Training Test Drivers with Data Acquisition

Wm. C. Mitchell
Wm. C. Mitchell Software

Mike Unger
Honda R&D Americas, Inc.

Roger Schroer
Transportation Research Center

Dennis B. Grisez
Transportation Research Center

Reprinted From: Proceedings of the 2000 SAE Motorsports Engineering Conference & Exposition (P-361)
ABSTRACT

Test-driving is a specialized art. Automotive manufacturers, parts suppliers, and tire manufacturers employ test drivers to evaluate their products in a variety of circumstances. But Honda and some other firms prefer the automotive engineer test his own product. This gives direct feedback and provides a better “feel” for how the vehicle reacts. It produces a better car and a better engineer. Some Formula One teams send their race engineers to a racing school.

Test drivers can be trained at commercial racing schools. These effectively teach students to drive at high speeds near the limit of the vehicle. The test driver must have the skills to perform a test with minimal danger to the driver and the vehicle.

But the demands of a test driver are not the same as a racing car driver, though many test drivers also race. The test driver must evaluate the vehicle as well as drive fast. The test driver must faithfully execute a test plan while observing vehicle behavior. The successful racing driver will recognize the failings of the vehicle and find a way to drive around them. The test driver must recognize the failings and find a way to fix them.

Honda and TRC recognized the difference and developed a driver training program to address these needs. The program was developed primarily to make sure Honda’s test engineers have the skills necessary to assure the car being delivered to the market is safe. In order to address these special needs Honda and TRC’s program is designed to provide high skill levels but more importantly to provide high safety levels.

Honda and The Transportation Research Center (TRC) use a four-step program to train automotive engineers as test drivers. The process described in this paper was used to help the test engineers improve their driving skills. The four students had a wide range of driving experience. One had raced Karts while another had never been to a race track.

The students completed one day at TRC and one at Mid-Ohio in a variety of cars, one of which had an on-board data acquisition system. The instructors rode with the students and used video and data analysis to reinforce and clarify their comments.

The students also learned how to analyze and evaluate driving techniques with a data acquisition system. The instructors learned how their subjective evaluation of a student can be supported with data.

This paper also shows common mistakes made by students of varying experience levels and how these can be detected in the data. This type of analysis is performed every race weekend by multi-driver race teams but is rarely documented because the data is proprietary.

The paper also demonstrates how simple statistics, including maximum speed, minimum speed in a turn and average throttle use, can be used to quickly spot and correct driving techniques. These statistics can direct the analyst’s attention to important portions of the data.

TRC and Honda developed an effective process that will be used for future events. TRC, as an independent organization, will continue to develop driver training programs.
PLANNING

The TRC Driver Development / Data Acquisition Seminar covered two days at TRC and Mid-Ohio. But planning and preparation began several weeks before the students got into a car.

1. The TRC portion of the event was given a “dry run” (on a wet day) by the authors of the paper. The data acquisition system and analytical methods were tested on the instructors. Data from this session was given to the students to begin their familiarization with data acquisition.

2. Students were given a booklet describing the entire event. This included written descriptions of Mid-Ohio (“a Lap Around … “ article by Bobby Rahal) and a video presentation created by The Mid-Ohio Driving School.

3. The instructors produced track maps with room for student’s comments. These were to be used after each session to develop good note-taking habits. Good notes make for good engineering reports.

DRIVING EVENTS

The two-day Driver Development / Data Acquisition Seminar schedule included the following driving events:

1. Laps around a 100-foot radius circular skid pad while increasing speed. This simple exercise displayed the relationship between lateral grip and steering input. It also introduced the students to data analysis.

2. Laps around a single turn in an instrumented Acura CL. This introduced the students to the cars they would be driving. It also provided the first exposure to data acquisition as a tool to analyze their driving techniques. Students could study driving techniques on a basic 180-degree turn without worrying about choosing a line.

3. Laps around the TRC Vehicle Dynamics Area Winding Course (VDA-WC). This sinuous course of constant turns introduced the need to determine the proper line and consider tradeoffs between carrying speed and using throttle and brake.

4. Laps around Mid-Ohio with higher speeds and more turns requiring the student to choose a line and a strategy. Students were scheduled on a grid with the day broken into twenty-minute segments. Each segment scheduled students and instructors in specific cars. The planned schedule was abbreviated due to fog but each student got about 30 laps with half in the data car.

INTRODUCTION TO DATA ACQUISITION

1. The use of data analysis began with the circular skid pad and a demonstration of how steering angle increases with speed and how eventually the car exceeds the slip angle peak and can no longer follow the path. See Figure 1. This got students accustomed to the presentation of data with multiple variables.

