ChatGPT

Metrics for Evaluating Automatic Transmission Shift Quality and Harshness

Introduction

Shift quality in automatic transmissions refers to how smooth, quick, and unobtrusive gear changes feel to the driver and passengers. In rear-wheel-drive, torque-converter automatics (such as the 6L80 in a 2015 Chevy Tahoe), shift quality is a key calibration attribute that affects both driving comfort and performance. **Shift harshness** generally describes undesirable aspects of a shift – like jolts, lurches, or clunks – whereas **shift feel** or quality encompasses the overall character of the shift event (smoothness, timing, etc.). Modern OEMs (including GM) use extensive calibration strategies and adaptive controls to optimize these traits, and standards like SAE J2872 provide guidance on objective evaluation of shift quality. In this report, we survey the metrics commonly used to quantify shift quality/harshness and propose a practical set of metrics that can be derived from time-series log data for a data-driven tuning pipeline. We focus on per-shift event metrics and consider special scenarios (e.g. garage shifts and low-speed vs. mid-speed upshifts), noting differences in targets for comfort vs. performance calibrations. All recommended metrics are defined in terms of log signals (time, throttle/pedal, brake, engine RPM, turbine RPM, output speed, gear states, TCC slip, etc.) and linked to their significance for shift feel.

Established Practices and Standards for Shift Quality Metrics

Automakers and researchers have developed both simple and composite metrics to objectively assess shift events. SAE and ISO have published guidelines on measuring shift disturbances, aiming to correlate objective signals with human perception. Notably, **SAE J2872** (shift quality evaluation) and various SAE papers describe how to extract meaningful metrics from the vehicle's longitudinal acceleration trace [1]. Common metrics and methods include:

- **Peak Acceleration Change (Shift "Shock"):** The maximum change in longitudinal acceleration during the shift, often measured as the peak-to-peak amplitude of the filtered acceleration signal [1]. A large drop or spike in acceleration indicates a harsh shift (a sudden "jerk" felt by occupants). Studies have found that peak acceleration (fore/aft) is a primary factor influencing perceived shift quality [2]. For example, an off-road vehicle study noted that the **peak acceleration during a shift was the most important factor** affecting shift feel [2]. Calibration guidelines therefore set limits on how much acceleration dip or surge is acceptable for a given vehicle class or drive mode. (One reference suggests that the threshold for *acceptable* fore-aft acceleration may depend on shift type; e.g. an upshift vs. a downshift might have different tolerance [3] [4].) In practice, luxury or comfort-oriented calibrations aim to keep longitudinal acceleration changes very low – often on the order of a few **tenths of a m/s^2** – so that the shift is barely perceptible. Higher-performance modes might tolerate larger acceleration changes in exchange for faster shifts.

- **Jerk (Derivative of Acceleration):** Jerk is the rate of change of acceleration (m/s^3), and it correlates strongly with the sharpness or harshness felt during a shift [5]. Early research by General Motors found that **peak jerk correlates well with subjective shift feel**, and GM even developed a "Jerkmeter" device in the 1960s to measure on-road acceleration and jerk during shifts [6]. High jerk (especially a sharp spike) indicates an abrupt change in force, contributing to the perception of harshness. Many shift-quality studies therefore monitor the **peak jerk** and sometimes the integrated jerk over the shift event. For example, one shift metric development paper extracted **peak-to-peak jerk** from the accel signal as one component of a composite metric [1]. Lower jerk values are better for comfort – one study classified *transient jerks* (short spikes) vs. *durative jerks* (sustained acceleration changes), proposing that both the magnitude and the duration (RMS) of jerk should be considered for evaluating ride comfort [7] [8]. In qualitative terms, a **"gentle" shift** might keep longitudinal jerk below ~5–10 m/s^3, whereas a very hard shift can produce jerk well above that (causing occupants to head-nod or jolt). Many OEMs will set a target peak jerk for each shift type; e.g. a mild 1–2 upshift might be calibrated for <10 m/s^3 jerk in comfort mode, whereas a performance WOT shift could be allowed to reach higher jerk (with the understanding that the driver expects a firm shift).

- **Shift Duration:** This is the time from the start of a shift command to the completion of the shift (typically when the gear change is fully executed and output speed/engine speed stabilize in the new gear). It can be further broken into the **torque phase** (time during which the off-going clutch releases and torque begins to transfer) and the **inertia phase** (time during which the on-coming clutch slips and the rotational speeds synchronize to the new ratio). Shorter shift durations generally improve performance (less time with reduced torque), but extremely short shifts can induce high acceleration spikes if not carefully managed. OEM calibration practices therefore balance duration and harshness. For instance, a **comfortable** Upshift in a passenger SUV might target a total shift time around *0.4–0.6 seconds*, while a **sport/performance** mode might aim for perhaps *0.2–0.3 seconds* by commanding faster clutch exchanges (with an acceptable trade-off in jerk). In literature, gear shift times around **0.3–0.4 s** are cited for typical automatic transmissions under normal conditions [9] [10]. The shift duration is a directly measurable metric from logs (using timestamps on gear command vs. gear achieved). It's often used in OEM testing as a basic metric (e.g. GM's "Adaptive Shift Time" control will adjust clutch pressures to achieve the target shift time). Consistency is also key: large variability in shift time can indicate control issues or adaptation in progress. **Shorter is better for performance**, whereas **longer (within reason) tends to be smoother** – but too long a shift (e.g. >1 s) can feel sluggish or "slippy," so there are usually upper bounds even for comfort calibration.

