PRODUCTS 0-6853-P1, P2, and P3

TxDOT Project Number 0-6853

0-6853-P1: Workshop Material
0-6853-P2: Instructor's Guide
0-6853-P3: Student's Guide

Research Supervisor:
Dr. Jorge Prozzi

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0-6853-P1 and P2

WORKSHOP MATERIAL (P1) AND INSTRUCTOR'S GUIDE (P2)

Research Supervisor:
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TxDOT Project 0-6853: Improvements to Ride Specifications

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CENTER FOR TRANSPORTATION RESEARCH

TXDOT Project No. 0-6853
Improvements to Ride Specification
Workshop Material (P1) and Instructor's Guide (P2)

Texas Department of Transportation

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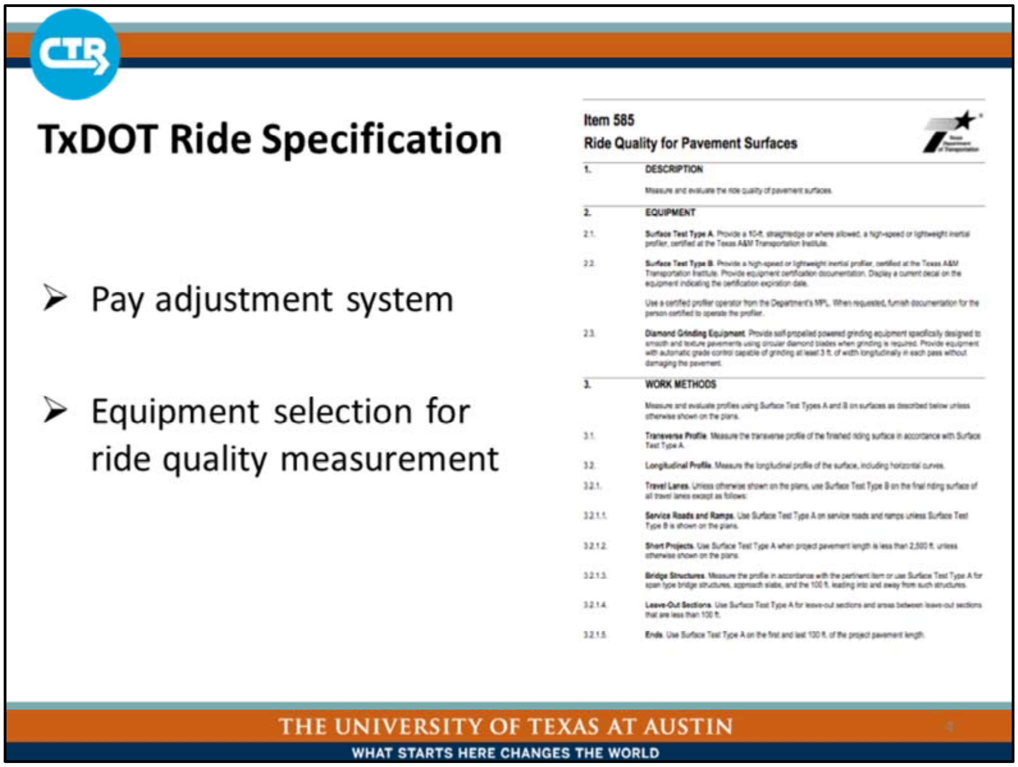
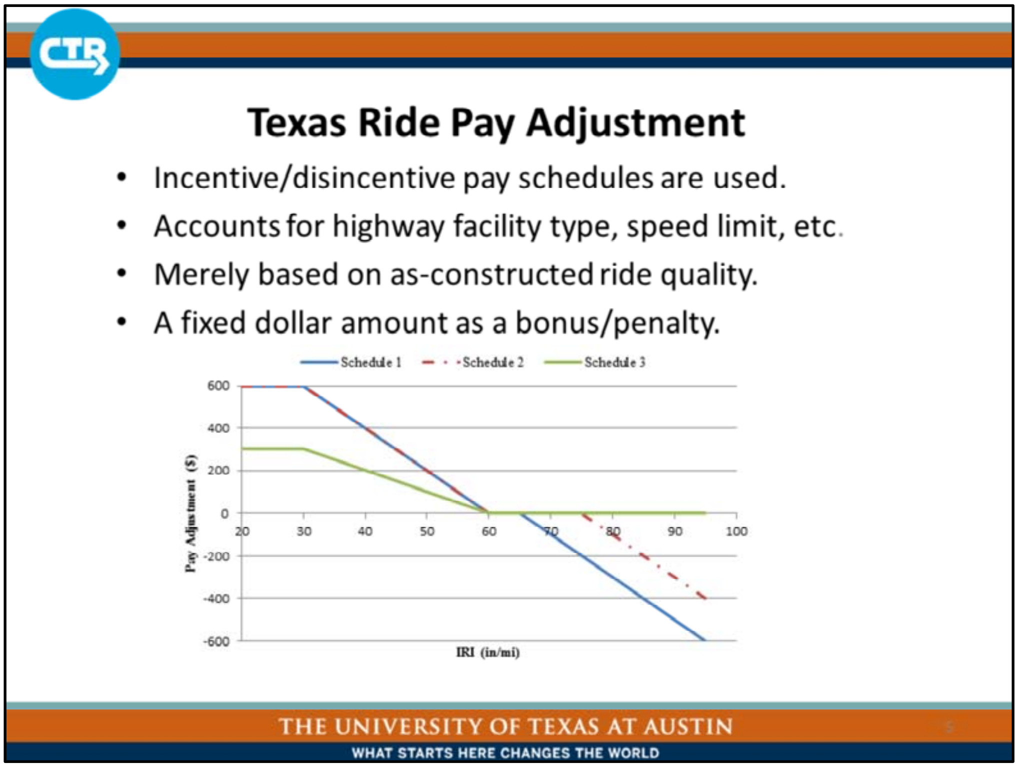


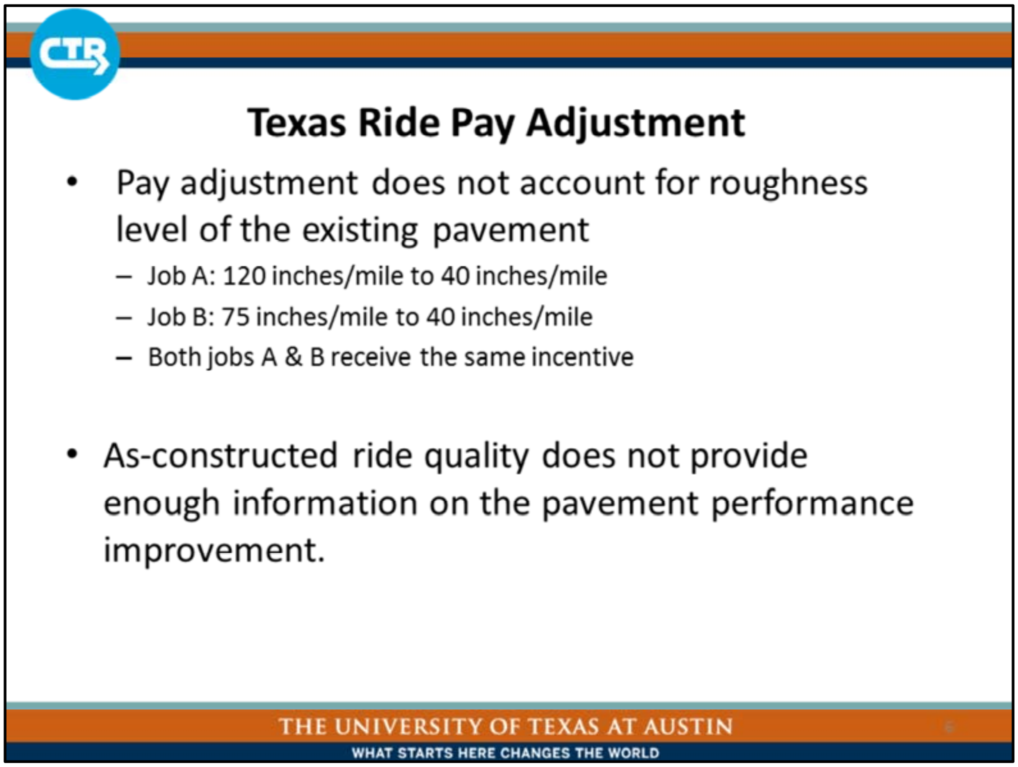
- TxDOT uses the guidelines provided as part of Item 585 specification to determine the pay adjustment schedule and measurements requirements for ride quality of pavements.
- TxDOT ride specification:
  - Has been in existence for more than one decade
  - Helps to provide safer and smoother pavements
  - Broadly divided into two components:

1- Pay adjustment system

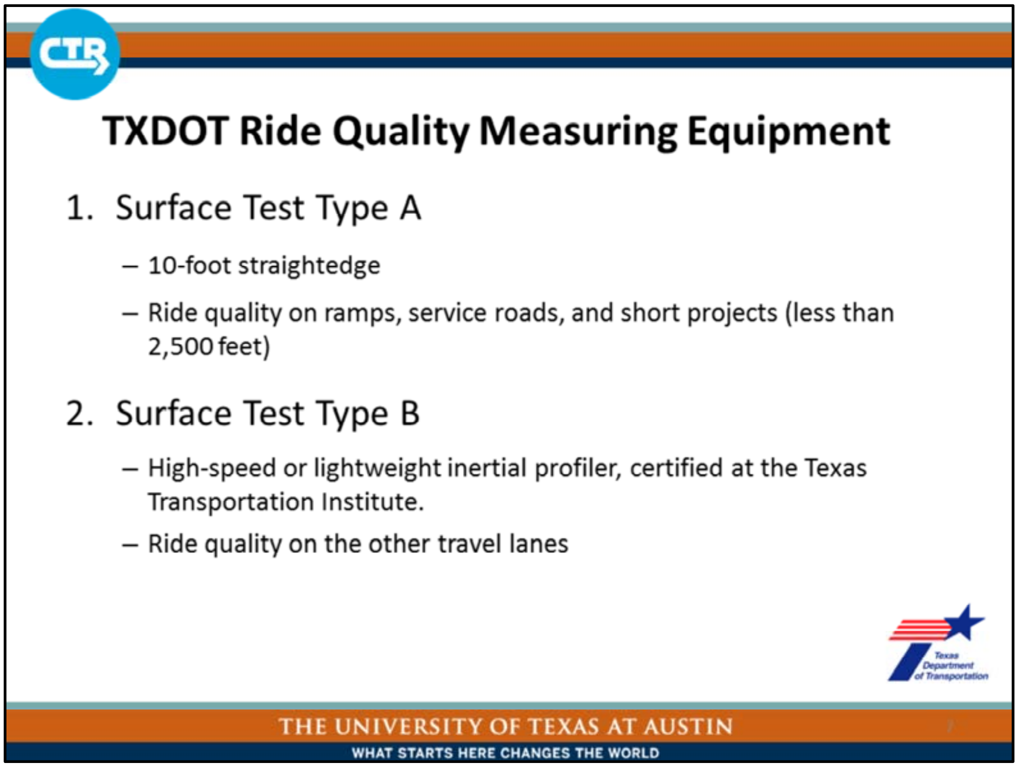
2- Selection of equipment to measure ride quality of constructed pavements.



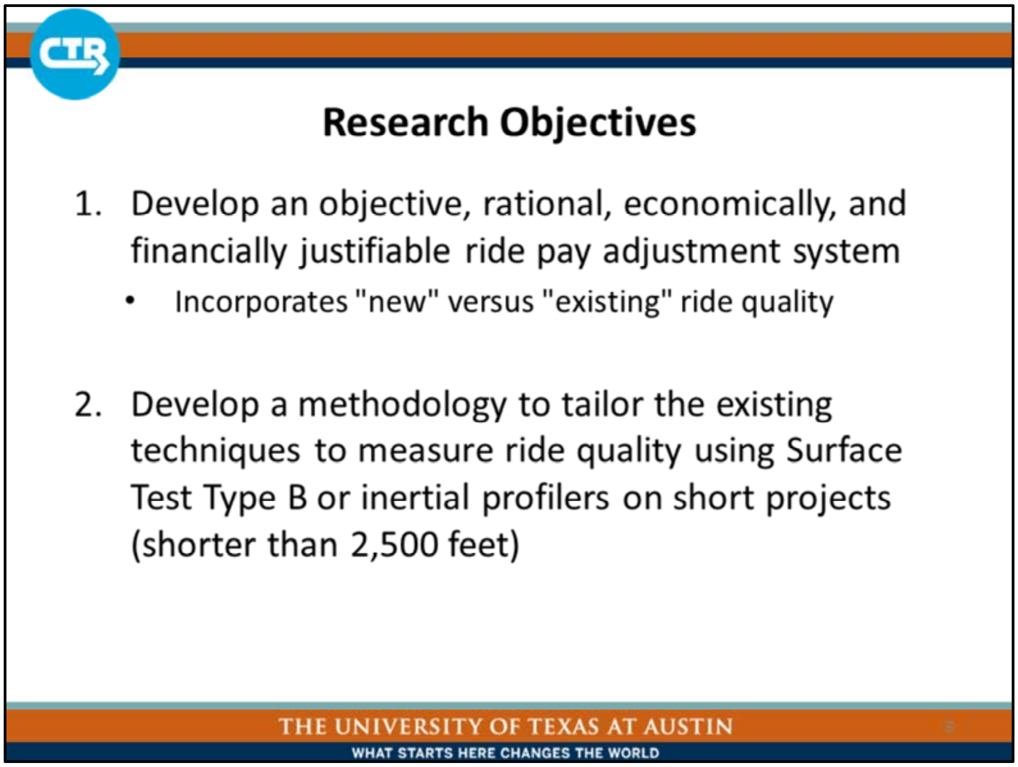
- Contains incentive/disincentive policy
- Three pay schedules, which are applied depending on the ease of achieving the desired post-construction ride quality
- TxDOT Construction Division (CST) provides the necessary guidelines for selection of the appropriate pay schedule.
- The procedure takes note of the existing IRI, facility type, posted speed, the number of smoothness opportunities, and other mitigating factors before identifying the pay adjustment schedule that fits the profile of the specific job.
- The existing pay adjustment specification is merely dependent on the ride quality of the final delivered pavement surface and does not explicitly account for the magnitude of ride improvement from the existing surface.
- As-constructed ride quality: ride quality measure immediately after construction.
- The current ride quality pay adjustment provides a fixed dollar amount (bonus/penalty) for achieving a given as-constructed ride quality.
- Ride quality is measured in terms of IRI (inches/mile) per 0.1 mile length of the project.



