 10 police participants providing the enforcement response into the SDT methodology also watched the same 36 clips, in the same order, as above. Two questions were asked. Firstly, if you were running Operation Close Pass, how likely "would you pull this vehicle over for a roadside education session?" Secondly, "what do you estimate the passing distance of this vehicle to be?" The enforcement survey responses were captured as shown in Table 2.

*Table 4 – Responses required of Police participants when watching the 36 video clips of passing manoeuvres.*

| "Would you pull this vehicle over for a 'chat on the mat'?" | | | | |
|---|---|---|---|---|
| Very Likely No | Likely No | Unsure | Likely Yes | Very Likely Yes |

| "What do you estimate the passing distance of this vehicle to be?" | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0.25m | 0.5m | 0.75m | 1m | 1.25m | 1.5m | 1.75m | 2m | 2.25m | 2.5m |

The median difference in police ratings of the identical clip was 0.5 of a category (18%) with a standard deviation of 1.04 (20.8%). There are clearly differences arising from the inherent ambiguity of the rating task, as above, however, five out of the ten officers achieved perfect scores (the same enforcement decision for both clips). Where differences existed, the scores increased suggesting the officer was slightly more likely to pull the vehicle over second time around. Overall, these intra-rater differences were not significantly different as revealed by a Wilcoxon Signed Ranks test ($Z = 0.68$, $p$ = ns) in which any observed effect was weak ($r = -0.15$). Again, the hypothesis that rankings of identical clips differed significantly, and are therefore unreliable, is rejected. Interestingly, the five officers who achieved perfect scores had all been involved in the delivery of #OpClossPass.

The corresponding intra-rater reliability for the police distance estimations shows that the identical clips received identical median ratings (MED = 1) with similar standard deviations (Clip 11 SD = 0.31, Clip 32 SD = 0.43). The officer's whose enforcement ratings increased (became slightly harsher) also increased their distance estimation (by between 0.25 and 0.5 metres). Thus the enforcement 'harshness' appears to be corrected by an increased distance rating, perhaps indicating these two factors are related. Once again, despite expected differences in subjective estimations of distance, a Wilcoxon Signed Ranks Test revealed the median ranks were not significantly different ($T = 1.73$, $p$ = ns) albeit with a moderate effect size($r = -0.39$). Yet again, the hypothesis that rankings of identical clips differed significantly, and are therefore unreliable, is rejected.

Comparing police distance estimations (MED = 1; SD = 0.41; $n = 10$) to road user ratings provided via the online questionnaire (MED = 0.75, SD = 0.52, $n = 18$) using a Mann Whitney U test revealed no significant difference ($U = 60.5$, $p$ = ns). Despite this, a small effect was noted ($r = -0.27$), the direction of which suggests that, if anything, police officers estimate distances a little more generously than normal road users. Overall, though, the hypothesis that distance rankings undertaken by police officers and public differ significantly can be rejected.

**Procedure**

*Collection of on-road and survey data*

Rear-facing video data were collected from an on-bike camera as it travelled on public roads interacting normally with traffic.  The video data were screened for all passing manoeuvres, then further screened for manoeuvres which met a range of vehicle size, road speed and passing distance criteria.  The resultant clips were compiled into a nine-minute video presentation, including practice trials.  Pre-set pause s after each clip were provided so that road users could give a subjective risk rating; or an on-line distance consensus rating; and police participants could provide a distance and enforcement rating.  Apart from the on-line distance survey, data collection took place in dedicated survey sessions with the video played to the participants' on-mass.  The survey booklets were collected afterwards.  The data collected from these input, response, and distance rating exercises were then subject to a range of preparatory steps in readiness for SDT analysis.

*Calculate risk rating*

The unmarked risk scale, completed en-mass by the 66 road users, was translated into a 71-point ordinal scale by measuring its width in 1mm increments.  This ordinal scale was then used to rank the clips from lowest (value 1, the least risky clip) to highest (value 36, the most risky clip) in perceived risk order.  Clips with the same ordinal score were given split-ranks.

*Set acceptable risk levels*

An acceptable risk level can be set by dividing the rank-ordered clips shown in Table 3 into safe manoeuvres, the 'noise' which does not require enforcement action.  Or the unsafe passing manoeuvres, the 'signal' which needs to be detected and enforced.  For this study an acceptable risk percentile of 90% safe separates the clips into 32 safe and the 4 most unsafe, with a summed risk value cut-off of 1888.2.  The ability to identify the top 10% most dangerous passing manoeuvres is a realistic goal for traffic enforcement.