- **Acceleration "Dip" or Torque Hole:** During an upshift, engine torque is typically reduced (via spark retard or throttle closure in modern electronic controls) to allow the clutches to swap without fighting each other. This intentional torque hole shows up as a dip in vehicle acceleration. The **depth of the acceleration dip** (how much acceleration falls relative to the pre-shift level) and its **duration** are critical to perceived performance. A deep or prolonged dip means the vehicle lost momentum (felt as a bog or hesitation). For comfort tuning, the goal is to minimize the acceleration loss (a shallow dip) while also avoiding any sudden rebound ("double bump"). A "double bump" is when the acceleration drops and then overshoots above the final steady level, causing a secondary jolt. (In manual transmissions, a similar phenomenon in shift force is quantified by the **double bump ratio**, which GM recommends to keep <0.4 – i.e., any second bump <40% of the primary bump [11] so that it's not noticeable.) In automatics, a well-calibrated shift will have a smooth acceleration trough that then gently returns to the steady-state value for the new gear without an overshoot. Metrics to capture this include the **maximum acceleration drop** (e.g. drop of –0.2g from baseline) and perhaps a **rebound ratio** if an overshoot occurs. Lower drops (i.e. maintaining closer to continuous acceleration) are better for comfort. Performance calibrations may allow a deeper dip (since aggressive torque reduction is used to cut shift time), but will try to fill the torque hole quickly after the shift to restore acceleration. Logging channels like vehicle speed or acceleration (if available) can be used; lacking a direct accelerometer, one can approximate acceleration from the change in vehicle speed. A related metric sometimes used is the **integral of acceleration deviation** during the shift (essentially the lost speed). This integral should be small for a snappy shift. However, if it's too small (meaning almost no torque reduction), it could indicate a **tie-up** (see below) – so calibrators aim for an optimal moderate torque hole that avoids both excessive sag and clutch overlap.

- **Frequency Content and Oscillations:** Some aspects of shift feel relate to vibrations excited in the driveline. Research has shown that certain frequency components in the acceleration signal correlate with disturbance feel – for example, one GM study identified content in the **10–14 Hz** range (likely corresponding to drivetrain resonances or engine mount shake) as affecting shift quality [1]. A harsh shift might excite a **driveline "shuffle"** or higher-frequency vibration, whereas a smooth shift avoids exciting those modes. Thus, metrics like **"impact severity"** or **power of vibration** can be considered. In the composite metric by Schwab et al., the **"maximum average power"** of the acceleration signal during the shift was one component [1], and the energy in the 10–14 Hz band was another. These relate to how much oscillatory motion the shift induced. Practically, one could measure the **settling time** after the shift (how quickly vibrations damp out) or compute an RMS of acceleration over the shift event. A more straightforward metric related to this is the **torque oscillation amplitude** – basically the amplitude of any ringing in output torque or acceleration after the initial shift event. A study on power-shift transmissions (clutch-to-clutch without torque converter) uses **"torque oscillation amplitude"** as a shift quality index, alongside peak impact and friction energy [12]. For our purposes, if the log has a high-resolution acceleration or output shaft torque estimate, we could quantify the magnitude of any oscillation following the gear change. Minimizing post-shift oscillations (no aftershocks) is better for comfort. This is especially relevant in **garage shifts** (P–R, N–D engagements) which can excite driveline lash – a poorly damped engagement can cause a low-frequency "clunk" or shuffle.

- **Vibration Dose Value (VDV):** VDV is an aggregate metric defined in ISO 2631 (originally for ride comfort due to vibration) but adapted to shift quality assessment. It essentially integrates the fourth power of acceleration (to heavily weight peaks) over the event duration [13]. The result is a single number that has been shown to correlate closely with human perception of shift harshness [13]. Ken Horste (1995) demonstrated that a **properly filtered fore-aft acceleration VDV correlates with drivers' subjective ratings** of shift disturbance [13] [14]. Unlike simple peak metrics, VDV captures both magnitude and duration of the acceleration fluctuation in one measure. Many OEMs (including GM) have used VDV or similar composite indices as an objective **shift quality index**. SAE J2872 likely includes or inspired such methods. In tuning, one might use VDV to get an overall "score" of a shift: for instance, a very gentle shift yields a low VDV value, while a harsh one yields a high value. (It's worth noting that VDV will penalize a long, low-magnitude disturbance less than a short, high spike – aligning with the idea that a drawn-out smooth shift can be more acceptable than a very sharp jolt [15].) While we won't directly compute VDV in every case, it's a useful reference – one could use it as a **composite metric** to rank shifts if needed.

In summary, decades of industry practice (and standards like J2872) revolve around a core set of signals: the vehicle's fore-aft acceleration profile, and its derivatives (jerk) or integrated values (energy, dose). These allow objective characterization of **shift shock, shift timing, and post-shift vibrations**, all of which must be managed by calibration. Table 1 below (our proposed metrics list) will build directly on these principles.

(Aside: SAE J2904, while not publicly detailed here, is understood to cover Torque Converter Clutch (TCC) behavior – for instance, guidelines on slip control and lock-up clutch engagement. TCC behavior can significantly influence shift quality, as discussed later. No known ISO directly defines "shift harshness" in a single metric, but ISO and SAE do provide frameworks (like the above VDV from ISO 2631) that can be applied to shifting events. In the absence of a universal standard for a "shift quality index," each manufacturer often develops their own weighted scoring system [16].)

Special Scenarios and Calibration Considerations

Different driving scenarios demand different shift quality priorities. Here we highlight a few critical ones and how metrics expectations differ:

- **"Garage" Shifts (P–R, N–D, R–D, D–R at standstill):** These range changes from rest are notorious for causing **clunk** or harsh engagement if not calibrated well. In a rear-drive vehicle, engaging Drive or Reverse applies a sudden torque to the driveline (taking up lash in the driveshaft and differential). *Metrics:* The key measures here are **engagement delay** and **engagement shock**. *Engagement delay* is the time from the driver's command (shifter moved) to the actual gear engagement (when the vehicle begins to creep or the gear indicator switches). Drivers perceive long delays as poor response, but a too-quick engagement with high torque can cause a bang. *Engagement shock* can be measured by the **peak acceleration or jerk** at the moment the gear engages. For example, a harsh Park-to-Drive might produce a sudden lurch of a few m/s² in acceleration; a well-calibrated one will barely nudge the car. Often, engineers measure the **seat track acceleration** in the fore-aft direction during a garage shift to quantify the clunk severity [17] [18]. Another aspect is the **driveline oscillation** after engagement – a poorly damped engagement can lead to a low-frequency (2–5 Hz) "aftershake" as the driveline torsionally oscillates (this is the classic "clunk-shuffle"). So we want to minimize the peak and also the number of oscillation cycles. Manufacturers like GM have published methods to predict and minimize seat track acceleration during garage shifts by tuning engine idle torque profiles and mount stiffness [17] [18]. *Comfort calibration:* will often use strategies like briefly dipping engine torque (or using the torque converter to soften the tip-in) to reduce clunk, even if it means a slight delay. *Performance or Normal mode:* differences are minor here (since these shifts happen at low/no throttle), but a performance calibration might allow a firmer initial engagement to ensure quick response (acceptable in a sporty car, but not in a luxury SUV). Our metrics thresholds for static engagements might be, for instance, **engagement delay** < ~0.5 s and **peak acceleration** < ~0.1–0.2 g for a comfortable feel – along with minimal post-engagement oscillation (no more than one minor overshoot). Keeping the **clunk jerk** low is paramount: a study on static engagements aimed to develop guidelines to keep **engagement clunk "acceptable"** to customers [19] [20] (implying objective limits on these measurements).