2. Data from the simple oval was examined for each student and compared to the instructor. Students studied their data and that of other students. The students learned to begin the analysis with speed and then add other variables (steering, throttle and braking) as necessary to understand what the student was doing. We also used G-G or traction circle plots and steering gradients. This was very useful in generating discussion among the engineer/students and vividly demonstrated how driving performance could be analyzed with data.

3. Data from the VDA-WC continued the learning process. The students learned how to expand the analysis from one simple turn to a series of turns.

4. At Mid-Ohio the students received feedback from the instructors, who rode in the cars, from a video camera mounted in the car, and from the data. After each 20-minute stint on the track the student made notes on a track map and discussed the session with his instructor. He then studied the data and video with an instructor and analyst. This process gave the student a specific plan and goals for his next session behind the wheel.

5. The data acquisition software calculated numerous statistics for each timed lap including sector times, minimum speeds, maximum speeds, and average and maximum values for steering, braking and throttle use. These were useful in documenting each student’s progress and suggesting events that warranted further analysis. These statistics are used in this paper.

6. After the event a 72-page report was prepared analyzing each student and comparing him with the instructors. Copies were distributed to each student.

CIRCULAR SKID PAD

The first exercise for the students was to drive around a 100-foot radius circular skid pad at increasing speed and observe the need for increasing steering input as speed increases. (This is an understeering street car.) Eventually the tires saturate and no longer generate additional lateral G even with increased steering. Then the car can not maintain the desired path. This simple exercise lets the students observe the tire’s slip angle response in the cars and in the data.
This exercise displayed the most common driver error: overdriving. This information is available in vehicle dynamics books but experiencing it was an eye opener to students who read about it but didn’t abide by it.

SIMPLE OVAL

A simple 180-degree turn was created with paint and cones on the TRC Vehicle Dynamics Area. The radius was similar to the circular skid pad. Drivers would approach the turn, brake, negotiate the turn, and then accelerate away. The turn was replicated with another 180-degree turn simply so drivers could make several trips through the primary turn.

Drivers approached the turn at 50-60 mph and braked to a speed of 25-35 mph for the turn.

This was the first opportunity for the drivers to combine braking, cornering and acceleration.

The example below shows two very different ways to negotiate the turn. The thin below shows a driver who brakes late, reaches a minimum speed of 27 mph, and then gets back to throttle to achieve a good exit speed.

The thick line shows a driver who brakes earlier but carries more speed through the turn (32 mph) but must wait to feed in throttle. The sector times are nearly identical, though the effectiveness of the technique depends on the length of the following straight.

This graph demonstrates the relationship between Speed and Longitudinal G. Both drivers obtain about the same level of Long G and their speed plots decline at the same rate. But one driver (thin line) continues braking to a slower speed and then gets rapidly to the throttle. He quickly gets to full throttle but must lift off the throttle and reduce acceleration in the exit.

The other driver (thick line) reduces his braking force and carries more speed across the middle of the turn. He uses a modest amount of throttle to maintain speed and then gradually increases to full throttle in the exit of the turn.

This event demonstrated the tire friction circle. Blending braking, cornering and acceleration can maximize the performance of tires and car. The graph shows friction circles for instructor and student. The instructor uses more of the circle and is more consistent.
COMMON ERRORS

The students commonly approached the turn slower than the instructors. They then used less Long G while braking and less Lateral G in the turn. The students often increased and decreased their steering angle as they tried to stay on the path. The instructors were able to make one steering input and then steadily decrease steering as they added throttle.

Some students were more aggressive on the short oval than at Mid-Ohio. The acres of open asphalt of the VDA provide a confidence that is not present at Mid-Ohio or other road courses.

The short oval and other simple tests provide a step-by-step training process that has proven very successful at TRC. Each event can teach one specific skill while revealing and correcting common mistakes. Students can develop skills as building blocks.

A 15-turn road course like Mid-Ohio can overwhelm the student. Each time he approaches Turn One he must recall his goals, errors and thoughts from 15-turns previously. A simpler event allows the student to concentrate and learn quicker.

VDA WINDING COURSE

The TRC VDA Winding Course is a 0.6-mile circuit with constant-changing radius. It is typical of “handling” courses on test tracks. There are no appreciable straights on this circuit. Minimum speed is about 25 mph and maximum 70.

Most road racing circuits have turns connected by straights. These require significant braking and provide potential passing zones. This is why road racing teams rarely test on “handling” circuits.

Figure 3 below compares an instructor and student on the VDA-WC. The instructor (thin line) brakes harder and accelerates harder. The student (thick line) carries more speed but uses less throttle.

