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Vehicle refinement: purpose and targets

1.1 Introduction and definitions

The book opens with one man's thesis:

> "Styling and value sell cars – Quality keeps them sold". Lee Iacocca, *Iacocca: An Autobiography**

To explain, it takes years and millions of US dollars to produce a new car. If the styling is attractive and the marketing is effective, and if the value for money is good then that car will probably sell moderately well for the first few months after launch. However, if the quality is bad then word will get round and sales will quickly drop off. It is vital that good sales are maintained for a significant period if the development costs for the car are going to be recouped.

Lee Iacocca was writing from Ford's and Chrysler's perspective. Both of these already had their own strong brand image and so branding was not included in his thesis, but it should be when comparing cars from different manufacturers.

To test this idea the following group activity can be tried. It has been found to work well with larger teams of people and needs a group of at least twenty to be effective:

Group exercise – Four corners

What is most important when deciding which new car to buy?

- styling?
- performance?
- value?
- brand?

Stand in the corner of the room associated with your choice. If you favour two of the above, stand midway between the appropriate corners. Be prepared to explain your decision.

At least ten minutes should be allocated to this exercise. A confident facilitator is required to interview team members as to the reasons for their choice.

*Lee Iacocca, former President of the Ford Motor Company, former President of Chrysler in *Iacocca: An Autobiography*, Lee Iacocca with William Novak, Bantam 1984.

The four-corners exercise can be used to obtain different effects from different groups of people. With a group of managers from the same automotive organisation the exercise can quickly identify if there is consensus on a marketing strategy (also it is interesting to watch peer-pressure at work as individual choice is being exercised in a very public way during this exercise). With a group of engineers the exercise can be used to remind them that their own work affects the customer's buying decision. With a group of engineering students, the exercise teaches them that the customer's buying decision is a multi-criteria choice and probably a compromise at the end.

It is useful to introduce some definitions at this point. The term *Vehicle Refinement** covers:

- noise, vibration and harshness** (NVH – a well-known umbrella term in the automotive industry);
- ride quality;
- driveability.

A refined vehicle has certain attributes,*** they being:

- high ride quality;
- good driveability;
- low wind noise;
- low road noise;
- low engine noise;
- idle refinement (low noise and vibration);
- cruising refinement (low noise and vibration, good ride quality);
- low transmission noise;
- low levels of shake and vibration;
- low levels of squeaks, rattles and tizzes;
- low level exterior noise of good quality;
- noise which is welcome as a 'feature'.

The term 'NVH' is usually taken to cover:

- noise suppression;
- noise design (altering the character of noise but not necessarily its level);
- vibration suppression;
- suppression of squeaks, rattles and 'tizzes'.

1.2 Scope of this book

The scope of this book is illustrated in Figure 1.1.

It has been designed to cover the core science, engineering and technology required by the NVH engineer with added material on ride quality and driveability. Wherever possible,

*Refine (vb) to make or become free from coarse characteristics; make or become elegant or polished (Collins English Dictionary). Refinement is both a process (the act of refining) and a description of the eventual state (fineness, polish, etc.).

**Harsh (adj) rough or grating to the senses (Collins English Dictionary).

*** Attribute (n) a property, quality or feature belonging to or representative of a person or thing (Collins English Dictionary).

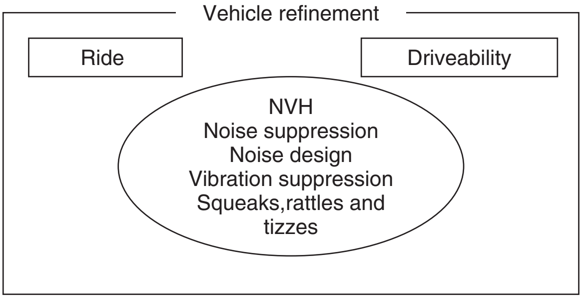

Figure 1.1 The scope of the term 'Vehicle Refinement'.

issues that affect the customer's buying decision have been emphasised. Refinement is a customer-facing subject as any refinement engineering undertaken affects the driving experience directly. Therefore, the reader is encouraged to think of refinement as being inextricably linked to the business of selling passenger cars (and increasingly this is being extended to vans, light trucks, trucks, buses, coaches and other road vehicles).

Some further definitions are offered for the sake of clarity. In this book the terms:

Noise shall be used to describe audible sound, with particular attention paid to frequencies in the range of 30–4000 Hz.

