The Little Book of Profiling

www.umtri.umich.edu/erd/roughness/index.html

Outline

- Ride Quality
- Smoothness Measurement
- Profile-Based Indices
- Construction Quality Control

Ride Quality

- Sine Waves
- Human Response to Vibration
- Vehicle Response to the Road
- Road Roughness

Ride Quality

- Sine Waves
- Human Response to Vibration
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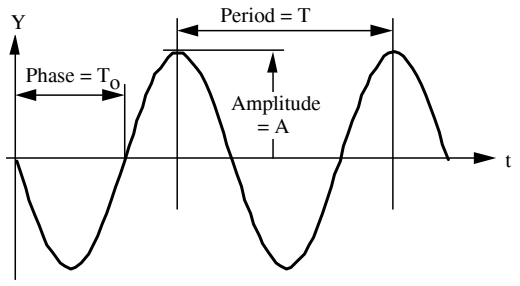
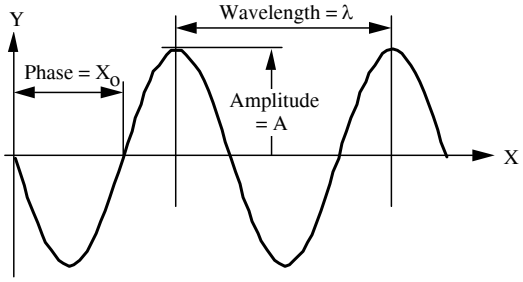
Sinusoid



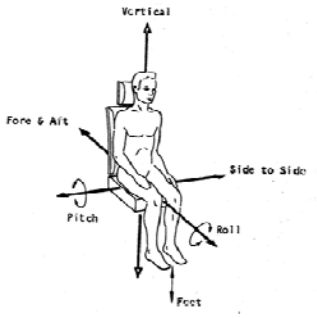
Sinusoid



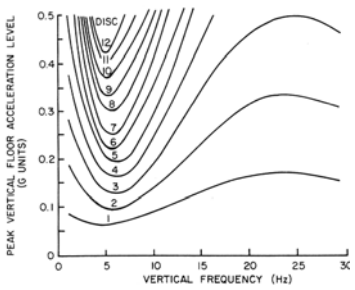
Ride Quality

- Sine Waves
- Human Response to Vibration
- Vehicle Response to the Road
- Road Roughness

Human Response to Vibration



Human Response to Vibration

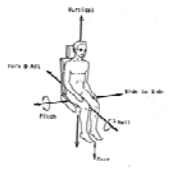


Human Response to Vibration

- Vital organs in the abdominal cavity "resonate" at about 5 Hz.
- A human head resonates at about 25 Hz.
- Human eyes resonate at 30-80 Hz.
- It is tough to grip a steering wheel if it is moving at 50-200 Hz.

Human Response to Vibration

The automobile industry estimates ride by measuring response at several interfaces:



Seat/buttock
Seat/back
Floor/feet
Steering Wheel/Hand

Human Response

Ride Quality

- Sine Waves
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- Vehicle Response to the Road
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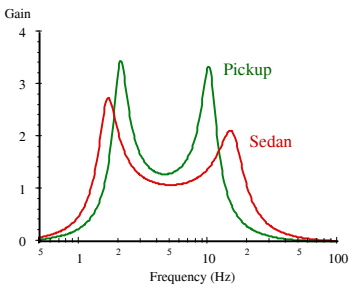
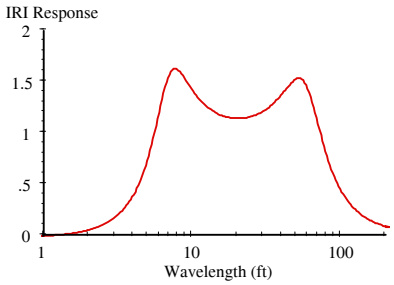
Vehicle Response to the Road

- Auto companies spend considerable effort study vehicle vibrations:
  - heave, waddle, shake, chatter, jitter, porpoise, tire nibble, etc.
- Two major motions are body bounce and axle hop.

