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Does the Innova's Engine Really Last? Failure and Survival of Toyota's Nine D-4D Diesels in British MOT Records

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Abstract: ***Toyota's 2.5-litre 2KD-FTV diesel, the engine of the first-generation Toyota Innova in India, has a reputation for running for hundreds of thousands of kilometres. The same engine was sold in Britain in the Hilux pickup and the HiAce van, alongside eight other Toyota-designed engines carrying the D-4D name. This study asks whether the reputation belongs to the whole family or to a few of its members, using about 119 million British MOT roadworthiness test records from 2015, 2019 and 2023. Each engine was identified from its recorded capacity and year of first use and compared with the rest of the British diesel fleet, with rival pickups and vans, and with petrol versions of the same Toyota cars, always inside cells of the same vehicle class, age and mileage. The hypotheses were written down before any comparison was run. In 2023 eight of the nine engines failed the MOT less often than comparable diesels and the ninth no more often, but only five by a material margin (odds ratios 0.368 to 0.882); the 2KD's margin was small (0.954), and the engines differed far more than chance allows (I-squared 0.983). Where the 2KD stood apart was in staying on the road: vehicles with it that were tested in 2015 were 33 percent more likely than comparable diesels to be tested again in 2023 (risk ratio 1.331), the highest figure in the family. Against vehicles built for the same work the picture narrows. The HiAce failed less often than rival vans (0.615), while the Hilux with the 2KD failed slightly more often than rival pickups (1.055) though with far fewer engine-and-emissions failures in 2023 (0.639). Toyota's car diesels held no material advantage over their petrol twins on the test as a whole, though the 1CD and 1ND had materially fewer engine-and-emissions failures. A positive control built on a documented Toyota bulletin for the AD engines worked only in part: the fault showed in survival but not in the MOT's engine section. Raw failure rates pointed the wrong way in 10 of 25 engine comparisons, a Simpson's paradox created by the D-4D fleet's greater age and mileage. The reputation survives as endurance under heavy use, not as a family-wide freedom from faults.***

Keywords: ***vehicle reliability, diesel engines, Toyota D-4D, Toyota Innova, MOT test data, vehicle survival, Mantel-Haenszel stratification, Simpson's paradox, pre-registered analysis***

I. INTRODUCTION

In India the Toyota Innova was launched in February 2005 as the successor to the Qualis, and its diesel versions carried a 2.5-litre four-cylinder engine with the factory code 2KD-FTV [1]. Among owners it acquired a reputation for durability that is usually expressed as an odometer reading counted in lakhs of kilometres. That reputation is the subject of this paper. It is not something any source cited here establishes, and the purpose of what follows is to test it rather than repeat it. The study was prompted by one vehicle, the author's own 2007 Innova 2.5 V, which has now passed two lakh kilometres.

Testing the reputation in India is not possible with public data, because no public record of vehicle faults exists there. Britain offers a way round the problem. Every car and light van there must pass an annual roadworthiness inspection, the MOT test, from its third year, and the government publishes the outcome of every test with the vehicle's make, model, fuel, cylinder capacity, first-use date and odometer reading [2], [3]. The Innova itself was never sold in Britain, but its engine was: Toyota's British specification lists the Hilux 2.5 D-4D as the 2KD-FTV [4], and the MOT record holds the same 2,494 cc diesel in the HiAce van. The 2KD is also one member of a larger family. Toyota's D-4D name, marked by the final V of an engine code [5], covers several engine families. Nine of them appear in the British record for these years, from a 1.4-litre four-cylinder to a 4.5-litre V8 [5], [6], and the later Innova Crysta used two of the nine [1]. Three further families carry the same marker but fall outside the study: the WW engines, whose 1,995 cc cannot be told apart from the 1CD's, and the F33A and 3GD engines, which are too recent to have reached a first test by 2023 [5].

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That family structure turns a question about one engine into a sharper one. If durability were a property of Toyota's diesel engineering as a whole, every member of the family should look better than comparable vehicles. If it belongs to a few engines, the family should split. Existing evidence cannot settle this. A recent study of vehicle longevity built from MOT records ranks makes, and in its ranking of diesel makes Toyota is not among the leaders; Škoda, Land Rover and Volvo, among others, rank ahead of it [2]. A make-level figure, however, averages over every engine a manufacturer sold, and the D-4D family is known not to be uniform: a Toyota warranty bulletin, quoted by a British consumer motoring site, set out how dealers should handle excessive oil consumption and head-gasket failure in its 2.0 and 2.2 litre AD engines built between 2005 and 2009, after the normal warranty had run out [7].

This paper therefore asks whether the reputation is a family trait. It makes five contributions:

- It identifies nine Toyota-designed D-4D engines inside the MOT record from recorded capacity and year of first use, checked against manufacturer specifications.
- It compares each engine with three kinds of comparator, the rest of the British diesel fleet, vehicles built for the same work, and petrol versions of the same Toyota model, always inside cells of the same vehicle class, age and mileage.
- It measures reliability in two ways, how often a vehicle fails its test and whether it is still being tested years later, and checks the second against the national vehicle register.
- It fixes its hypotheses in writing before any comparison, including a positive control built on the documented AD-engine fault.
- It shows how far raw failure rates mislead in this setting, a case of Simpson's paradox.

Section II reviews the literature, and Section III identifies the gap. Section IV states the objectives and hypotheses, and Section V the method. Section VI reports the analysis, Section VII summarises the results, and Sections VIII to XI discuss them, set out the limitations and recommendations, and conclude.

II. REVIEW OF LITERATURE

A. *The MOT Record as Evidence*

The MOT record was first opened to researchers as a source of mileage data. The Department for Transport found that the odometer was noted in around 95 percent of tests, and that median readings rose with vehicle age before falling again, which it read as a sign that heavily used vehicles leave the stock earlier in life [8]. That observation matters here, because it means an analysis of old vehicles is always an analysis of survivors. Wilson and colleagues then set out procedures for cleaning erroneous MOT records and for linking a vehicle's consecutive tests so that the distance covered between them could be inferred [9]. Chatterton and colleagues used the same record to estimate annual mileage, fuel use and emissions for every light vehicle more than three years old in Great Britain, and to attach vehicles to areas through the postcode area of the testing station [3]. Davison and colleagues paired 197,000 roadside emission measurements with odometer readings taken at the MOT, and found that the way nitrogen oxide emissions worsened with mileage differed between manufacturers [10].

Two recent studies used the record to study how long vehicles last. Nguyen-Tien and colleagues treated a vehicle as retired when it failed to reappear for a test within a buffer period, for which they preferred 18 months. They fitted hazard models to around 30 million cars and found that longevity varied with engine size, location and make [2]. Their make ranking is the one referred to in Section I. Newman analysed survival and failure for every privately registered British vehicle from 2005 to 2021, drawing on 397 million inspections, and argued that survival is not a simple product of wear: from around the eighteenth year the probability of a vehicle's death fell with age, and the lowest failure rates per mile belonged to vehicles widely used as taxis, including the Toyota Prius [11]. Both studies work at the level of make, model or fuel. Neither separates the engines inside one manufacturer's diesel range.

B. *How Long Vehicles Last, and Why They Leave*

Vehicle lifetimes vary widely between countries. Held and colleagues derived survival curves for the car fleets of 31 European countries. Average lifespans ranged from 8.0 to 35.1 years; the western countries averaged 18.1 years and the eastern 28.4, a gap the authors traced largely to used cars moving across borders [12]. In the United States, Bento, Roth and Zuo found that the average passenger-car lifetime rose from 12.2 years in the 1970s to 15.6 in the 2000s, and that scrappage responds to used-car prices [13], which is to say that when a vehicle dies is partly an economic decision. Exports complicate the picture further. Newman and colleagues showed that used vehicles exported from Britain failed roadworthiness standards and produced markedly more emissions than vehicles scrapped at home [14], so a vehicle that disappears from the British record has not necessarily been scrapped.

Ownership is selective too. Using Swiss inspection records, Emons and Sheldon found that cars sold privately were more likely to carry a defect than cars that were not sold [15]: owners keep the good ones. Which vehicles are still on the road is therefore shaped by prices, exports and owners' choices as well as by durability.

C. How Diesel Engines Age

Diesel engines do not all age in the same way. From fifteen years of roadside measurements in Zurich, Chen and Borken-Kleefeld found that nitrogen oxide emissions from Euro 2 and Euro 3 diesel cars rose with use while those from Euro 1 and Euro 4 cars stayed stable [16], so the technology generation matters. The British evidence of Davison and colleagues points the same way: diesel cars fitted with particulate filters kept their particle emissions under control even at high mileage [10]. The emission equipment added to later diesels brings its own failure modes. Yang, Fox and Hunsicker classified particulate filters that failed in commercial fleet use into pinhole, melting, cracking and fouling failures [17], and Park, Lee and Park showed that deposits in exhaust gas recirculation coolers grow heavier, and the coolers less effective, as the coolant temperature falls [18]. For a family of engines spanning two decades of emission rules, these findings suggest that members may differ in how they age for reasons unrelated to the basic engine.