Vibration shall be used to describe tactile vibration, with particular attention paid to frequencies in the range of 30–200 Hz.

Other terms that will be encountered include:

Primary ride taken to be the rigid body motion of the passenger compartment relative to the road. Typical frequency range – 0–6 Hz.

Secondary ride taken to be the relatively large amplitude motion of sub-elements of the vehicle such as individual wheels, axles or elements of the powertrain. Typical frequency range – 6–30 Hz.

Structure-radiated noise being airborne noise radiated by a structural surface that is vibrating. Also known as 'structure borne noise'.

1.3 The purpose of vehicle refinement

Refinement helps manufacturers sell their vehicles. Brandl et al. (2000) published the results of a formal investigation of customer attitudes to vehicle refinement. Customers were asked to complete a questionnaire relating to their own vehicle. They were asked questions relating to their attitudes on vehicle prestige (brand by another name), performance, convenience, family friendliness, noise quality and cost. Although there was scatter in the results obtained, there was evidence of clustering with certain classes of customer showing predictable tastes with vehicle-refinement issues helping to define that taste.

Throughout the 1990s Rover Group in the UK (subsequently they traded under the MG badge) defined ‘Refinement’ as *the invisible feature* of their vehicles suggesting a strong commitment to it.

Refinement (or NVH) has always been a consideration for vehicle design and development. However, over the last 20–30 years it has assumed a greater importance (witness the advertisements by manufacturers that stress how quiet their cars are). Reasons for this include:

- *Legislation* Since the adoption by Member States of Council Directive 70/157/EEC (1970) limiting the permissible levels of noise emitted by accelerating vehicles, the sale of new non-conforming vehicles is prohibited in the European Community. Similar legislation has been adopted in many non-EU countries, and certainly in all the main automotive territorial markets.
- *Marketing to new customers* Refinement is a feature that may be used to distinguish a vehicle from its otherwise similar competitors, thus attracting customers not necessarily loyal to that particular brand.
- *Customer expectation* Customers have come to expect continuous improvement in the new vehicles that they buy. They expect their new purchase to be better equipped, more comfortable, and perform better than the vehicle they just traded in (which may only be a few years old). The new vehicle may be better in all respects than the old one on paper, but if it lacks refinement then it *will not feel better* and the customer will not be fully satisfied. They may choose to take their loyalty to another vehicle manufacturer next time.
- *Marketing to existing customers* ‘Trade your old model in for this year’s model: it is loaded with features, more comfortable and more *refined*.’ The modern car industry needs turnover to survive. People need to be encouraged to trade in regularly. The increase in vehicle leasing schemes for retail customers encourages this turnover.

The importance of vehicle refinement can be tested using the following group exercise where team members put a monetary price on refinement. This is an absolute test on the value that they place on refinement.

Group exercise – Line up

How much extra are you willing to pay for a B+ class vehicle (such as a small family sedan) that offers significant additional refinement compared to its rivals?

Stand up and form a line – those willing to spend nothing extra at one end and those willing to pay a significant sum at the other.

You should interview those standing next to you in line to make sure that you are in the right place. You should consider the basis for your value judgement and be prepared to share it with the group.

At least ten minutes should be allocated to this exercise. A facilitator is required to interview a selection of people in front of their peers on the reasons for their choice.

1.4 How refinement can be achieved in the automotive industry

The traditional vehicle manufacturer is organised according to functional divisions being typically: Design, Engineering, Manufacturing, Marketing and Sales. Each division might be divided further into groups. For simplicity, an Engineering Division shall be divided into three groups: Powertrain, Vehicle and the Suppliers of components to the engineering effort as shown in Figure 1.2.

The refinement sub-group straddles the interface between the three main groups, having influence on each one in turn but not enjoying any decision-making authority. For example, consider the engine mounts: they are attached to both the powertrain and the vehicle and they are manufactured by a third party supplier. The refinement sub-group has an interest in their performance in order to improve NVH but no over-riding authority to broker compromises between the three main groups. Management of such an interface is never going to be easy, and inefficiencies, misunderstandings, mistakes or arguments that result may delay the development programme.

An alternative organisational structure is that of the 'Extended Enterprise' (Ashley, 1997) where suppliers assume greater responsibility for the design and development of their particular contribution to the whole vehicle. Such organisations are more fluid as illustrated in Figure 1.3.