*Table 5* – Video clips of passing manoeuvres ranked in order of perceived risk (n = 66)

| Risk Value Ranking | Sum Risk Value | Clip Number | Category | Risk Value Ranking | Sum Risk Value | Clip Number | Category |
|---|---|---|---|---|---|---|---|
| 1 | 301 | 27 | 10 | 19 | 1264 | 5 | 1 |
| 2 | 311 | 13 | 10 | 20 | 1281 | 21 | 12 |
| 3 | 496 | 30 | 12 | 21 | 1290 | 6 | 5 |
| 4 | 589 | 11 | 9 | 22 | 1362 | 23 | 8 |

| | | | |
|---|---|---|---|
| 5 | 659 | 12 | 6 |
| 6 | 662 | 32 | 9 |
| 7 | 678 | 4 | 4 |
| 8 | 797 | 33 | 11 |
| 9 | 811 | 1 | 2 |
| 10 | 832 | 2 | 8 |
| 11 | 849 | 25 | 8 |
| 12 | 1008 | 34 | 4 |
| 13 | 1009 | 3 | 11 |
| 14 | 1034 | 35 | 6 |
| 15 | 1054 | 19 | 4 |
| 16 | 1089 | 14 | 8 |
| 17 | 1145 | 26 | 4 |
| 18 | 1235 | 22 | 2 |

| | | | |
|---|---|---|---|
| 23 | 1375 | 10 | 2 |
| 24 | 1425 | 20 | 8 |
| 25 | 1482 | 28 | 8 |
| 26 | 1567 | 16 | 5 |
| 27 | 1568 | 36 | 10 |
| 28 | 1568 | 29 | 1 |
| 29 | 1651 | 15 | 3 |
| 30 | 1678 | 9 | 4 |
| 31 | 1860 | 31 | 5 |
| 32 | 1883 | 24 | 12 |
| 33 | 1896 | 7 | 7 |
| 34 | 1971 | 17 | 11 |
| 35 | 2127 | 8 | 11 |
| 36 | 2159 | 18 | 1 |

*Undertake performance-based enforcement transformation*

The performance-based responses gathered from the police survey need to be transformed into a range of binary 'illegal' and 'legal' classifications. Four levels of enforcement 'harshness' criterion were developed, giving four separate cut-offs for the illegal/legal boundary (Green & Swets, 1966). These are shown in Table 4.

*Table 6 – Performance-based enforcement criterion defining four different levels of legality/harshness.*

| | | | | | | Criterion |
|---|---|---|---|---|---|---|
| Binary Classification | Legal | Illegal | | | | Very lenient |
| | Legal | | Illegal | | | Lenient |
| | Legal | | | Illegal | | Harsh |
| | Legal | | | | Illegal | Very harsh |
| Police response: "would you pull this vehicle over for a 'chat on the mat'?" | Very Likely No | Likely No | Unsure | Likely Yes | Very Likely Yes | |

*Undertake compliance-based method transformation*

The road speed, vehicle size, and passing distance estimates gathered from the police participants also need to be transformed, this time to derive a range of compliance-based criteria. This means judging the legality of a passing manoeuvre is not based on a performance judgement about whether a manoeuvre constitutes "careless and inconsiderate driving" under the Road Traffic Act

1988, but by applying specific MPDL rules. Table 5 provides an example of how a given passing manoeuvre (a small vehicle, on a 50km/h road, being passed at one metre) would be legal or illegal depending on the specific MPDL in place.

*Table 7* – A passing manoeuvre involving a small vehicle, on a 50km/h road, passing a cyclist at an estimated 1m, complies with (is classified as legal) by the Q-Law, the 2F and TX-Laws. It does not comply (is classified as illegal) under the 1.5m law.

| Passing Manoeuvre | | |
|---|---|---|
| Vehicle Size | Road Speed | Passing Distance |
| Small | 50kmph | 1m |

| Legality Compared to Different MPDLs | | | |
|---|---|---|---|
| Q-Law | 2F | 1.5m | TX-Law |
| Legal | Legal | Illegal | Legal |

*Undertake combined method transformation*

In addition to examining performance and compliance-based enforcement separately, it is also possible to combine them into a hybrid enforcement method. In other words, a passing manoeuvre will only be deemed illegal if both the MPDL and the police officer classified the clip as illegal. For example, a small vehicle, on a 50km/h road, being passed at one metre would, under the combined method with a police officer applying a lenient criterion (i.e. likely, or very likely not to enforce) would be legal under a combined Q-Law and 1.5m Law. Blending the Q-Law and the 1.5m Law with a very harsh performance criterion would be legal on the former, but illegal on the latter.