The instructor has hundreds of laps of the TRC and is better able to create acceleration and braking zones. He uses both heavy braking and full throttle acceleration as much as possible. The student uses part throttle for much of the course and does not distinguish between braking and acceleration as well as the instructor.
The maps shown below compare the instructor and student on the VDA-WC. The maps show how much throttle each student is using at each point on the map. This graphic display makes it clear where the instructor is using more throttle than the student.

But this display does not indicate speed and show where one driver is faster than the other.

**INSTRUCTOR on TRC VDA–WC track. Map shows throttle use.**

**STUDENT uses less throttle.**

**MID-OHIO SPORTS CAR CIRCUIT**

This 2.4-mile road course near Lexington, Ohio, is used for a variety of events including CART races, the SCCA Runoffs, vintage car events, motorcycle races and marque club events. It is also busy as a test track when the weather permits. The road course includes several combination turns (The Keyhole with the SCCA Runoffs chicane, Madness, Thunder Valley and The Carrousel).

Only Turn One is a basic road racing turn with a straight entry and straight exit. All drivers enter on the right side of the track, make an apex on the left side, and exit on the right side of the track. But Turn One is also the fastest turn on the course and drivers can not see the exit from the entrance. It will be interesting to see how students perform on a fast but “basic” (not easy) turn with those requiring more planning and line choice.

At Mid-Ohio the test car, with a maximum Lateral G of 1.1g, was over 0.2g for more than 70% of a lap.

**Keyhole**

**Thunder Valley**

**Madness**

**One**

Figure 4 Mid-Ohio map with sectors.

The TRC driver training event used the Turn Two–Three switchback introduced for the SCCA Runoffs. Most professional events do not use this portion of the track but go straight from Turn One to the Keyhole/Turn 4. This version makes a more interesting approach to The Keyhole but eliminates one passing area.
For this event the timing beacon for the data acquisition system was located at the Start line on the back straight, as indicated by the flag in the map above. Placing the timing beacon here reduced the “out lap” to just the distance from pit exit (in Turn One) to the Start line. The standard location for timing beacons is at the Finish line before Turn One.

The “in lap” was now the distance from the timing beacon to the pit-in located in the Carousel turn. Placing the timing beacon here produced one more lap of usable data for each session.

The sector names used in this paper were selected for convenience and may not exactly match the names commonly used at the track. The speeds are the minimum speeds for the Bogey lap by Chief Driving Instructor Roger Schroer.

Madness begins with the fastest part of the circuit (about 100 mph in the test vehicle) and features a downhill braking area to a tight Turn 6 (52 mph). This leads to 7 (42 mph), which crests a sharp rise and then runs downhill to Turn 8 (43 mph). These three turns comprise the usual “Madness” section. There is then a short straight to Turn 9 (54 mph), that can be taken at full throttle. Turns 10 and 11 (50 mph) are really one turn which crests another significant hill.

Thunder Valley begins with a downhill run to a fast sequence of turns. Drivers generally brake from 74 mph entering 12 in preparation for 13 (60 mph). This is a fast left turn leading into the Carousel or Turn 14 (41 mph). This is a nearly-180 degree right-hander. The driver much choose a line which facilitates the exit from 13 but also permits a good entry to the Carousel. Then there is 15, a slight left-hand bend leading onto the front straight.

Turn One is a fast but basic 90-degree turn with a minimum speed of 63 mph. It has a straight entry (77 mph) and a straight exit. But the bridge over the track makes it a blind turn – the driver can not see the exit from the entrance to the turn.

The Keyhole follows the Turn Two switch-back introduced for the SCCA Runoffs. Turns Two and Three (61 mph) are a fast right-left-right swerve leading uphill into The Keyhole or Turn 4 (38 mph). This is the slowest part of the lap. The Keyhole is over 180-degree turn which crests a slight hill. The entrance is uphill but the exit is downhill and has an increasing radius.

PREPARATION FOR MID-OHIO

1. Students read the “Lap Around …” article and watched the Mid-Ohio Driving School video.

2. Each student was driven around Mid-Ohio with an instructor who discussed the proper line.

3. All students walked the Mid-Ohio course with the instructors.

COURSE FAMILIARIZATION

The TRC event description included the TRC “Approach to Vehicle Testing.” Portions are presented below:

“Whenever possible take the time to learn the test course. This is a good idea regardless of the test configuration; it is essential if you may be testing at high speeds or near the vehicle’s limit.

A) Understand facility rules and guidelines.

B) Be certain of communication with control personnel.

C) Ask about current special conditions – traffic schedules, test patterns and construction.