Design authority is pushed out from the small client team to the various engineering functions (including a refinement function). With this fluid structure, design information is visible to all interested parties and compromises are brokered 'out in the open'. Responsibility for delivering refinement targets, defined by the client team in a PDS (Product Design Specification), is shared by all. However, in many cases the bulk of the responsibility falls to the Supplier, with the refinement function checking for compliance with the PDS.

The wider adoption of the Extended Enterprise structure within the global automotive industry has led to new opportunities for refinement engineers, particularly within component supply organisations used to manufacture but now required to design and engineer as well.

The Extended Enterprise also leads to consolidation in the industry, with the big organisations getting bigger by acquisition (Hibbert, 1999).

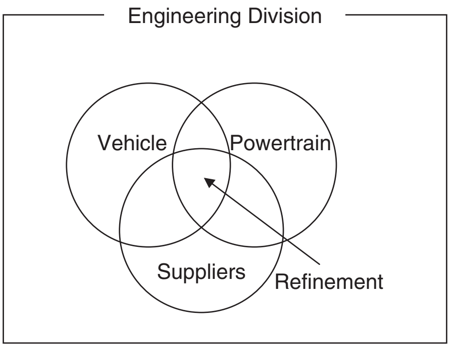

Figure 1.2 Refinement within the traditional vehicle manufacturer.

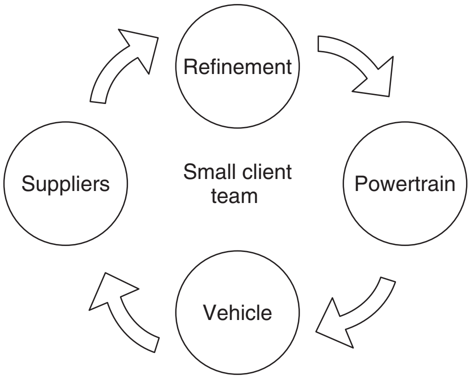

Figure 1.3 Refinement in the 'Extended Enterprise'.

1.5 The history of vehicle refinement: one representative 20-year example

In 1979, Vauxhall offered the Royale for sale in the UK – a 2.8-litre, six-cylinder, executive class (small) car for the on-the-road cost of £8354 (1979 prices). Motor magazine described it as being 'in general a refined car' (Vauxhall Royale – Star road test, Motor Magazine, 13 January 1979).

By 1989, that car had been replaced by the Vauxhall Senator 2.5i – a 2.5-litre, six-cylinder, executive class (small) car for the on-the-road cost of £16 529 (1989 prices). Autocar & Motor magazine attributed refinement as one of the car's strengths (Vauxhall Senator 2.5i – Test extra, Autocar & Motor, 21 September 1988).

By 1999, that car had been replaced by the Vauxhall Omega 2.5 V6 CD – a 2.5-litre, V6, executive class (small) car for the on-the-road cost of £21 145 (1999 prices). Autocar & Motor magazine described it as having 'one of the most refined, well mannered six-cylinder engines . . .' (Vauxhall Omega 2.5I V6, Autocar & Motor, 1 June 1994).

By 1999, Vauxhall had also launched a smaller vehicle with what seems on paper to be the same degree of sophistication – the 2.5-litre V6 Vectra GSi. Autocar & Motor magazine (New cars – Vauxhall Vectra GSi, Autocar & Motor – 14 July 1999) were not so complimentary about its refinement as they had been with the Omega.

The specifications and relative costs of these four cars are compared in Table 1.1 (non-SI units are retained for historic authenticity).

This comparison of scaled historic costs with the costs in 1999 for new vehicles (99MY denotes the 1999 model year) is shown in more detail in Figure 1.5.

The above comparisons tell us something about vehicle refinement over the twenty-year period 1979–1999, although any conclusions drawn apply strictly only to the development of one series of vehicles produced by one manufacturer on sale in one territory. It can be seen that:

1. The term 'Refinement' has been used by motor journalists since the 1970s (and indeed probably quite sometime before that). Therefore, the term has been placed in the mind of the consumer as being a relevant factor in the decision-making process of buying a car for a generation.