*Calculate Hit/False Alarm/Miss/Correct Rejection Rates*

The risk perception inputs (road users) and enforcement responses (police) to each of the 36 clips results in hits, misses, false-alarms, and correct rejections (H, M, F, and Cr). The value of these can be used to calculate the rates (R) of H, M, F, and Cr as follows.

$$\textit{Equation 1} - R_H = \mathrm{P(I|U)} = \frac{H}{H+M}$$

$$\textit{Equation 2} - R_F = P(L|U) = \frac{F}{F+Cr}$$

$$\textit{Equation 3} - R_M = P(L|S) = \frac{M}{H+M}$$

$$\textit{Equation 4} - R_{Cr} = P(I|S) = \frac{Cr}{F+Cr}$$

(Stansilav & Todoroz, 1999)

*Calculate Bias (C) and Sensitivity (d')*

A positive bias value (C) signifies a bias towards passing manoeuvres being classified as legal and vice versa. A high sensitivity value (d') signifies a good ability to correctly detect unsafe manoeuvres (the signal) from the unsafe manoeuvres (the noise). In other words, to maximise Hits and Correct Rejections, and minimise False Alarms and Misses.

*Equation 5* - $d' = \Phi^{-1}(R_H) - \Phi^{-1}(R_F)$

*Equation 6* - $C = \frac{\Phi^{-1}(R_H) + \Phi^{-1}(R_F)}{2}$

(Stansilav & Todoroz, 1999)

Sensitivity (d') and bias (C) are assumed to be independent if the distributions of signal and noise are normally distributed and have the same standard deviation/variance (Green & Swets, 1966; Stansilav & Todoroz, 1999). The assumption of a normal distribution is considered reasonable in this instance as the decision to classify the clips as unsafe and safe, or illegal and legal, is based off of an unknown number of random and independent variables (Green & Swets, 1966). The fully compliance-based methods could be said to have too few variables to qualify for the central limit theorem but to develop a consistent criterion, the same consistent assumptions are applied to the whole analysis.

*Calculate Likelihood Ratios*

The likelihood ratios give a measure of how trusted a given classification is. A high illegal likelihood ratio L(I) indicates a better performing law type for illegality classification. The legal likelihood ratio L(L) gives another measure of trust but this time for legal classifications. This time, low values show better performance. These values are calculated as per the following equations:

*Equation 7* - $L(e) = \frac{P(e|s)}{P(e|n)}$

(Green & Swets, 1966)

Where "e" is the event under consideration (Legal or Illegal), "s" is the condition that the signal is present (a passing manoeuvre is rated as unsafe), and "n" is the condition that the signal is absent (the passing manoeuvre is rated as safe). This gives rise to the following likelihood ratios:

Equation 8 - $L(L) = \frac{R_M}{R_{Cr}} = \frac{P(L|U)}{P(L|S)}$

Equation 9 - $L(I) = \frac{R_H}{R_F} = \frac{P(I|U)}{P(I|S)}$

(Green & Swets, 1966)

*Construct Receiver Operating Characteristic (ROC) Curves*

ROC curves are then constructed to visualise how a given law performs on two key criteria; false-alarm and hit rates. The closer the law is to the ideal (hit-rate = 1.00 hit and false-alarm rate = 0.00) the better the minimum passing distance approach performs.

# Results

**Sensitivity (d')**

It can be reasoned that MPDLs which lead to higher sensitivity (d') ratings are preferable. They represent laws which are better at distinguishing 'signal' (illegal close passes) from 'noise' (legal safe passes). The analysis shows that compliance-based laws elicit a range of d' values from 0.96 (the Q-Law) to 2.17 (the 4F and 1.5m laws) as shown in Figure 3. This spread of results seems to indicate that the distance variable, albeit estimated, is nonetheless helpful to police officers in distinguishing the unsafe/illegal 'signals' from the safe/legal 'noise'. Interestingly, laws which consider more variables (e.g. vehicle size and road speed) do not perform consistently better than those which consider distance only.

