VEHICLE SPEED MEASUREMENT II

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Abstract
This paper discusses uncertainties and errors in vehicle speed measurement and the legal implications of these. It provides a proven method of measuring vehicle speed over its working range, without the use of extrapolation, which is conducted in a controlled environment rather than on public roads.

Keywords: speed, speedometers

Introduction

Both federal and state legislation set standards for the accuracy of speedometers installed in motor vehicles. Unless these legislative provisions are compatible, and prosecution policies recognise the accuracy achievable by speedometers installed in vehicles, there is danger that motorists could offend unwittingly. This paper will discuss the interaction of the federal design standard, individual state prosecution policies and the performance of speedometers and associated testing equipment.

The Australian Motor Vehicle Standards Act, (known as the Australian Design Rules, or ADR [1]) sets requirements for speedometers installed in vehicles to be used on the road throughout Australia as:

> *"indicate the actual speed, for all speeds above 40 km/h, to an accuracy of ± 10 percent."*

State Legislatures have also set their own minimum requirement. For example New South Wales Traffic Law [2] requires that speedometers:

> *"indicate, when the vehicle is travelling at a speed in excess of 50 km/h, a speed that is not more than 10% less than actual speed".*

The individual State requirements are all worded differently and may impose different constraints on the performance of speedometers. However none change the "*10% less*" requirement, which is a main contributing factor to the system failure. This accuracy guide method has severe limitations and is only used by persons with a lack of understanding of measurement.

Uncertainties are an integral part of regulations administered by the National Standards Commission, such as those concerning the weighing of products in commerce. Since there is a trend to base the level of fines on exactly how much the speed limit is exceeded, the policy should recognise the effect of uncertainty of measurement and fall into line with other measurements with financial implications. The ADR [1] should take account of the requirements of the ISO Guide to the Expression of Uncertainty in Measurement [3]. This reference to uncertainty is an integral part of weight measurement and is found in Australia's adoption of "Organisation Internationale De Métrologie Légale Recommendation R111" [4].

There is a system that would enable drivers to reliably determine if they are travelling within the posted speeds limits. This paper will endeavour to prove the accuracy and safety aspects of a test system that once used, will enable the public to travel within the posted speed and furthermore be expected to do so.

Monash University Research Notes

The Monash University Accident Research Centre published research notes with the heading "Accuracy of vehicle speedometer readings with respect to speed enforcement tolerances" [5]. Table 1 gives a compilation of statistics summarised in the notes.

Actual speed relationship to indicated speed in km/h					
Actual	40	60	80	100	120
Max indicated	43	64	83	108	130
Min indicated	27	48	71	84	105

Table 1: Summary of results of speedometer tests carried out by Monash University Accident Research Centre and others between 1982 and 2001

The University used some collated results from other sources and whilst the test methodology was not described these results indicate either a failure by manufacturers to meet the minimum requirement of the relevant ADR [1], or that other mechanical factors are affecting the results.

Speed indication errors and variations

Speedometers in vehicles respond to the rotational velocity of the wheels. Errors and variations in vehicle speed indication will then be due to either the relationship between a rotation of the wheels and the actual distance travelled, or to the errors in measuring rotational velocity. The nature of the tyres contribute the first type, and instrument errors the second.

Rolling road testing

The speed indication in a vehicle is tested by either measuring the time to travel a known distance (measured by numerous methods), or on an apparatus consisting of rollers with known circumference and measurable rotational velocity (a "rolling road"). Some instrument repair companies merely "check" the odometer over a distance and conclude the speedometer accuracy from this data. Some have recently used GPS units. The latter options require conducting tests on public roads.

Testing of speedometers should ideally be conducted throughout the usable range as this eliminates the need for extrapolation. There are obvious safety implications if speedometers installed in vehicles are tested throughout their range on public roads. However using a rolling road for such measurements reduces the safety issues and the latest computerised rolling road machines provide a printout of the parameters tested.

Another machine that utilises rollers is the dynamometer and these can be used to test speedometers. Most rolling road testers are primarily a dynamometer. Its main function is to introduce resistance to wheel rotation by absorbing test vehicle energy into a load, and measuring the force developed by the drive wheels. Care should be taken when using a dynamometer that slippage is not induced by the machine's resistance. Some operators use the loading to minimise hunting (the failure to maintain a constant speed due to engine behaviour). Load generation should be minimised as should tie-down pressures. It is normal practice to chain or strap the vehicle under heavy loading conditions for measuring engine torque to avoid the vehicle climbing up and out of the roller valley. In these tests, lateral restraining of the vehicle was used instead of tie down, since vertical restraining caused tyre distortion, which can lead to an error in the region of 2 km/h. It would be difficult to balance normal tyre load distortion, aerodynamic and centrifugal force to a corresponding offset for the rollers, because the forces are not linear and combined to create a complex response curve. At best only a "best fit" correction can be given.