D. Engine Load and Durability

A common explanation for a durable engine is that it is not worked hard. The materials literature gives this some physical basis. Natesan and colleagues describe how downsizing and rising specific power have increased the thermal load on cylinder heads and made early fatigue failures more likely [19], and Szmytka and colleagues, writing from inside a car manufacturer, explain that such parts are designed to endure a defined standard of use, the average conditions plus a margin, together with a set number of exceptional events [20]. The 2KD itself was built in more than one state of tune. A test-bed study rates it at 75 kW at 3,600 rpm with a compression ratio of 18.5:1 [21], while Toyota's British specification for the Hilux lists the same 2,494 cc engine at 142 bhp [4]. Reliability also runs on two clocks at once. Kleyner and Sandborn point out that automotive warranties are defined on both time in service and distance covered, and that the spread of distance has to be estimated from field data rather than assumed [22]. Both clocks are held fixed in the comparisons below.

E. The Indian Setting

The Innova arrived during India's diesel boom. Among buyers choosing between the petrol and diesel versions of the same hatchback, the share taking the diesel was 46 percent in 2002 and had reached 74 percent by 2006 [23]. Fuel standards were uneven too: the cleaner Bharat Stage 4 fuel standard applied in 20 cities while researchers were arguing for the tighter Bharat Stage 5 standard nationwide [24]. The Innova line later moved to newer members of the same family. The Innova Crysta used the 2.8-litre 1GD-FTV and the 2.4-litre 2GD-FTV, and the 2.8 was dropped in India in 2020 when Bharat Stage 6 emission rules took effect [1].

F. Comparing Like with Like

Vehicles with different engines differ in age, use and body type, so a fair comparison must hold those things fixed. The Mantel-Haenszel procedure does this by comparing groups within strata and pooling the stratum-specific odds ratios into one estimate [25]. When strata are ignored, an association can weaken, vanish or reverse, the pattern known as Simpson's paradox [26]. Survival analysis adds the further problem of censoring: for many subjects the event of interest has not yet occurred when observation ends [27], which here means that a vehicle still on the road has an unknown final lifespan.

III. GAP ANALYSIS

Four gaps follow from this review. First, no published analysis separates a manufacturer's diesel engines inside the MOT record. The make-level results that exist [2] average over every engine a make sold, so they cannot say whether a reputation belongs to an engine or to a badge. Second, engine reputations rest on owners' accounts rather than measurement, and the Innova's is no exception. Third, the fairest comparisons, with vehicles built for the same work and with the same car fitted with a petrol engine, have not been made for any engine family. Fourth, no study has checked whether MOT-based measures can see a known engine fault at all, so it is not known how much weight they can bear when they show nothing.

This paper addresses all four. It works at the level of the engine, uses three kinds of comparator within strata of class, age and mileage, and includes a positive control built on a documented fault.

IV. OBJECTIVES, VARIABLES AND HYPOTHESES

A. *Objectives*

- To identify every Toyota-designed D-4D engine in the British MOT record.
- To measure, for each engine, how often it fails the MOT and whether vehicles fitted with it remain in use, relative to comparable vehicles.
- To test whether any advantage is shared by the whole family or confined to some engines, and specifically whether the KD engines behind the Innova's reputation outperform vehicles built for the same work.
- To check whether the measures can detect a documented engine fault.
- To show how the answers change when age and mileage are ignored.

B. *Variables*

Table I lists the variables. The unit of analysis for failure is one completed normal MOT test, and for survival one vehicle.

TABLE I
VARIABLES USED IN THE ANALYSIS

Variable	Role	Definition
Initial failure	Outcome	Test result Fail, or Pass after Rectification at Station, PRS (the definition of the testing agency, the DVSA)
Engine-and-emissions failure	Outcome	At least one Fail or PRS item in the section 'Exhaust, Fuel and Emissions' (to May 2018) or 'Noise, emissions and leaks' (from May 2018)
Still tested	Outcome	The vehicle tested in 2015 (or 2019) appears in any 2023 test
Engine family	Exposure	Toyota, fuel diesel, exact capacity and first-use year of one of nine D-4D engines (Table III)
Comparator	Exposure	Diesel fleet; rival pickups; rival mid-size vans; petrol version of the same Toyota model
Class	Stratum	MOT class 4 (cars, light vans) or 7 (goods vehicles 3,000 to 3,500 kg)
Age	Stratum	Whole years from first use to test, 3 to 25
Mileage band	Stratum	20,000-mile bands to 200,000, then 200,000 and above
Model	Stratum	Added only in petrol-twin comparisons

C. *Hypotheses*

The hypotheses below were written into a dated file before any failure or survival rate of a Toyota engine, rival or petrol twin had been computed. A difference is called material only when its 95 percent interval excludes 1 and the estimate lies outside 0.90 to 1.11, a gap of more than about ten percent; with samples in the tens of thousands, smaller differences reach significance without mattering in practice.

- H1, the legend is not a family trait: at least one of the nine engines does not fail the MOT materially less often than comparable British diesels, and the engines are heterogeneous (Cochran's Q significant, I-squared above 50 percent). The family-trait view, the null, requires all nine to be materially better.
- H2, the KD engines beat their rivals: the Hilux with the 2KD (a) and with the 1KD (b) fail materially less often than rival pickups, the HiAce with the 2KD (c) materially less often than rival mid-size vans, and all three (d) remain in use materially more often than their rivals.

- H3, in Toyota's cars the D-4D has no reliability advantage: each car engine fails at least as often as petrol versions of the same model.
- H4, a known fault is visible: AD engines built inside the bulletin's production windows (a) remain in use materially less often than petrol twins and (b) have materially more engine-and-emissions failures in 2015, and (c) AD engines built later show a smaller survival gap.

V. RESEARCH METHODOLOGY

A. Data Sources

The MOT data are the anonymised test results and failure items released under the Open Government Licence, first by the Department for Transport and, for recent years, by the Driver and Vehicle Standards Agency. Three years were used, four years apart, avoiding 2020, when the COVID-19 pandemic disrupted the testing rules [11]. The year 2023 is the primary one, with 2015 and 2019 used to see whether the same comparisons held earlier. Table II gives their size. Each test record carries a vehicle identifier built from the registration and the vehicle identification number, which allows the same vehicle to be followed across years; a check on all vehicles found that 81 percent of four-year-old cars tested in 2015 were tested again in 2023. The files differ in format: the 2019 file is comma-delimited with quotation marks escaped by a backslash, and the 2023 archive uses a compression method that required the system unzip tool. Six rows, four in 2015 and two in 2019, had the wrong number of fields and were excluded. The Department for Transport's licensing table VEH0124, which counts vehicles on the register by model and year of first use, was used to validate the survival measure.

TABLE II
MOT DATA USED

Year	Test records	Failure-item records	Diesel-fleet tests kept	D-4D tests kept
2015	37,490,736	70,077,368	10,246,753	236,931
2019	39,310,698	79,966,042	12,673,187	245,108
2023	42,216,721	89,302,632	14,187,980	206,145

Kept tests are completed normal tests of classes 4 and 7 with an age of 3 to 25 years and a recorded mileage of 1 to 600,000 miles.

B. Identifying the Engines

The MOT record gives the make, model, fuel and cylinder capacity but not the engine code. A Toyota test was assigned to a D-4D engine when the vehicle's fuel was diesel, its recorded capacity matched that engine's exact published capacity, and its year of first use fell within the engine's production years plus one year for registration lag. Capacities come from Toyota's British specifications for the Hilux and Avensis [4], [6] and, for the other engines, from an encyclopedia list of Toyota engines [5]. Two capacities are shared with other engines. The 2,982 cc of the 3.0-litre 1KD is also that of the older 1KZ-TE, built until 2004, so the 1KD is counted only from 2005; and the 1,995 cc of the 2.0-litre 1CD is also that of the later 2WW, so the 1CD is counted only to 2007, one year after it left production, which leaves 1,995 cc Toyota diesels first used between 2008 and 2014 unassigned [5]. Round figures that a tester may have typed, such as 2,500 or 3,000 cc, were not assigned. Table III shows the nine families and how they appear in 2023.

C. Comparison Groups

Four comparison groups were fixed in advance. The diesel fleet is every non-Toyota diesel in classes 4 and 7. Rival pickups, for the Hilux, are the Mitsubishi L200, Nissan Navara, Ford Ranger, Isuzu D-Max, Isuzu Rodeo, Volkswagen Amarok and Mazda BT-50. Rival mid-size vans, for the HiAce, are the Volkswagen Transporter, Mercedes-Benz Vito, Renault Trafic, Vauxhall Vivaro, Nissan Primastar, Citroën Dispatch, Peugeot Expert and Fiat Scudo. Petrol twins are petrol versions of the Toyota car models that were also sold with a D-4D. For the positive control, AD-engine cars were split into two groups: those first used inside the bulletin's production windows, and those first used from 2010 onwards. The windows run from April 2005 to February 2009 for the Avensis, July 2005 to December 2008 for the RAV4, September 2006 to September 2009 for the Auris and April 2005 to November 2008 for the Verso [7], each with three months added for the gap between building a car and registering it. That allowance is tighter than the one year used for the engine windows above, because these windows are given to the month.