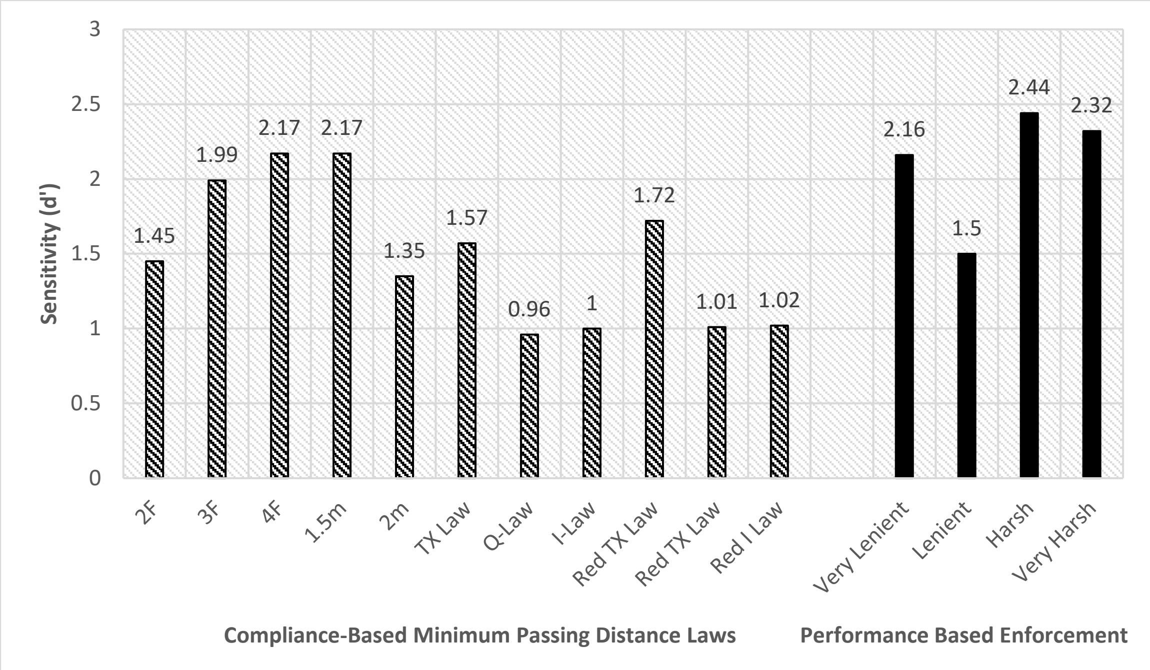


*Figure 3 – Sensitivity (d') values associated with each compliance-based MPDL, and each level of performance-based enforcement*

The performance-based enforcement approaches elicited d' values ranging from d' = 1.5 for the lenient criterion (i.e. police officers likely and very likely *not* to take enforcement action), through to d' = 2.44 for the harsh criterion (i.e. enforcement will occur when police officers feel it very likely, likely, and even when unsure). In fact, the harsh performance-based enforcement approach leads to the highest sensitivity of all measures under consideration. The second highest sensitivity (d' = 2.32) is for another performance-based enforcement measure (the very harsh criterion). The very lenient performance-based enforcement is almost equal to the two best performing compliance-based laws (i.e. 4F and 1.5m). The performance-based approach with the lowest d' ('lenient') still elicits higher sensitivity than six of the compliance-based laws. Importantly, none of the compliance or performance-based approaches fail regarding sensitivity (i.e. none have negative d' values) so all elicit some degree of positive effect on decision-making under uncertainty.

**Bias (C)**

Bias describes an inherent tendency to respond in one direction or another and, generally speaking, is to be avoided. As an artefact of decision-making under uncertainty, however, some level of response bias is common. The question then becomes what sort of bias may be appropriate for a given situation, and if it is present, what steps need to be taken to correct it. In the context of a hard, zero-tolerance policing approach to unsafe passing manoeuvres perhaps a positive bias (C) would be preferred.  This would evidence a propensity towards enforcement and a larger number of safe passes being punished.  In the context of UK policing, which is 'by consent', then 'erring on the side of caution' and allowing a number of unsafe passes to go un-enforced might be desirable compared to the loss of public goodwill that may occur otherwise.  In either case, the results shown in Figure 4 reveal all but three of the compliance-based laws are positively biased.  That is, they err towards punishing safe drivers.  Two of the four performance-based enforcement approaches are also positively biased (Harsh, C = 0.84 and Very Harsh, C = 1.95).