Table 1.1 Some Vauxhall executive cars (small) 1979–1999

Vehicle	*Peak power (bhp @ rpm)*	*Peak torque (lbft @ rpm)*	*Weight (kg)*	*Cost new*	*Estimate of real cost in 1999*
1979 Royale (Ref.a)	140 @ 5200	161 @ 3400	1402	£8354	£28832*
1989 Senator 2.5i (Ref.b)	140 @ 5200	151 @ 4200	1465	£16528	£28333*
1999 Omega V6 2.5 CD (Ref.c)	168 @ 6000	167 @ 3200	1480	£21145	£21145
1999 Vectra V6 Gsi (Ref.d)	193 @ 6250	193 @ 3750	1431	£21700	£21700

Source: Autocar & Motor magazine

* An estimate of what the real cost of that particular vehicle would be in 1999 relative to the cost of other goods included in the Retail Price Index. It has been calculated by scaling the cost when new by data obtained for the percentage change in Retail Price Index in the period 1979–1999, shown in Figure 1.4.

References

(a) Vauxhall Royale – Star road test
Motor Magazine, 13 January 1979
(b) Vauxhall Senator 2.5i – Test extra
Autocar & Motor, 21 September 1988
(c) Vauxhall Omega 2.5I V6
Autocar & Motor, 1 June 1994
(d) New cars – Vauxhall Vectra GSi
Autocar & Motor – 14 July 1999

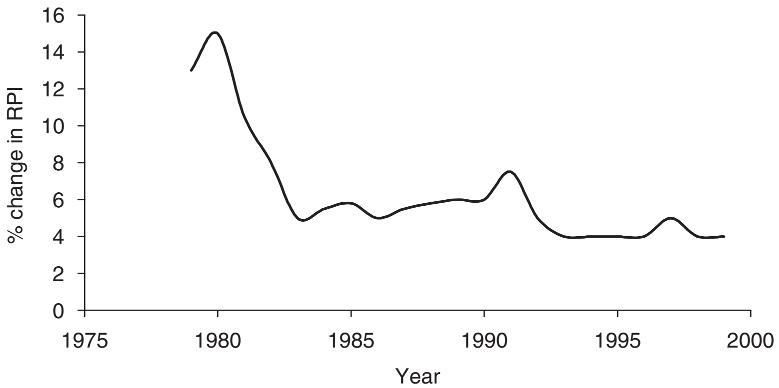

Figure 1.4 Change in Retail Price Index in the UK.
Source: www.bizednet.bris.ac.uk — University of Bristol.

2. The real cost of buying an executive class (small) Vauxhall car that has been commended for its refinement dropped significantly after 1979 – Table1.1 suggests that this drop might be as large as 25% by 1999. The drop seems to have occurred in the years between 1989 and 1999 (the scaled cost of the 1979 model year (79MY) Royale matches almost exactly the 1989 retail price for the Senator, but the scaled cost of the Senator is much greater than the 99MY Omega). During that ten-year period, the

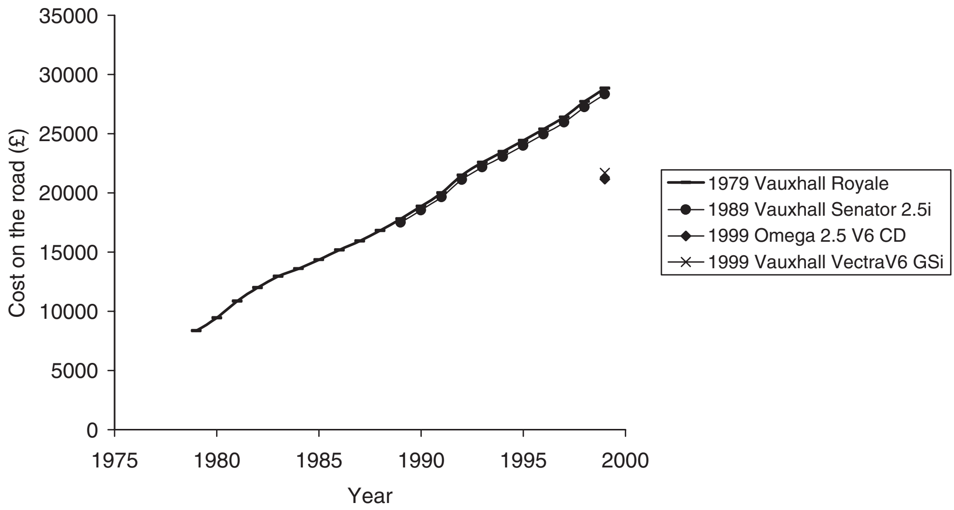

Figure 1.5 Comparing the cost of 99MY vehicles with the historic costs of equivalent 79MY and 89MY, scaled according to the UK Retail Price Index.
Data sources: References a – d in Table 1.1 and www.bizednet.bris.ac.uk – University of Bristol.

