mix TELEMATICS
MOBILE INFORMATION EXCHANGE

Moving average speed filters and thresholds

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1 Introduction

The goal of this document is to demonstrate the effect of Moving Average (MA) filters on the speed input source. The reason why this is important is because there will always be irregularities and noise on the input speed and since the OBC simply records what is presented to it, these values affect the performance of the system. Speed spikes and dips can be created by numerous factors and the following are a few of the most common causes:

- GPS lock quality - urban canyons, reflections of high buildings, bridges/overpasses, tunnels, covered parking etc.
- Bad installations - floating ground, cross-talk, faulty alternators connected to supply voltage, quality of speed sender etc.
- Signal dropout – CAN and J1708 issue with variable sampling rates, frame errors, missing samples etc.

With the older generation of OBC hardware some of these disturbances were automatically filtered out/ignored since the sampling rate was limited to one speed sample every 2 to 3 seconds, but with the advances in technology it is now possible to sample real time second-by-second speed inputs with the newer OBC's and firmware. This means that when the newer hardware is used with "1-second" filters, many more of these irregularities will be visible to the users and it is therefore extremely important that the end-users understand the concept of filtering and how to configure the system for optimum performance.

Another side effect of the older OBC hardware is the conversion between imperial and metric values and the fact that it could only work in integer numbers and not in decimals (i.e. the number **12** can be represented but **12.3** could not be represented). The user interfaces however have to allow users to enter decimal values, since newer OBC hardware can work with decimal numbers.

The base units for all systems is **km/h**, this means when a user enter a value in **mph**, the mph value is converted to km/h and rounded down to the nearest integer (i.e. anything after the decimal point is discarded). This can have unexpected results, since the user expects, for example, an event to trigger at **6.5 mph**, but it will in fact trigger at **6.2 mph** due to the imperial to metric conversion and rounding process.

1.1 Summary

The following list of items is a summary of the recommendation and findings of this article (please refer to the rest of the document for proof and more detail):

1. MiX Telematics recommends the use of "3-second" moving average filters for fleet management, since this has the biggest positive effect on the quality of the speed signal and is the most compatible with older hardware and firmware.
2. The longer delay smoothing filters ("2-second" and "3-second" filters) will generate less false HA and HB events than a "1-second" filter (no filter) and the system will be more immune to noise and irregularities on the input signal.
3. A "2-second" filter will suppress all events shorter than 2 seconds and a "3-second" filter will suppress all events shorter than 3 seconds. This is generally not a problem in practice since we will show in this document that most vehicles are incapable of accelerating or braking in less than 3 seconds.
4. If you want to get short duration HA and HB events that last for 1 second or more, for example on performance cars or motorbikes or drive style applications, then "no filter" must be applied ("1-second" filters). ***It is however important to realize that a "1-second" filter will generate a lot of false HA***

and HB events if there is noise or irregularities on the input signal and the end-user should be advised of this effect.

5. If vehicle specific thresholds are used for Maximum Speed and Maximum Acceleration (i.e. what the vehicle is capable of doing), then false HA events can be eliminated for most cases without applying any smoothing filters.
6. Conversion between metric and imperial units, as well as rounding down for integer arithmetic, can cause HA/HB events to trigger at slightly lower values than what is configured in the user interface.

2 Moving Average Speed Filters

The rest of this document assumes a sampling rate of one value per second, i.e. a new speed value every second.This is the standard rate used to update the TACHO graphs and the timeline in FM-Pro and FM-Web. The same principles apply for any of the following speed sources; VSS (speed sender), GPS velocity or CAN speed.

All the values and figures used in this article are exported TACHO data from a truck (Scania P-Series). Definitions of a moving average (MA) Filter:

- 1 Second Filter = “No filtering” is applied, i.e. the raw input speed value is used.
- 2 Second Filter = The sum of 2 consecutive speed values divided by 2.
- 3 Second Filter = The sum of 3 consecutive speed values divided by 3.

The effect of these filters is depicted in Figure 1 below. It can be seen that the filter with the longest duration (3 seconds) has the smoothest curve, but also introduces the biggest delay in time when compared to the raw input (1 second).