- **Low-Speed Part-Throttle Upshifts (e.g. 1–2, 2–3 at city speeds):** These are often the most **noticeable shifts** in everyday driving because engine torque at low speed can be high (in lower gears the torque multiplication is greater), and the vehicle's acceleration is very sensitive to any torque disturbance. The 1–2 shift also typically has the largest ratio drop (for example, 6L80 goes from 4.0 in 1st to 2.4 in 2nd – a big change). *Comfort tuning:* will prioritize smoothness here – meaning a moderate torque hole (to avoid tie-up) but followed by a very soft inertia phase to prevent any second bump. It's common to keep the **TCC unlocked** in these low gears for smoothness, allowing the torque converter to absorb some shock. That means a bit of slip, but improved NVH. Metrics wise, we expect **longer shift durations** (perhaps ~0.5 s) and **very low peak jerk/accel**. Acceptable acceleration dip might be, say, only –0.05 to –0.1 g so that passengers barely feel a gentle loss of push. Any **engine RPM flares** should be minimal; a well-calibrated 1–2 shift might have the engine RPM drop smoothly as the next gear engages, whereas a bad calibration might show a spike (engine revs up momentarily) or a severe undershoot. Low-speed shifts are also where **shift scheduling** (timing the shift vs. throttle) matters – if the shift happens while the driver is modulating throttle (as in stop-and-go), it can feel jerky. So consistency is key. *Performance tuning:* (if applicable at low speed) might hold gears longer and then shift more firmly. For instance, in a sport mode, the 1–2 shift might come at higher RPM and with more clutch pressure, causing a perceptible thump (higher jerk) which some drivers equate with a "crisp" shift. But even in performance mode, absolute harshness in low gears is often limited to avoid traction issues and because at low speed, harshness is very evident. Thus, the differences might be smaller at low speed – mostly in shift timing (RPM) and perhaps a slightly firmer feel allowed.

- **Mid-Speed Upshifts (e.g. 3–4, 4–5 around 40–50 mph):** By mid-speed, the vehicle momentum is higher and gear ratio steps are usually smaller, so shifts tend to be intrinsically smoother. Engine torque may be lower (if in a light cruise) or moderate (if climbing). Comfort calibrations here still aim for smoothness, but since the impact is naturally less, they may allow a bit quicker shifts. *Metrics:* A mid-speed upshift might complete quicker (maybe 0.3–0.4 s) even in comfort mode, yet still without exceeding, say, 5–8 m/s^3 jerk. Often these shifts can be almost unnoticeable if TCC is managed. In many automatics, the TCC might start to engage in these higher gears – which introduces another aspect: **TCC slip during the shift**. Some transmissions will momentarily **unlock or increase slip** during the gear change (to smooth it), then re-lock the converter afterward. Others might keep it locked if the shift is gentle enough (common in modern designs to save fuel). If locked, the shift disturbance might transmit more directly (slightly higher jerk), but if the shift is small it could be fine. *Performance vs Comfort:* At mid speeds, a performance calibration might clearly diverge – for example, a sport mode might keep TCC locked and use a quick torque cut for a fast, firm shift (you'd feel a quick jolt but also a quick completion), whereas a comfort mode might allow a bit of slip or softer torque transfer for a wafting feel. So **gear shifts around 4–5** in a comfort tune could be almost imperceptible in light throttle cruising (tiny accel dip, maybe 0.05 g or less), whereas in a performance tune you might feel a distinct shift bump (maybe 0.1–0.2 g but very brief). These differences reflect the trade-off: **low disturbance vs. fast shift**.

- **Kick-downs and Downshifts:** (The user's question doesn't explicitly ask, but for completeness.) A kick-down (e.g. 6→3 sudden downshift for passing) is a scenario with inherently large disturbances (engine has to flare to higher RPM). OEMs often focus on making these *feel deliberate but not abusive*. Metrics would include **engine RPM overshoot** (how much beyond target it revs), and **re-bind jerk** when the lower gear engages. SAE J2872 and others have looked at multi-dimensional measures for kick-down quality [21]. Generally, comfort mode might hesitate or downshift in two steps (to avoid a big jolt), whereas performance just slams to the target gear. The metrics from upshifts still apply (accel, jerk), but acceptable values are higher since the driver has requested power (thus expects a bump).

In all scenarios, one can see a pattern: **comfort-oriented calibrations** strive to minimize acceleration disturbances (dip/overshoot) and jerk, even if it means slightly slower or less direct shifts. **Performance-**

oriented calibrations prioritize quick torque transfer and positive gear engagement, accepting higher jerk and a firmer feel (indeed some drivers desire that "bang" as a performance cue). Table 1 will indicate for each metric whether "high" or "low" values are desirable for comfort vs. performance.

Before moving on, it's worth noting that OEMs like GM use **adaptive learning** in the transmission control to maintain these targets. The 6L80, for example, monitors clutch fill times and shift timing on-the-fly, adjusting line pressure to hit the calibrated shift time. This means our log-derived metrics can also be used to see if the trans is operating as intended (e.g. a spike in shift duration might indicate an adaptation event or incipient clutch wear). So, a consistent log-driven metric pipeline can not only guide tuning changes but also catch anomalies in shift behavior.