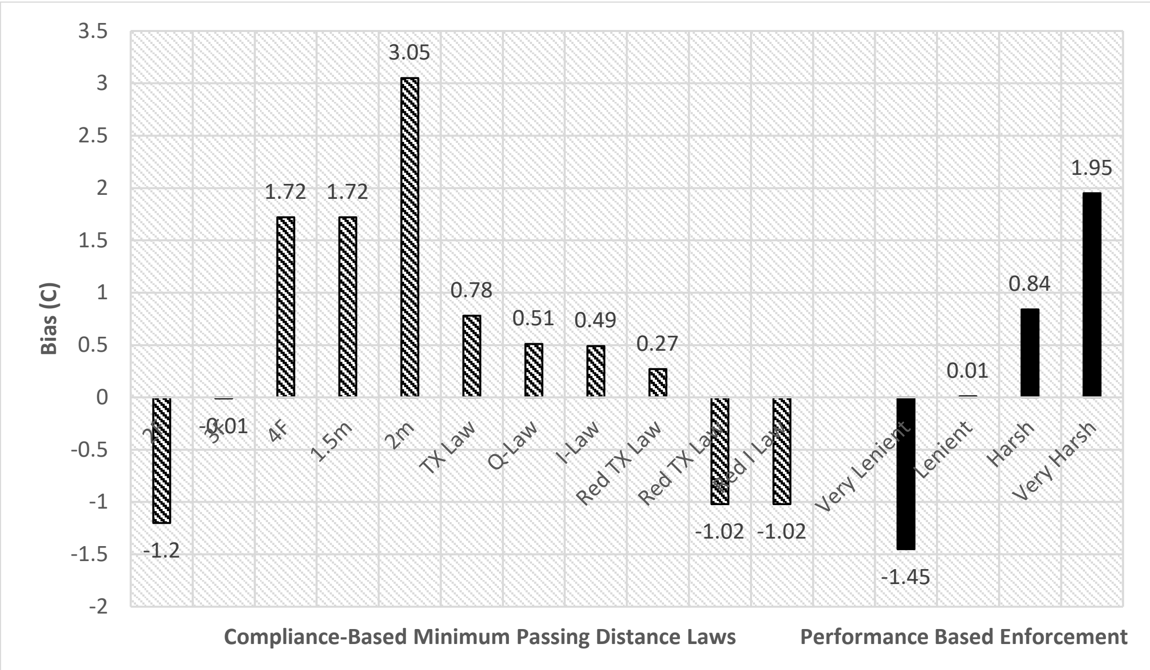


*Figure 4 – Bias (C) values associated with each compliance-based MPDL, and each level of performance-based enforcement*

**Likelihood Ratios**

The illegal likelihood (L(I)) represents trust that when a given law type classifies a manoeuvre as illegal that it is *also* perceived as unsafe.  Given an illegal classification by the police, the manoeuvre is thus L(I) times as likely to be unsafe versus safe.  The legal likelihood (L(L)) is the inverse measure of trust that when a given law type classifies a manoeuvre as legal that it is also perceived as safe. Given a legal classification by the police, the manoeuvre is thus L(L) times as likely to be safe versus unsafe.  The level of trust in L(I) and L(L) judged to be desirable depends on the objectives of the enforcement approaches.  From a policing point of view, high trust in illegal classifications (L(I)) may be of greater importance than trust in legal classifications when called upon to defend such decisions in court. Likewise, trust that offenders will be caught (L(I)) may be of greater importance to cyclists, but trust that safe manoeuvres will not be needlessly punished (L(L)) may be of greater importance to drivers. In general high illegal likelihood (L(I)) values, denoting illegal/unsafe manoeuvres, would be considered desirable. L(I) values around one represent chance performance and are to be avoided. Figure 5 makes these trade-offs explicit.