Except where indicated otherwise, the tests described in this paper were carried out on a free-running rolling road, that is, without applying a load to the wheel rotation. This machine held a current NATA accredited certificate of accuracy. The measurements described in this paper are traceable to an Australian National Standard and have adhered to the requirements of ISO 17025 [7].

Tyre contributions

Errors due to tyres may be long-term (e.g. tyre type and size), medium-term (e.g. tread wear), or short-term (e.g. pressure and loading). The author undertook measurements of both true and indicated vehicle speed with varying tyre brands, wear and tyre fill pressures.

Inflation pressure:
Increase in pressure will occur as the tyre increases with heating due to use. This pressure increase is as much as 28 kPa (4 psi). An increase in tyre temperature will increase pressure and cause the indicated

speed to be lower. The tyre inflation pressures referred to in the following tests were hot pressures and should not be confused with cold pressures settings recommended by manufacturers. Tyre pressures were adjusted after the tyre had reached operating temperature.

To examine how pressure affects the tyres, they were initially inflated to 160 kPa. The first run at this pressure was followed by tests in increments of 30 kPa to a maximum tyre pressure of 280 kPa. One of the tests was conducted with a standard tyre pressure of 190 kPa and the equivalent weight of four adult males in the car, all the other tests in this series were with one adult male only. The deviations from true speed occurring at indicated speeds of 30, 60, 80 and 120 km/h were recorded. Three readings were made at each speed and pressure, and mean of the readings were calculated. Results of these tests are given in Table 2.

Speedometer error versus tyre pressure						
***speed* ⇓**	**280 kPa**	**250**	**220**	**190**	**160**	**190+ load**
30	1.5	1.4	1.4	2.3	2.6	1.8
60	1.9	1.6	1.8	2.3	3.6	3.8
80	1.8	1.6	2.3	2.6	3.3	3.7
120	3.4	3.6	3.4	4.1	4.8	5.1

Table 2: Speedometer error variation with tyre pressure.

Brand and model:

Examination of model and brands were undertaken using 17 and 18inch rims with low profile tyres. Some 20 different tyre models were tested to consider variations between brands. It was found that a variation of speedometer reading of 1.5% resulted from the same vehicle and speedometer calibration settings over the twenty types.

Wear:

The change in the tread depth of a Dunlop Monza 205/65R15 tyre, from new through to the 1mm above wear indicator bars, was measured to change the diameter by 12 mm (although the diameter change can be 14 mm if worn completely). This is equivalent to a change in circumference during its life of 2.0%.

Tyre distortion

On the face of it, the circumference of a tyre is constant whatever the tyre pressure. However tyres compress as the tyre surface changes shape when it meets the road surface squeezing and then stretching each portion of tread during a cycle so that the distance travelled per revolution of the wheel changes. It was found that a worn tyre does not compress to the same amount as a tyre with new tread although smaller in circumference. During these experiments it was found that tyre growth under the influence of centrifugal force was only significant when the tyres were under-inflated and at speeds of more than 120 km/h. A Dunlop 215/60R16 95V inflated to 240kPa was roller-driven to 160 km/h and had expanded 3.5mm on radius or approximately 1.1% of indicated speed. This expansion increases with speed in an approximate logarithmic fashion.

Experiments showed that a Dunlop Monza 205/65R15 tyre fitted to a rim had an undistorted radius of 320mm at a pressure of 220 kPa, a compressed radius of 295mm and, a compressed radius of 290mm at a pressure of 190kPa. The calculated circumferences for the three radii were 2011mm, 1854mm and 1822mm respectively. The distance travelled in one rotation, for the compressed tyres was measured to be 1966.5mm at 220kPa and 1908.0mm at 190kPa. The difference in the measured distances travelled was 0.7% yet the radii differed by 1.7%. Further clarification of this phenomenon would require test throughout the pressure range for a number of combinations of vehicle and tyres. The actual results from direct comparison to laser and radar measurements at speeds from 30 to 160km/h had indicated only a 0.7% difference at 100km/h dropping to 0.4% at 160km/h. This suppression may be a result of aerodynamic behaviour of the vehicle. The results are given in Table 3.

Indicated	30.0	60.0	80.0	100.0	120.0	160.0
Rollers	29.7	57.3	76.3	96.4	116.1	157.3
Laser	30.0	57.0	77.0	96.0	116.5	156.5
Radar	29.5	57.0	77.0	96.0	116.0	156.5

Table 3: Comparisons of different methods of speed measurement.