D) Study the course map.

E) Drive slowly to get a sense of the layout.

F) Drive slowly or walk the course to examine:

1) Surface construction – asphalt, concrete or a mix.

2) Surface condition – cracks, holes, bumps, dips, gravel, sand, water, oil.

3) Camber of turns.

4) Elevation changes.

5) Course edges, especially apex and exits. Are there dropoffs or is it level with the test surface.

6) Runoff – how much, is it flat or sloped, are there ditches, guardrail or trees.

DRIVING

Before starting out:

A) Achieve comfort/efficiency with the seat, controls and mirrors.

B) Become familiar with the controls, switches and gears to reduce distractions when driving.

As you begin driving:

A) Give yourself – your senses – time to adapt to the car’s response characteristics.

B) Take time to build to the car’s limits, especially cars new to you, rather than immediately pushing hard.
C) Drive within your limits. If you sense that events are happening at a speed exceeding your ability to process them and respond properly, slow down.

D) Train yourself to observe the vehicle’s behavior, to be able to devote a portion of your senses to feeling the car mechanically. Be sensitive to changes in that feel that might indicate a developing problem, especially with the tires, drivetrain and suspension.

LAP TIMES

Table 1 shows the lap times of the students. This shows the progress of the students and how close they came to the instructors’ lap time of 2:04.1 on a damp track.

Table 1: Mid-Ohio lap times in the data car

<table>
<thead>
<tr>
<th>Lap</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–1</td>
<td>2:20.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1–2</td>
<td>2:26.8</td>
<td>2:27.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1–3</td>
<td>2:18.5</td>
<td>2:20.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1–4</td>
<td>2:16.3</td>
<td>2:20.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1–5</td>
<td>2:16.7</td>
<td>2:15.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2–1</td>
<td>2:17.6</td>
<td>2:19.2</td>
<td>2:13.9</td>
<td></td>
</tr>
<tr>
<td>2–2</td>
<td>2:17.4</td>
<td>2:25.3</td>
<td>2:17.6</td>
<td>2:09.8</td>
</tr>
<tr>
<td>2–3</td>
<td>2:16.8</td>
<td>2:24.9</td>
<td>2:13.9</td>
<td>2:10.3</td>
</tr>
<tr>
<td>2–4</td>
<td>2:15.6</td>
<td>2:27.0</td>
<td>2:15.2</td>
<td>2:09.4</td>
</tr>
<tr>
<td>2–5</td>
<td>2:13.3</td>
<td>2:25.1</td>
<td>2:14.9</td>
<td>2:10.2</td>
</tr>
<tr>
<td>3–1</td>
<td>2:14.7</td>
<td>2:15.7</td>
<td>2:13.5</td>
<td>2:09.1</td>
</tr>
<tr>
<td>3–2</td>
<td>2:12.5</td>
<td>2:12.7</td>
<td>2:13.4</td>
<td>2:09.0</td>
</tr>
<tr>
<td>3–3</td>
<td>2:12.0</td>
<td>2:11.9</td>
<td>2:14.5</td>
<td>2:09.3</td>
</tr>
<tr>
<td>3–4</td>
<td>2:11.6</td>
<td>2:11.2</td>
<td>2:14.6</td>
<td>2:09.1</td>
</tr>
</tbody>
</table>

Improvement in lap times comes from many sources. Experienced driving instructors understand that students will almost always improve in their second session as they become familiar with the course and more confident in their abilities. The use of data and video analysis after the first session is not really necessary but does get the student accustomed to analyzing the data.

There is no objective way to attribute the improvement in lap times to simple repetition, the riding instructor’s comments, video analysis or data analysis. In many cases the data analysis repeated the instructor’s comments. Driving flaws noted after a driver’s first stint were corrected or improved in later sessions, but this does not identify the source of the improvement.

The TRC instructors believe the use of data facilitates the teaching process, particularly with engineers. Data provides objective evidence to support the instructor’s subjective comments. It also provides quantitative results to help the student mark his progress.

Student 1 was told to slow down after his first lap because he was being too aggressive. Student 4 had a very cautious first lap, the slowest of the event, but finished with the fastest lap by a student.

The students also drove the other cars, which were not equipped with data.

LAP STATISTICS

In addition to Lap Times we calculated many parameters for each timed lap. These parameters include sector times, maximum speeds on straights, minimum speeds in turns, maximum and average braking, throttle and steering values.

These computed parameters do not provide all of the answers, but they do reliably suggest which turns and laps should be studied in greater detail. Some of these parameters are included in this paper.