Recommended Log-Derived Metric Set and Definitions

Leveraging the above insights, we propose the following set of metrics to quantitatively evaluate shift quality and harshness from time-series log data. Each metric is defined in terms of the available channels (time, engine RPM, turbine RPM, output RPM, vehicle speed, throttle, brake, gear commanded/actual, TCC slip, etc.), with an explanation of what it indicates and typical desired values. These metrics can be computed for each individual shift event in the logs, enabling a **"shift scorecard"** that can drive automated tuning adjustments.

Note: In the definitions below, "positive" acceleration refers to forward acceleration (vehicle speeding up) and "negative" implies deceleration (or a reduction in acceleration). Many metrics assume we have either a direct longitudinal acceleration signal or can derive it (e.g. differentiate vehicle speed). If direct acceleration isn't logged, approximate values can be inferred from the change in output shaft speed or vehicle speed (bearing in mind smoothing may be needed). Time stamps are used to compute durations. Also, *engine RPM* vs. *turbine RPM*: since a torque converter is present, engine RPM and trans input (turbine) RPM may differ when the TCC is unlocked; we will specify which to use for clarity.

Below is a list of **per-shift metrics**:

- **Shift Duration (Gear Command to Completion):** *Definition:* The elapsed time from the initiation of a shift to its completion. In practice, we can use the log's **gear commanded** signal (or "gear requested") as a start point and the moment the **gear actual** changes to the new gear (and remains there) as the end point. Alternatively, if a "time_of_latest_shift" channel is logged (as noted in the user's data), the difference between successive shift timestamps can be used. *What it indicates:* Shift duration is a primary performance metric – a shorter shift means less interruption to power delivery. However, if a shift is too short, it may be achieved by a harsh clutch engagement. *Tuning implications:* If durations are longer than desired, it might indicate soft clutches or excessive torque management; if extremely short but accompanied by high harshness, it may be too aggressive. **Comfort vs. Performance:** For comfort-oriented driving, a moderately longer duration with smooth torque transfer is preferred (lower NVH). For performance, shorter is better (quick shifts keep acceleration up), as long as it doesn't introduce too much harshness. *Typical values:* ~0.3–0.6 s in normal light-throttle shifts, perhaps up to ~0.8 s on very gentle roll-out shifts. In performance/WOT, modern automatics often target ~0.2–0.3 s or even less. **Lower durations** improve performance (and even fuel economy slightly), whereas **higher durations** generally improve smoothness (up to a point). No absolute "good/bad" threshold fits all cases, but for instance, a **1.0 s** upshift at moderate throttle would be considered very sluggish (calibrators might target ~0.5 s instead). On the flip side, anything under ~0.2 s is extremely quick and likely indicates a performance shift (or a dual-clutch style rapid shift). This metric should be monitored alongside the following disturbance metrics – a very short shift coupled with high jerk is a trade-off scenario.

- **Peak Acceleration Drop (Torque Hole Depth):** *Definition:* The maximum decrease in longitudinal acceleration (or vehicle acceleration relative to pre-shift level) during the shift. We measure the vehicle's acceleration just before the shift (call it a_{before}) and find the lowest acceleration during the shift event (call it a_{min}). The drop = $a_{min} - a_{before}$ (which will be negative for a drop). For example, if the car was accelerating at +1.2 m/s² before the shift and it momentarily falls to 0.4 m/s², the drop is –0.8 m/s². (If using g units, that's roughly –0.08 g). *What it indicates:* This directly quantifies the **loss of acceleration** felt by the occupants – essentially how much the car "bogs down" during the shift. A large drop means the shift had a pronounced sag (the "pause" in acceleration is big). *Why it matters:* In terms of feel, a smaller drop is preferable for keeping the ride smooth (the vehicle continues moving forward with only a slight relent). A large dip can feel like the car hesitated or lost power momentarily. **Comfort vs. Performance:** Comfort tunes aim to minimize this drop. They may, for instance, leave a bit of overlapping torque (or use the torque converter's cushion) so that acceleration never falls too far. Performance tunes, on the other hand, often do cause a noticeable dip because they cut torque sharply to swap gears quickly (you feel a brief "no-push" sensation), but then the acceleration resumes quickly. So in comfort, **shallower drop (closer to 0)** is better; in performance, a deeper drop is acceptable if it shortens the shift. *Guidance:* It's hard to give universal numeric thresholds because it depends on baseline acceleration (a 0.5 g drop is huge if you were only at 0.2 g to start, but is less alarming if you were at 0.8 g). As a ballpark, for mild acceleration (say casual driving), a drop of more than ~0.1–0.2 g would likely be noticeable and possibly objectionable. Many passenger cars try to keep the drop so small that the casual driver barely perceives it (perhaps on the order of 0.05 g). In contrast, at wide-open throttle, a momentary drop might be 0.3–0.4 g but drivers tolerate it since they initiated a kickdown, etc. We can define an *acceptable range* per shift type: e.g. **1–2 upshift at 20% throttle** – maybe aim for <0.1 g drop; **full-throttle upshift** – drop might be larger but duration short.

- **Acceleration Overshoot (Post-Shift Bump):** *Definition:* The maximum increase in acceleration *above* the post-shift steady value, occurring after gear engagement. Essentially, we look for any rebound or secondary "bump" in the acceleration trace. For example, if right after the shift, acceleration briefly spikes to 1.0 m/s² before settling at 0.8 m/s², the overshoot is +0.2 m/s². We can compute overshoot as $a_{max\_post} - a_{final}$ (where a_{max_post} is the peak acceleration in a short window after the shift, and a_{final} is the settled acceleration in the new gear at the same throttle). *What it indicates:* An overshoot suggests a **"double bump"** behavior – the shift not only removed torque then restored it, but actually overshot the target torque. This often happens if the oncoming clutch grabs a bit too hard or engine torque reapplication overshoots (perhaps due to inertia or aggressive torque ramp-in). *Why it matters:* A pronounced bump after a shift can feel like a kick forward – an unnecessary jolt after the shift should have finished. This is typically felt as a two-stage shift: "shift – then bump." **Comfort calibrations** absolutely try to avoid this; the ideal is a single smooth transition. **Performance calibrations** also usually try to avoid true overshoot (it's generally unproductive shock loading), though a slight firmness at completion is sometimes present. *Guidance:* We want this as close to zero as possible in most cases. In objective terms, some manuals (synchronizer design) work used a *double bump force ratio* < 0.4 as a target [11]; for automatics, we similarly want any secondary acceleration peak to be a small fraction of the main event. If our shift caused a dip then recovery, the recovery should not overshoot by more than maybe 20–30% of the lost acceleration. If we see an overshoot, it might mean we can soften the clutch apply or reduce engine torque overshoot. A well-behaved shift often has *no overshoot at all* – it just smoothly transitions to the new acceleration. Thus, a threshold might be set that **acceleration overshoot < 0.05 g** (example) for a high-comfort calibration. Any significant positive spike after the shift is a sign of harshness.