D. Outcomes

Initial failure follows the DVSA's definition, a Fail or a Pass after Rectification at Station. Engine-and-emissions failure is the closest the MOT comes to the engine itself: the section covering smoke and emission limits, the exhaust, and oil and fuel leaks. Survival is measured by linkage. A vehicle's last completed normal test in 2015 (or 2019) assigns it to a cell of class, age and mileage, and it counts as still in use if its identifier appears in any 2023 test. A vehicle that does not reappear may have been scrapped, exported or declared off the road. The MOT record alone cannot tell these apart: separating scrapping from export needs the scrappage and export certificates used by Newman and colleagues [14], and a vehicle declared off the road simply stops being tested [11].

E. Stratified Comparison

Every comparison is made within cells of the same class, whole year of age and mileage band, up to 506 of them, fewer where a cell holds only one of the two groups (335 cells carry the 2KD against the fleet in 2023), with the Toyota model added as a further stratum for petrol-twin comparisons. The cells are pooled with Mantel-Haenszel weights, giving an odds ratio for failure outcomes, in the form re-derived by Fidler and Nagelkerke [25], and a Mantel-Haenszel risk ratio for survival, each with a 95 percent interval and a Cochran-Mantel-Haenszel p-value. Where two risk ratios are set against each other, as in H4c, the interval on their ratio combines the two standard errors as if they were independent; both are measured against the same petrol comparator, so that interval is conservative.

Crude, unstratified ratios are reported beside them, with Cohen's h for the crude difference in rates, so that the effect of stratifying can be seen. Heterogeneity across engines is measured with Cochran's Q and I-squared, and Holm's correction is applied within each hypothesis.

Two of the odds ratios, the HiAce against rival vans and the 2KD against the fleet, were reproduced exactly, to six decimal places and with the same intervals, by an independent statistics library; the risk ratios, Cochran's Q and the Holm steps were not checked that way.

F. Pre-registration and Reproducibility

The hypotheses, definitions and reading rules were written into a dated file before any comparison was run. One amendment was made, also before any test: a sensitivity check and a descriptive measure that referred to mileages of 300,000 and 250,000 were restated in terms of the top mileage band, because the fleet counts had been stored by band. The same amendment set out exactly which cars the bulletin covered. A second correction, recorded after the results were known, concerns an arithmetic slip rather than a test: the pre-registration describes the cars covered by the bulletin as six to ten years old in 2015, when their first-use dates make them five to ten.

The analysis always used the dates themselves, so no number changed. Every number in this paper was produced by a script that reads the raw files, and the scripts, logs and results file are kept with the paper. The raw files themselves are the published government releases named above, each recorded with its checksum so that it can be fetched again.

VI. DATA ANALYSIS AND FINDINGS

A. The Nine Engines in 2023

Table III describes the nine families in the primary year. Together they accounted for 206,145 kept tests of 197,605 vehicles in 2023. They differ in almost every respect that matters for a comparison.

The car engines sit in the Yaris, Auris, Avensis, Corolla, RAV4 and Verso; the KD engines in the Hilux, HiAce and Land Cruiser; and the two GD engines, introduced in 2015, were only four and five years old at the median. Only the 1CD, out of production since 2007, had a higher median mileage than the 2KD's 121,312 miles, and 10.6 percent of the 2KD's tests recorded 200,000 miles or more, 1.72 times the share expected from diesels of the same class and age. That figure describes use as much as durability, which is why it was fixed in advance as descriptive only.

TABLE III
THE NINE D-4D ENGINE FAMILIES IN THE 2023 MOT RECORD

Engine	Capacity (cc)	First use	Tests	Median age	Median miles	200,000+ share (O/E)	Main models
1CD 2.0	1,995	2000-2007	13,387	18	133,068	0.0664 (0.70)	RAV4, Avensis, Corolla
1ND 1.4	1,363-1,364	2001-2021	35,478	13	99,536	0.0298 (0.62)	Yaris, Auris
1AD 2.0	1,998	2006-2020	26,619	11	105,749	0.0677 (2.11)	Avensis, RAV4, Verso
2AD 2.2	2,231	2005-2016	46,340	13	108,721	0.0302 (0.65)	RAV4, Avensis, Corolla
2KD 2.5	2,494-2,495	2001 on	31,588	14	121,312	0.1062 (1.72)	Hilux, HiAce
1KD 3.0	2,982	2005 on	27,520	11	104,104	0.0503 (1.24)	Hilux, Land Cruiser
1VD 4.5 V8	4,461	2007 on	948	9	90,317	0.0306 (1.18)	Land Cruiser
2GD 2.4	2,393	2015 on	21,727	4	56,502	0.0044 (0.76)	Hilux
1GD 2.8	2,755	2015 on	2,538	5	46,940	0.0032 (0.75)	Land Cruiser

O/E: observed share of tests at 200,000 miles or more divided by the share expected from the diesel fleet at the same class and age.

B. Each Engine Against the Diesel Fleet (H1)

Table IV and Fig. 1 give the primary result. In 2023 every one of the nine engines had lower odds of failing the MOT than diesels of the same class, age and mileage, and for eight of them the interval excluded 1. The size of the advantage, however, varied widely. Five engines were materially better: the 1VD (odds ratio 0.368), the 1GD (0.652), the 2AD (0.765), the 1AD (0.818) and the 1CD (0.882). Three were only slightly better: the 1KD (0.930), the 1ND (0.937) and the 2KD (0.954, interval 0.933 to 0.976). The 2GD showed no detectable difference (0.988). The engines were strongly heterogeneous (Cochran's Q 481.8 on 8 degrees of freedom, $p < 0.001$, I-squared 0.983).

By the rule fixed in advance, H1 is supported: the family does not share a material advantage, and the engine behind the Innova's reputation has one of the smallest advantages.

TABLE IV
EACH ENGINE AGAINST DIESELS OF THE SAME CLASS, AGE AND MILEAGE (2023)

Engine	**MOT failure, odds ratio [95% CI]**	**Reading**	**Engine-and-emissions failure, odds ratio [95% CI]**	**Still tested 2015 to 2023, risk ratio [95% CI]**
1CD 2.0	0.882 [0.852, 0.913]	materially lower	1.290 [1.201, 1.385]	0.951 [0.937, 0.965]
1ND 1.4	0.937 [0.917, 0.958]	slightly lower	1.134 [1.078, 1.194]	1.143 [1.134, 1.151]
1AD 2.0	0.818 [0.797, 0.840]	materially lower	0.537 [0.494, 0.583]	0.911 [0.901, 0.921]
2AD 2.2	0.765 [0.750, 0.781]	materially lower	0.915 [0.872, 0.960]	1.064 [1.057, 1.071]
2KD 2.5	0.954 [0.933, 0.976]	slightly lower	0.928 [0.877, 0.982]	1.331 [1.320, 1.342]
1KD 3.0	0.930 [0.907, 0.954]	slightly lower	0.799 [0.745, 0.856]	1.064 [1.053, 1.075]
1VD 4.5 V8	0.368 [0.308, 0.440]	materially lower	0.301 [0.156, 0.579]	0.937 [0.874, 1.004]
2GD 2.4	0.988 [0.956, 1.022]	no detectable difference	0.458 [0.399, 0.526]	-
1GD 2.8	0.652 [0.581, 0.733]	materially lower	0.329 [0.194, 0.556]	-

Odds ratios below 1 mean fewer failures than comparable diesels; risk ratios above 1 mean more vehicles still in use. A dash marks the two engines that were too new to appear in the 2015 survival cohort.