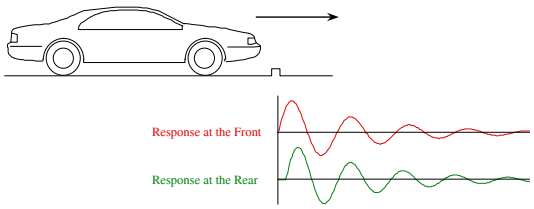
Vehicle Response to the Road



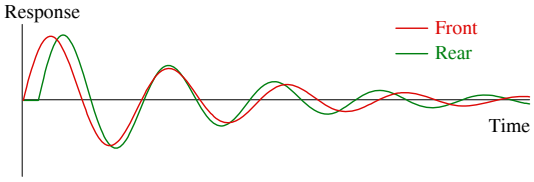
International Roughness Index



Bump Response



Bump Response



Vehicle Response to the Road

- The vehicle exaggerates some road features and isolates you from others.
- Each vehicle responds to the roughness of the road differently.
- Some features in the road are more significant to vehicle response than others.

Ride Quality

- Sine Waves
- Human Response to Vibration
- Vehicle Response to the Road
- Road Roughness

Road Roughness as Vehicle Input

- Pavements have certain roughness characteristics that are predictable.
- Short wavelength roughness often has lower amplitude.
- New pavements often have roughness characteristics that can be related directly to construction practices.

Smoothness Measurement

- Straightedges
- Profilographs
- Response-Type Measurement
- Inertial Profilers
- Inclinometer-Based Profilers

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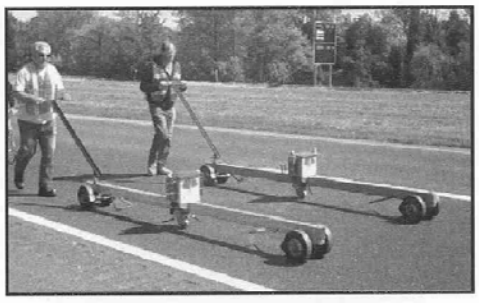
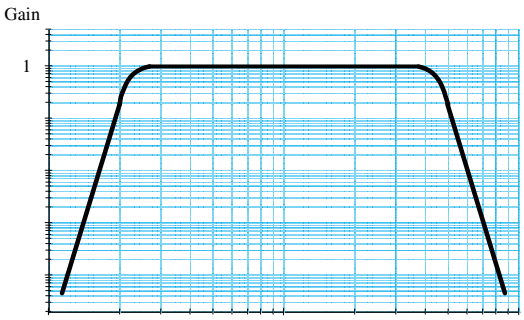
Profilograph

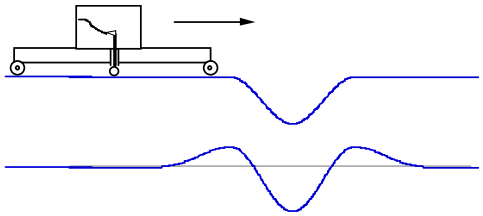
Rolling Straightedge



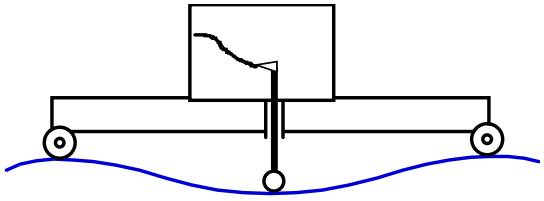
Measurement Distortion



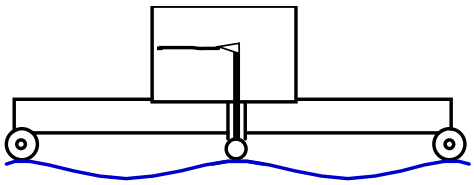
Rolling Straightedge Response



Rolling Straightedge Response



Rolling Straightedge Response



Smoothness Measurement

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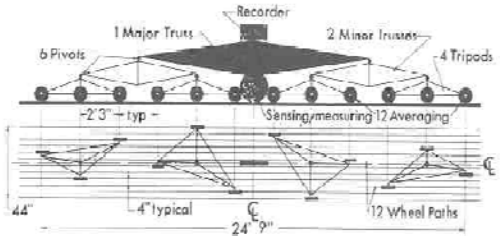
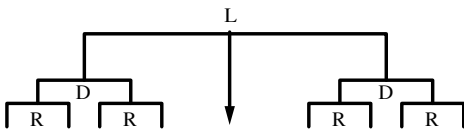
Rainhart Profilograph