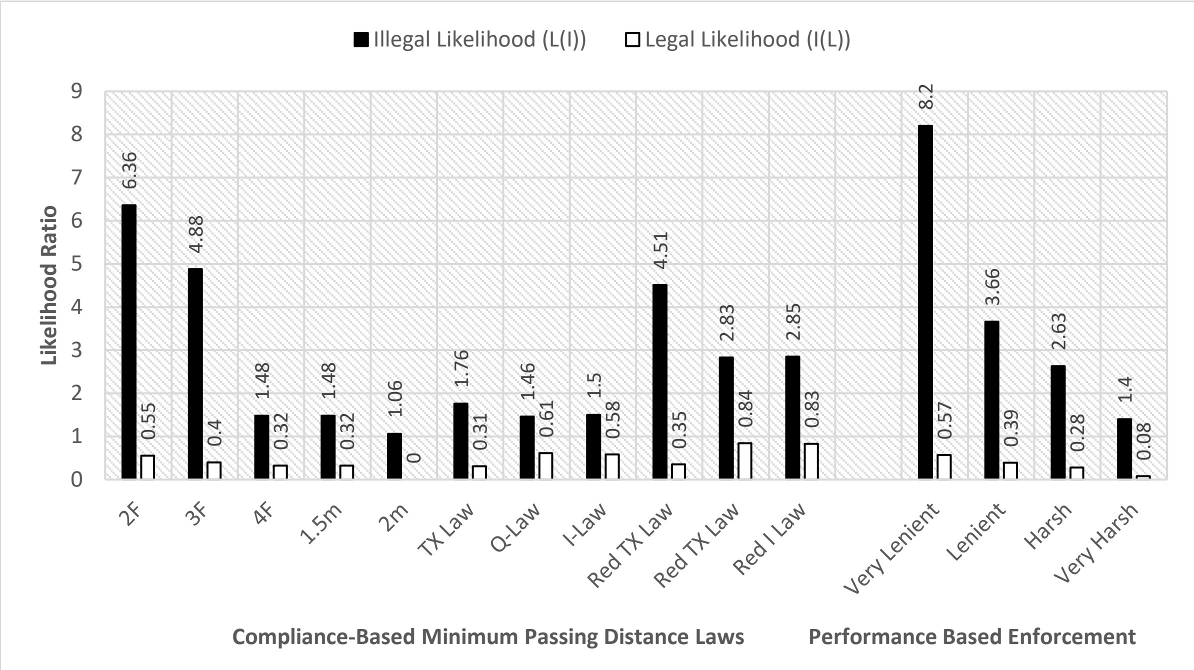


*Figure 5 – Illegal ((L(I)) and legal (L(L)) likelihood ratios associated with each compliance-based MPDL, and each level of performance-based enforcement.*

Many of the compliance-based laws approach a near random chance performance with an illegal likelihood value near one (e.g. L(I) = 1.06 for the 2m law). The harsher MPDLs, such as the 2 foot law (L(I) = 6.36) or reduced Texas law (L(I) = 4.51), are more reliable when they elicit illegal response. This is intuitive because an extreme manoeuvre is required to breach such laws. The more liberal laws (e.g. 4F, 2M, Q-Law, I-Law) perform only slightly better than random chance. The performance-based laws perform markedly better, with all but the harshest criterion achieving L(I) > 2.5, and in the case of the very lenient criterion, as high as L(I) = 8.2, the highest L(I) of the sample. Overall, the performance-based laws are more trust worthy than the compliance-based laws for identifying illegal manoeuvres.

The legal likelihood (L(L)) values for the compliance laws, in which lower values are desirable, show that the most liberal MPDLs perform the best. That is, the majority of clips classified by the police under these rules as being legal are also felt to be subjectively safe. The most generous two metre law performs exceptionally with a zero failure rate. Every police officer in the study identified all of the safe clips using this particular law. The performance-based approaches all perform well again, with some of the lowest L(L) and highest L(I) values. The Very Lenient performance-based approach, for example, elicited a legal likelihood of L(L) = 0.57, equal to the strictest of the MPDLs, but simultaneously eliciting the highest illegal likelihood of L(I) = 8.2.

**Receiver Operating Characteristics (ROC) Curves**

ROC curves show the relationship between Hits and False Alarms under changing decision criteria. In this case, the closer the enforcement approach (compliance or performance-based) is to $R_H = 1$ and $R_F = 1$, the better it performs. Figure 6 shows the ROC-curve for the performance-based enforcement approaches is closer to $R_H$ and $R_F = 1$ than the comparable compliance-based MPDLs. In other words, for similar $R_F$ the performance-based approaches achieve a higher $R_H$ within a given harshness of officer discretion. Only the 1.5m and 4 foot laws perform better than the nearby Very Harsh performance-based approach. Even here, though, the $R_H$ for the Very Harsh performance-based criterion is only slightly lower, but for substantially lower $R_F$. Combined, this can be seen as evidence that the performance-based approach, allowing officer discretion, is superior in supporting decision-making under uncertainty in ways that maximise illegal/unsafe enforcements whilst avoiding legal/safe enforcements.