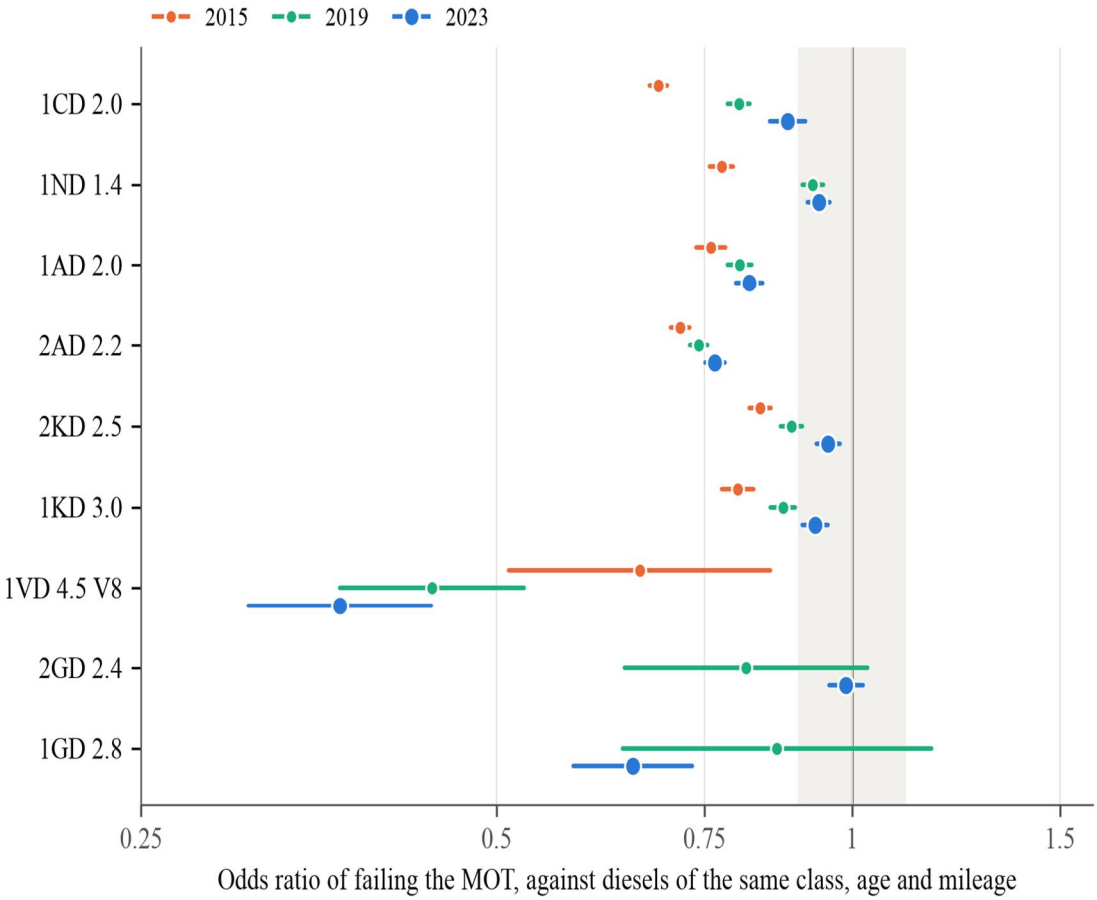


Fig. 1 Odds of failing the MOT for each D-4D engine against diesels of the same class, age and mileage band, in 2015, 2019 and 2023. Bars are 95 percent intervals; the shaded band, 0.90 to 1.11, marks differences too small to count as material.

The replication years tell a more favourable story for the family, and that difference matters. In 2015 all seven engines then in service were materially better than the fleet, the 2KD at 0.836 and the 1KD at 0.800. In 2019 six of nine were, with the 2KD at 0.888. The gap between the D-4D engines and comparable diesels therefore narrowed over the eight years, for six of the seven engines present in both 2015 and 2023; only the 1VD moved the other way. On engine-and-emissions failures alone, the 2023 picture splits again: the 1CD (1.290) and 1ND (1.134) failed that section materially more often than comparable diesels, while the 1KD (0.799), 1AD (0.537), 1VD (0.301) and the two GD engines failed it materially less often.

C. Staying on the Road

Survival separates the 2KD from the rest of its family (Fig. 2). Of the 37,152 vehicles with a 2KD that were tested in 2015, 55.1 percent were tested again in 2023, against 45.2 percent across the diesel fleet. Within cells of the same class, age and mileage, a 2KD vehicle was 33 percent more likely to still be in use (risk ratio 1.331, interval 1.320 to 1.342), the largest figure of any engine and one of only two that were materially above the fleet; the other was the 1ND (1.143). Over the shorter period from 2019 the 2KD was the only engine materially above the fleet (1.131); in that cohort the two GD engines were materially below it (2GD 0.875 on 581 vehicles, 1GD 0.896 on 350), on numbers too small and ages too young to carry much weight. The 1CD (0.951) and 1AD (0.911) remained in use slightly less often than comparable diesels. The family-trait view required every engine to be materially above the fleet on survival as well, and only two of seven were.

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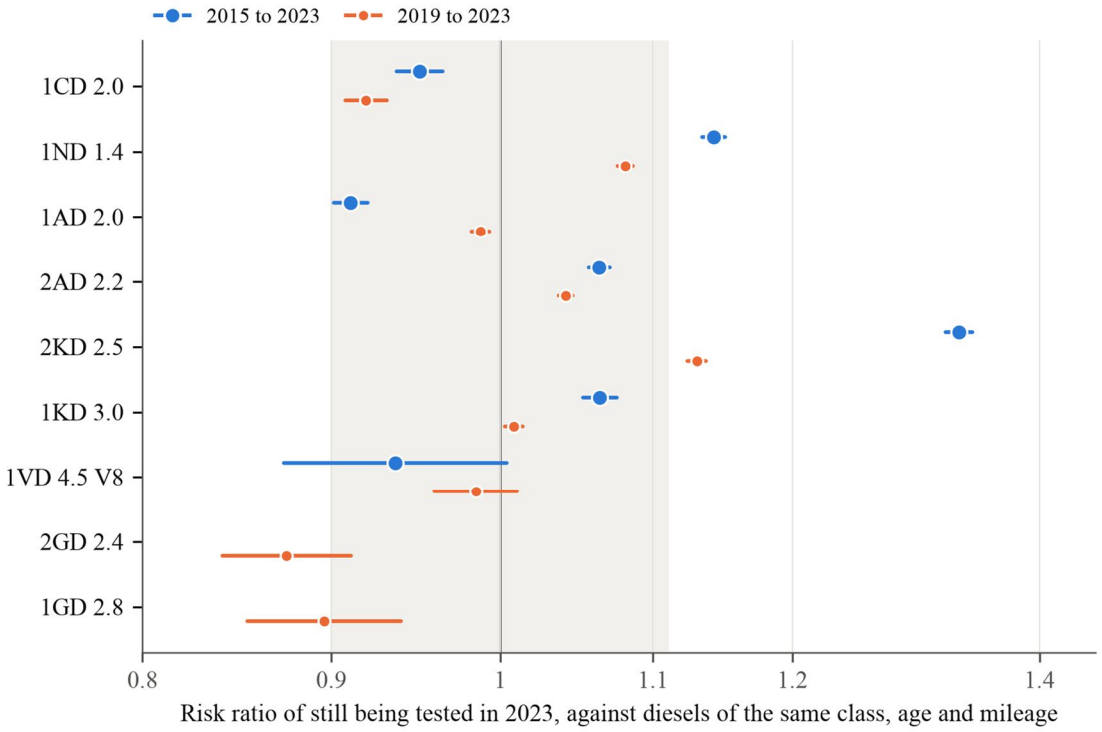


Fig. 2 Chance of still being tested in 2023 for each D-4D engine, relative to diesels of the same class, age and mileage band in the starting year. The 2GD and 1GD entered service too late for the 2015 cohort.

D. The KD Engines Against Their Rivals (H2)

Comparisons with the fleet confound the engine with the vehicle type, and a pickup or van leads a different life from a family car. The fairer test of the KD engines is against vehicles built for the same work, reported in Table V. The results separate the two vehicles sharply. The HiAce with the 2KD failed the MOT materially less often than rival mid-size vans in every year, with odds ratios of 0.558 in 2015, 0.560 in 2019 and 0.615 in 2023. The Hilux with the 2KD did not: it showed no detectable difference in 2015 (0.977) or 2019 (1.022), and in 2023 it failed slightly more often than rival pickups (1.055, interval 1.023 to 1.088). The Hilux with the 1KD was materially better in 2015 (0.798) and 2019 (0.881) and slightly better in 2023 (0.940). Fig. 3 shows the same pattern by age.