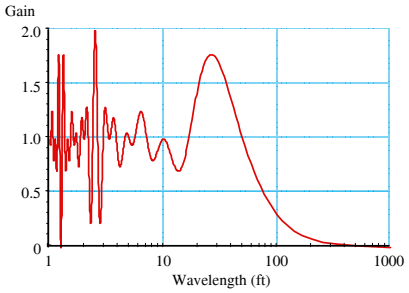


Profilograph

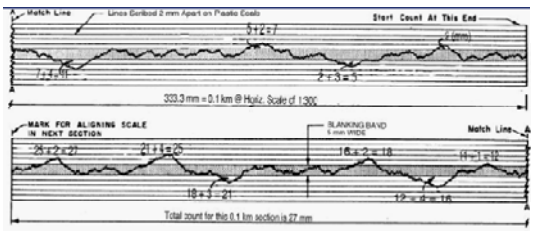
Profilograph



Profilograph Response



Manual Trace Reduction

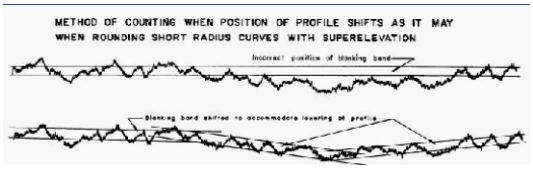


Automated Trace Reduction

Need 6 “settings”:

1. blanking band
2. high-pass filter cutoff
3. minimum scallop width
4. minimum scallop height
5. scallop rounding increment
6. drift removal strategy

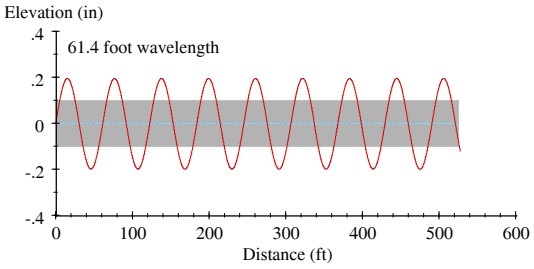
Blanking Band Placement



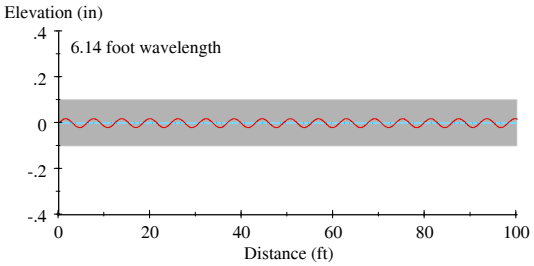
Major Vehicle Vibrations

Body Motion: 1-3 Hz
(pitch and bounce)
Axle Motion: 10-15 Hz
(axle hop and axle tramp)

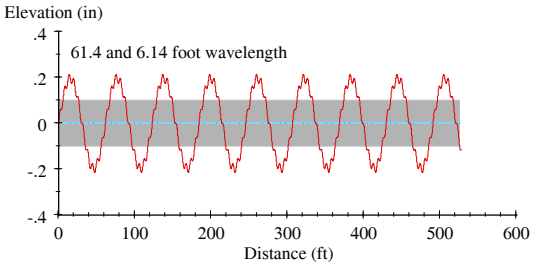
Long Wavelength Response



Short Wavelength Response



Response to a Mixture

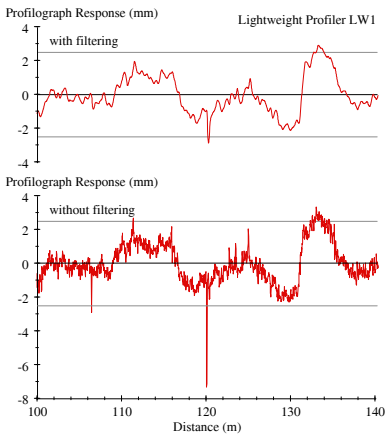


Summary Results

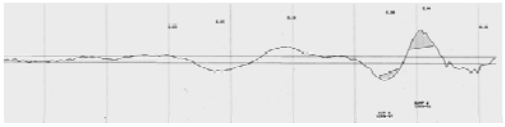
Feature	PI, 0.2-in band (in/mi)	PI, zero band (in/mi)	IRI (in/mi)
Long Duration	7.6	24.7	93.1
Short Duration	0	41.8	90.0
Both	11.4	28.5	116.6

Chatter Examples

- In ProVAL, demonstrate chatter caused by:
  - Roller problems
  - Oscillating screed



Profilograph Output



Profilograph output can be used to:
1. Estimate smoothness.
2. Determine a grinding strategy.
3. Help improve construction practice for *smoothness*.