Many driving schools do not use data systems because the analysis is time consuming. For the introductory student an instructor’s comments are sufficient and quicker than reviewing data. But as the students get closer to the instructor’s pace and the flaws become less obvious the data becomes more critical. But the analysis is still time-consuming. At a race weekend the analyst may have several hours to study the fastest laps of a session. In the TRC format there was only twenty minutes to download and analyze each student’s data. The lap statistics suggested where the analysis should begin.

In some cases the lap statistics are sufficient alone. If a student is consistently using less brake or less steering than an instructor and is slower then the student is probably not driving the vehicle near it’s limit. If the student is using less brake and is faster then he may have found a more efficient way to drive the turn. If there is little difference in the lap statistics than further analysis is warranted.
STUDENT 1

Student 1 tests brakes. Table 2 below shows his fastest laps of each of three sessions in the data car. Sector times for those laps are also shown. At the bottom are the quickest sector times for the student, even if they did not occur on one of the fastest laps.

<table>
<thead>
<tr>
<th>Table #2 Student 1 sector times</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>Bogey</td>
</tr>
<tr>
<td>Ses1</td>
</tr>
<tr>
<td>Ses2</td>
</tr>
<tr>
<td>Ses3</td>
</tr>
<tr>
<td>Best</td>
</tr>
</tbody>
</table>

Table 2 shows that Student 1 gains 4.7 seconds during his three sessions. Madness provides 2.30 seconds while Thunder Valley contributes 1.64 seconds. There was very little change in Turn One but 0.59 seconds gain in The Keyhole.

Why is there no improvement in Turn One? This is the fastest turn but the most basic because it has a straight entry and exit. Most Mid-Ohio turns are combinations with the exit on one turn being the entrance to the next turn.

Parameters for Student 1 in Turn One suggest some answers:

<table>
<thead>
<tr>
<th>Table #3 Student #1 in Turn One</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>Bogey</td>
</tr>
<tr>
<td>Ses1</td>
</tr>
<tr>
<td>Ses2</td>
</tr>
<tr>
<td>Ses3</td>
</tr>
</tbody>
</table>

Student #1 did not change his braking point appreciably but his braking effort doubled from 0.24g to 0.50g as his lap times came down. By Ses3 the brake tester was braking as well as the instructor. But his minimum speed in the turn did not change. He did use more throttle and his exit speed increased. But with all this improvement in technique his sector time did not improve.

His maximum steering was 74 with an average of 56.3. His steering input did not change much during the day and was far below the instructor’s 130.7 max and 82.4 average.

The instructors used much more steering input in Turn One. They were willing to be more aggressive with the controls of the car. This reflects the fact the data car was a street car on tires designed for thousands of safe (understeering) reliability. Race cars are designed for speed with tires created for an hour or use, or less.

With racing drivers in cars designed for racing the better drivers are usually the smoothest and use less steering.

Figure 5 below compares the instructor (thin line) with student 1 (thick line) in Turn One. The braking point and effort (LongG) are identical but the instructor carries more speed through the turn and uses more throttle.
STUDENT #2

Student 2 made steady progress from a first lap of 2:25.3 to a final lap of 2:11.2. Three of his four fastest sector times occurred on his last lap. This is impressive consistency.

<table>
<thead>
<tr>
<th>Table #4 Student #2 sector times</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>Bogey</td>
</tr>
<tr>
<td>Ses1</td>
</tr>
<tr>
<td>Ses2</td>
</tr>
<tr>
<td>Best</td>
</tr>
</tbody>
</table>

STUDENT 2 IN MADNESS

His technique in Madness (thick line) mimicked that of the instructor, but he was slower. He used less steering and generated less lateral G.

Notice how student 2 rolls off the throttle before braking for Turn 6. This is a common mistake as the driver gets nervous before reaching the braking point. Student 1 (the brake tester) and the instructor maintained full throttle right to the brake point. The student does the same thing in the other turns.

STUDENT 2 IN THUNDER VALLEY

The story is the same here but the differences are larger. The greatest difference is in the fast right-left-right swerve before The Carousel. Student 2 is 12 mph slower in this part of the track. He uses less steering input and generates less Lateral G. He is also tentative with the throttle as he rolls-off the throttle rather than establishing a firm braking point. The instructor is also able to use full throttle through much of this segment while the student uses part throttle.

Lap statistics would point out the difference in entry speed. They would not detect the G-G patterns shown below.

Traction circles (G-G diagrams) are nearly identical with student #2 (on the right) having a bit nicer translation from braking to cornering. The traction circles show that the instructor generated more lateral G and a bit more braking force. But G-G diagrams do not show the crucial difference in speed or throttle.
STUDENT 2 IN TURN ONE

In this turn student #2 is only 4 mph slower than the instructor. He brakes a bit earlier and carries almost as much speed across the apex but is unable to use as much throttle.