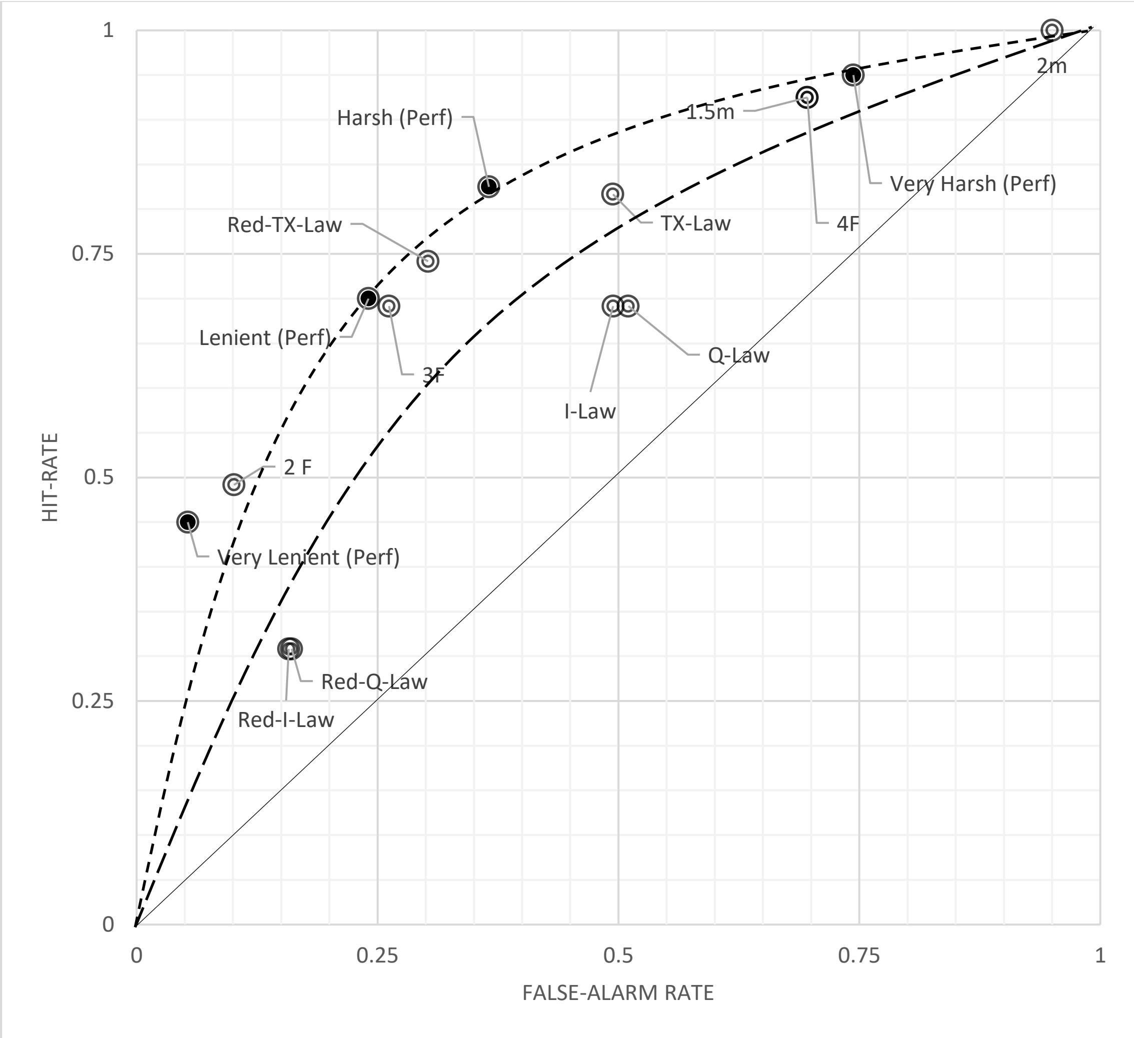


*Figure 6– Receiver Operating Characteristic (ROC) graph showing the ROC curves for compliance-based MPDL (long dashed curve) and performance-based enforcement methods (short dashed curve).*