Profilograph Output

From	To	Dist	Count	PI(in/mi)
1189+00	1191+64	264	0.38	7.60
1191+64	1194+28	264	0.23	4.60
1194+28	1196+92	264	0.11	2.30
1196+92	1199+56	264	0.13	2.60
1199+56	1202+20	264	0.01	0.30
1202+20	1204+84	264	0.05	1.00
1204+84	1207+48	264	0.03	0.70
1207+48	1210+12	264	0.10	1.90
1210+12	1212+76	264	0.00	0.00
....				
1278+76	1281+40	264	0.12	2.40
1281+40	1284+04	264	0.02	0.40
1284+04	1286+68	264	0.04	0.90
1286+68	1289+32	264	1.03	20.60
1289+32	1289+76	44	0.27	31.80
1286+68	1289+76	308	1.29	22.20
Total		10076	6.00	3.15

Profilograph Output

<- Bump/Dip Locations Track 1 ->

Type	From	Peak	To	Height(in)
Dip	1269+38	1269+38	1269+38	0.02
Bump	1270+33	1270+35	1270+37	0.12
Dip	1270+39	1270+41	1270+48	0.26
Bump	1270+56	1270+57	1270+59	0.06
Bump	1270+62	1270+63	1270+69	0.11
Bump	1288+99	1289+00	1289+02	0.05

<- Bump/Dip Locations Track 2 ->

Type	From	Peak	To	Height(in)
Bump	1269+07	1269+12	1269+19	0.26
Dip	1269+38	1269+39	1269+43	0.04
Bump	1270+29	1270+30	1270+34	0.04
Dip	1270+36	1270+41	1270+48	0.38
Bump	1270+62	1270+63	1270+64	0.07
Dip	1288+85	1288+87	1288+93	0.09
Bump	1288+97	1289+02	1289+07	0.27

Smoothness Measurement

- Straightedges
- Profilographs
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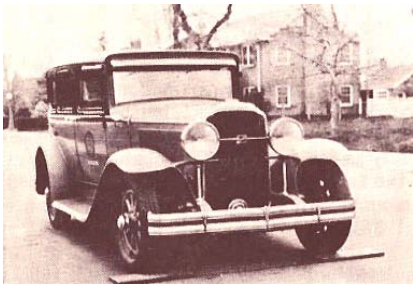
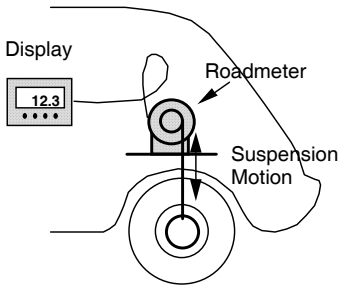
- Inertial Profilers
- Inclinometer-Based Profilers

Response Measurement



Response Measurement



"Roughometer"

Response-Type Trailer

Suspension Stroke

Smoothness Measurement

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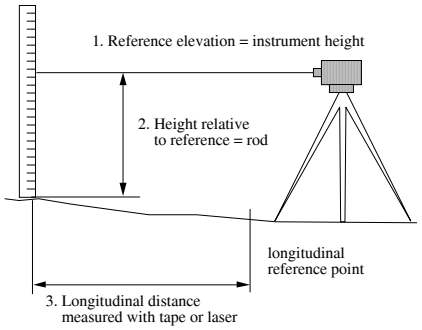
Inertial Profiler

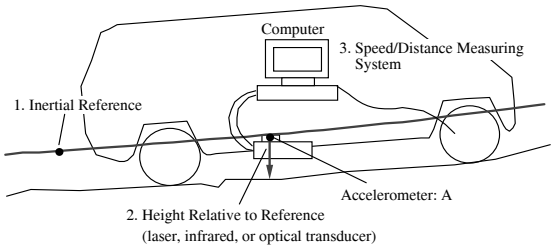
- A profiler works by combining three ingredients:
  (1) a reference elevation,
  (2) a height relative to the reference, and
  (3) longitudinal distance.