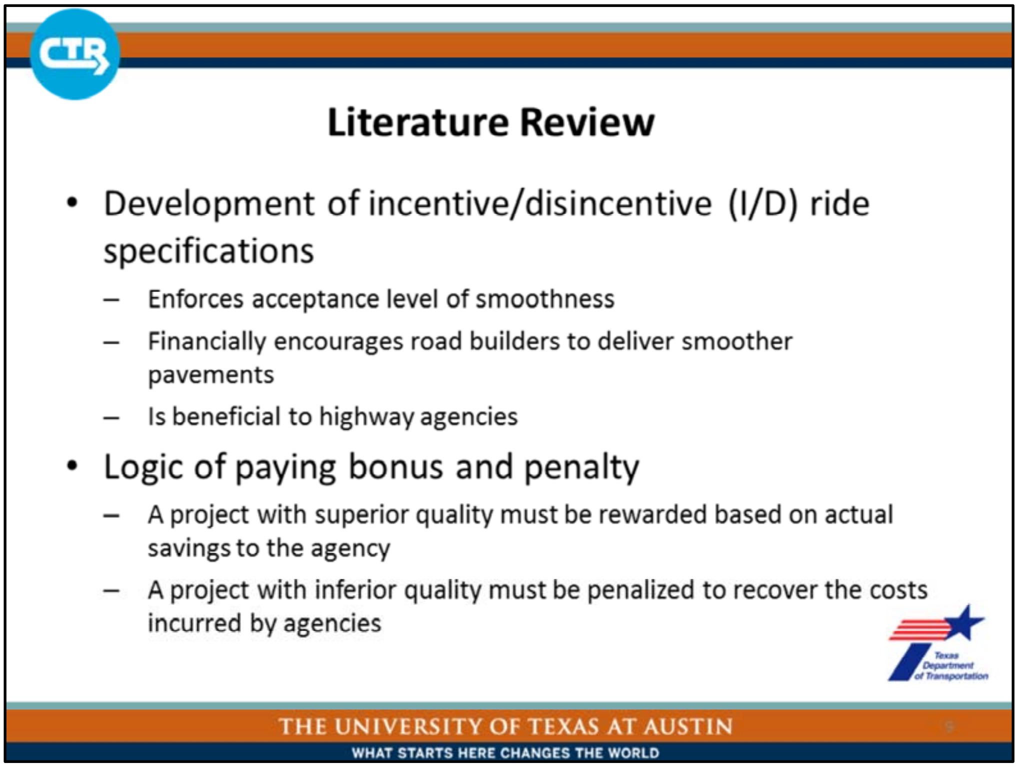
- For example: the bonus received by a contractor who has improved a roadway with an average IRI of 120 inches/mile (before rehabilitation) to an IRI of 40 inches/mile (after rehabilitation) is identical to the bonus paid to another contractor who marginally improves an existing IRI of 75 inches/mile to 40 inches/mile.
- A contractor who has improved ride from 120 to 40 inches/mile should earn a higher bonus than the one that improves the riding quality from 75 to 40 inches/mile.
- Pre-construction ride quality affects the performance life of pavement after construction.
- Ride quality measured immediately after construction alone is not sufficient to obtain information on construction quality. The change in the ride quality should be considered.



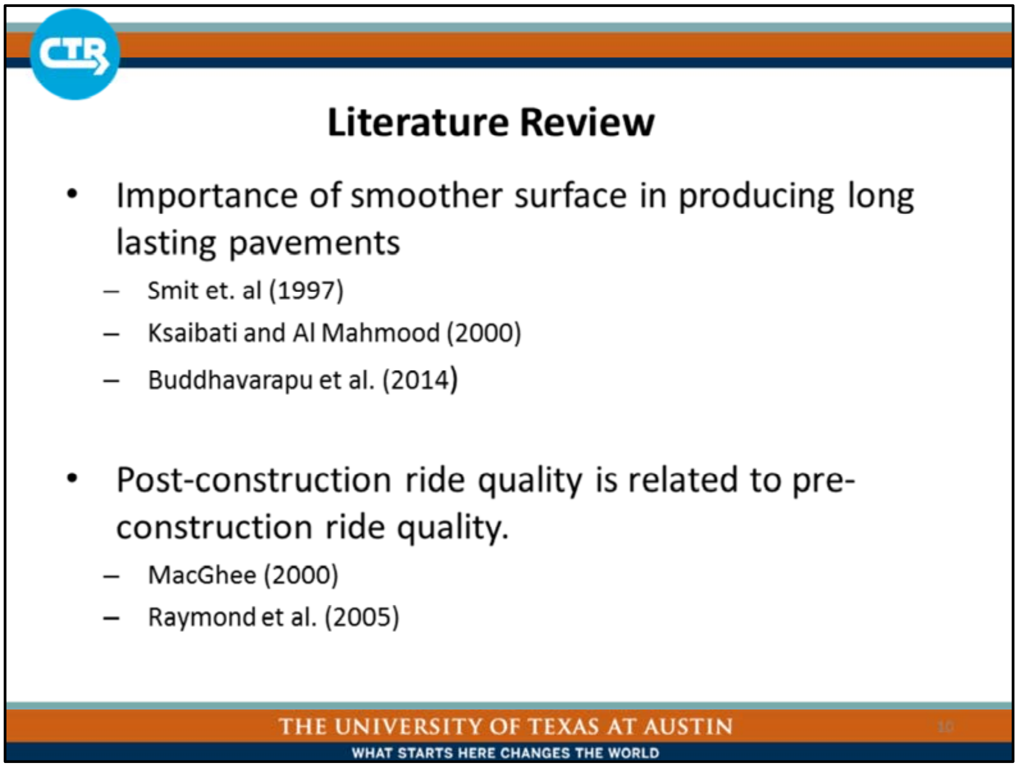
- TxDOT standard specifies two types of ride quality measuring equipment:
    - 1- Surface Test Type A, which involves 10-foot straightedge. The variation between any two contact points on a 10-foot straightedge shall not exceed 1/8 inch in order to comply with the ride specification.
    - 2- Surface Test Type B, which involves high-speed or lightweight inertial profiler, certified at the Texas A&M Transportation Institute.
- Surface Test Type B involves collecting longitudinal profile and calculation of International Roughness Index (IRI) using TxDOT's Ride Quality software program.
- Straightedge testing is time consuming, laborious, requires traffic closure, and there is a lack of consistency.
- Inertial profiler is faster, accurate, and efficient.



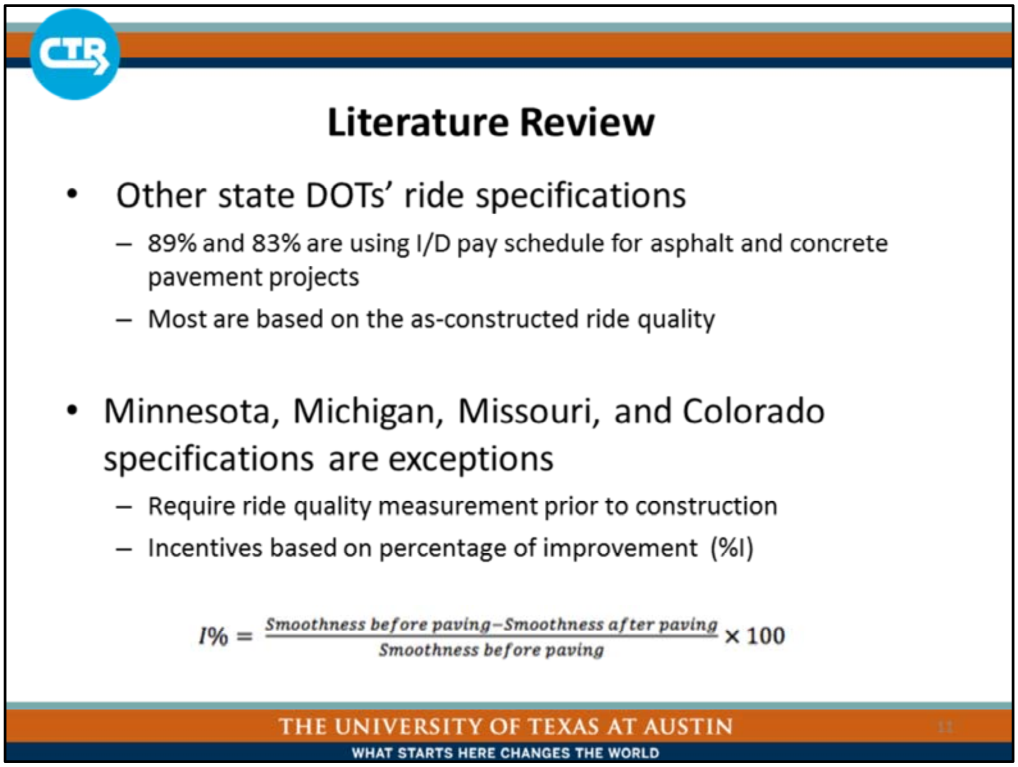
- A performance-based pay adjustment system that incorporates both the new and existing riding quality would enable TxDOT to reward/penalize contractors based on the total quality and the gain/loss in the expected life of the pavement.
- The inertial profiler measurements are more reliable and consistent than measures obtained from the straightedge. The existing ride specification needs to be revised to address the equipment and data collection methods for measuring ride quality on short pavement sections.
- Both types of measurement are inconsistent so the same pay adjustment schedule cannot be applied.