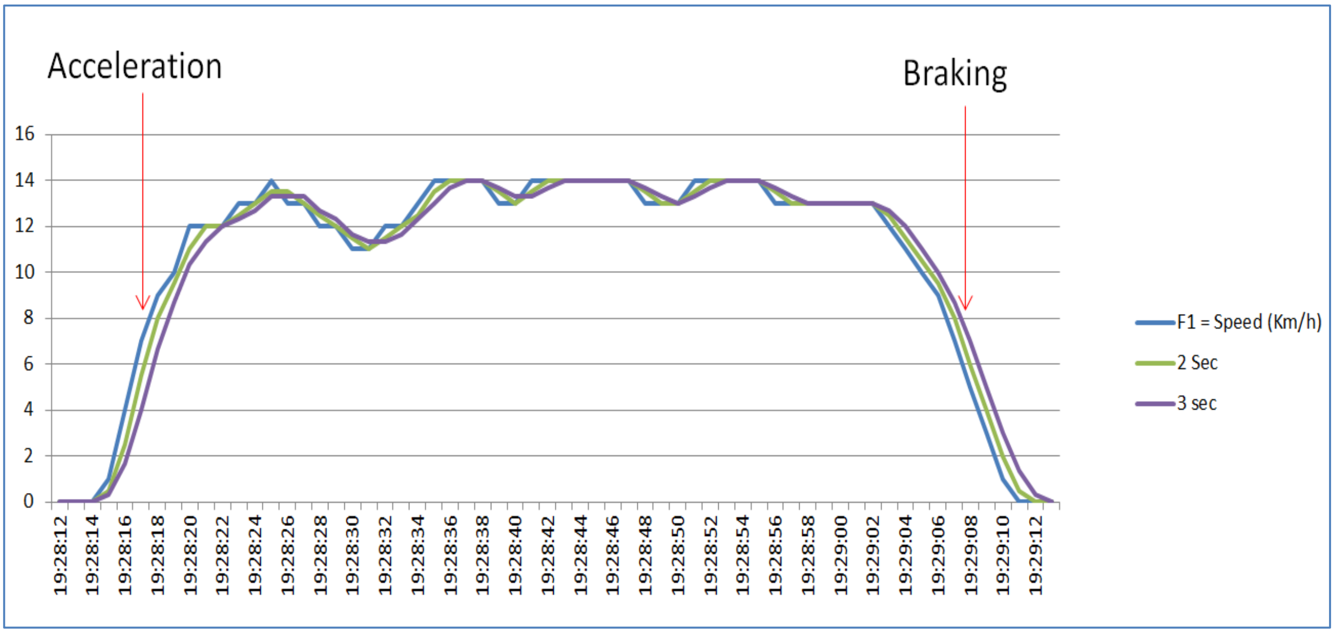


Figure 1: The effect of smoothing filters on Speed Values

When the speed increases by a value in Km/h/s it is called "***Acceleration***" and when the speed decreases by a value in Km/h/s it is called "***Braking***".

Km/h/s = Kilometer per hour per second

From Figure 1 we see the following Acceleration and Braking:

- The truck ***accelerates*** from 0 Km/h to 12 km/h in 6 seconds (19:28:14 to 19:28:20) – this means it accelerates at 2.016 km/h/s
- The truck ***brakes*** from 13 Km/h to 0 Km/h in 10 seconds (19:29:02 to 19:29:12) – this means it brakes at 1.299 Km/h/s.

To examine the effect of the moving average (MA) filter when there is "noise" or errors in the input speed values, we firstly introduce a "Speed dip" at the maximum point in this graph at 19:28:44, i.e. we will make the speed value 0 Km/h for one second and then return to the original value (14 Km/h). The effect can be seen in the graph below:

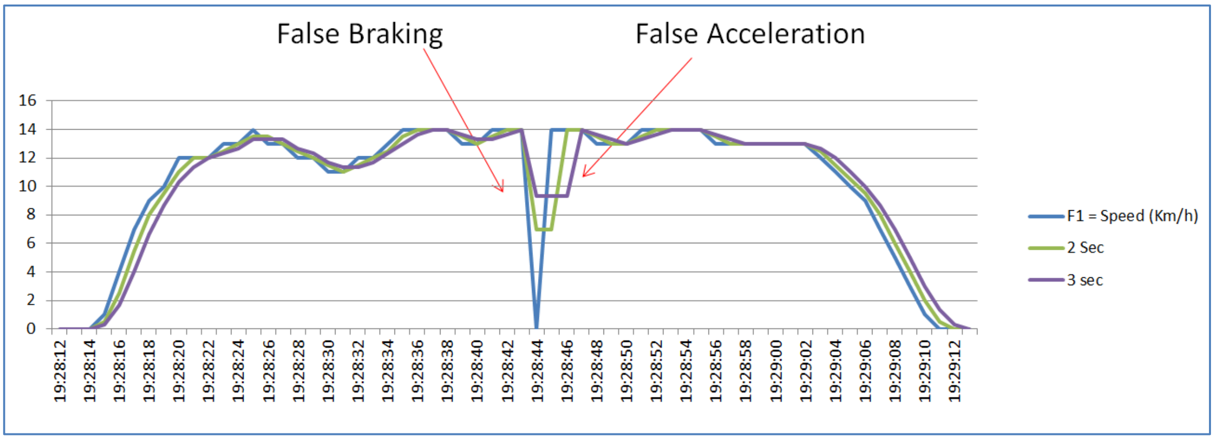


Figure 2: False Acceleration and False Braking due to speed dips

From the example above it is clear that if the "Harsh Acceleration (HA)" and "Harsh Braking (HB)" thresholds were both set to 10 Km/h/s, then the following would happen:

- If you are using a 1 second speed filter - You *will* get false HA and HB events, since the braking was 14km/h in one second and the acceleration were 14 km/h in one second, which is above the threshold of 10 km/h/s.
- If you are using a 2 second speed filter – You *will not* get false HA/HB events, since the braking was 7 Km/h in one second and the acceleration was only 7 Km/h in one second, which is below the thresholds of 10 Km/h/s.
- If you are using a 3 second speed filter – You *will not* get false HA/HB events, since the braking was 3 Km/h in one second and the acceleration was only 4 Km/h in one second, which is below the thresholds of 10 Km/h/s.

Secondly we introduce a "Speed spike" at the maximum point in this graph at 19:28:44, i.e. we will make the speed value maximum (254 Km/h) for one second and then return to the original value (14 Km/h). The effect can be seen in the graph in Figure 3 below.

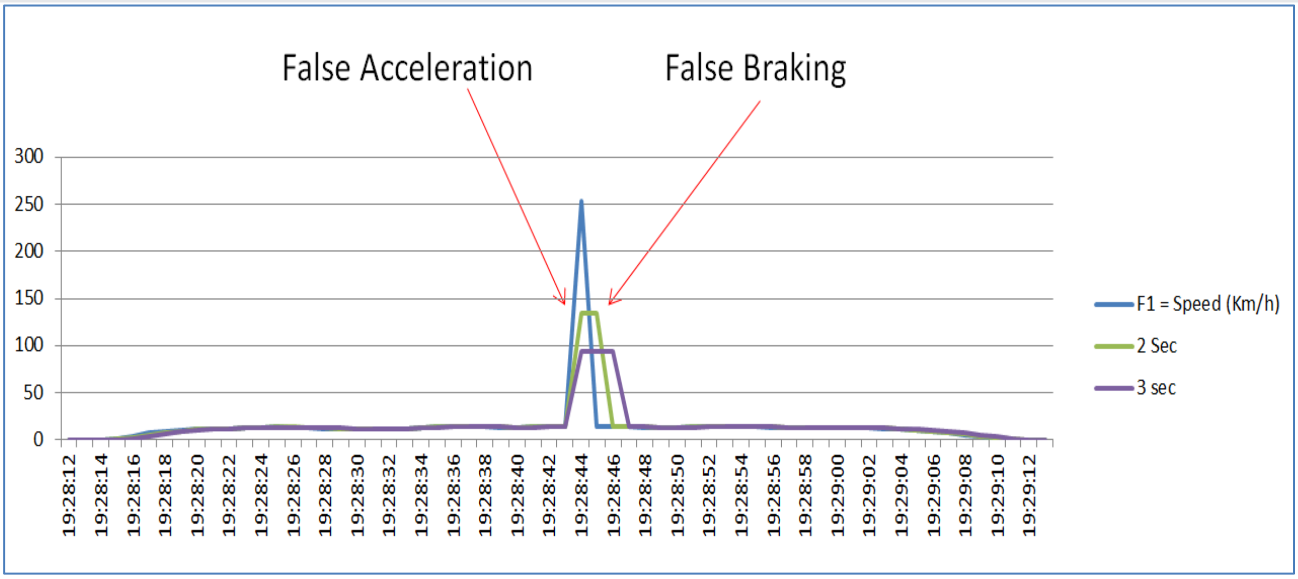
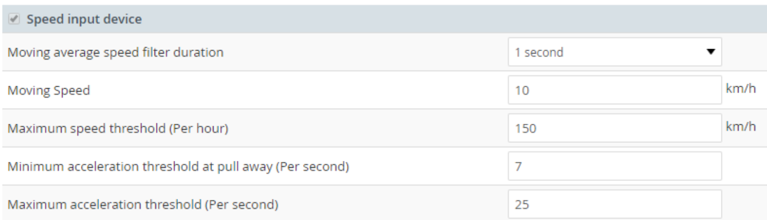