performance of the vehicle increased significantly in terms of specific engine torque and power (Table 1.1). In addition vehicle emissions dropped because of tougher legislation. The 99MY cars are more refined having to meet noise drive-by levels of 74 dBA compared with 82 dBA in 1979 (8 dBA is a significant drop in noise, equivalent to almost a halving in loudness). Also 99MY vehicles are generally better equipped than their predecessors (air conditioning, satellite navigation, CD-players, etc.).

3. The price of many new cars in the UK dropped by 10–15% in mid-2000 due to action by the UK Government and pressure from consumers. This makes the results discussed in (2) even more startling.
4. The consumer looking for a six-cylinder Vauxhall car in 1999 could choose between the Omega and the Vectra for virtually the same price. The Vectra seems to offer better performance, whilst the Omega is reported to offer more space and better refinement.

The situation described above is counter-intuitive – 99MY vehicles that have better performance, less emissions, better refinement and more equipment than 89MY vehicles but cost less in real terms. It is possible to speculate how the industry found itself in that position. It might have been due to:

- The effects of increased competition in a saturated market.
- Action by the UK Government (only applies to 2000MY prices).
- The effects of vehicle leasing schemes and manufacturer's vehicle finance schemes.
- The adoption of measures to improve organisational efficiency such as the 'Extended Enterprise' and technology employed in design and manufacturing activities.
- Macro political and economic factors affecting the automotive industry but not generated by that industry (globalisation, problems in Pacific Rim countries, etc.).

Table 1.2 Some six-cylinder Ford executive cars (small) 1979–1999

Vehicle	*Peak power (bhp @ rpm)*	*Peak torque (lbft @ rpm)*	*Weight (kg)*	*Cost new*	*Estimate of real cost in 1999**
1979 (no comparable model)					
1989 Granada 2.4I V6 Ghia (Ref. e)	130 @ 5800	142 @ 3000	1340	£16 045	£25 996
1999 Mondeo 2.5 litre V6 Ghia X (Ref. f)	168 @ 6250	162 @ 4250	1408	£21 680	£21 680
1999 Mondeo 2.5 litre V6 ST24 (Ref. g)	168 @ 6250	162 @ 4250	1410	£19 680	£19 680

* Calculated in the same manner as Table 1.1.

References

(e) Test Update: Ford Granada 2.4i Ghia
Autocar & Motor, 11 February 1987
(f) Autocar Twin Test: Ford Mondeo 24v Ghia X vs Peugeot 406 3.0 SVE
Autocar & Motor, 6 November 1996
(g) Autocar Twin Test: Ford Mondeo ST24 vs Vauxhall
Vectra Gsi
Autocar & Motor, 22 April 1998

A similar trend can be shown with Ford, one of Vauxhall's traditional competitors. Data for six-cylinder executive (small) cars manufactured by Ford (broadly competing vehicles to the Senator/Omega/Vectra) are shown in Table 1.2 and these show similar trends to the data for the Vauxhall cars shown in Table 1.1.

1.6 Refinement targets

The setting of refinement targets is important for the successful operation of the so-called Extended Enterprise that is described in Section 1.4. Without these, individual system suppliers would determine their own interpretation of an appropriate level of refinement for their component and the final vehicle would most likely be truly refined only in some aspects and not in others. In addition, it should be noted that type approval testing (at present) is undertaken as 'whole vehicle' type approval (see Section 3.1.1) and therefore by definition it is only undertaken once the production intent vehicle is fully developed. If one component or sub-system causes the vehicle to fail its type approval test due to excessive noise then the cost implications are obviously serious.

The standard management tool for setting refinement (and other) targets is the PDS document. This is written by the brand holder and adherence to it becomes a conditions of contract for any supplier. A typical PDS will contain the following refinement targets:

- whole vehicle exterior noise targets;
- single component exterior noise targets;

- whole vehicle interior noise targets;
- ride quality targets (including tactile vibration targets).