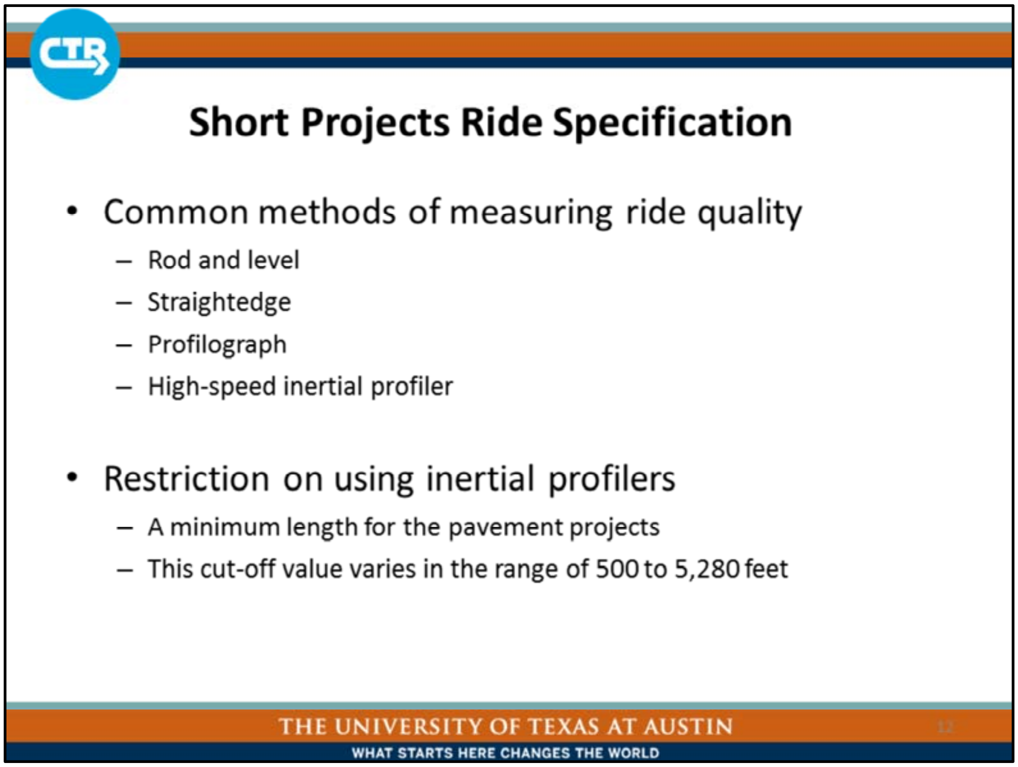
- The main purpose of the literature review was to gather information on pay adjustment systems and short projects ride quality specifications used in other state departments of transportation (DOT) and other highway agencies.
- According to the results of a survey conducted in 1994, the initial roughness of pavement projects has been reduced significantly by applying smoothness specifications.
- Enforcement of ride quality with incentive/disincentive specifications is beneficial to highway agencies.
- The logic behind paying a bonus is that this additional incentive improves pavement quality and contractors' performance, resulting in pavements with better ride quality and user costs (vehicle operating costs).
- A project with superior quality must be rewarded based on actual savings to the agency. The bonus cannot be higher than the agency's benefit.
- The purpose of penalty is not only to financially penalize the contractors that do not deliver quality, but it plays an important role to demonstrate the actual financial burden of an inferior construction practice to highway agencies and road users.
- A construction project that deviates from the required quality level should always result in a reduction in contractor payment to recover the costs incurred by the agency for additional future maintenance costs.



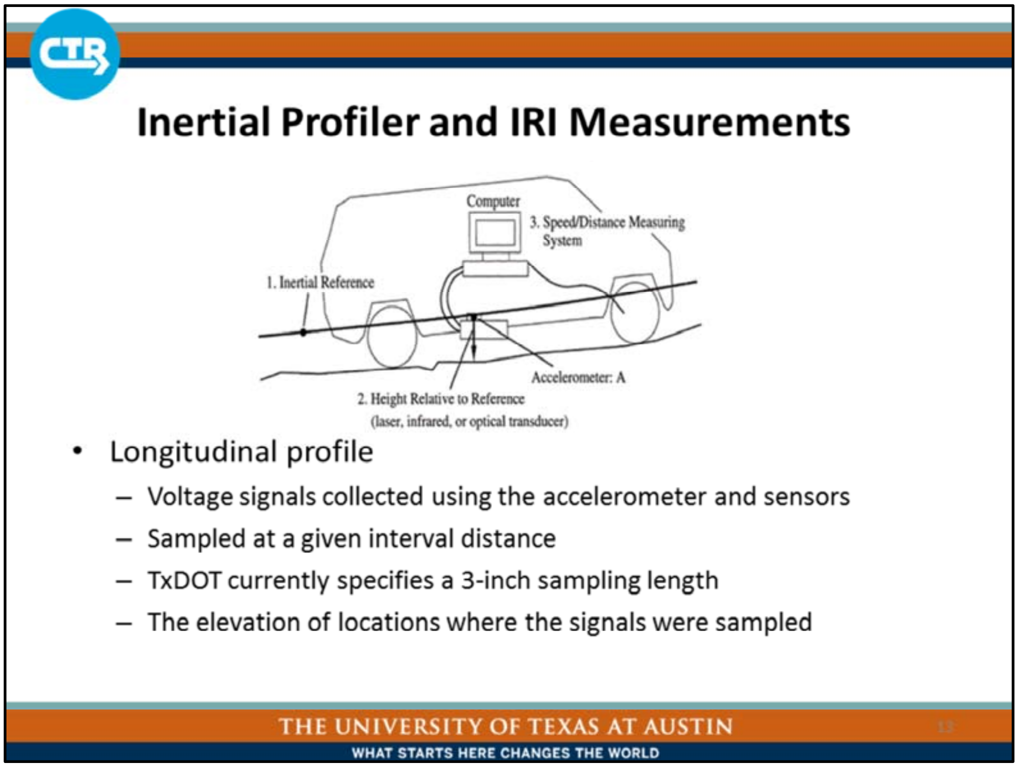
- Smit et. al (1997), Ksaibati and Al Mahmood (2000), Buddhavarpu et al. (2014), and several others have stated that higher level of initial smoothness results in extension of pavement service life.
- Smoother roads extend pavement life, enhance safety, reduce agency's maintenance costs, and reduce user's vehicle operating costs.
- The above-mentioned studies did not account for the impact of per-overlay construction ride quality on post-overlay construction and pavement life.
- MacGhee (2000) found that smoothness of the pre-existing surface prior to the overlay has a significant impact on the post-construction ride quality. He found a positive correlation between pre- and post-construction ride quality that emphasizes the importance of pre-existing ride quality.
- Raymond et al. (2005) studied a large number of test sections located throughout the United States and Canada in terms of the factors associated to the roughness after the rehabilitation. His study demonstrated that pavement roughness before resurfacing has a consequential impact on the roughness of a pavement after rehabilitation.