Rod and Level

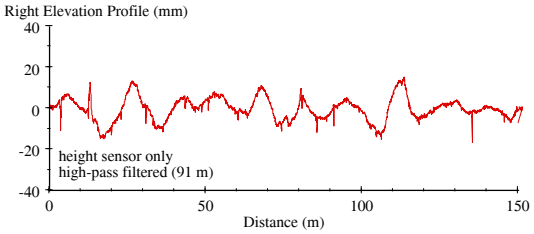


Rod and Level

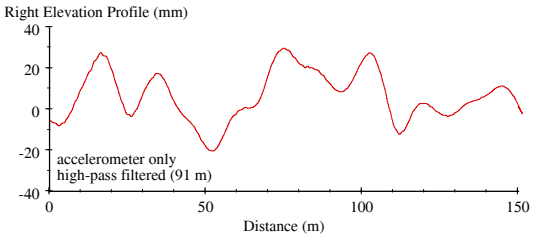
Inertial Profiler



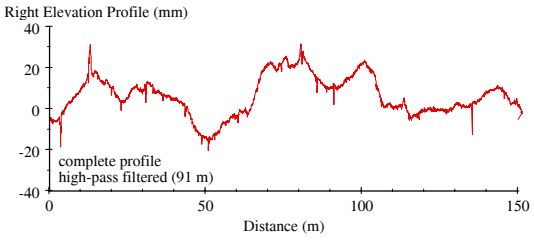
Height Sensor



Accelerometer



Profiler Output

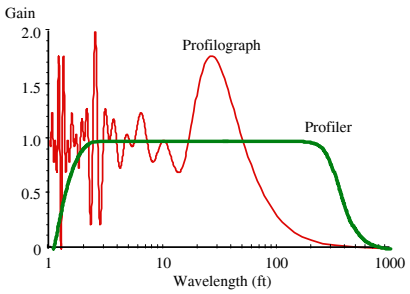


High-Speed Profiler

High-Speed Profiler

Lightweight Profiler

Profiler "Gain"



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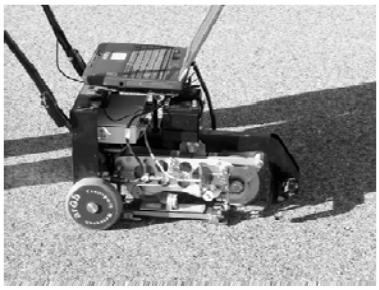
ARRB Walking Profiler



SurPro 1000

Questions?

Profile-Based Indices

- International Roughness Index
- Half-Car Index
- Ride Number

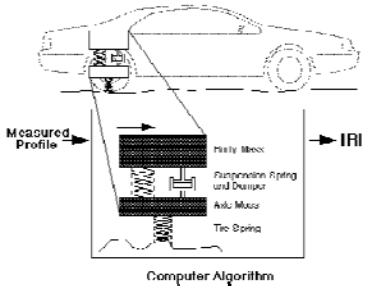
Profile-Based Indices

- International Roughness Index
- Half-Car Index
- Ride Number

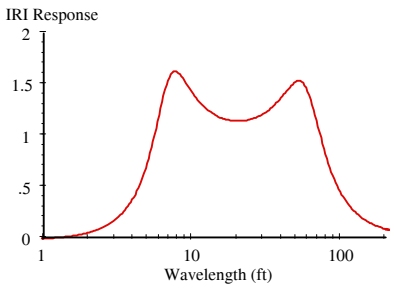
What is the IRI?

- IRI was originally developed as a correlation standard for response-type systems.
- The Index was tuned to maximize correlation with a large collection of response type systems.