Student 2 reduced his Turn One sector time from 13.59 to 12.29 by increasing his braking, his minimum speed in the turn, and his use of the throttle. This is good progress.

Lap statistics show how student #2 is close to the instructor in Turn One. The statistics do not indicate the patterns shown in the G-G diagrams. Statistics work much better for minimums, maximums and averages than for patterns. But time saved by looking at lap statistics can be used to look at G-G diagrams.

Once again the Traction circles (G-G diagrams) for Turn One are nearly identical with student #2 (on the right) having a bit nicer translation from braking to cornering. The instructor again generated more lateral G and a bit more braking force. But G-G diagrams still do not show the crucial difference in speed or throttle.

---

STUDENT 2 IN THE KEYHOLE

The pattern remains the same, Student 2 is slower on the difficult entrance to Turn Two (9 mph) but nearly as fast in The Keyhole (4 mph). Fast turns with difficult entrances separate drivers.

Lap statistics show how student #2 is close to the instructor in Turn One. The statistics do not indicate the patterns shown in the G-G diagrams. Statistics work much better for minimums, maximums and averages than for patterns. But time saved by looking at lap statistics can be used to look at G-G diagrams.
STUDENT #3

This student began with a 2:13.9 and improved only half-a-second to 2:13.4. Table 1 shows his quickest lap did not come on his last lap but his last two laps were a second slower than his best lap. This suggests consistency is a problem. He was also the slowest student.

Table #6  Student #3 sector times

<table>
<thead>
<tr>
<th>Driver</th>
<th>Time</th>
<th>Madness</th>
<th>Valley</th>
<th>One</th>
<th>Keyhole</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bogey</td>
<td>2:04.1</td>
<td>48.50</td>
<td>31.77</td>
<td>11.93</td>
<td>29.81</td>
</tr>
<tr>
<td>Ses1</td>
<td>2:13.9</td>
<td>53.16</td>
<td>34.43</td>
<td>12.69</td>
<td>31.32</td>
</tr>
<tr>
<td>Ses2</td>
<td>2:13.4</td>
<td>52.09</td>
<td>33.93</td>
<td>12.90</td>
<td>32.16</td>
</tr>
<tr>
<td>Best</td>
<td>52.09</td>
<td>33.50</td>
<td>12.61</td>
<td>31.32</td>
<td></td>
</tr>
</tbody>
</table>

Turn One shows that Student 3 is simply slower. He brakes earlier and generates only half as much braking force. He is 8 mph slower in his minimum speed. He also uses less throttle in the exit of the turn.

CORNERING IN TURN ONE

Student 3 uses only half as much steering input and generates considerably less Lateral G through the entire turn. This student needs more time in the car and on the track.

Table #7: Student 3 in Turn One

<table>
<thead>
<tr>
<th>Driver</th>
<th>Lap</th>
<th>Time</th>
<th>Min. Speed</th>
<th>Max. Brake</th>
<th>Avg. Brake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bogey</td>
<td>2:04.1</td>
<td>62.9</td>
<td>0.26</td>
<td>0.13</td>
<td>0.49</td>
</tr>
<tr>
<td>Ses1</td>
<td>2:19.2</td>
<td>55.6</td>
<td>0.26</td>
<td>0.13</td>
<td>0.49</td>
</tr>
<tr>
<td>Ses1-2</td>
<td>2:17.6</td>
<td>53.9</td>
<td>0.33</td>
<td>0.26</td>
<td>0.49</td>
</tr>
<tr>
<td>Ses1-3</td>
<td>2:13.9</td>
<td>58.9</td>
<td>0.44</td>
<td>0.18</td>
<td>0.49</td>
</tr>
<tr>
<td>Ses1-4</td>
<td>2:15.2</td>
<td>57.7</td>
<td>0.29</td>
<td>0.24</td>
<td>0.49</td>
</tr>
<tr>
<td>Ses1-5</td>
<td>2:14.9</td>
<td>58.0</td>
<td>0.31</td>
<td>0.19</td>
<td>0.49</td>
</tr>
<tr>
<td>Ses2-1</td>
<td>2:13.5</td>
<td>58.8</td>
<td>0.37</td>
<td>0.24</td>
<td>0.49</td>
</tr>
<tr>
<td>Ses2-2</td>
<td>2:13.4</td>
<td>54.7</td>
<td>0.32</td>
<td>0.24</td>
<td>0.49</td>
</tr>
<tr>
<td>Ses2-3</td>
<td>2:14.5</td>
<td>56.6</td>
<td>0.39</td>
<td>0.33</td>
<td>0.49</td>
</tr>
<tr>
<td>Ses2-4</td>
<td>2:14.6</td>
<td>56.1</td>
<td>0.55</td>
<td>0.42</td>
<td>0.49</td>
</tr>
</tbody>
</table>