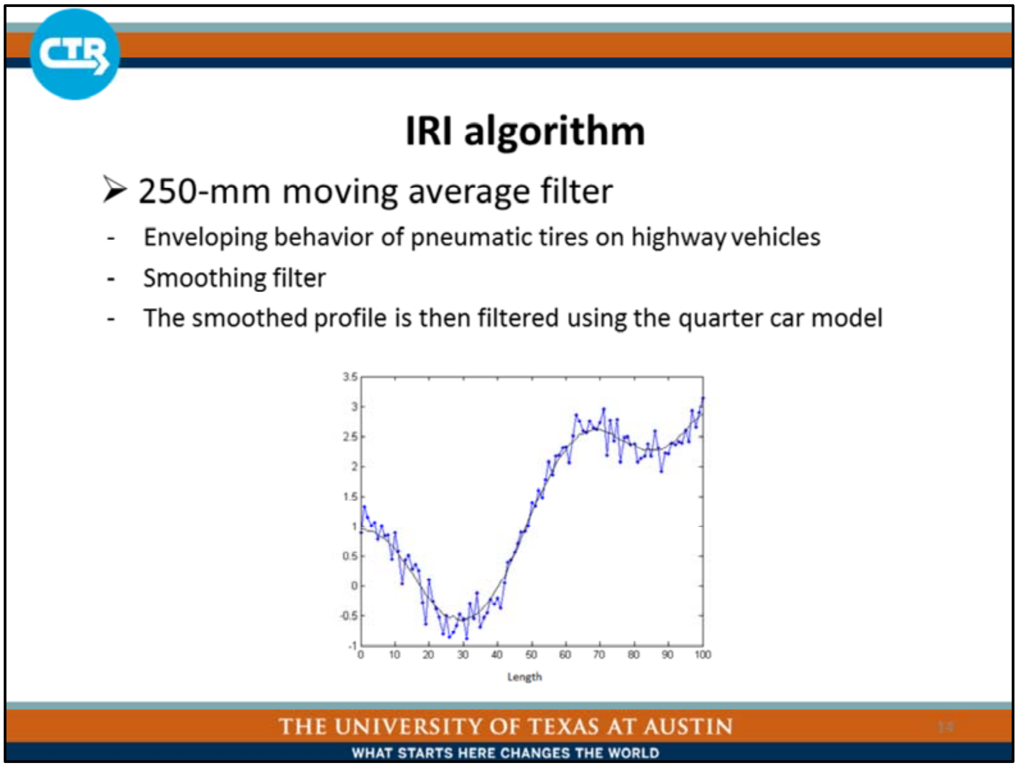
- The review of state DOTs' ride specifications has shown that policies such as positive or negative adjustment to contractors' payment, and correction activities are included in the majority of highway agencies' smoothness specifications.
- In 2014, The Transtec Group summarized the smoothness pay adjustment specifications among the US states as part of an FHWA study . This study revealed that 89% and 83% of the US states are using some type of I/D pay schedule policy for asphalt pavement projects and concrete pavement projects, respectively.
- State DOTs such as Minnesota, Michigan, Missouri, and Colorado measure the smoothness prior to the start of construction (smoothness before paving) and after the completion of construction (smoothness after paving) with the same stationing and the same profiler.



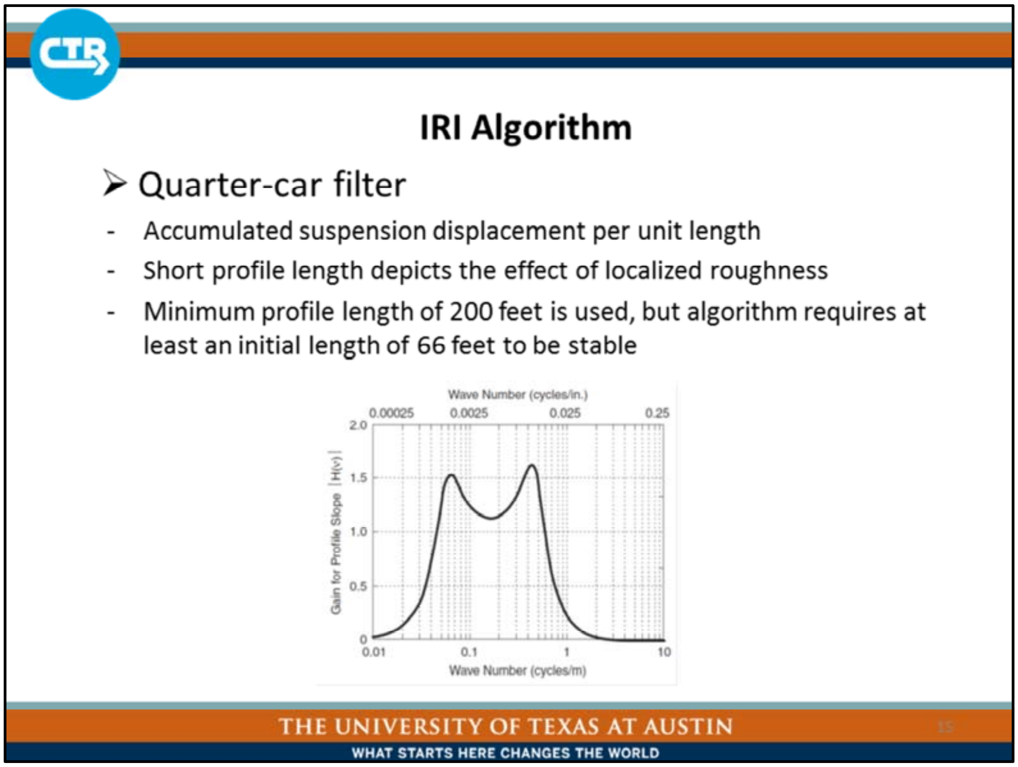
- The literature review identified different methods of measuring road's ride quality, including rod and level, dipstick, straight-edge, profilograph, high-speed inertial profilers, and lightweight inertial profilers. The most common devices currently used by highway agencies to measure road roughness on short- and long-pavement roads are the straightedge and the inertial profiler, respectively.
- About 50% of the US states that are employing inertial profilers specify a minimum length for the pavement projects.
- TxDOT's minimum length is currently 2,500 feet



- To employ the inertial profilers and IRI on short projects, it is essential to thoroughly understand the profile data processing algorithms and standard IRI calculation methodology.
- Inertial profilers (shown in the figure) include three fundamental components: accelerometers, proximity sensors, and a distance measuring system.
- The accelerometer measures the vertical motion.
- The proximity sensors measure the distance between the pavement surface and the inertial profiler vehicle.
- Distance measuring system collects the longitudinal distance traveled by the vehicle.
- The inertial profiler collects voltage signals from the accelerometer and other sensors. Accelerometer and sensor signals are processed using a signal processing algorithm. This process samples the signals at a given interval of time and distance to obtain a sequence of readings. These sampled readings are imported and processed through another filter to calculate the elevation of locations where the signals were sampled.
- TxDOT currently specifies a sampling interval of 3 in. (76.2 mm).
- This specification is being change to 2 in.