The exterior noise targets will mostly be objective relating to the passing of the type approval noise test although occasionally subjective criteria might be included in addition (exhaust noise quality in particular for sports cars). The interior noise, ride quality and tactile vibration targets will be a mix of objective and subjective criteria.

1.6.1 Whole vehicle exterior noise targets

Whole vehicle noise targets are set in terms of drive pass noise levels for the type approval test required in the territory in which the vehicle will be offered for sale. Separate noise targets are commonly set for each sub-system on the vehicle. A typical set is given in Table 1.3 for vehicles offered for sale in the EU.

It is not possible to determine a single set of such targets for a given territory as every vehicle will have its own unique noise signature. This is made clear in Tables 3.2 and 3.3 (see Section 3.1.6) where it is clear that the EU passenger car fleet exhibits type approval noise levels that vary by as much as 10 dB. Notwithstanding this, Table 1.3 is offered as a starting point. If a particular vehicle is diesel powered, perhaps the engine noise target should be increased by 1–2 dB. If the vehicle is a sports-utility then perhaps the tyre noise and transmission noise targets should be raised by 1–2 dB apiece.

1.6.2 Single component exterior noise targets

In order to minimise the risk that the whole vehicle exterior noise targets are not met at the final type approval testing, the PDS will routinely include separate airborne noise targets for certain components or vehicle subsystems. The most common targets relate to engine-radiated noise, intake noise and exhaust noise.

1.6.2.1 Engine-radiated noise targets

These are normally set in terms of sound power level (see Section 2.5.1). European engine suppliers are now required by law to measure and declare the sound power emissions of their engines. This makes a comparison between competitor engines easy.

Table 1.3 Suggested target noise levels for achieving type approval under 9297/EEC. See Section 3.1.6 for further details

	Passenger car	*Light truck*	*Heavy truck*
	Target levels at 7.5 m, acceleration test (dBA)		
Engine	69	72	77
Exhaust	69	70	70
Intake	63	63	65
Tyres	68	69	75
Transmission	60	63	66
Other	60	72	65
Combined level	74.2	77.3	80.1

Engine-radiated noise targets are more important for diesel engines than for gasoline engines as the various type approval tests undertaken around the world demand only quite low engine speeds where gasoline engines are generally quiet and rarely cause failure of the test.

Again, it is not possible to adopt a single set of noise targets applicable to all potential engines, but an indicative set is offered in Table 1.4. This relates to a particular diesel engine used in light European trucks and sports-utility vehicles.

An alternative target for a 4.0 litre four-cylinder DI diesel is offered by Pettitt (1988) at 107 dB re 10^{-12} W. An alternative (and rather different) noise source ranking is offered for a six-cylinder diesel engine by Beidl et al. (1999).

1.6.2.2 Intake orifice–radiated noise targets

These are commonly set as maximum sound pressure levels to be recorded at a distance of 100 mm from the intake orifice at an angle of incidence of 90°. Common targets are:

- An overall A-weighted sound pressure level of 90 dBA at 1000 rev min^{-1} wide-open throttle (full load) rising at a rate of 5 dBA per 1000 rev min^{-1} to a maximum of 115 dBA at 6000 rev min^{-1}. The adoption of this target is likely to result in an intake level of 63 dBA during an EC type approval test (as required by the targets shown in Table 1.3) without relying on any attenuation offered by the vehicle bodyshell.
- A firing order sound pressure level (see Section 2.4.2.5) of 105 dB (lin) at low drive-away engine speeds (full load), a level of 100 dB (lin) at moderate engine speeds and a level of 105 dB (lin) at high engine speeds.
- Sound pressure levels for other higher orders of 95 dB (lin) at low drive-away engine speeds (full load), a level of 90 dB (lin) at moderate speeds and a level of 95 dB (lin) at high engine speeds.