# Discussion

A SDT approach was used to test the efficacy of compliance and performance-based passing distance enforcement. A successful enforcement method would yield high levels of sensitivity (d'), neutral or negative decision bias (C), high illegal likelihood ratios (L)I)), and low legal likelihood ratios (L(L)). Overall, the results suggest that performance-based enforcement, relying on officer discretion, outperforms compliance-based enforcement, relying on explicit laws. In other words, performance-based enforcement tends to strike a better balance between hits (the classification of illegal/unsafe manoeuvres) and false alarms (illegal yet safe manoeuvres). Whilst the unambiguous nature of rules has an intuitive appeal, and they do (on the whole) elicit non-random beneficial effects on decision-making under uncertainty, the more flexible approach involving police officer discretion offered better performance for both cyclists and motorists. They resulted in fewer motorist being punished for illegal manoeuvres which cyclists feel are safe, yet prosecuting the worst manoeuvres that cyclists feel are unsafe. An interesting feature of the analysis was that the introduction of more rules in the form of additional MPDL variables does not necessarily lead to better classification performance. Indeed, additional rules such as contingence on vehicle size and/or road speed appeared to depend on circumstance. 'Dependence on circumstance', unfortunately, is something MPDLs tend to remove or restrict.

Another important consideration emerges when viewing the ROC curve (Figure 6). The MPDLs are fixed by legislation to a particular point on the curve, or in the case of MPDLs with contingent additional variables, to two or three additional fixed points. Performance-based enforcement, on the other hand, can be easily shifted to any point on the ROC curve by redefining the criterion values of decision-bias (C) and likelihood ratios, depending on the objectives of the law enforcement in a given circumstance. For example, a zero-tolerance campaign could involve officers adopting a very harsh criterion, whereas a softer 'policing by consent' approach would be more lenient. Performance-based enforcement allows full flexibility in how different policing objectives are achieved, when, and where.

MPDLs with particularly generous passing distances (e.g. 4F, 2M, Q-Law, I-Law) were observed to perform only slightly better than random chance in terms of eliciting correct illegal/legal and safe/unsafe classifications. It seems unlikely such performance would find favour with drivers who will be subject to enforcement under them. Linked to this are concerns put forward by the police officers involved in the study. A view was expressed that if punitive enforcement is compromised by having a more difficult to prosecute law, then drivers whose behaviour will only change via punitive measures and not education will be less likely to positively change their behaviour. On the other hand, drivers who are receptive to education will likely change their behaviour equally as much whether reminded that close passing a cyclist is "careless and inconsiderate driving" or whether told that it is a breach of a new specific MPDL.

Thinking more broadly, for nations considering MPDLs this study suggests that SDT metrics would be an effective way of understanding the tactical enforcement options. The results of this study are a clear advance on what is currently known, and the focus on subjective ratings of risk and distance link to both the main driver of mode shift to cycling (e.g. perceptions of risk) and to the method of distance measurement used in practice (e.g. police estimates and judgement). Being based around subjective perceptions of risk and distance, care must be taken to ensure the ratings are appropriate for a given location and culture as they are likely to vary. In terms of SDT's future role in tactical enforcement options for the police, the following high-level approach is recommended:

1. Decide the safety threshold (most likely 90% or above, thus targeting the 10% most dangerous manoeuvres).
2. Decide acceptable false-alarm and hit rates limits.
3. Eliminate enforcement options which fail the bias, sensitivity, and likelihood tests.
4. Consider the remaining options with respect to their performance in these four detailed criteria.
5. Select the option(s) which perform best within culturally and politically acceptable boundaries.

# Conclusions

For a MPDL to be introduced it has to show improvement over the existing traffic laws. Comparing the SDT values of compliance-based MPDLs against the values of existing performance-based regulation suggests that in almost every measure, according to the criteria presented in Table 13, the existing performance-based law is preferable. Officer discretion of what is considered "careless, and inconsiderate driving" under the Road Traffic Act 1988, c.52, Section 3 is aligned more closely to public perceptions of risk than an objective compliance-based view of risk represented by strict MPDL enforcement. The SDT analysis shows that any level of enforcement harshness can be achieved equally well, if not better, through officer discretion than through MPDL, with the former being significantly easier to adjust if needed. MPDLs also run the risk of a net loss to the effectiveness of cyclist safety because it is more difficult to prosecute and enforce manoeuvres which make cyclists feel unsafe than current performance-based regulation. In contrast, the first year of results from the performance-based UK pilot scheme of #OpClosePass shows a promising 20% reduction in cyclist injuries compared to the previous year.

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