Roller effects

When speed is measured using rollers the compressed diameter of the tyre varies from the compressed diameter of the same tyre on the road surface. This is due to the rollers creating two curved surfaces rather than one flat surface on the tyre (load surface area and shape, or tyre footprint).

The effective circumference of a tyre on the road can differ with brand, ply rating, belt type (steel or nylon) and tread depth. This circumference variation can be minimised when the vehicle is on the rollers by increasing the tyre pressure. The required increase will depend on tyre type, but early test results indicate it is about 30 kPa.

Experiments on the tyre distortion with different diameter rollers was undertaken starting with 203mm (8.0 inch) to 266mm (10.5inch) in 12.5mm intervals
Some experiments are still being analysed that look at leading edge roller speed sensing verses trailing edge roller speed sensing. This plays a roll in the effective diameter seen be the rolling road tester.

Tyre slippage for a sedan on the roller was measured at a range of speeds using a strobe light and was found to be minimal. Great care was given to minimise slippage during the tests, and the measured slippage was less than 100 mm over the test distance of three kilometres. The total effect of slippage on speed accuracy was not deemed as significant in free-rolling testing.

Instrument Errors

Systematic corrections that are not eliminated during calibration or applied as a correction, will contribute with opposite sign to the results of speed measurement by a police pursuit vehicle. For example, consider a police car tested at 100 km/h with a reported error with new tyres of +1.5 km/h (that is, the true speed is 1.5 km/h lower than the indicated speed) and which eventually has tyres at half wear equating to 1km/h. A motorist's vehicle is then perceived to be travelling 2.5 km/h faster than actual. If the motorist has a speedometer error of -1.5 km/h and is travelling at an indicated speed of 100 km/h we can see that it has been measured to exceed the speed by 4 km/h, enough to be considered a breach of traffic rules. These errors created by, (a) tyre wear, (b) not applying calibration corrections, and/or (c) the roller-to-road anomaly, are critical to the overall picture, since the accumulative affect can be as much as 4 km/h. These three items were intentionally not calculated in this first view of the uncertainty assessments (subject discussion to follow) since the corrections may or may not be deemed as uncertainty components.

To calculate the uncertainty associated with a driver's knowledge of the true speed of his or her vehicle, a review of the components of uncertainty arising from interpretation of speedometer indication, vehicle load, engine power management and tyre behaviour was undertaken by the author.

The driver's ability to accurately determine the vehicle speed using an ordinary speedometer is affected by:
*The intrinsic accuracy of the instrument (the residual systematic error after calibration).
*Parallax error.
*Size of minor graduations (normally 5 or 10 km/h).
*Readability (usually one fifth of one minor graduation).
Based on these factors uncertainty (expressed as 95% confidence intervals) for a speedometer read to 2 km/h was as follows:

60 km/h is ±8 km/h
80 km/h is ±10 km/h
110 km/h is ±13 km/h.

A calibrated speedometer read to 2 km/h and tested with certified speedometer testing reaches a better accuracy than the ADR18.5.1.2, that is the accumulated uncertainty described in this paper is less than the ±10% specified by ADR. The calculated uncertainty is ±4.9 km/h at 110 km/h without any account for tyre wear and roller to road anomaly. This assumes that the speedometer was either adjusted to read true or the calibration correction was applied. Failing this, the uncertainty must be calculated with an uncertainty components added for the systematic errors.

The needle in an analogue speedometer will be about 2 mm from the gauge face. This results in a parallax error, which will depend on the position of the driver's dominant eye. The maximum error derived from experimentation was less than 2 km/h. With the advent of liquid crystal displays with either synthesized analogue or numerical readout, parallax problems are not an issue. On the other hand rounding of the displayed speed may create errors but these would be less than 1 km/h.

Analogue instruments display information by indicating with a needle or a pointer. The graduations on the display face limit the precision of the instrument readability. With a minimum division of 5 km/h and a needle width of the equivalent of 1 km/h, resolution to a fifth of a division or 1 km/h can be expected. Examples of the application of this convention can be found in Australian Standard AS1349 [6]

Since infringements can occur in just a few metres, we investigated other sources of speed control and measurement and found a significant problem with smaller vehicles. Measurements with an air-conditioned four-cylinder vehicle showed a 5km/h variation in speed with the air-conditioning compressor cycling. This variation is created by the driver compensation for power fluctuations by his efforts to maintain constant speed. Policy makers may wish to include this in the big picture.

Calibration of the testing machine

The measurements of the roller diameters and rotational speed gives a standard uncertainty component of less than 0.1 to 0.3 km/h between the speeds of 30 and 180 km/h. The stability of performance of all the roller machines tested throughout most of Australia over the last six years has been in the region of ± 0.2 km/h. Plotted roller wear on the Adelaide based unit was less than 0.01% over six years.