Figure 3: False Acceleration and False Braking due to speed spikes

From the example in Figure 3, it is clear that this change is too big and if the "Harsh Acceleration (HA)" and "Harsh Braking (HB)" thresholds were both set to 10 Km/h/s, then the following would happen if you are using a:

- 1 second speed filter - You *will* get false HA and HB events, since the braking was 240km/h in one second and the acceleration was 240 km/h in one second, which is above the threshold of 10 km/h/s.
- 2 second speed filter – You *will* get false HA/HB events, since the braking was 120 Km/h in one second and the acceleration was 120 Km/h in one second, which is above the thresholds of 10 Km/h/s.
- 3 second speed filter – You *will* get false HA/HB events, since the braking was 80 Km/h in one second and the acceleration was 80 Km/h in one second, which is above the thresholds of 10 Km/h/s.

The only mechanism to filter out such big values is to implement realistic "acceleration" and "maximum speed" threshold for a particular type of vehicle. In FM-Pro the following thresholds can be configured to eliminate false events. These settings are applied to the output of the MA speed filter.

The ***Minimum Acceleration Threshold at pull away*** is used to limit an internal filter that ramps up to the ***Maximum Acceleration Threshold*** at pull-off. This filter is most aggressive during the first second of acceleration (pull-off), limiting the permissible acceleration to the ***Minimum Acceleration Threshold*** value, then for subsequent seconds allowing higher and higher values until it gets to the ***Maximum Acceleration Threshold*** value. This is used because some speed senders don't work properly below a certain minimum speed.	 Speed input device Moving average speed filter duration: 1 second Moving Speed: 10 km/h Maximum speed threshold (Per hour): 150 km/h Minimum acceleration threshold at pull away (Per second): 7 Maximum acceleration threshold (Per second): 25 Note: The units of ***Minimum Acceleration Threshold*** and ***Maximum Acceleration Threshold*** is ***<u>Km/h/s</u>*** (not Km/h) The settings should be interpreted as: • Minimum Acceleration Threshold @ Pull-Away. • Maximum Acceleration Threshold @ "Moving" Speeds.

The simplest way to try and understand the use of these thresholds is:

1. HA (Harsh Acceleration) and HB (Harsh Braking) will be ignored if Speed or Acceleration values exceed what is specified in the Maximum Speed or Maximum Acceleration Thresholds..
2. If the thresholds are exceeded, speed will only be able to ramp up very slowly (e.g. 5Km/h/s).
3. The system will internally decrease the “Maximum Acceleration Threshold” for the first 4 seconds of motion. Every second after pull-away, this value will be increased until it is back at its original value. It will also not be decreased to a value less than the “The “Minimum Acceleration Threshold”.
4. The system uses the Maximum Speed and Maximum Acceleration thresholds to calculate what acceleration is possible for the vehicle at any particular speed. Note the acceleration threshold will be internally decreased the faster the vehicle is travelling and for the first 4 seconds of motion.

A simple rule is that acceleration depends on two important vehicle variables; they are the **power** and the **body mass** of the vehicle. *The more power the engine has and the lighter the vehicle is, the faster the acceleration. The less power the engine has and the heavier the vehicle is, the slower the acceleration.*
At higher speeds (above 100km/h) acceleration depends on air resistance and power rather than body mass.