In this case the lap statistics confirm what the data shows: student #3 uses less throttle and steering but he does improve his throttle use as he accumulates more laps. But his minimum speed and brake use is inconsistent, as shown in Table 7. This is probably more apparent in the lap statistics than it would be in plots.
STUDENT #4

Student 4 is an experienced Kart racer. In Table One he is credited with the largest improvement of all the students, 18 seconds from 2:27 to 2:09. But this is misleading because his first lap was very cautious. His fastest lap of the first session was a 2:15.5. This was the fastest student with a best lap of 2:09.0. His last four laps ranged from 2:09.3 to 2:09.0 for admirable consistency.

<table>
<thead>
<tr>
<th>Table #9</th>
<th>Student #4 sector times</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lap</td>
<td>Driver</td>
</tr>
<tr>
<td></td>
<td>Bogey</td>
</tr>
<tr>
<td>Ses1</td>
<td>2:15.5</td>
</tr>
<tr>
<td>Ses2</td>
<td>2:09.4</td>
</tr>
<tr>
<td>Ses3</td>
<td>2:09.0</td>
</tr>
<tr>
<td>Best</td>
<td>50.68</td>
</tr>
</tbody>
</table>

Student 4 is quite similar to the instructor in Madness and Thunder Valley. But he has a different approach to Turn One. He brakes half as hard and carries considerable speed across the apex with a minimum speed of 60.8 mph compared to 62.9 for the instructor.

The Turn One parameters for student 4 are interesting. Student 4 uses more steering than any other student with the greatest steering input coming on the Ses3-1 lap when he also carried two mph more across the middle of the turn.

<table>
<thead>
<tr>
<th>Table 10</th>
<th>Student 4 in Turn One</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lap</td>
<td>Driver</td>
</tr>
<tr>
<td></td>
<td>Bogey</td>
</tr>
<tr>
<td>Ses3-1</td>
<td>2:09.1</td>
</tr>
<tr>
<td>Ses3-2</td>
<td>2:09.0</td>
</tr>
<tr>
<td>Ses3-3</td>
<td>2:09.3</td>
</tr>
<tr>
<td>Ses3-4</td>
<td>2:09.1</td>
</tr>
</tbody>
</table>

Traction circles (G-G diagrams) for Turn One. These graphs show significant differences in braking effort. The lap statistics confirm that student #4 uses less brake entering Turn One while carrying impressive speed through the turn.
TURN TWO AND THE KEYHOLE

Student 4 rolled off the throttle entering Turn Two and did not brake as hard as the instructor. But he was within 5 mph of the instructor through Turn Two.

Student 4 used failed to downshift for the Keyhole. This allowed him to use considerable amounts of full throttle but he had to lift off the throttle in the exit and this cost him exit speed.

GEAR CHOICE IN MADNESS

Having identified a different gear strategy in The Keyhole it is worth going back to Madness. Sure enough, Student 4 is using a taller gear there also. His Throttle use is almost identical to the instructor but the car is less responsive in a higher gear.

Student #4 focused on learning the proper line by minimizing downshifts in the more complex series of turns. This simplified the task and accelerated the learning curve.

GEAR CHOICE IN THUNDER VALLEY

Once again Student 4 uses a taller gear in the Carousel. This costs him exit speed.
THE INSTRUCTORS AND A CHIEF ENGINEER

After a day of riding with students the instructors had to have a try at the course. Forrest Granlund works for Honda R&D and races with HART (Honda America Racing Team) at Mid-Ohio and other tracks.

Two other instructors are engineers with Honda R&D. Ken Martin is a SCCA showroom stock racer and works in the steering group. Nick Robinson is a Canadian Rally champion and works in the reliability group, but never got into the data car.

Ted Klaus is the chief engineer of the suspension group. He has hundreds of hours of track time testing prototypes.

It should be noted that Granlund was limited to just two timed laps and that weather conditions changed during the day.

MADNESS – THE FIRST THREE TURNS

Chief instructor Schroer (thin line) carries more speed through the first turns (the right-left combination) and has a higher exit speed on the run down to the right-hander. He gets to full throttle much sooner. Granlund goes deeper into that turn and carries more speed across the apex.