- **Peak Jerk (Max dA/dt during shift):** *Definition:* The maximum instantaneous jerk (derivative of acceleration) during the shift event. In practice, since our data is sampled, we can approximate jerk by the difference in acceleration between consecutive time steps divided by the time step. We then find the maximum (and minimum) of this during the shift. Often the *peak positive jerk* occurs when the oncoming clutch grabs (acceleration shoots back up), and the *peak negative jerk* might occur at initiation (accel dropping). We could track both, or a single absolute peak. *What it indicates:* Jerk captures the **abruptness** of the acceleration change. Even if the total acceleration change is moderate, if it happens very quickly, jerk will be high and the event feels sharp. High jerk is what causes the "snap" felt in shifts. *Why it matters:* Human sensitivity to jerk is high – a quick change in force is startling and uncomfortable. A shift with identical acceleration profiles but one done slower (lower jerk) will feel smoother than one done faster (high jerk). As noted, GM found jerk to correlate well with subjective harshness [6]. *Comfort vs. Performance:* This is the metric that often diverges most. **Comfort-oriented shifts** intentionally lengthen the torque transfer to keep jerk low (spread out the accel change). **Performance shifts** compress the event, leading to higher jerk. So ideally we set a **limit on jerk for comfort** (e.g. "no shift in normal mode shall exceed X m/s^3 jerk"). For instance, luxury cars might try to keep longitudinal jerk < maybe ~5–10 m/s^3 for gentle shifts. Performance cars might routinely hit 15–20 m/s^3 in sport mode upshifts (these numbers can vary, but the idea is comfort < sport). *Guidance:* If we have good acceleration data, we might set threshold like **jerk > 15 m/s^3 = harsh shift** for our vehicle class, whereas **jerk < 5 m/s^3 = very smooth**. These are just indicative; actual acceptable jerk also depends on frequency (a very brief spike might be tolerated more than a sustained high jerk). In our analysis, we'll monitor peak jerk for each shift. Notably, SAE J2872's methodology of extracting peak-to-peak jerk [1] underlines its importance. We should note both the negative and positive jerk peaks, as they indicate the onset and conclusion harshness respectively. For example, a sharp negative jerk at shift start means the torque was removed too abruptly (felt as a sudden drag), while a sharp positive jerk at shift end means torque came back too suddenly (felt as a kick). Both should be minimized for comfort.

- **Shift Energy (Integral of Accel Disturbance or VDV):** *Definition:* This is a more aggregate measure. One approach is to integrate the **absolute acceleration deviation** during the shift – essentially the area between the acceleration curve and a baseline "no shift" acceleration. Another is to compute the **Vibration Dose Value (VDV)** as mentioned: $\mathrm{VDV} = \left(\int_0^{T_{\text{shift}}} [a(t) - a_{\text{baseline}}]^4 \, dt\right)^{1/4}$ after appropriate filtering [13]. For simplicity, even an RMS acceleration change or power metric over the shift can serve. *What it indicates:* A single composite number for the shift's overall disturbance. This metric encapsulates both magnitude and duration of the event. *Why it matters:* It's useful for ranking shifts or creating an objective "shift quality index." It directly relates to what a driver would rate as smoother vs harsher by combining the effects of drop, jerk, oscillations into one. As reported, a properly tuned single metric like VDV correlates well with subjective ratings [14]. **Comfort vs. Performance:** Naturally, comfort tune shifts should have lower shift disturbance energy/VDV, and performance ones can be higher. *Guidance:* If implementing, one could define a target maximum VDV for acceptable comfort shifts. For example (hypothetical), if in testing a certain shift yields VDV = 1.0 (units depend on filtering) at the threshold of where customers start to complain, you'd want normal mode shifts < 1.0. More concretely, some research indicated that an acceleration change of around 1.2 m/s^2 was a threshold for "acceptable" in general ride comfort [4] – though that was not specific to shifts – and jerk thresholds around 0.9 m/s^3 for discomfort in general driving [22]. Our VDV or energy metric would combine such factors. We will use this primarily to compare shifts; a lower value means a smoother shift in general. This composite metric is **"high = bad"** for comfort. For automated tuning, this could be the metric to minimize overall, once individual constraints (like not too slow) are satisfied.

- **Engine Speed Flare (RPM Overshoot):** *Definition:* The peak engine RPM attained during the shift minus the RPM it *should* be at after the shift (at the given vehicle speed). Essentially, if the engine revs higher than the synchronous speed for the new gear, that difference is the flare. We can compute the expected post-shift engine RPM: e.g. *RPM_expected = output_speed * new_gear_ratio* (adjusted for converter slip if unlocked). Then *flare = max(engine_rpm) – RPM_expected*. If the flare happens before the new gear fully engages (common), we compare to the new gear's eventual RPM. *What it indicates:* Flare is a sign of **clutch overlap mis-timing** or insufficient torque capacity – the off-going clutch released too early or the oncoming clutch applied too late, allowing the engine (or turbine) to free-rev momentarily. It's a form of **shift disturbance** – the driver hears/feels the engine rev up unexpectedly. *Why it matters:* A mild flare might just feel like a soft shift, but a large flare feels like a surge (and can be harsh when the clutch finally grabs, as it will then pull the RPM down rapidly – causing jerk). Also, flare can be bad for clutch wear (the oncoming clutch has to catch a spinning-up engine). **Comfort vs. Performance:** Comfort tunes generally avoid noticeable flare by coordinating clutches (and often by reducing engine torque so there isn't excess power to cause a rev spike). Performance tunes also avoid flare, instead tending toward the opposite (tie-up), but a slight flare is more acceptable than a tie-up in any case. Ideally, we want near-zero flare. *Guidance:* So this metric should be **as low as possible**. In well-calibrated shifts, flare might be <100–200 RPM. If we see e.g. a 500+ RPM spike (especially if throttle wasn't fully released), that's a problem. Our logs have both engine and turbine RPM, so we might track flare on the **turbine RPM** as well – turbine flare indicates the trans input sped up, which is similar to engine flare if TCC is locked or partially locked. Large turbine flare means oncoming clutch wasn't holding as it should. We'll flag any shift where engine or turbine overshoot is beyond a threshold (say >200 RPM) as a potential **flare event**. High flare correlates with a mushy or drawn-out shift feel (and often a subsequent harsh catch).