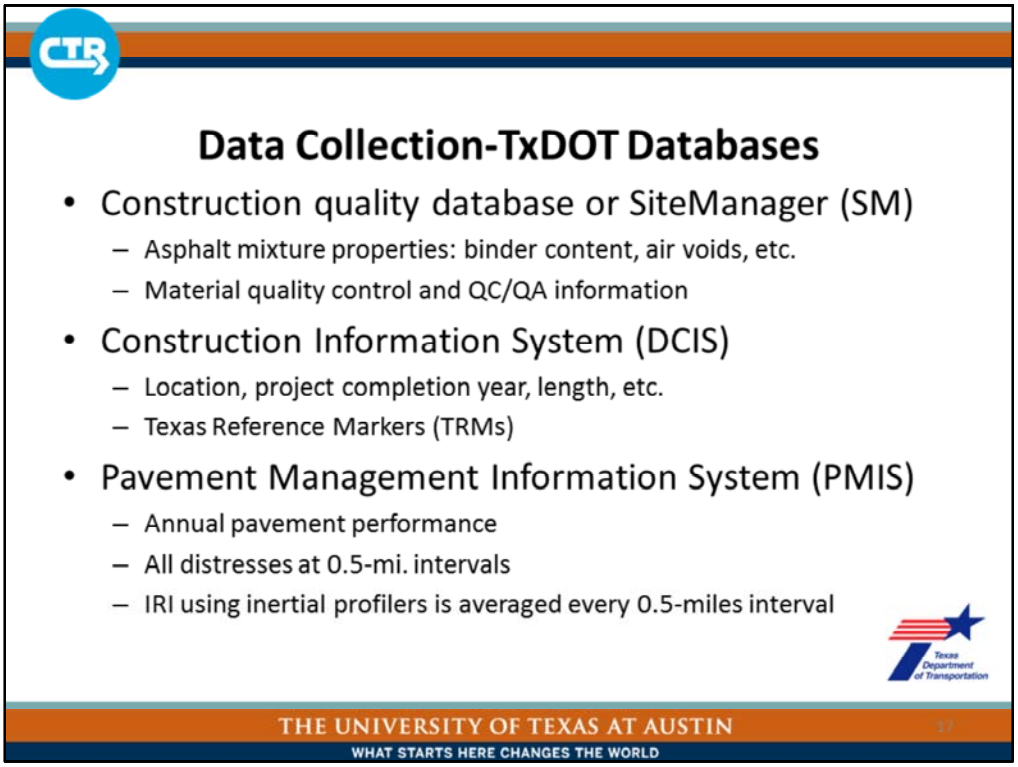


- IRI is widely accepted and has become a standard statistic for measuring roughness and ride quality of the pavement surfaces in the US and worldwide.
- The IRI was established in 1986 by the World Bank.
- The IRI calculation algorithm involves two distinct filters: 1) a moving average filter, and 2) quarter-car filter.
- The moving average filter simulates the potential enveloping behavior of pneumatic tires on highway vehicles. The length of the contact area of a typical highway vehicle is approximately 250 to 300 mm. The standard IRI algorithm includes a moving average filter of 250 mm base length.
- This filter lowers the sensitivity of the IRI algorithm to simulate the effect of the tire.
- The smoothed filter is then filtered using quarter-car model to calculate the IRI.

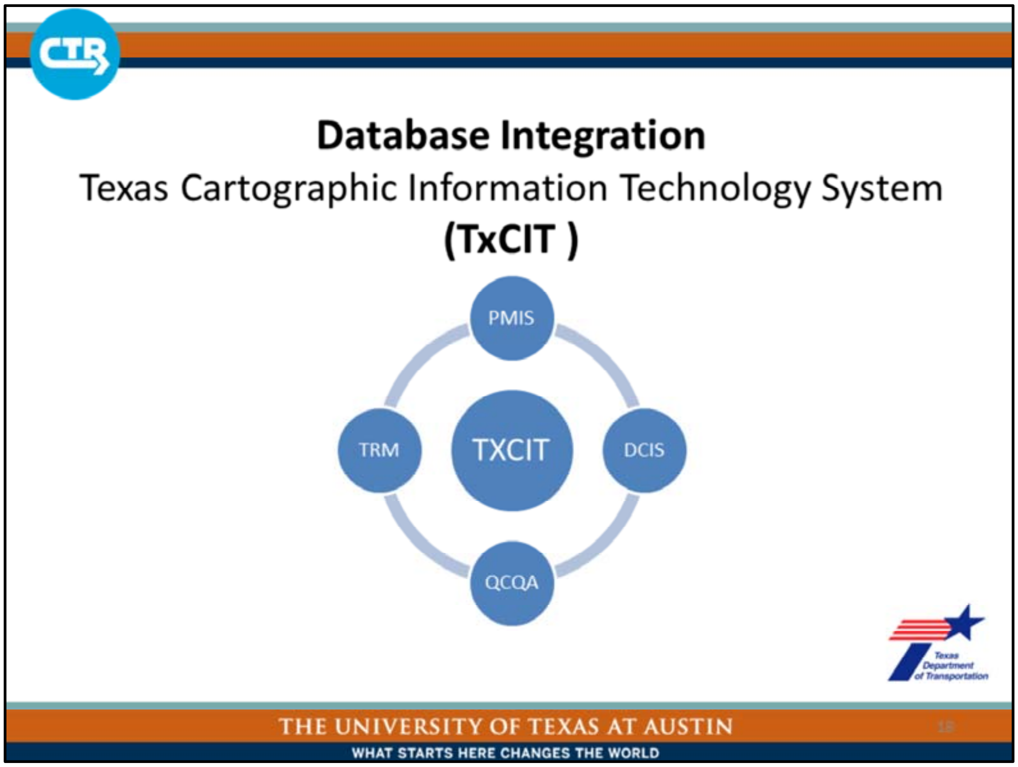


- A quarter-car filter is utilized to calculate the suspension deflection.
- The imaginary quarter car is mathematically represented with a vertical spring, the mass of the axle supported by the tire, a suspension spring and damper, and the mass of the body supported by the suspension for that tire.
- The accumulated suspension displacement per unit length of the profile is defined as IRI, which has units of slope (in/mi or m/km).
- The length of test segment influences strongly the IRI values. According to Sayers (1995), IRI can be calculated over different lengths.
- Various test segment lengths provide different values of a pavement roughness. The IRI calculated for a long segment shows overall ride condition of a pavement and diminishes the effect of localized roughness. In contrast, IRI values calculated for short test segments depict the effect of localized roughness such as cracking and joints.
- This is statistically know as the regression to the mean.
- Any road profile can be mathematically expressed as an infinite sum of sinusoids and subsequently the frequency content of the profile can be extracted.
- Road roughness is particularly captured by sinusoids within certain ranges of frequencies or wave bands (see figure).
- The IRI algorithm filters the wavebands that do not contribute toward the road roughness at highway speeds.
- The IRI algorithm is primarily influenced by wavelengths ranging from (3.9 to 98.4 feet)
- We would need at least a project length of 196.8 feet to measure IRI. Larger wavelengths cannot be detected.
- It should be mentioned that the inertial profiler should be initialized before the starting point of profiling to stabilize all filters. For instance, quarter-car filter requires at least 66 feet initial length to be stabilized.