THUNDER VALLEY

Granlund brakes later but does not get to full throttle as soon. Braking and cornering efforts are similar but each driver makes different choices as where to brake and where to get to full throttle.

TURN ONE

Both instructors approach Turn One at the same speed but Granlund rolls off the throttle before reaching the braking point and does not brake as hard. He carries more speed across the middle of the turn but at part-throttle. The Chief instructor braked harder, was slower across the middle of the turn, but used much more throttle after the apex. Exit speeds were nearly identical.

This illustrates a common trade-off racing drivers must consider. Carrying more speed through the turn may reduce the amount of throttle that can be used. The racing driver must decide how to compromise between carrying speed and accelerating off the turn. The decision depends upon the turn, the type of car (more powerful cars should concentrate on throttle use) and the tactical situation.
KEYHOLE

There are smaller differences in the Turn Two-Keyhole combination. The Chief instructor carries a bit more speed across Turn Two but a bit less into The Keyhole. He is also able to use more throttle in the exit from The Keyhole.

TIME GAIN / LOSS

There is no particular pattern to the difference in lap times. If you ignore the 0.20 seconds Granlund loses on the straight at the beginning of his lap, the other differences display no particular pattern. There are minor differences in various portions of the track.

COMPARE INSTRUCTORS IN TURN ONE

The lap statistics show how similar the instructors are in Turn One. With drivers of nearly equal skill levels more detailed analysis of the data is required. This is similar to the analysis required of multi-driver professional racing teams.

Suspension engineer Ted Klaus had the fastest Turn One sector time. The graph below shows how he did it.

The above graph compares Schroer (thin line) and Ted Klaus (thick line) in Turn One. Klaus braked late and lightly to carry impressive speed across the middle of the turn.
The final comparison is Ken Martin in Turn One.

This is classic technique. Ken (thick line) brakes late and harder than the Chief instructor. He then gets immediately to full throttle and maintains full throttle through the exit. His minimum speed is comparable to Schroer but a bit slower than Ted Klaus on the previous page.

All four instructors are very experienced and capable drivers. Analysis of their laps is akin to comparing professional drivers. This is an interesting subject but is beyond the scope of this paper.

THE RESULTS

This process was successful in several training areas:

1. Training test drivers. The event taught a detailed process for learning a new circuit. This process can be applied whenever the students encounter a new track. This will avoid the horror stories of $1,000,000 prototypes being destroyed by over-enthusiastic drivers on their first lap of a new circuit.

2. Training engineers to test cars. Engineers can successfully test cars and learn first-hand rather than relying on the results of a non-engineer test driver. Mike Under of Honda says “Having engineers talk about their experiences led to discussions of how the vehicle feels”.

3. Training engineers to use data acquisition to evaluate driving technique. This proved a very successful way to teach analysis of driving techniques. An engineer studying his own data is more motivated than one simply completing exercises in a class. The competitive instinct also motivates students to improve their driving with the data.

4. There were no accidents or serious incidents in spite of wet weather at TRC and dampness at Mid-Ohio. There was one minor off course excursion Mid-Ohio but no damage. Students must learn to cope with the unexpected in a proper manner and not to panic. The cold and wet conditions did not stop the event.

5. The students felt the use of data contributed to the event. One student wrote the following in an after-event questionnaire: “It is a better way of training for engineers, proving that better performance is measurable, even just looking at one corner. It teaches a better way of thinking about your driving. It makes it more of a science and less of an art.” But the student still felt the instructors were necessary: “It still requires the instructor to see your actual technique. You can’t just look at the data.”

Another student mentioned the data helped him “understand the vehicle reaction to every driver action.” He also said that both (lap) time and technique are important in driver development.

6. The traditional driver training methods are highly subjective with only the stop watch to evaluate results. Instructions like “You need to blend forces” may be taken as artistic criticism rather than scientific directions to drive better. The use of data reinforces the subjective opinion with objective facts. “Engineers prefer to be shown the numbers,” Roger Schroer says.

Mike Unger of Honda felt that “Engineers do not take everything at face value – they need to see data.”

7. After the event TRC received requests for additional tests with the data acquisition system.

8. TRC is planning new driver training events and incorporating data acquisition into existing events. Data will be used for instruction and evaluation. One event will introduce chassis changes so students can feel the effects. This should be popular with racing engineers.

CONCLUSION

The process described above was quite effective. The next step is to produce similar teaching materials for other circuits. Future research will include the teaching of vehicle dynamics by changing the car and letting the student feel the difference on the track.

REFERENCES

2. “In the Driver’s Seat”, Mid-Ohio Video, Brian Till, Mid-Ohio Driving School, Dublin Ohio