- **Engine Speed Drop (RPM Undershoot / Tie-Up):** *Definition:* Conversely, the amount the engine RPM drops *below* the expected synchronous speed for the new gear (if any). This would happen if the oncoming clutch applies too soon or too hard while the off-going is still holding – effectively momentarily locking the transmission in two gears (tie-up). The engine (or turbine) is suddenly dragged down. We can compute if the lowest engine/turbine RPM during the shift goes below the new gear's expected RPM. *What it indicates:* This is a sign of a **tie-up or shock loading** during the shift – clutches fighting each other. It usually manifests as a sharp jerk (since the vehicle is momentarily braked by the transmission). *Why it matters:* Tie-ups are very harsh (often more so than flare) – the car may nose-dive (negative acceleration spike) and then continue. It's also very bad mechanically (spikes torque in the driveline). Avoiding tie-up is a fundamental goal; controls are designed to ensure the releasing clutch fully hands off torque before the new one locks in. A research study on power-shift control explicitly aimed to **keep the driving side speed always above the driven side to avoid the power cycle (tie-up) and thus improve shift quality** [23]. **Comfort vs. Performance:** Neither mode wants tie-up, but an overly aggressive performance shift can verge on tie-up if timings overshoot. Comfort calibrations leave more margin (softening the handoff to be safe). *Guidance:* Ideally this value is **zero** – any undershoot is undesirable. So our analysis will treat any detected RPM tie-up (even a small one, say >100 RPM drop below target) as a serious calibration fault for harshness. If, for example, engine RPM momentarily dipped when the new gear engaged (beyond just following the gear ratio), that likely correlates with a big negative acceleration spike. We can cross-check by seeing a sharp deceleration at the same time. In summary: **Zero tolerance for significant tie-up**; it should be tuned out. If logs show e.g. a –300 RPM undershoot, that shift is very harsh.

- **Peak Output Shaft Accel (or Decel) During Shift:** *Definition:* This metric directly looks at the vehicle's output behavior by differentiating the output shaft (or vehicle speed) to acceleration. We then identify the peak deceleration or acceleration that the output shaft experienced due to the shift. It's similar to the earlier "peak acceleration change" but specifically focusing on the vehicle's deceleration spike if any. *What it indicates:* A spike in output shaft decel means the vehicle actually slowed down briefly during the shift (a clear sign of harsh torque interruption or tie-up). A spike in acceleration (above the steady level) could indicate a rebound. While the **acceleration drop** metric looked at net change, this looks at instantaneous effect. *Why it matters:* This is essentially measuring **shift shock** at the driveline level – how abruptly the vehicle's motion was affected. Some standards refer to **"impact severity"** which could be quantified this way [12]. **Comfort vs. Performance:** Similar to jerk, comfort wants this low. Performance may allow a higher spike (especially for a downshift where a quick clutch engagement might momentarily slow the driveline). *Guidance:* We could set a threshold in physical terms: e.g. "no shift should cause more than 0.3 g deceleration spike" in a comfort tune – meaning the passengers shouldn't feel a jerk harder than, say, lightly pressing brakes. Typically, well-managed upshifts cause at most a very mild decel (the car might "quiver" but not actually dip speed noticeably). If we record, for instance, a –2 m/s^2 (about –0.2 g) spike at shift, that's on the high side for a mild throttle shift (would be felt clearly). For kickdowns or very aggressive shifts, one might see such values. But our pipeline could flag any shifts exceeding a chosen threshold (maybe –1 m/s^2 for normal shifts) as harsh. This metric is effectively another way to capture jerk/accel behavior but focusing on the vehicle's perspective.

- **TCC Slip Profile Metrics:** These involve the torque converter clutch behavior around the shift:

- **TCC Lock/Unlock Timing:** *Definition:* When (relative to the shift) the TCC unlocks and re-locks. For example, some transmissions will **unlock the TCC just before the shift**, then re-lock after it's completed to smooth the shift. We can detect in the log if TCC went from "locked" (slip ~0) to "unlocked" (slip spikes) around the shift. The metric could be the **time delay after shift completion until TCC re-locks**. *Significance:* If the TCC stays unlocked too long post-shift, the vehicle may waste energy (efficiency loss) and the driver might feel a prolonged slip (slight engine flare). If it locks too quickly right after a shift, it might introduce an additional jerk. **Comfort vs. Performance:** Comfort calibrations tend to delay re-locking slightly to let things settle, whereas performance (and fuel-economy algorithms) lock as soon as possible. *Guidance:* We might say, for a comfort tune, TCC re-lock ~0.5–1.0 s after shift is fine (ensuring no compound events), while in performance it might lock almost immediately if throttle is high (since you want full drive). The metric "TCC lock delay after shift (s)" we'll track. No strict good/bad, but we interpret in context: a *shorter delay* = more efficiency, but potentially a bit more harshness, a *longer delay* = smoother but slight slippage.
- **Peak TCC Slip during Shift:** *Definition:* The maximum difference between engine RPM and turbine RPM during the shift. If the TCC was locked and then allowed to slip, how much did it slip? Or if it was unlocked already, did slip increase? *Significance:* This tells us how much the torque converter absorbed the shift. A higher slip spike means the converter buffered more of the shift energy (which

can improve smoothness but also generate heat in the fluid). A low slip (near zero) means the TCC remained engaged – typically resulting in a crisper, more direct shift feel (and sometimes a harsher shift). **Comfort vs. Performance:** Many comfort tunes will introduce say 50–150 RPM of slip transiently to cushion the shift. Performance tunes often keep slip minimal to not waste torque. *Guidance:* We'll note if slip exceeds some value. For instance, if a shift sees TCC slip jump to 300 RPM, it means the converter was heavily used to smooth it. That might be fine for a gentle shift, but if our goal is crispness (or if fluid temp is a concern), we might tune it differently. So there's not exactly a "bad" threshold here, but rather an indicator: **High slip = smoother shift, but more heat; Zero slip = possibly harsher**. We balance according to the mode.