For a vehicle with a mass of 1000 kg that accelerate between 0 – 100 km/h in 10 seconds, 38.6 kW power is required.	Change in Velocity : 100 (km/h) Time Used : 10 (sec) Acceleration : 10.008 (km/h/s) Distance travelled : 139 (m) Power : 38.6 (kW)
For a vehicle with a mass of 6000 kg that accelerate between 0 – 100 km/h in 10 seconds, 231 kW power is required.	Change in Velocity : 100 (km/h) Time Used : 10 (sec) Acceleration : 10.008 (km/h/s) Distance travelled : 139 (m) Power : 231 (kW)

Most standard light vehicles can only achieve a maximum acceleration of 10 km/h/s to 14 km/h/s due to this power and weigh ratio.

For example, if we look at the typical specifications for a **heavy vehicle** (*a Scania's P-Series was used in the example to generate the data in all the graphs in the document*):

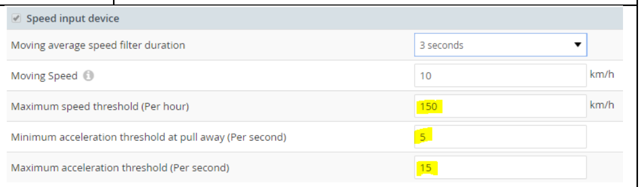
- Engines with output ranging from 170 KW to 320 KW and 2100 NM of torque.
- Curb Weight: 6,205 kg (Max. Weight GTW technical: 56,000 kg).
- Top Speed: 136 km/h (limited at 85 km/h).

If we go back to our initial observations of this vehicle and we assume that the following values from Figure 1 are generated during "normal" driving:

- The truck ***accelerates*** from 0 Km/h to 12 km/h in 6 seconds (19:28:14 to 19:28:20) – this means it accelerates at 2 km/h/s.
- The truck ***brakes*** from 13 Km/h to 0 Km/h in 10 seconds (19:29:02 to 19:29:12) – this means it brakes at 1.3 Km/h/s.

The following table of thresholds can subsequently be formulated:

<table>
<tr><th>Action</th><th>Normal</th><th>Maximum</th></tr>
<tr><td>Speed</td><td>0 to 85 km/h</td><td>133 Km/h</td></tr>
<tr><td>Acceleration</td><td>2 Km/h/s</td><td>10 Km/h/s</td></tr>
<tr><td>Braking</td><td>1.3 Km/h/s</td><td>16.66 Km/h/s</td></tr>
<tr><td colspan="2">This means we can apply the following thresholds for the Scania P-Series to the Speed filter output:

• Max Speed = 150 Km/h
• Minimum Acceleration Threshold = 5 Km/h/s
• Maximum Acceleration Threshold = 15 Km/h/s</td><td>
</td></tr>
</table>

Look at the example where we injected a Speed spike of 254 km/h using the thresholds calculated above.

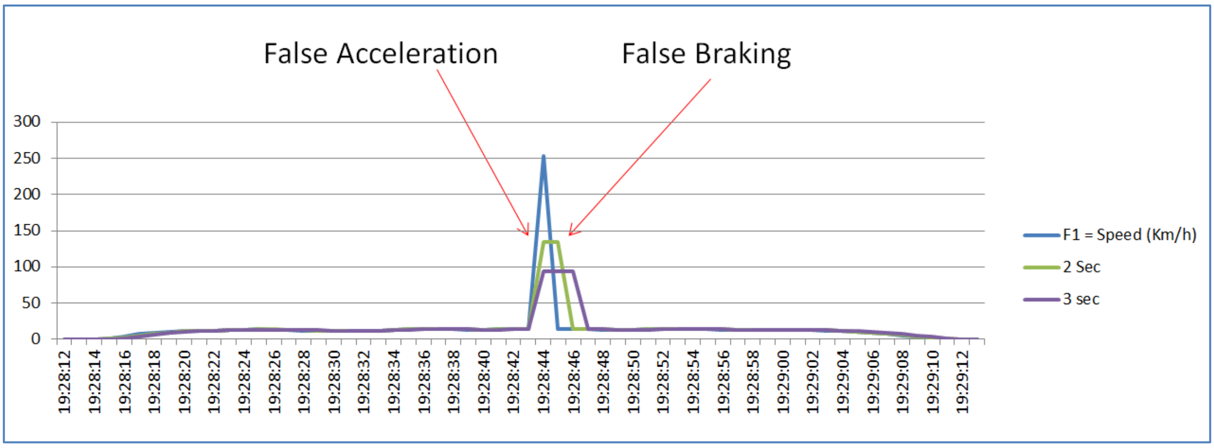


Figure 4: The effect of smoothing filters on speed spikes

From Figure 4 it is evident that the following will happen:

- 1 second speed filter - You *will not* get false HA and HB events, since the ***Maximum Speed*** of 254 Km/h and ***Maximum Acceleration*** of 242km/h/s are impossible for the Scania and the sample will be ignored.
- 2 second speed filter – You *will not* get false HA/HB events, since the ***Maximum Speed*** 134 Km/h and ***Maximum Acceleration*** 121 Km/h/s are impossible for the Scania and the sample will be ignored.
- 3 second speed filter – You *will not* get false HA/HB events, since the ***Maximum Acceleration*** was 81 Km/h/s is impossible for the Scania and the sample will be ignored, even though the ***Maximum Speed*** of 92 Km/h is possible.

In this example the effect of a speed spike on acceleration is demonstrated. Note that this logic is not valid for harsh braking and speed dips, since an accident scenario can cause virtually unlimited results.

These acceleration thresholds only have an indirect relationship to harsh braking events (HB) for speed spikes in the sense that if an invalid "acceleration" value is ignored, it will ensure that you do not get an invalid HB event when the value return to its normal value. For speed dips, these thresholds will not apply and the system may still generate a false Harsh Braking (HB) event.

2.1 The effect of smoothing filters on valid HA/HB events

The smoothing effect of the moving average speed filters can mask short and sharp changes in speed and therefore can mask real HA and HB events. Although it might at first be seen as a "bad" thing, it is important that readers realize that such short times as 1, 2 or 3 seconds are not really possible or practical values to use in order to detect abnormal (harsh) acceleration and braking.

It is important to keep perspective by remembering:

- A light vehicle of 1000 kg will typically take more than 10 seconds to accelerate from 0 to 100 km/h and for a heavy vehicle will take much longer, so 3 seconds is ample time to detect harsh accelerations.
- Similarly a light vehicle of 1000 kg braking from 50 km/h to standstill in 3 seconds will only reach a maximum deceleration (Braking) of 20 km/h/s and will require 25m distance to stop. A heavy vehicle will take much longer to decelerate and it will cover a much longer distance, so 3 seconds is ample time to detect harsh braking.

In the next example we will examine this "masking" effect by accelerating and braking for the following three cases:

- Accelerate @ 8 Km/h/s for 1 second, Brake @ 8 Km/h/s for 1 second.
- Accelerate @ 8 Km/h/s for 2 seconds, Brake @ 16 Km/h/s for 1 second.
- Accelerate @ 8 Km/h/s for 3 seconds, Brake @ 24 Km/h/s for 1 second.

It is important to realise that the braking values are extreme and not necessarily possible with a real vehicle, but it is required to use these values to demonstrate the effect.