TABLE V
THE KD ENGINES AGAINST RIVALS OF THE SAME CLASS, AGE AND MILEAGE

Comparison	MOT failure 2023, odds ratio [95% CI]	Engine-and-emissions failure 2023, odds ratio [95% CI]	Still tested 2015 to 2023, risk ratio [95% CI]	MOT failure 2015; 2019
Hilux 2KD vs rival pickups	1.055 [1.023, 1.088]	0.639 [0.590, 0.693]	1.084 [1.069, 1.099]	0.977; 1.022
Hilux 1KD vs rival pickups	0.940 [0.910, 0.970]	0.574 [0.527, 0.626]	0.987 [0.972, 1.002]	0.798; 0.881
HiAce 2KD vs rival vans	0.615 [0.591, 0.640]	1.031 [0.945, 1.125]	1.025 [1.013, 1.038]	0.558; 0.560
Hilux 2GD vs rival pickups*	0.896 [0.865, 0.929]	0.325 [0.283, 0.375]	-	-; 0.766

*Odds ratios for failure, risk ratios for survival; intervals for the earlier years are given in the text. *Not pre-registered; the 2GD was too new to be tested in 2015.*

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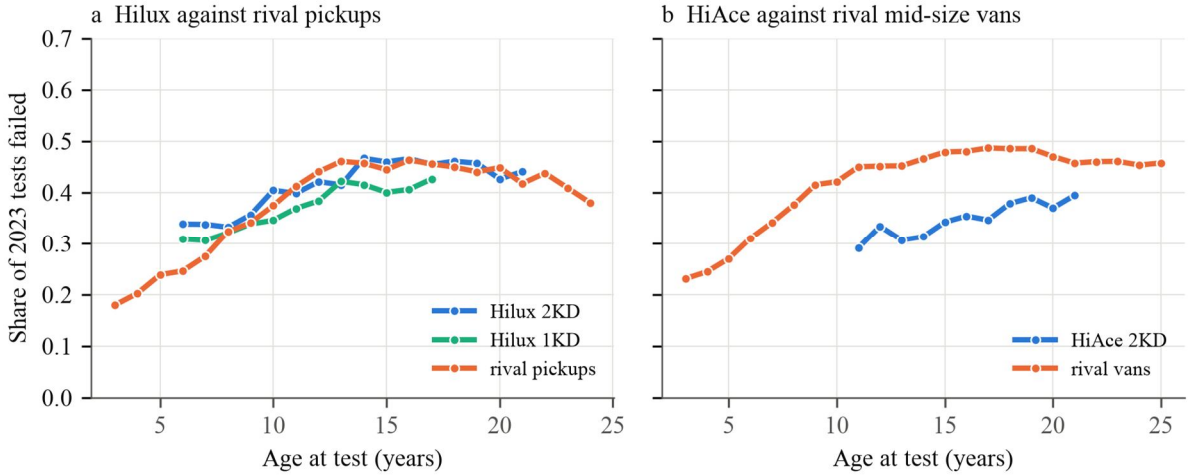


Fig. 3 Share of 2023 MOT tests failed at each age: (a) the Hilux with the 2KD and 1KD against rival pickups; (b) the HiAce with the 2KD against rival mid-size vans. Crude rates, shown where at least 150 tests were recorded at that age.

The engine-and-emissions section reverses the Hilux result. There, both KD engines were materially better than rival pickups in 2023, the 2KD with an odds ratio of 0.639 and the 1KD 0.574, and the 2019 figures were almost the same (0.639 and 0.620). The 2015 figures were not: the 2KD showed no detectable difference (0.936), and the 1KD failed that section materially more often than rival pickups (1.690), so the advantage belongs to the later years. The HiAce moved the other way: it was materially better than rival vans on that section in 2015 (0.811) but showed no detectable difference in 2019 (1.011) or 2023 (1.031), while keeping a large advantage on the whole test in all three years. In the two later years, then, what stands out in the Hilux is the part closest to the engine, and what stands out in the HiAce lies elsewhere in the vehicle (Fig. 4).

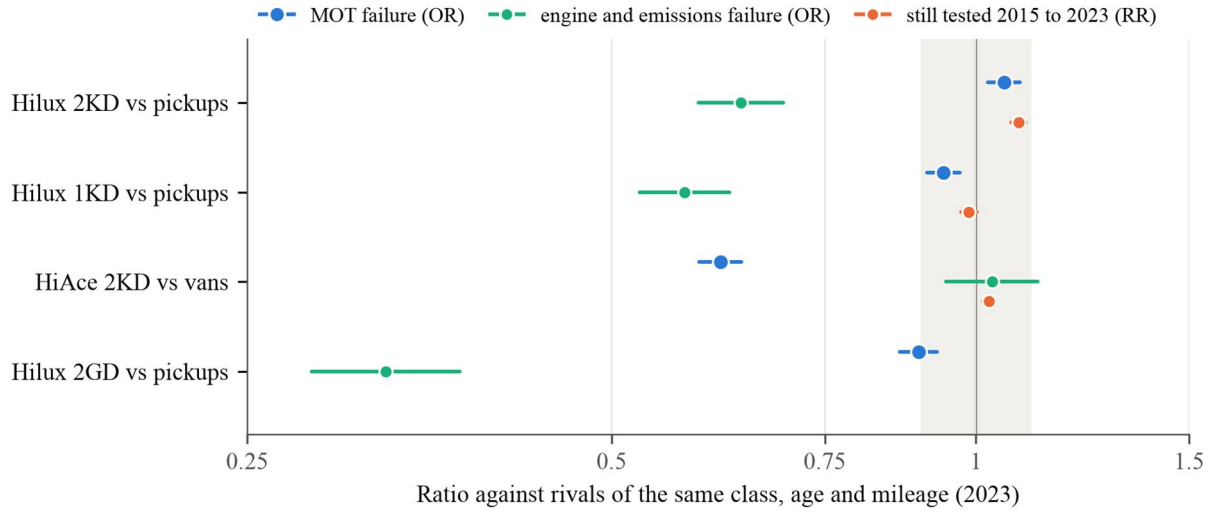


Fig. 4 The Hilux and HiAce against rivals of the same class, age and mileage: odds of MOT failure and of an engine-and-emissions failure in 2023, and the chance of still being tested in 2023 for vehicles tested in 2015.

On survival the rivals close most of the gap that the fleet comparison showed. Against rival pickups the Hilux 2KD was only slightly more likely to remain in use (1.084), the Hilux 1KD showed no detectable difference (0.987), and the HiAce was slightly ahead of rival vans (1.025). So the 2KD's 33 percent survival advantage over the fleet is mostly an advantage of working vehicles over the average diesel, not of the 2KD over other working vehicles. H2 is supported only for the HiAce's failure rate (c); parts (a), (b) and (d) are not supported.

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E. Car Engines Against Petrol Twins (H3)

The car engines were compared with petrol versions of the same models, within cells that also fix the model (Table VI, Fig. 5). None held a material advantage in 2023. The 1AD (1.027) and 2AD (1.005) showed no detectable difference. The 1ND failed slightly less often than its petrol twins (0.904), and the 1CD also slightly less often (0.952), though that difference did not survive Holm's correction (adjusted p = 0.0594). H3 was pre-registered as the prediction that each car D-4D would fail at least as often as petrol, with no materiality band attached. By that criterion it holds for the AD engines and is contradicted for the 1ND and, before Holm's correction, for the 1CD; neither breach is a material difference. On engine-and-emissions failures the 1CD (0.717) and 1ND (0.806) were materially better than petrol in 2023, but in the same comparison for 2019 the 1ND, 1AD and 2AD all failed that section materially more often than petrol (1.243, 1.657 and 1.286), so no stable pattern emerges.

TABLE VI
CAR D-4D ENGINES AGAINST PETROL VERSIONS OF THE SAME MODELS

Comparison	MOT failure, odds ratio [95% CI]	Engine-and-emissions failure, odds ratio [95% CI]	Still tested 2015 to 2023, risk ratio [95% CI]
1CD 2.0 vs petrol	0.952 [0.914, 0.992]	0.717 [0.662, 0.777]	0.839 [0.825, 0.852]
1ND 1.4 vs petrol	0.904 [0.882, 0.927]	0.806 [0.761, 0.853]	0.992 [0.984, 1.000]
1AD 2.0 vs petrol	1.027 [0.989, 1.066]	1.075 [0.962, 1.202]	0.853 [0.842, 0.863]
2AD 2.2 vs petrol	1.005 [0.973, 1.037]	1.060 [0.983, 1.144]	0.929 [0.919, 0.938]
AD inside bulletin windows vs petrol (2015)	0.923 [0.899, 0.949]	0.917 [0.831, 1.012]	0.893 [0.883, 0.902]
AD built from 2010 vs petrol	-	-	0.919 [0.907, 0.930]

Failure ratios are for 2023 except the bulletin row, which is 2015, the year the covered cars were five to ten years old. Stratified by model, class, age and mileage.