- **TCC Engagement Jerk:** *Definition:* The jerk or acceleration change when the TCC clutch locks or unlocks, either as part of the shift or right after. For example, if right after a shift, the converter goes from slipping to locked, that can cause a mild bump. *Significance:* Sometimes a shift itself is fine, but the subsequent TCC lock-up gives a bump – this metric catches that. **Comfort vs. Performance:** Comfort calibrations often modulate TCC apply to be gradual (avoiding a sudden lock-up clunk). Performance might lock harder for efficiency. *Guidance:* If logs have a clear "TCC locked" flag, we can see if a lock event coincides with an acceleration blip. We ideally want the lock-up to be seamless (no noticeable jerk). So we could treat any significant acceleration spike at TCC apply as an issue to mitigate (perhaps by ramping pressure).

- **Clutch Pressure or Slip Metrics (Optional):** If the log provides things like **oncoming clutch ID** and pressure commands (PCS1-5 channels, etc.), we can derive additional metrics:

- **Clutch Fill Time:** time from shift command to the point the oncoming clutch achieves fill pressure (sometimes logged or deduced from slip start). A long fill time can extend shift duration; a short one can cause a harsh initial engagement. This metric is more for calibration diagnostics than direct shift feel (though too long can cause delay). We'd aim for consistent fill times per clutch across shifts.
- **Clutch Overlap Time:** if both off-going and oncoming clutches have torque concurrently, that overlap duration can be inferred from when slip starts and ends. Minimizing this avoids tie-up. This again is more internal, so we mention it as a tuning metric rather than something a driver feels directly (except via its effect on acceleration which we already measure).
- **Friction Energy:** as noted in literature [12], one can compute the energy dissipated in clutch slip (∫ torque * slip speed dt). This is related to shift quality in that extremely low energy might mean a very abrupt engagement (all energy went into moving the car, not slipping the clutch) – which is harsh – whereas extremely high energy means a very soft shift (but lots of heat). While we likely won't compute this from standard logs (torque at clutch is not directly logged), it's conceptually useful. A balanced shift has moderate friction work. If one had transmission input torque (from engine) and output torque (from inertia), one could estimate this.

Having defined these metrics, we can summarize **which direction is better for comfort vs. performance**:

- *Shorter* **Shift Duration** is better for performance; *longer* (to a point) is smoother for comfort. We will monitor that comfort shifts stay above a minimum duration (to avoid abruptness) and performance shifts stay below a max (to ensure quick response).
- *Smaller* **Accel Drops** (shallower torque holes) are better for comfort (continuous push), whereas performance may allow bigger drops (with quick recovery). We'll ensure drops aren't excessive even in performance (to avoid too much lag).

- *Minimal* **Accel Overshoot** is desired in all cases; comfort absolutely requires none/very low. Performance ideally also keeps it low (overshoot isn't really beneficial to acceleration, it just jolts).
- *Lower* **Peak Jerk** is better for comfort. Performance shifts will have higher jerk by design. We might set different jerk targets for each mode (e.g., <X m/s^3 in "Tour" mode vs Y in "Sport" mode).
- *Lower* **VDV/energy** is better for comfort. Performance can tolerate higher, but we still monitor it to ensure shifts aren't unnecessarily harsh beyond what performance needs.
- *Zero or tiny* **Engine RPM Flare** is ideal for both (flare just wastes time and causes revving). Performance tunes might accept a *tiny* flare instead of a tie-up, but generally both want minimal flare.
- *Zero* **RPM Tie-Up** (undershoot) is absolutely required for both comfort and performance. This is essentially a calibrator's "no-go." If any tie-up is observed, the clutch timing needs adjustment.
- *Lower* **Output Shaft Decel Spike** is better for comfort. Performance may allow some, but if it's too high, it actually hurts acceleration, so it's not desired either. So this metric we want low in all cases (just tolerance differs).
- *For TCC:* **Longer slip** (or unlocked operation) can improve comfort (no shudder or lugging), whereas **early lock** improves efficiency and direct feel (performance/economy). So if we see, for example, a calibration that locks TCC during a 3–4 shift in a comfort mode and it causes a bump, we might choose to change that so that in comfort it stays unlocked until after the shift. Metrics here will guide such decisions (e.g., if **TCC engagement jerk** is high in a certain shift, consider altering TCC timing).

Table 1: Proposed Shift Quality Metrics (Log-Derived)

[1] [13]

- **Shift Duration (s):** *Time from shift command to completion.* **Indicates:** responsiveness of shift; shorter = faster performance, but too short can be harsh. **Comfort:** slightly longer (e.g. ~0.5 s) for smooth torque handover. **Performance:** shorter (as low as ~0.2–0.3 s) for quick shifts. *(Lower is better for performance; adequate length needed for comfort.)*
- **Acceleration Dip (m/s^2 or g):** *Max drop in accel during shift relative to pre-shift.* **Indicates:** torque hole depth; large negative dip means a noticeable lull [2]. **Comfort:** keep dip small (vehicle maintains near-constant acceleration). **Performance:** a deeper dip is acceptable to enable fast clutch swap, but should recover quickly. *(Closer to 0 (small drop) is better for comfort; moderate drop acceptable in performance.)*
- **Acceleration Overshoot (m/s^2 or g):** *Any rebound/overshoot in accel above the new steady-state.* **Indicates:** secondary bump ("double bump") [11]. **Comfort:** avoid overshoot completely (no secondary jolt). **Performance:** also generally avoid – overshoot provides no benefit and can unsettle the car. *(Lower is better for both; ~0 ideally.)*
- **Peak Jerk (m/s^3):** *Highest rate of accel change (either direction) during shift.* **Indicates:** abruptness/ shock feeling [6]. **Comfort:** low jerk (gentle slope changes) [15]. **Performance:** higher jerk inevitable with fast shifts, but should be controlled (not beyond what driver expects). *(Lower is better for comfort; higher allowed for performance if it reduces shift time.)*
- **Shift Disturbance Energy (VDV or analogous index):** *Composite metric of accel disturbance (e.g. VDV, RMS accel or integrated jerk).* **Indicates:** overall severity of shift as a single score [13]. **Comfort:** keep this low – smooth shifts yield low values correlating to good ride [14]. **Performance:** will have higher values, but should still be minimized to what's necessary (avoid excessive harshness). *(Lower is better for comfort; higher tolerated in performance.)*
- **Engine/Turbine Flare (RPM):** *Max engine or turbine speed overshoot above target.* **Indicates:** clutch overlap delay; a measure of slip or free-rev during shift. **Comfort:** minimize – typically <100–200 RPM