International Roughness Index



IRI Sensitivity



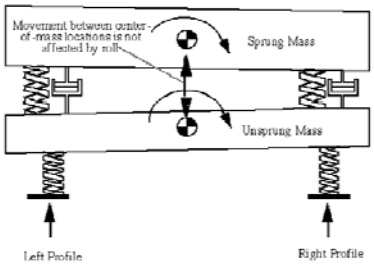
Profile-Based Indices

- International Roughness Index
- Half-Car Index
- Ride Number

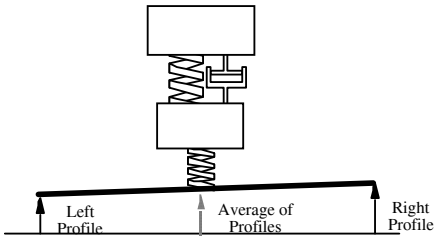
Half-Car Roughness Index

- The HRI is calculated from a two profiles.
- The profiles are averaged point by point to create an “average” profile.
- The IRI algorithm is applied to the resulting profile.

Half Car Index

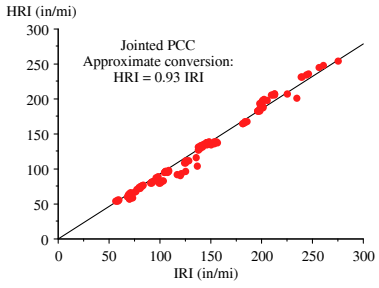


Half Car Index

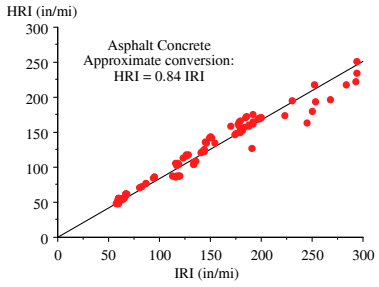


1/2 Car = 1/4 Car using averaged profile input

Half Car Index



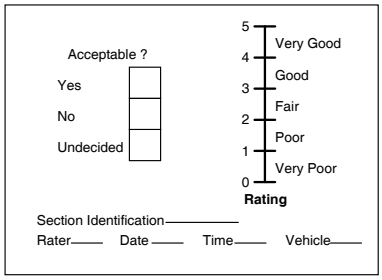
Half Car Index



Profile-Based Indices

- International Roughness Index
- Half-Car Index
- Ride Number

Panel Ratings



Ride Number

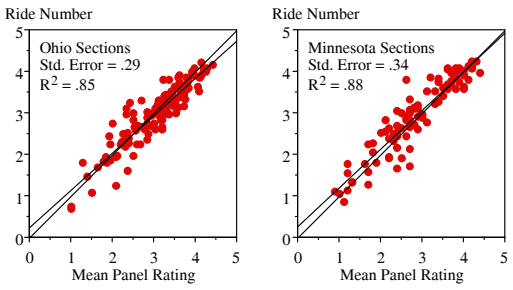
- Ride Number (RN) is an estimate of Mean Panel Rating.
- Ride Number is the result of NCHRP research in the 1980's.

Ride Number

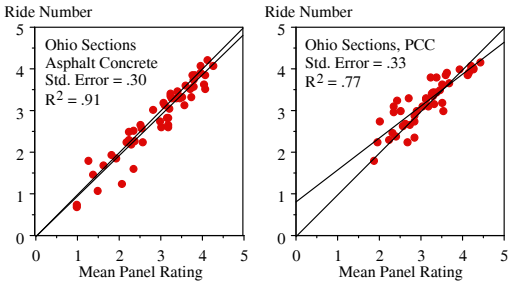
- Ride Number uses the 0 to 5 PSI scale.
- Ride Number is a nonlinear transform of a statistic called PI.