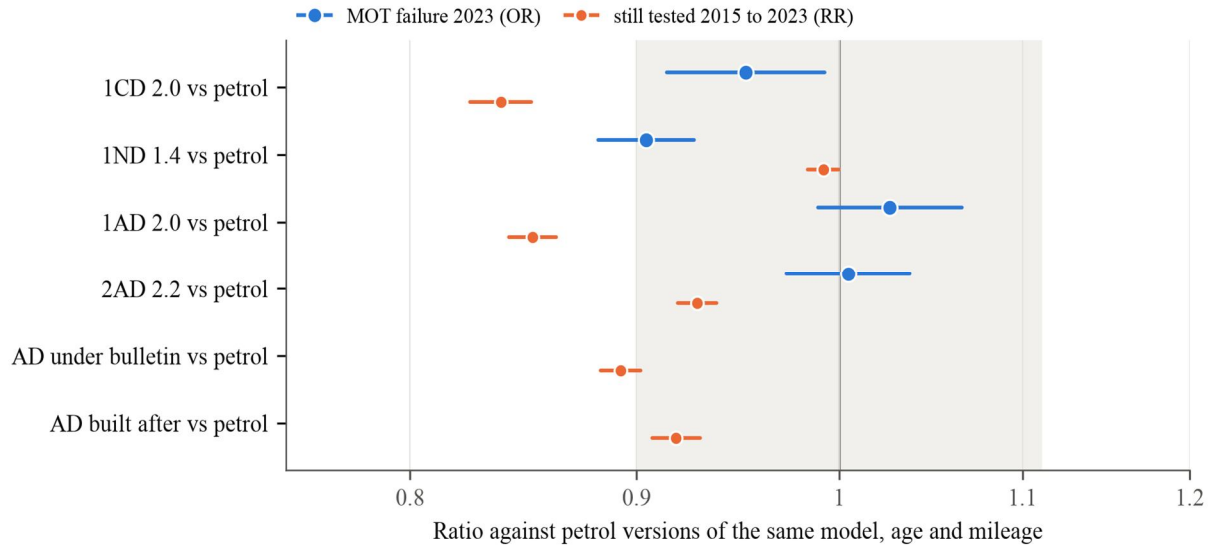


Fig. 5 Toyota's car D-4D engines against petrol versions of the same models, and the AD engines built inside and after the bulletin's production windows.

Survival favoured petrol throughout. Cars with the 1CD (0.839) and the 1AD (0.853) remained in use materially less often than petrol versions of the same model, age and mileage, and the 2AD (0.929) and 1ND (0.992) slightly less often. This is not necessarily a verdict on the engines. London's Ultra Low Emission Zone restricts diesel cars older than Euro 6 but petrol cars only when they are older than Euro 4 [10], and a policy of that kind shortens diesel lives regardless of reliability.

F. The Positive Control (H4)

The 2015 cohort held 55,098 AD cars built inside the bulletin's windows, 12,026 with the 1AD and 43,072 with the 2AD, and 19,260 built from 2010, set against 232,179 petrol cars of the same four models. The covered AD cars were materially less likely than their petrol twins to still be in use in 2023 (risk ratio 0.893, interval 0.883 to 0.902), so H4a is supported. The gap was widest for the 1AD (0.816), which fits the consumer site's note that 2.0-litre D-4Ds had suffered head-gasket failures [7]. AD cars built from 2010 showed a smaller gap (0.919), and the ratio between the two, 1.029 with an interval of 1.013 to 1.046, supports H4c, though the difference is small. H4b is not supported: in 2015, when the covered cars were five to ten years old, their engine-and-emissions failure odds did not differ detectably from petrol twins (0.917, interval 0.831 to 1.012).

The control therefore passed only in part, and one detail weakens even that. The 1CD, which no bulletin covered, showed a survival gap to petrol (0.839) at least as large as that of the covered AD engines. The survival measure can register a documented fault, but it also registers whatever else shortens diesel lives, and the MOT's engine section did not register the fault at all.

G. Checks

Simpson's paradox is not a curiosity in these data. In 10 of the 25 comparisons of an engine with the fleet, the crude odds ratio pointed the other way from the stratified one (Fig. 6). The 2KD in 2023 is typical: its raw failure rate was 38.4 percent against the fleet's 30.9 percent, a crude odds ratio of 1.391, yet within cells of the same class, age and mileage it failed less often (0.954). The D-4D vehicles look worse in raw rates largely because they are older and have covered more miles, the confounding structure described by Kievit and colleagues [26]. Among the petrol-twin comparisons six of 12 reversed, most of them in the same direction, and among the comparisons with rivals one of 11.

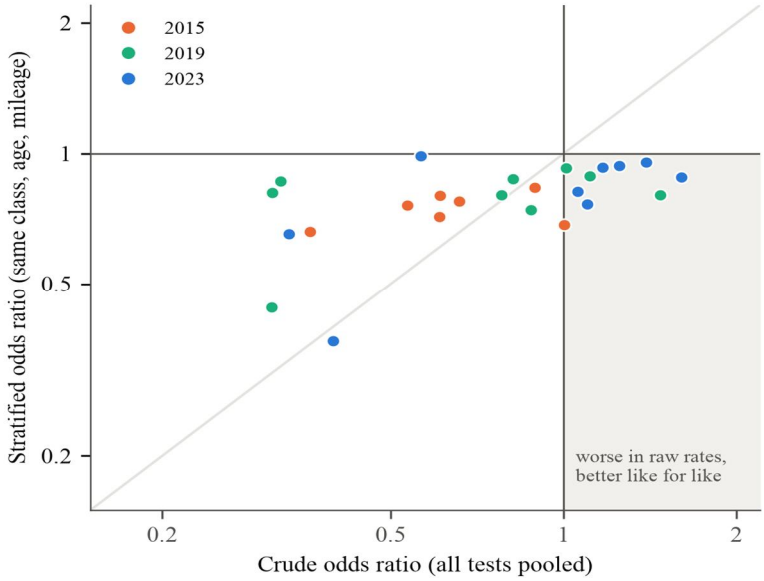


Fig. 6 Crude against stratified odds ratios for the 25 comparisons of an engine with the diesel fleet. Points in the shaded area look worse than the fleet in raw rates but better once class, age and mileage are held equal.

The survival measure was validated against the national register. For Toyota models badged D-4D and first used from 2005 to 2010, the register held 155,854 vehicles, licensed or declared off the road, at the end of 2015 and 94,650 at the end of 2023, so 60.7 percent of them survived on the register; counting licensed vehicles only, 52.2 percent did. Of the 158,517 D-4D vehicles from the same years tested in 2015, 53.3 percent were tested again in 2023. The MOT measure sits between the two register figures, close to the licensed-only ratio, as it should, since vehicles declared off the road are not tested.

Two sensitivity checks left the main conclusions unchanged. Restricting to class 4 moved the 2KD's fleet-relative odds ratio to 0.966 and the Hilux 2KD against rival pickups to 1.059; dropping the top mileage band moved them to 0.949 and 1.050. The HiAce's advantage over rival vans held at 0.615 in class 4 alone and 0.581 without the top band. The only reading that changed was the 2GD's, which in class 4 alone failed slightly more often than the fleet (1.036).

VII. RESULTS

Table VII sets each hypothesis against its outcome.

TABLE VII
HYPOTHESES AND OUTCOMES

Hypothesis	Key estimate	Outcome
H1: not every engine materially better than the fleet	five of nine materially better in 2023; I-squared 0.983	Supported in 2023 and 2019; not supported on the failure prong in 2015, when all seven were materially better; the engines were heterogeneous in all three years
H2a: Hilux 2KD better than rival pickups	1.055	Not supported; slightly worse
H2b: Hilux 1KD better than rival pickups	0.940	Not supported; slightly better
H2c: HiAce 2KD better than rival vans	0.615	Supported
H2d: KD vehicles survive better than rivals	1.084, 0.987, 1.025	Not supported
H3: car D-4Ds no better than petrol	0.952, 0.904, 1.027, 1.005	Largely supported; the 1ND slightly better
H4a: covered AD cars survive less	0.893	Supported
H4b: covered AD cars fail engine section more	0.917	Not supported
H4c: later AD cars show a smaller gap	1.029	Supported; no materiality threshold was pre-registered for this part, so it is read on direction and interval alone

Three findings stand out. Every one of the nine engines fails the MOT at least as seldom as comparable British diesels, but not by a shared material margin, and the margin has been shrinking. The 2KD's distinction lies in how long its vehicles stay in use, and most of that distinction is shared with other working vehicles. Against its direct rivals, the 2KD's advantage in the Hilux is concentrated where the MOT looks at the engine, in 2019 and 2023 though not in 2015, and not in the Hilux's overall failure rate.

VIII. DISCUSSION

A. What the Legend Turns Out to Be

The reputation the paper set out to test is not contradicted, but it is reshaped. If it meant that every Toyota diesel is better than its peers, the MOT record does not support it: the family is heterogeneous, and the 2KD's failure advantage over comparable diesels is one of the smallest. If it meant that 2KD vehicles keep going when others stop, the record does support it: vehicles with the 2KD remained in use a third more often than comparable diesels. Their odometers also passed 200,000 miles far more often than the fleet's, although that measure was fixed in advance as descriptive only, and the 1AD's excess over expectation (2.11) is larger still. These are different claims, and owners usually make the second. A vehicle can fail its annual inspection on brakes, lights or corrosion and still be worth repairing because its engine is sound; the survival figures are consistent with that, and the failure figures are not evidence against it.