if any (too much flare feels like a surge). **Performance:** also minimize – flare actually delays acceleration; small flare might be allowed to avoid tie-up, but generally both modes aim for near-zero [23]. *(Lower (closer to 0) is better for both.)*

- **Engine Undershoot (RPM):** *Engine/turbine drop below expected speed (tie-up).* **Indicates:** clutch overlap (both clutches briefly engaged) causing sudden drag. **Comfort: zero** – tie-up is extremely harsh, not acceptable [23]. **Performance:** also **zero** – tie-up shock is to be avoided (even if chasing quick shifts, one uses just-in-time torque handoff to prevent this). *(Zero is expected; any significant tie-up is bad.)*
- **Peak Decel/Accel of Output (g):** *Max deceleration or acceleration spike of vehicle output during shift.* **Indicates:** immediate vehicle jerk/shock – e.g. a sudden slowdown = shift shock. **Comfort:** should be very low (no perceptible jerk; e.g. <0.1–0.2 g decel spike). **Performance:** may see higher spikes (a firm shift might give a brief jolt), but generally keep within manageable levels (e.g. a –0.3 g spike might be borderline acceptable during a hard launch upshift). *(Lower is better; set allowable limits per mode.)*
- **TCC Slip Behavior:**
- *Lock/Unlock Timing (s):* **Indicates** when the converter clutch is released/applied relative to shift. **Comfort:** often unlock before shift and re-lock after a delay to smoothness [15]. **Performance:** might keep locked or lock quickly after for efficiency. *(No strict numeric "better" – but for comfort, a slight delay in re-lock (~0.5 s) can avoid compounding events; performance will trade that off.)*
- *Peak Slip RPM:* **Indicates** how much slip was introduced. **Comfort:** moderate slip (e.g. +100–300 RPM) during shift can absorb shocks. **Performance:** minimal slip (keep tight, <50 RPM if possible) to maintain direct feel and efficiency. *(Higher slip = smoother but less efficient; low slip = more direct but potentially harsher.)*
- *TCC Lock-up Jerk:* **Indicates** any jolt when TCC clutch engages. **Comfort:** should be negligible – lock-up calibrated with ramp to avoid feeling it. **Performance/Eco:** might be a bit firmer lock-up, but still ideally no harshness (if a shudder or clunk is felt, that's a problem in any mode). *(Lower is better; if high, adjust lock-up strategy.)*

Using these metrics, our log-driven pipeline can automatically characterize each shift. For example, for a given 2–3 upshift at 30 mph, we would record: duration 0.45 s, accel drop –0.7 m/s^2, no overshoot, peak jerk 8 m/s^3, VDV X, flare 50 RPM, tie-up 0, etc. Comparing against target ranges, we might rate that shift as "good" for a normal mode (smooth and reasonably quick). If another shift shows, say, a –2 m/s^2 acceleration dip with a 20 m/s^3 jerk, we'd flag it as harsh – perhaps an indication that line pressure was too high or torque management insufficient.

Lastly, if any **composite "shift quality index"** is desired (like an overall score), one could combine some of these metrics. For instance, GM's approach was to use a linear or neural-net mapping of metrics (peak accel, jerk, frequency content) to predict subjective ratings [1] [24]. In our case, we might not need AI – even a weighted sum could work (e.g. Score = w1*jerk* + *w2*accel_drop + w3*overshoot* + *w4*VDV, etc.). However, given that we have the actual breakdown, tuning decisions can be made on individual metrics (e.g. if jerk is high but duration is low, maybe soften the clutch; if duration too high but everything smooth, maybe we can quicken it a bit without hurting others).

Conclusion: By monitoring this comprehensive set of metrics, engineers can objectively quantify shift quality and harshness for the 6L80 (or similar transmissions) in both comfort and performance contexts. The metrics are all derivable from standard logging channels and align with OEM practices and SAE guidelines (e.g. using acceleration and jerk as core indicators [6] [1], avoiding tie-up [23], and considering vibration/comfort indices [13]). This data-driven approach will support a log-driven tuning pipeline by highlighting where shifts deviate from desired behavior and by measuring improvements when calibration changes are made. Each shift event can be scored, and over time the goal would be to optimize the calibration such that **comfort shifts** consistently stay below harshness thresholds (low jerk, minimal acceleration disturbances) while **performance shifts** meet response time targets without crossing into unacceptable harshness. Using the metrics above as a feedback loop ensures that tuning changes are grounded in real, quantitative outcomes – ultimately leading to a transmission that is both smooth in daily driving and crisp when performance is demanded, with clearly defined limits for each attribute.

Sources: The definitions and guidelines above are informed by SAE publications and standards on shift quality (e.g. SAE J2872, which emphasizes metrics like peak acceleration, jerk, and frequency content in evaluating shift feel [1]) and on torque converter clutch behavior (e.g. SAE papers on TCC slip control). Notably, Schwab's work on a shift quality metric [1] and Horste's study on using VDV for shift feel [13] provided a foundation for objectively linking these metrics to driver perception. OEM calibration insights (such as GM's guidelines to avoid double bumps [11] and to use adaptive controls to maintain shift timing) and research on power shift transmissions [12] [23] further guided the selection of metrics like torque phase characteristics and oscillation amplitude. By adhering to these well-established metrics and thresholds, our proposed metric set should reliably characterize shift quality in a way that is reproducible and engineering-focused, suitable for automated log analysis and iterative tuning.

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