1.6.2.3 Exhaust tailpipe–radiated noise targets

These are commonly set as maximum sound pressure levels to be recorded at a distance of 500 mm from the exhaust tailpipe at an angle of incidence of 45°. Common targets are:

Table 1.4 Typical sound power targets in dB re 10^{-12}W for a 4.0-litre I4 NA (naturally aspirated) IDI (in-direct injection) diesel used in light trucks and sports-utility vehicles

Component	*Sound power level* (dB re 10^{-12} *W*)
Sump	102
Block	104
Head	93
Exhaust	102
Intake	97
Fuel injection pump	96
Total	108

- An overall A-weighted sound pressure level of 82 dBA at 1000 rev min^{-1} wide-open throttle (full load) rising at a rate of 5 dBA per 1000 rev min^{-1} to a maximum of 107 dBA at 6000 rev min^{-1}. The adoption of this target is likely to result in an exhaust level of 69 dBA during a type approval test (as required by the targets shown in Table 1.3).
- A firing order sound pressure level (see Section 2.4.2.5) of 120 dB (lin) at low drive-away engine speeds (full load), a level of 100 dB (lin) at moderate speeds and a level of 115 dB (lin) at high engine speeds.
- Sound pressure levels for other higher orders of 105 dB (lin) at low drive-away engine speeds (full load), a level of 95 dB (lin) at moderate speeds and a level of 105 dB (lin) at high engine speeds.

1.6.3 Whole vehicle targets for interior noise

Interior noise levels are routinely measured at the driver's ear position (and elsewhere in the vehicle interior) in accordance with BS 6086 1981 (ISO 5128, 1980) (see Section 4.1.3 for details). Either of two basic schemes for objective interior noise targets can be adopted.

1.6.3.1 Interior noise targets: perceptible improvement in sound pressure level

In this scheme, sound pressure levels in the vehicle interior are measured in accordance with BS 6086 1981 (ISO 5128, 1980) in the competitor vehicle. Then a target is set for the vehicle under development in terms of relative improvement. Bies and Hansen (1996) summarise:

Change in apparent loudness	*Change in sound pressure level (dB)*
Just perceptible	−3
Clearly noticeable	−5
Half as loud	−10
Much quieter	−20

Recordings of interior noise can be analysed to obtain the following metrics:

- Overall sound pressure level. This would normally be A-weighted for sound pressure levels below 55 dB (re 20 micro-pascals) and C-weighted for sound pressure levels in the range of 55–85 dB (Bies and Hansen, 1996). Typical targets would be devised in terms of maximum sound pressure level at certain road speeds under cruise conditions and at certain engine speeds under full load acceleration.
- Sound pressure level at the engine firing frequency order (see Section 2.4.2.5).
- Sound pressure level at higher engine orders.

Perceptible improvement targets can be set for each of these metrics. Such targets are most likely to be 3 dB lower than the metrics measured in the competitor vehicle in order to achieve tangible improvement at minimum cost.

1.6.3.2 Interior noise targets: brand value

In this scheme, a definitive set of interior noise targets are adopted, irrespective of the relative performance of competitor vehicles, in order to make a particular brand statement. The targets might apply to either aural comfort, or more usually speech intelligibility. Such targets are obviously brand specific but some general rules do apply:

- American Standard ANSI S3.1–1977 shows that effective speech communication can take place at normal voice levels between two persons spaced 1 m apart (in a free acoustic field) providing the background noise level is less than 65 dBA (or the so-called speech interference level (SIL) being the arithmetic average sound pressure level in the 500, 1000 and 2000 Hz octave bands is less than 58 dB (lin)). These two targets are the upper limits for just acceptable speech communication. Bies and Hansen (1996) describe this as being 95% sentence intelligibility or 60% word-out-of-context recognition.

  In accordance with this, and assuming a highly sound absorbing vehicle interior, a rational target for interior noise level with a vehicle under steady-state cruise conditions would be an interior sound pressure level of 65 dBA at the driver's ear. When intelligibility of the female voice is of particular importance, this target might be lowered to 60 dBA. When front seat to back seat communication is of particular importance, the target might be lowered to 55 dBA. With the general adoption of hands-free mobile phones in vehicles, a target in the range of 60–65 dBA is prudent. A survey of a 2003 MY executive class sedan revealed interior cruise noise levels in the range of 60–65 dBA at 80 km hr^{-1} on B-class roads. Speech communication in the front seats in this vehicle should be adequate but front to back seat communication would be compromised. By way of historical comparison, Rust et al. (1989) suggested an interior noise level of 70 dBA at 80 km hr^{-1} for a 1980s direct injection (DI) diesel.
- Priede (Priede, 1974; Priede and Anderton, 1984) showed that typically, full-load engine noise increases by 5 dB per 1000 rev min^{-1} increase in engine speed. Challen and Crocker (1982) suggest that the maximum effect of engine load on engine noise levels is of the order of 1–2 dB. Priede (1974) suggests that intake and exhaust noise levels increase by 5 dB per 1000 rev min^{-1} and it is well known that intake noise is strongly affected by load (±15 dB) whereas exhaust noise levels are not so strongly affected (±10 dB). Underwood (1973) suggested that tyre noise increases by 9–13 dB per doubling of vehicle speed.