B. Engine or Job?

The comparisons with rivals show how much of the 2KD's standing belongs to the work its vehicles do. Once the Hilux and HiAce are compared with vehicles doing the same work, their survival advantage shrinks to between two and eight percent. What remains distinctive is narrower. In the Hilux, both KD engines had around 36 to 43 percent lower odds of an engine-and-emissions failure than rival pickups in 2023, and a similar margin in 2019, though not in 2015. That is the most engine-specific evidence the MOT can offer, and in the two later years it favours the KD engines. The HiAce's large advantage over rival vans lies elsewhere in the vehicle, which the MOT data cannot pin down further. The pattern fits the view in the literature that how long a vehicle lasts depends on use, prices and owners' decisions as well as engineering [11], [13], [15].

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The narrowing of the family's failure advantage between 2015 and 2023 is harder to explain. The comparisons fix age, so it is not simply that the Toyota vehicles have grown older. It may be that the rest of the diesel fleet improved, that the D-4D vehicles still being tested are increasingly the hard-worked ones, or that British policy has changed which diesels are kept. Three years of data cannot separate these explanations.

C. What the Positive Control Says About the Method

A measure that cannot detect a known fault cannot be trusted to confirm the absence of one. The AD engines built under the bulletin left the road faster than their petrol twins, and faster than AD engines built later, so the survival measure has some sensitivity. But the gap was modest, the 1CD showed a similar gap without any bulletin, and the engine section of the MOT showed nothing. The honest reading is that the MOT sees engine trouble mainly through its consequences, when owners decide a vehicle is not worth keeping, and that it sees them blurred together with everything else that shortens a diesel's life, including exports [14] and clean-air policy [10]. The 2KD's strong showing on survival should be read with that blur in mind.

D. What This Means for an Innova in India

For an Innova owner the British evidence is encouraging but indirect. It says that the 2KD, in vehicles worked hard, is associated with long service and heavy odometer readings, and that its engine-related MOT record in pickups is better than its rivals'. It cannot say how the engine fares on Indian roads and Indian fuel. Much of the Innova's early life fell in a period when the cleaner Bharat Stage 4 fuel standard applied in only 20 cities [24], and the 2KD was built in more than one state of tune [4], [21], so British experience of the Hilux is not Indian experience of the Innova. The newer engines of the Innova Crysta, the 1GD and 2GD [1], are too young in Britain for their durability to be judged: the 1GD failed the MOT materially less often than comparable diesels and the 2GD no more often, but neither has yet reached the ages at which the older engines built their reputation.

IX. LIMITATIONS AND THREATS TO VALIDITY

1) The MOT checks roadworthiness and emissions on the day of the test. The user guide published with the data (Section V-A) states that a test certificate relates only to the condition of the testable items at the time of the test and is not evidence of the vehicle's general mechanical condition; a failure can also have nothing to do with the engine.
2) Survival cannot distinguish scrapping, export and a vehicle declared off the road. Export alone took millions of used vehicles off British roads over these years [14], and working vehicles such as pickups may be exported at different rates from cars, which would bias fleet comparisons.
3) Engines are identified from a capacity entered at the test. Wrongly recorded capacities, fuel types and model names add noise, and some vehicles of each engine will have been missed. Two capacity overlaps required year windows that also exclude some genuine 1KD and 1CD vehicles.
4) Engine and vehicle cannot be fully separated. Each engine went into few models, so a difference between engines is also a difference between vehicles and their owners. The rival and petrol-twin comparisons reduce this problem but do not remove it.
5) Mileage before 2022 was sometimes recorded in kilometres, which puts some 2015 and 2019 tests in the wrong band.
6) Survivors are selected. Old vehicles still being tested are those their owners chose to keep [15], and high-mileage vehicles leave the fleet at younger ages [8].
7) British use, climate and fuel differ from Indian conditions, and no Innova is in the data.
8) The positive control passed only in part, which limits the weight any null result can bear.
9) The ten percent materiality band is a convention fixed in advance, not a property of the data.
10) Engine capacities for seven of the nine engines and the text of the AD bulletin come from web sources, an encyclopedia list and a reader-contributed quotation on a consumer site, rather than from original Toyota documents. The MOT data documentation is the dataset's own user guide rather than a peer-reviewed source.
11) Only three test years were used, so changes over time cannot be separated into effects of age, period and cohort.

X. RECOMMENDATIONS AND FUTURE WORK

1) For buyers of used Toyota diesels, the engine name is a weak guide on its own. The evidence favours the 2KD on length of service against the diesel fleet, though not against other working vehicles, and both KD engines on engine-related faults in 2019 and 2023 but not in 2015. It does not favour them on overall inspection results, and it favours none of the car engines over petrol.

2) For researchers using the MOT record, engine-level analysis is feasible and changes conclusions drawn at the level of the make. Stratifying by age and mileage is essential; without it, 10 of the 25 comparisons of an engine with the fleet would have pointed the wrong way.

3) For the agencies that publish the data, recording the engine code, or the engine family given at type approval, would remove the need to infer engines from capacity.

4) For India, a public record of periodic inspections would allow questions like this one to be answered on Indian roads, with Indian fuel, for the Innova itself.

5) For future work, following vehicles through every annual test rather than three snapshots would give a fuller picture, and the same approach applies to other manufacturers' engine families.

XI. CONCLUSION

This study set out to test a reputation that began with one family's Innova. In about 119 million British MOT records, nine Toyota-designed D-4D engines were identified and compared with vehicles of the same class, age and mileage. Not one of the nine failed the MOT more often than the fleet in 2023, but the advantage was not shared by a material margin, differed sharply between engines and narrowed between 2015 and 2023. The 2KD, the Innova's engine, had one of the smallest failure advantages and the largest survival advantage: its vehicles were a third more likely to still be in use eight years later. Against vehicles doing the same work, that survival advantage almost disappeared, while the Hilux's KD engines held a clear lead on engine-related faults in 2019 and 2023.

The legend, then, is not a family trait, and it is not a claim about passing inspections. What the record supports is narrower and closer to what owners actually say: in vehicles that are worked hard, the 2KD tends to keep going. The analysis also shows how easily the opposite conclusion could have been reached. Measured by raw failure rates, without holding age and mileage fixed, the 2KD would have looked worse than the average diesel. The reputation deserves to be tested by comparing like with like, and on that test it holds, in a narrower form than the one usually repeated.

REFERENCES

[1] Wikipedia contributors, "Toyota Innova," Wikipedia, The Free Encyclopedia, revision of Sept. 2026. [Online]. Available: https://en.wikipedia.org/wiki/Toyota_Innova. Accessed: Sept. 22, 2026.

[2] V. Nguyen-Tien, C. Zhang, E. Strobl, and R. J. R. Elliott, "The closing longevity gap between battery electric vehicles and internal combustion vehicles in Great Britain," Nature Energy, vol. 10, no. 3, pp. 354–364, 2025. doi: 10.1038/s41560-024-01698-1.

[3] T. Chatterton, J. Barnes, R. E. Wilson, J. Anable, and S. Cairns, "Use of a novel dataset to explore spatial and social variations in car type, size, usage and emissions," Transportation Research Part D, vol. 39, pp. 151–164, 2015. doi: 10.1016/j.trd.2015.06.003.

[4] Toyota (GB) PLC, "Toyota Hilux technical specification," Toyota UK media site, Epsom, UK, 2012. [Online]. Available: http://media.toyota.co.uk/wp-content/files_mf/1351767083TOYOTAHILUXTECHNICALSPECIFICATION.pdf (Internet Archive copy of 15 June 2016). Accessed: Sept. 22, 2026.

[5] Wikipedia contributors, "List of Toyota engines," Wikipedia, The Free Encyclopedia, revision of 17 Sept. 2026. [Online]. Available: https://en.wikipedia.org/wiki/List_of_Toyota_engines. Accessed: Sept. 22, 2026.

[6] Toyota (GB) PLC, "The new Toyota Avensis," UK launch press pack, Toyota UK media site, Epsom, UK, 2008. [Online]. Available: https://media.lexus.co.uk/wp-content/files_mf/1429103584AvensisGen3launchpack2008.doc (Internet Archive copy of 26 Oct. 2020). Accessed: Sept. 22, 2026.

[7] Honest John, "Review: Toyota Avensis (2003–2009)," HonestJohn.co.uk, archived 3 Dec. 2021. [Online]. Available: https://www.honestjohn.co.uk/carbycar/toyota/avensis-2003/ (Internet Archive copy of 3 Dec. 2021). Accessed: Sept. 22, 2026.

[8] Department for Transport, "Analysis of vehicle odometer readings recorded at MOT tests," Experimental Statistics, Department for Transport, London, 2013. [Online]. Available: https://assets.publishing.service.gov.uk/media/5a7c729c40f0b626628ac212/experimental-statistics-mot-data.pdf. Accessed: Sept. 22, 2026.

[9] R. E. Wilson, S. Cairns, S. Notley, J. Anable, T. Chatterton, and F. McLeod, "Techniques for the inference of mileage rates from MOT data," Transportation Planning and Technology, vol. 36, no. 1, pp. 130–143, 2013. doi: 10.1080/03081060.2012.745768.