$$RN = 5e^{-160PI}$$

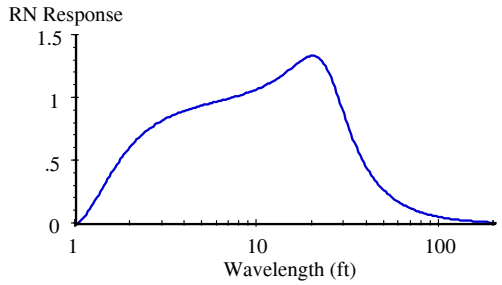
Ride Number



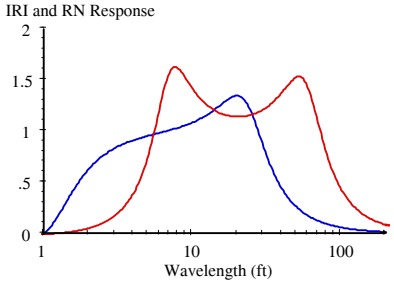
Ride Number



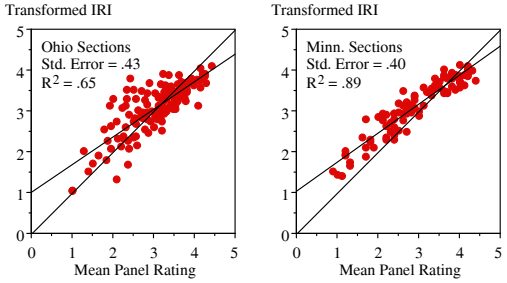
Ride Number



IRI versus Ride Number



Ride Number



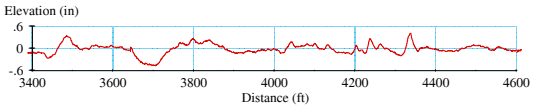
Questions?

Interpretation for Quality Control

- Fixed Interval Report
- Job Summary
- Hot Spot Plot
- Hot Spot Table

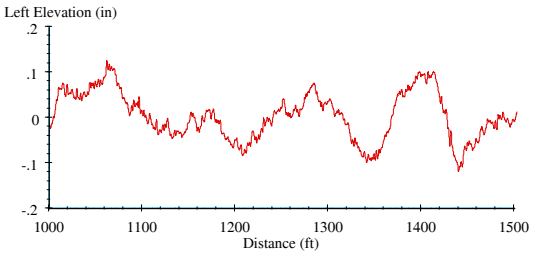
Ohio Turnpike Third Lane

Profiler Output

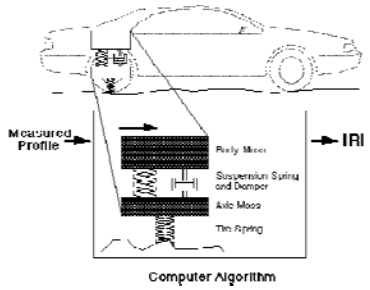


Profiler output can be used to:
1. Estimate ride quality.
2. Determine a grinding strategy.
3. Help improve construction practice for *ride*.

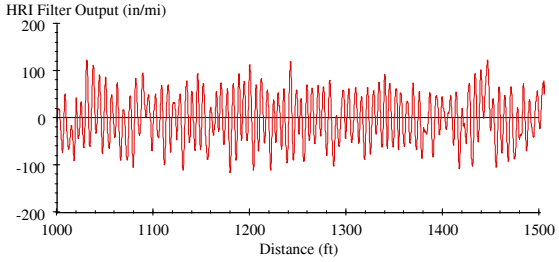
Elevation Profile



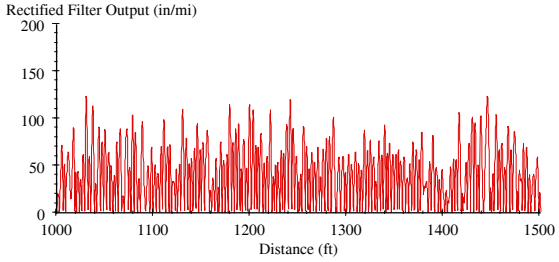
International Roughness Index



IRI Filter Response



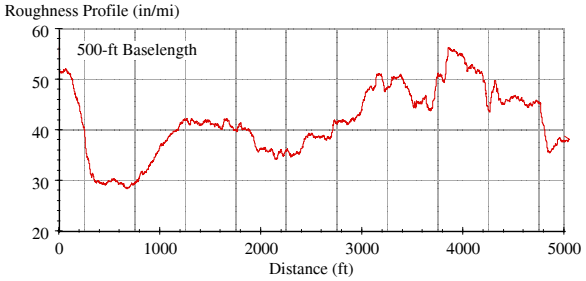
Rectified Response



Fixed-Interval Report

Start(ft)	End(ft)	HRI(in/mi)
0	500	39.8
500	1000	29.7
1000	1500	42.0
1500	2000	40.1
2000	2500	36.2
2500	3000	41.6
3000	3500	48.5
3500	4000	51.0
4000	4500	44.0
4500	5000	45.5