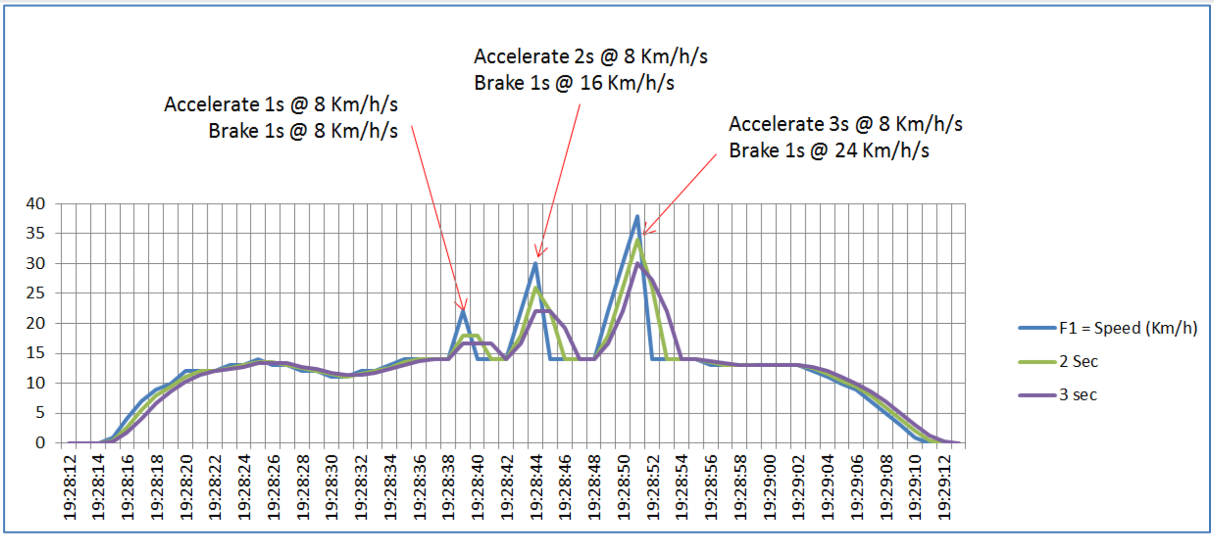


Figure 5: The effect of smoothing filters on short bursts of acceleration and braking

Assume that the HA threshold is set at 7 Km/h/s and the HB threshold is also set at 7 Km/h/s. This means the smallest change of 8 Km/h/s should trigger both a Harsh Acceleration and Harsh Braking event.

The table below shows the result in a tabular format so that it is easy to compare. It is important to note that ***acceleration*** was at a constant rate (8 Km/h/s) for all three cases, but that ***braking*** was at a different rate for the three cases (8 Km/h/s, 16 Km/h/s and 24 Km/h/s).	Accelerate for 1 second Brake for 1 second (1'st in Figure 5)	Accelerate for 2 second Brake for 1 second (2'nd peak in Figure 5)	Accelerate for 3 second Brake for 1 second (3'rd peak in Figure 5)
1s Speed Filter	HA = Yes, 8 Km/h/s > 7 Km/h/s HB = Yes, 8 Km/h/s > 7 Km/h/s	HA = Yes, 8 Km/h/s > 7 Km/h/s HB = Yes, 16 Km/h/s > 7 Km/h/s	HA = Yes, 8 Km/h/s > 7 Km/h/s HB = Yes, 24 Km/h/s > 7 Km/h/s
2s Speed Filter	HA = No, 4 Km/h/s < 7 Km/h/s HB = No, 4 Km/h/s < 7 Km/h/s	HA = Yes, 8 Km/h/s > 7 Km/h/s HB = Yes, 8 Km/h/s > 7 Km/h/s	HA = Yes, 8 Km/h/s > 7 Km/h/s HB = Yes, 12 Km/h/s < 7 Km/h/s
3s Speed Filter	HA = No, 2.7 Km/h/s < 7 Km/h/s HB = No, 2.7 Km/h/s < 7 Km/h/s	HA = No, 5.3 Km/h/s < 7 Km/h/s HB = No, 5.3 Km/h/s < 7 Km/h/s	HA = Yes, 8 Km/h/s > 7 Km/h/s HB = No, 5.3 Km/h/s > 7 Km/h/s

If you examine the pattern in this table it is important to realize that:

- A 3 second speed filter, will allow events greater than or equal to 3 seconds to generate a HA or HB with their full magnitude.
- A 2 second speed filter, will only allow events greater than or equal to 2 seconds to generate a HA or HB with their full magnitude.
- A filter of 1 second will generate HA and HB events for any value that exceed the threshold.

2.2 The effect of unit conversions on HA/HB events

The base unit for all systems is km/h. This means when a user enters a value in mph, the mph value is converted to km/h and since the older OBC can only work with integer arithmetic, all values are rounded down to the nearest integer.

For speed the following conversion factors can be used:

- 1 km/h = 0.621371 mph
- 1 mph = 1.60934 km/h

For acceleration and deceleration (HA/HB) the following factors can be used:

- 1 km/h/s = 0.0283254504 G-Force
- 1 mph/s = 0.04558528 G-Force

If a user with the imperial settings for example wants to set up a Harsh Braking (HB) event of **6.5 mph/s** the following will happen. The threshold of **6.5 mph/s** is equal to **10.46 km/h/s**, which is rounded down to **10 km/h/s**. If this number is converted back to mph it becomes **6.2 mph/s**.

This can have unexpected results, since the user expects for example an event to trigger at **6.5 mph (0.296 G-Force)**, but it will in fact trigger at **6.2 mph (0.283 G-Force).** ***It is therefore important to understand that rounding will have an effect when the thresholds are specified and that it is advisable to only specify thresholds in integer numbers. Select the maximum G-Force and pick the closest integer to it.***