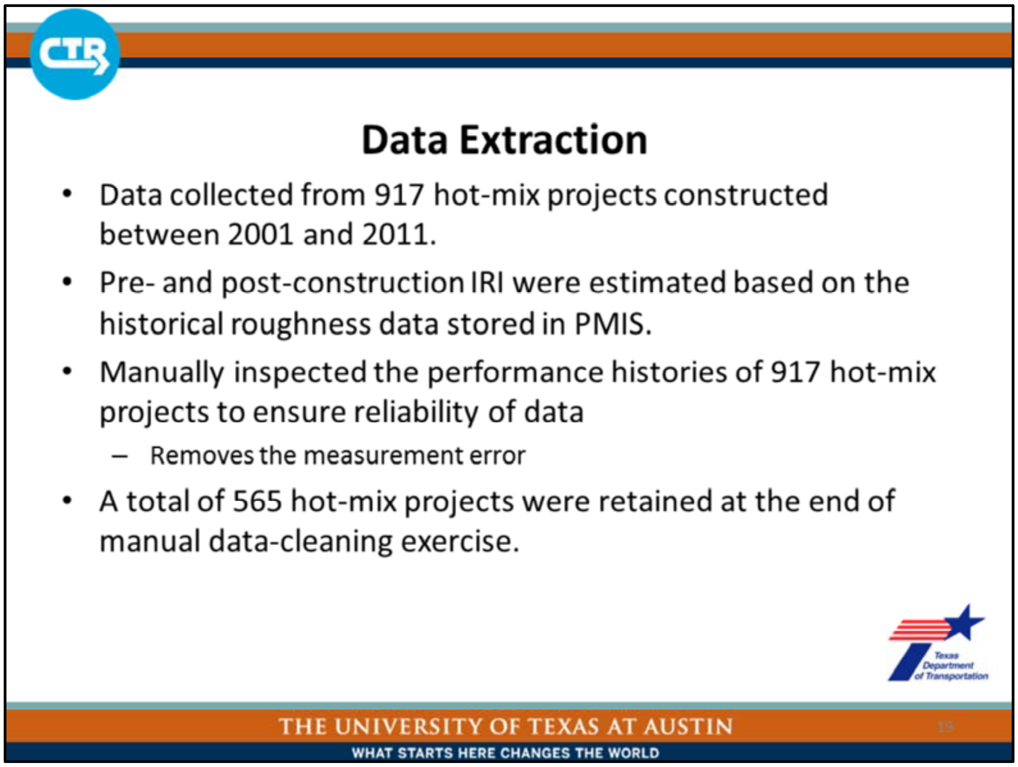
Part 1
Pay Adjustment



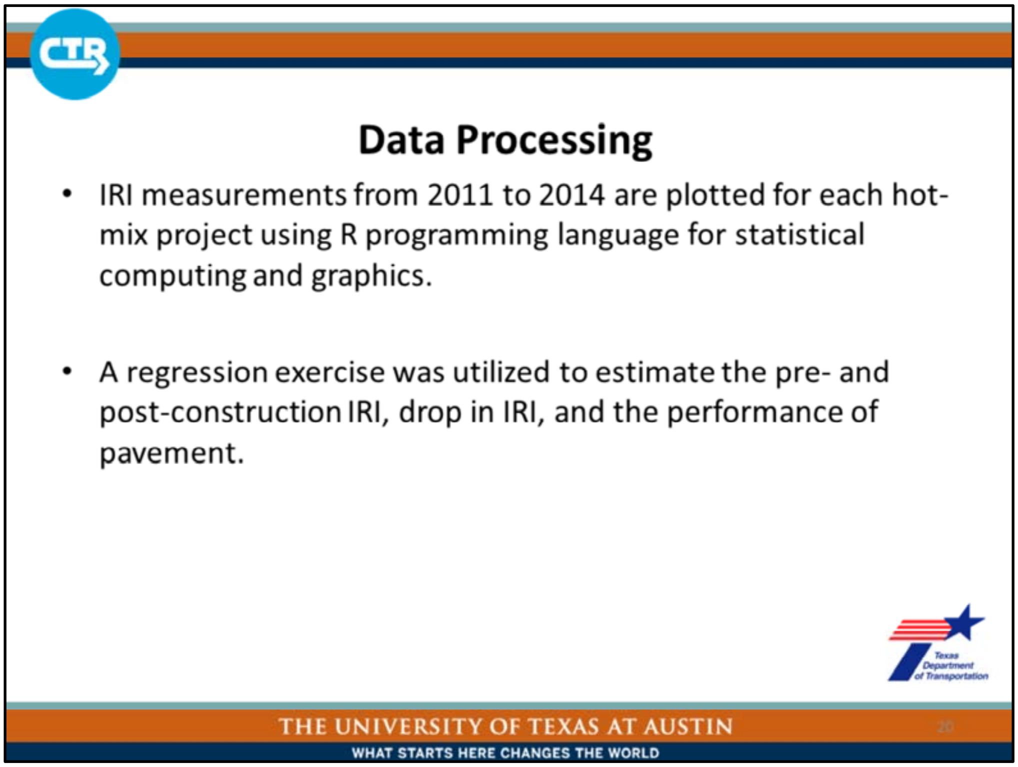
- Annually, the TXDOT visual raters travel along the side of the road at no more than 15 miles-per-hour to rate the target lane.
- Pavement condition information includes the type and quantity of distresses (e.g., cracks, patches, etc.), the depth of deformation (e.g., rutting), and the roughness (e.g., ride score and IRI).
- The combination of the distress score (DS) and the ride score (RS) is used to calculate the condition score (CS), which is an overall performance indicator.
- In this study, only distress score, ride score, condition score, and IRI were extracted.
- The research team utilized IRI as the major performance measure, which is arguably the most consistent and reliable performance measure in PMIS.



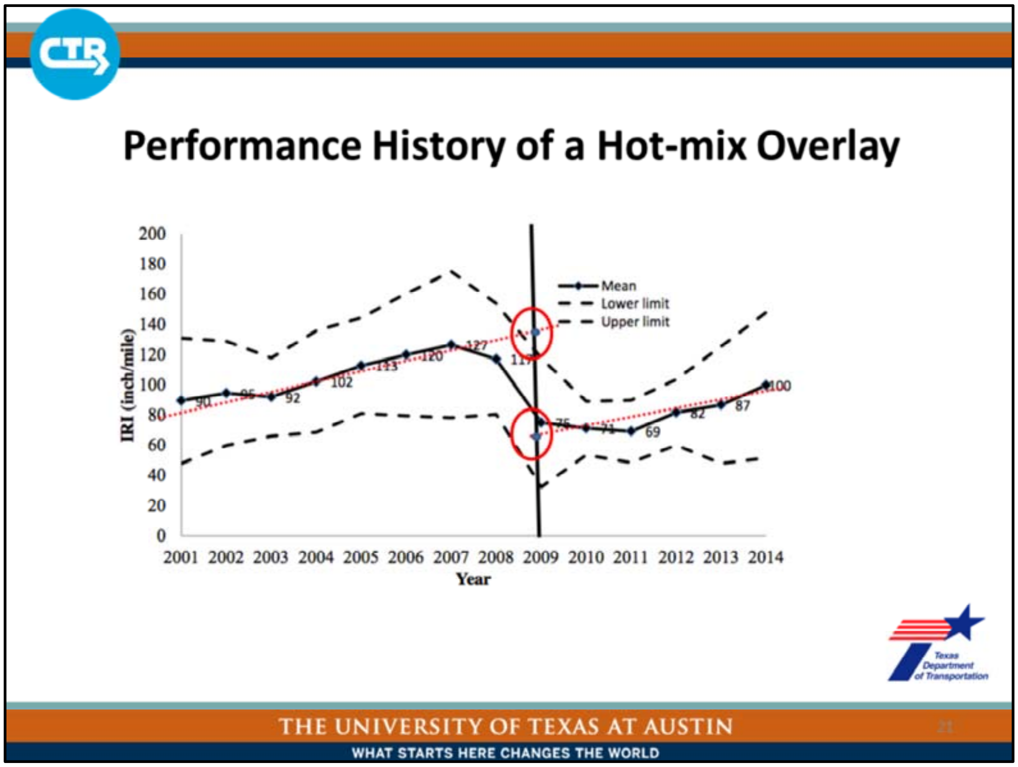
- The GIS-based Texas Cartographic Information Technology System (TxCIT) database provides the framework for the development of this study's data warehouse.
- TxCIT contains as-constructed ride quality data and performance history of road projects across the state.
- TxCIT establishes a link between the SM and PMIS databases by using Texas Reference Marker (TRM) information obtained from DCIS and a geographical TRM database developed by TxDOT.
- Thus, TxCIT links as-constructed ride quality of road projects, stored within the SM database, and the respective performance data from PMIS database.



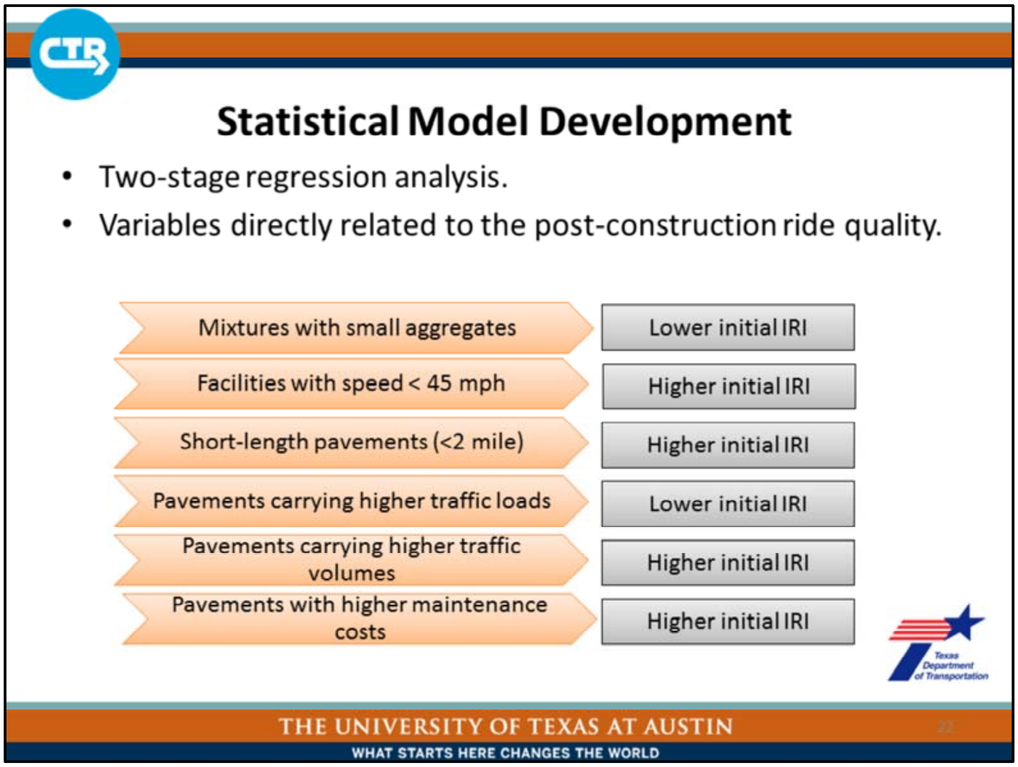
- It should be mentioned that the pavement performance history is not always clear.
- The research team manually inspected the performance histories of 917 hot-mix projects to ensure the reliability of the data. Although it is tedious and time consuming, the exercise was intentionally kept manual to avoid any unforeseen inconsistencies in the data. Several projects containing missing values, unrealistic and outlier data points, and unexpected patterns were discarded.
- Because of missing values in several projects, total of 565 hot-mix projects were retained toward the end of the manual data-cleaning exercise.