[10] J. Davison, R. A. Rose, N. J. Farren, R. L. Wagner, S. E. Wilde, J. V. Wareham, and D. C. Carslaw, "Gasoline and diesel passenger car emissions deterioration using on-road emission measurements and measured mileage," Atmospheric Environment: X, vol. 14, art. 100162, 2022. doi: 10.1016/j.aeaoa.2022.100162.

[11] S. J. Newman, "British automobiles, aging theory, and the death of complex machines," arXiv:2505.11505, 2025. doi: 10.48550/arXiv.2505.11505.

[12] M. Held, N. Rosat, G. Georges, H. Pengg, and K. Boulouchos, "Lifespans of passenger cars in Europe: empirical modelling of fleet turnover dynamics," European Transport Research Review, vol. 13, no. 1, art. 9, 2021. doi: 10.1186/s12544-020-00464-0.

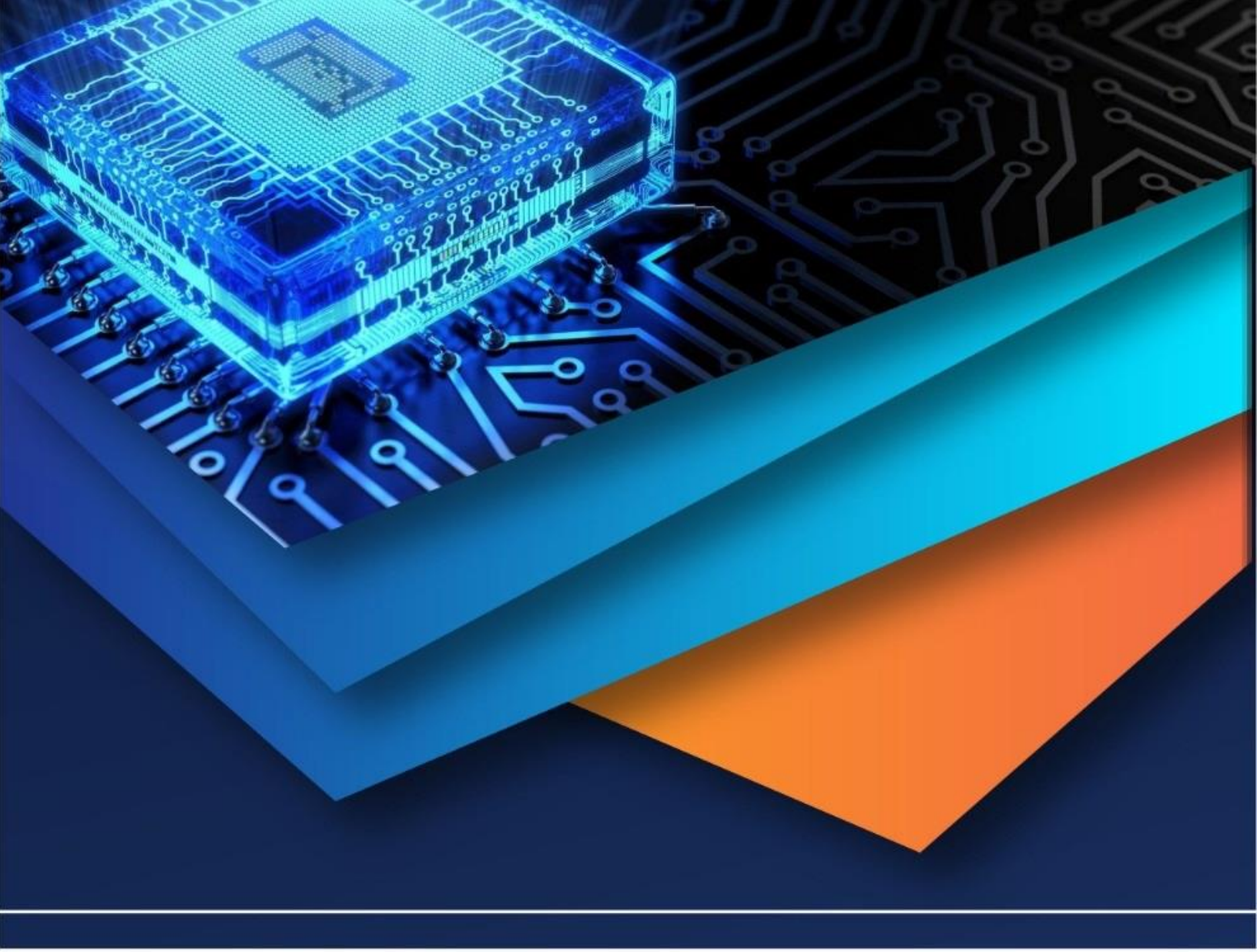
[13] A. Bento, K. Roth, and Y. Zuo, "Vehicle lifetime and scrappage behavior: trends in the U.S. used car market," The Energy Journal, vol. 39, no. 1, pp. 159–184, 2018. doi: 10.5547/01956574.39.1.aben.

[14] S. J. Newman, K. Schulte, M. M. Morellini, C. Rahal, and D. R. Leasure, "Offshoring emissions through used vehicle exports," Nature Climate Change, vol. 14, no. 3, pp. 238–241, 2024. doi: 10.1038/s41558-024-01943-1.

[15] W. Emons and G. Sheldon, "The market for used cars: new evidence of the lemons phenomenon," Applied Economics, vol. 41, no. 22, pp. 2867–2885, 2009. doi: 10.1080/00036840802277332.

[16] Y. Chen and J. Borken-Kleefeld, "NOx emissions from diesel passenger cars worsen with age," Environmental Science & Technology, vol. 50, no. 7, pp. 3327–3332, 2016. doi: 10.1021/acs.est.5b04704.
[17] K. Yang, J. T. Fox, and R. Hunsicker, "Characterizing diesel particulate filter failure during commercial fleet use due to pinholes, melting, cracking, and fouling," Emission Control Science and Technology, vol. 2, no. 3, pp. 145–155, 2016. doi: 10.1007/s40825-016-0036-0.
[18] S. Park, K. S. Lee, and J. Park, "Parametric study on EGR cooler fouling mechanism using model gas and light-duty diesel engine exhaust gas," Energies, vol. 11, no. 11, art. 3161, 2018. doi: 10.3390/en11113161.
[19] E. Natesan, S. Eriksson, J. Ahlstrom, and C. Persson, "Effect of temperature on deformation and fatigue behaviour of A356-T7 cast aluminium alloys used in high specific power IC engine cylinder heads," Materials, vol. 13, no. 5, art. 1202, 2020. doi: 10.3390/ma13051202.
[20] F. Szmytka, P. Osmond, L. Remy, P.-D. Masson, A. Forre, and F.-X. Hoche, "Some recent advances on thermal-mechanical fatigue design and upcoming challenges for the automotive industry," Metals, vol. 9, no. 7, art. 794, 2019. doi: 10.3390/met9070794.
[21] E. S. Mohamed, "Experimental analysis of the EGR and TEG systems effect on the thermal characteristics and emissions for a diesel engine," International Journal of Thermofluid Science and Technology, vol. 12, no. 1, paper 120102, 2025. doi: 10.36963/IJTST.2025120102.
[22] A. Kleyner and P. Sandborn, "Forecasting the cost of unreliability for products with two-dimensional warranties," in Safety and Reliability for Managing Risk (ESREL 2006), C. Guedes Soares and E. Zio, Eds. London: Taylor & Francis, 2006. [Online]. Available: http://escml.umd.edu/Papers/Kleyner-Sandborn%20ESREL06.pdf. Accessed: Sept. 22, 2026.
[23] R. Chugh, M. L. Cropper, and U. Narain, "The cost of fuel economy in the Indian passenger vehicle market," Energy Policy, vol. 39, no. 11, pp. 7174–7183, 2011. doi: 10.1016/j.enpol.2011.08.037.
[24] S. K. Guttikunda and D. Mohan, "Re-fueling road transport for better air quality in India," Energy Policy, vol. 68, pp. 556–561, 2014. doi: 10.1016/j.enpol.2013.12.067.
[25] V. Fidler and N. Nagelkerke, "The Mantel-Haenszel procedure revisited: models and generalizations," PLoS ONE, vol. 8, no. 3, art. e58327, 2013. doi: 10.1371/journal.pone.0058327.
[26] R. A. Kievit, W. E. Frankenhuis, L. J. Waldorp, and D. Borsboom, "Simpson's paradox in psychological science: a practical guide," Frontiers in Psychology, vol. 4, art. 513, 2013. doi: 10.3389/fpsyg.2013.00513.
[27] T. G. Clark, M. J. Bradburn, S. B. Love, and D. G. Altman, "Survival analysis part I: basic concepts and first analyses," British Journal of Cancer, vol. 89, no. 2, pp. 232–238, 2003. doi: 10.1038/sj.bjc.6601118.

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