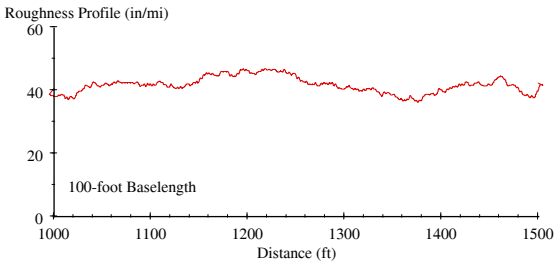
Continuous Roughness Report



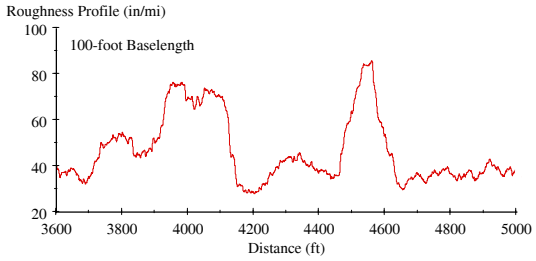
Job Summary

Low IRI (in/mi)	High IRI (in/mi)	Percentage
0	10	0.0
10	20	0.0
20	30	8.3
30	40	35.4
40	50	40.5
50	60	15.8
60	70	0.0
70	80	0.0
80	90	0.0
90	100	0.0

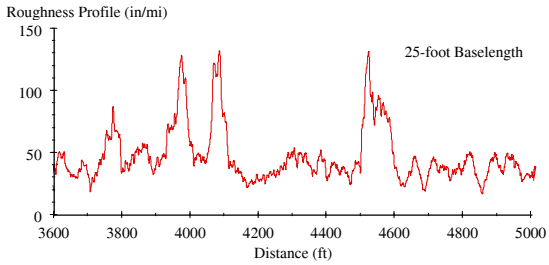
Roughness Profile



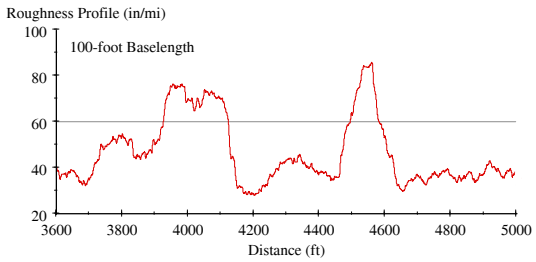
Short Interval Report



Short Interval Report



Short Interval Report

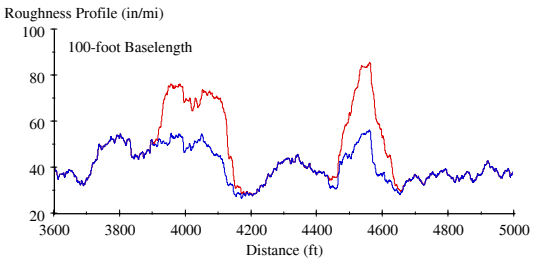


Hot Spot Locations

Segment Start (ft)	Segment End (ft)	Peak HRI (in/mi)
3201	3274	64.6
3276	3280	60.3
3925	4123	76.5
4495	4583	85.9

Target 3804 Grinder

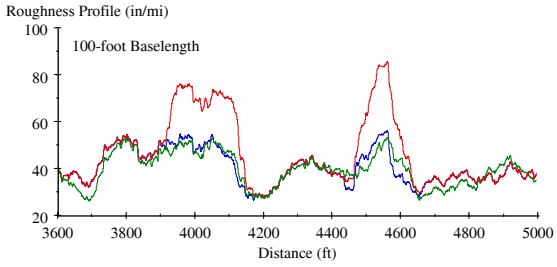
Grinding Simulation



Optimal Grinding Strategy

Grind Start (ft)	Grind End (ft)	HRI Change (in/mi)	Max. Depth (in)
3945	3990	4.8	0.36
4058	4093	5.4	0.33
4473	4587	6.1	0.16

Validation



Essential Features

1. Use of profilers over profilographs.
2. Choice of and index.
3. Continuous reporting.
4. Short and long interval criteria.
5. Grinding simulation.

Questions?

Thank you.