  In accordance with this guidance, any objective interior noise target for any metric should vary with engine speed, road speed and engine load as appropriate. A consistent set of interior noise targets for a mid-priced family car powered by a four-cylinder gasoline engine might be:

- 65 dBA at the driver's inner ear at 80 km hr^{-1} cruise and 70 dBA at 120 km hr^{-1}.
- Under full load acceleration in second or third gear, a sound pressure level at the driver's inner ear of 55 dBA at 1000 rev min^{-1} rising linearly to 80 dBA at 6000 rev min^{-1}. Under overrun (zero load) the targets should be 10 dB less.
- The level of any engine order should be at least 3 dB lower than the overall noise level.

For the case of an executive or luxury car, these targets should all be reduced by at least 5 dB.

Alternative brand-value interior noise targets can be set in terms of:

- (Zwicker) loudness in accordance with ISO 532 – 1975. This method is suitable for calculating the loudness level (in 'phons') of combinations of octave bands for random-like noise in which there are prominent tonal components. The loudness in phons is given by the set of equal loudness contours (BS 3383 – 1988, ISO 226 – 1987). Each contour is labelled with X phons, X being the sound level at 1000 Hz for that particular contour.
- Articulation index (AI) in the range of 0.5–0.6. The calculation method is given in ANSI S3.5 – 1969 and the long-term rms. speech level in 1/3 octave bands is compared against the long-term rms. masking noise level, and the 1/3 octave results so generated are aggregated using separate weighting functions for each 1/3 octave band.
- Speech transmission index (STI) and the more rapid RASTI (rapid speech transmission index) (BS 6840: part 16 – 1989) are commonly used alternatives to articulation index. Rust et al. (1989) suggest a RASTI of 0.8 at 50 km hr^{-1} reducing linearly to 0.4 at 125 km hr^{-1}.

1.6.3.3 Interior noise: subjective targets

There are several different strategies for the subjective assessment of interior noise. These are discussed, along with target levels in Section 4.1.4. An engineering method for subjective appraisal involves a panel of people driving and riding in the vehicle(s) along a pre-determined test route on public roads and rating the following noise (and vibration) attributes:

- wind noise;
- road noise;
- engine noise;
- idle refinement;
- cruising refinement;
- transmission noise;
- general shakes and vibrations;
- squeaks, rattles and tizzes;
- ride quality;
- driveability;
- noise that is a 'feature' (sporty exhaust notes, etc.).

Table 1.5 Common subjective rating scheme

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Not acceptable			Objectionable	Requires improvement	Medium	Light	Very light	Trace	No trace

The ratings are made to a common scale from 1 to 10 as per Table 1.5.

- A rating of less than 4 is unacceptable for any attribute.
- A rating of 5 or 6 is borderline.
- A rating of 7 or more on any attribute is acceptable.

Most new passenger cars are launched with a subjective rating of 7 or 8 on most attributes.

1.6.4 Targets for ride quality (including tactile vibration)

Ride quality is taken here to be the subjective response to a low-frequency vibration phenomenon. There are several different strategies for the assessment of in-vehicle vibration levels and these are discussed in Section 6.5. A summary is measured vibration levels are rated according to objective criteria, and the most commonly used criteria are offered in:

- ISO 2631 Part 1 (1985);
- BS 6841 (1987);
- NASA discomfort level index (1984) (Leatherwood and Barker, 1984).

Experience of using all three has led to the conclusion that a family class vehicle for either the European or the US Federal markets will be ready for sale when the appropriately frequency-weighted seat rail vibration levels measured at 80 $km\,hr^{-1}$ on a straight road with 5–10-year-old tarmac and a few spot repairs (in other words a typical B-class inter-urban road) are:

- Close to the four-hour reduced comfort boundary in the vertical direction as defined in ISO 2631 Part 1 (1985).
- Have an rms. level less than 0.63 $m\,s^{-2}$ (classed as better than 'a little uncomfortable' according to BS 6841 (1987)).
- Have a NASA discomfort rating below 4.0 (Bosworth et al., 1995).

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