Police tolerances for speed infringements

The inconsistency between Australian States in their tolerance of small infringement of speed limits means that there is no single system in use. The most widely used system is the decade method. The posted speed limit can be exceeded by 9 km/h eg 69 in a 60km/h zone (89 in 80 km/h zone etc) and incurs a fine if 70 km/h is detected. This method was introduced to compensate for the ADR 18.5.1.2 speedometer error of ±10%.

One State has recently introduced a 3km/h tolerance, since their detecting equipment carried an uncertainty in the region of ±2 km/h. This system has the implicit assumption that the drivers must not exceed the speed limit regardless of measurement errors and the onus is upon the driver to ensure that they comply with the law irrespective of accuracy of their speedometer.

Discussion

Achievable aims:
The statistics collated by the Monash University, the police departments, the Royal Automobile Association and myself, indicate that a high proportion of speedometers are set to read 3 km/h high to minimise liability and supposedly to compensate for possible drift. There has been no response from manufacturers confirming this practice. The application of this offset does not improve the accuracy of speedometers. The latest manufactured vehicles have an accuracy of 3% or better, of reading with one brand offering an adjustable version correct to within 2% of full scale. In the first instance, the use of "3%" is an archaic method of describing accuracy and creates a distorted view of the errors expected. Statistics have shown that ADR [1] should be amended to read:
"an accuracy of ±(0.65% of full scale + 1.75% of reading)",or *"±(1.5 km/h + 1.75% of reading)"*.

This would ensure that the tolerance does not limit the lower values to impossible accuracies or the upper value becoming too large.

Tyre behaviour:
The tests conducted were not intended to measure individual effects of tyre behaviour on speed but was a measure of an overall effect. The "lumping" of the tyre effects was purely to extract expected overall variations in speed measurement.

Tyre wear and low fill pressure just resulted in a higher indicated speed, which may not be of concern in a motorist's vehicle, but in a police vehicle will result in a high reading of the speed of motorists. A worry for motorists is the fact that tyre pressure increases from cold to hot, lower indicated speed.

Improved method:
With the adoption of the suggested changes to the design rules, and with roller anomaly taken into account, we can then address the policy of dealing with the error caused by tyre wear, so that the uncertainty can be calculated considering all significant components. The author suggests taking measurements for the tyre wear at the half wear point since a tread depth at time of test can be obtained and results of the speedometer test mathematically corrected to the half wear point. The tyre wear can then be included in the uncertainty to reflect results by tyre~~s~~ wear being other than half worn. The combined uncertainty components mentioned earlier and these latest additions were calculated to be ±6.7 km/h for a Dunlop Monza 205/65R15 tyre at 110 km/h.

No mans land:
In some Australian States road works and children's crossing zones are automatically classed as 25 km/h zones. As the wording of the design rules (ADR 18.5.1.2) does not call for any accuracy for speeds below 40 km/h, the driver has no assurance of the vehicle's true speed in these zones.

Driver's responsibility:
Other errors that have been attributed to outside interference (for example incorrect tyre size fitted, or differential ratio altered), or a deviation from manufacturers specifications are a separate issue. With vehicles made to the amended ADR as suggested above in paragraph "*Achievable aims*", the uncalibrated speedometer would have a lower calculated uncertainty of speed measurement and can be expected to perform within a smaller infringement tolerance.

Breach of natural justice:
The calculation of uncertainty associated with speeds up to 120km/h shows that the decade method used by police forces allows infringement notices to be issued to drivers travelling within the region of uncertainty. The issuing of infringement notices using the 3 km/h tolerance system can be even unfair to drivers who use a speed-measuring instrument conforming to Australian design rules.

A temporary measure:
A suggested policing policy is to allow 7 km/h at speeds of up to 50 km/h and an additional 1 km/h for every 10 km/h of speed up to 110 km/h speed. This policy will prevent infringements notices being issued for the region of uncertainty and therefore should not be legally challengeable. This policy of expanded tolerances would only be an interim measure to correct the present situation, prior to public testing facilities being introduced.

The solution:
I believe that this paper lays the groundwork to give the Federal Government, State Governments, State Police Forces and motorists the tools to operate motor vehicle speed control measures correctly and fairly. If all recommendations are accepted, a fixed tolerance of 7 km/h (or a sliding scale of tighter constraint but more cumbersome to apply) can be used without compromising the motorists and afford them their right to an accurate form of speed measurement. However this policy assumes the application of calibration offsets to correct the speed value. The process of testing and calibration of rolling road testers that is traceable to a national standard must be made publicly available. A series of approved testing stations should be available so that motorists can confirm their speedometer accuracy and drive accordingly.

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