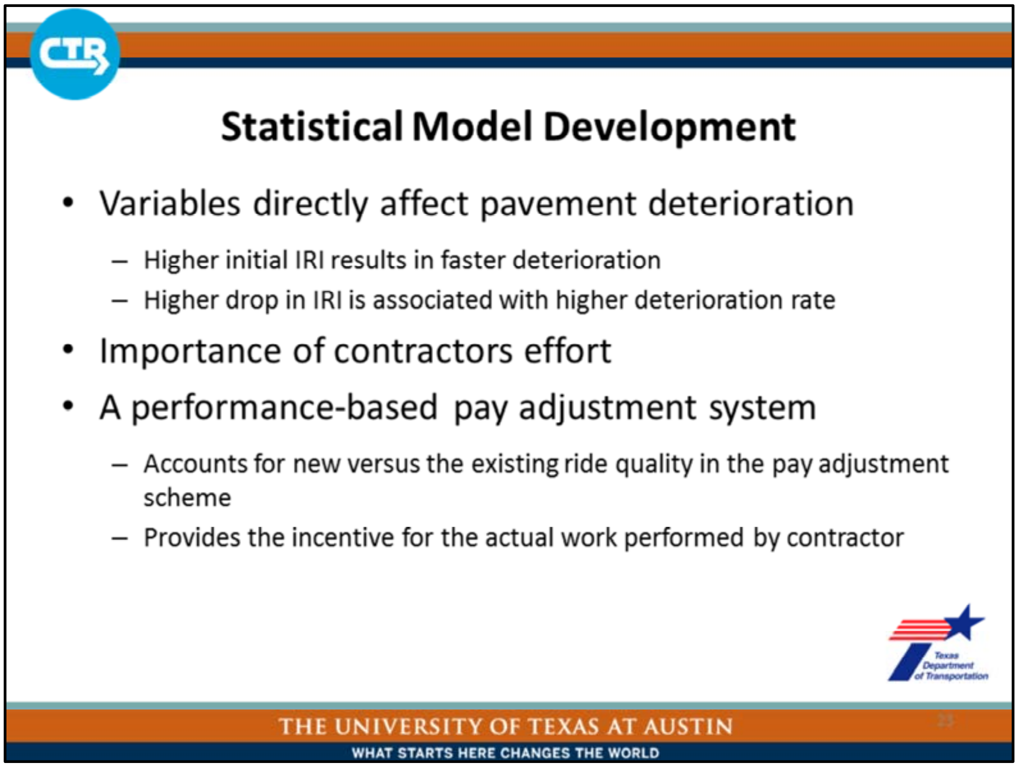
- Project-level IRI values are subjected to the measurement error. For this reason, the study team utilized the available IRI data during both prior- and post-construction periods to estimate trend lines.
- Linear regression analyses were performed to estimate the trend-line equations (shown in red dots).
- Subsequently, the trend-line equations were utilized to estimate the pre- and post-construction IRI values, and to estimate the drop in IRI due to the construction.
- A similar regression exercise was performed for each project to estimate the respective drops, initial ride quality values, and deterioration rate after construction.
- Deterioration rate is determined using the slope of regression lines corresponding to IRI values after the construction year.



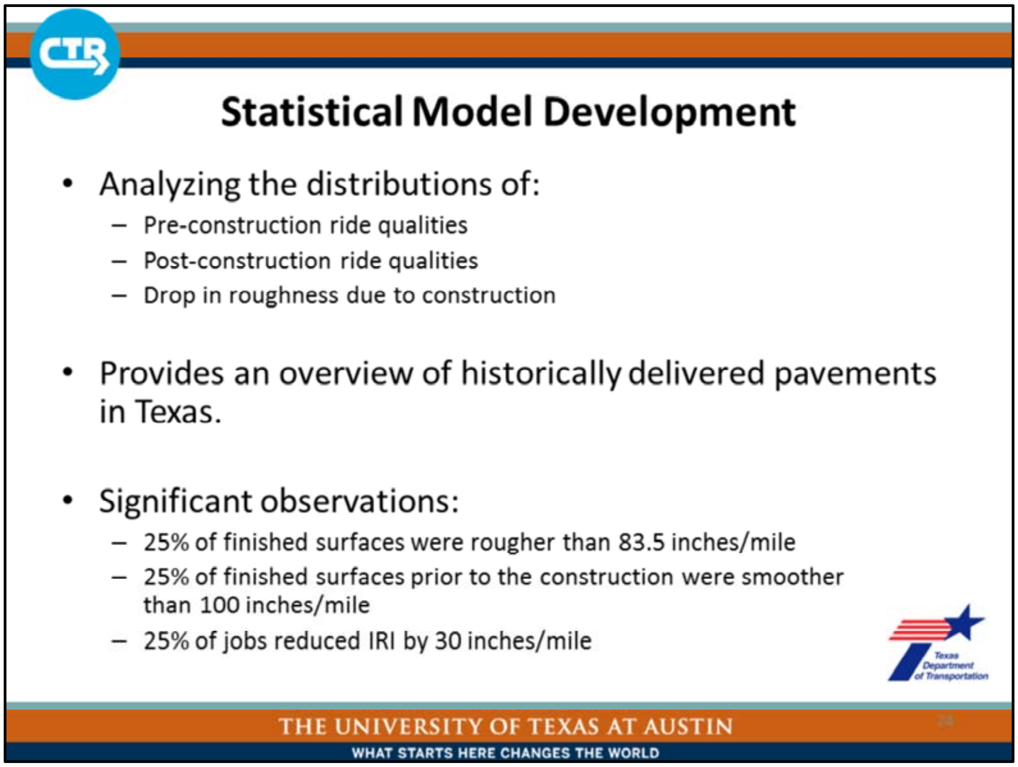
- It should be noted that multiple IRI values are available for each project depending on the length of the project.
- Mean, mean + 2 std. deviations (upper limit), and mean - 2 std. deviations (lower limit) were also calculated.
- The pavement roughness (in IRI) is expected to increase over the time until the next rehabilitation or overlay project. At that point, IRI suddenly drops due to the new construction. Subsequently, the IRI increases over time again.
- In this example, the x-axis represents the year in which the IRI measurements were collected, and the y-axis is the average IRI value across the entire project.
- The vertical line represents the project completion/construction year.
- The project was completed and opened to traffic between 2008 and 2009 PMIS measurements.
- A significant drop in the IRI value is evident immediately after the construction.
- The positive slopes of IRI change-along-time, both before and after the construction, indicate the average rate of deterioration of pavement roughness over time.



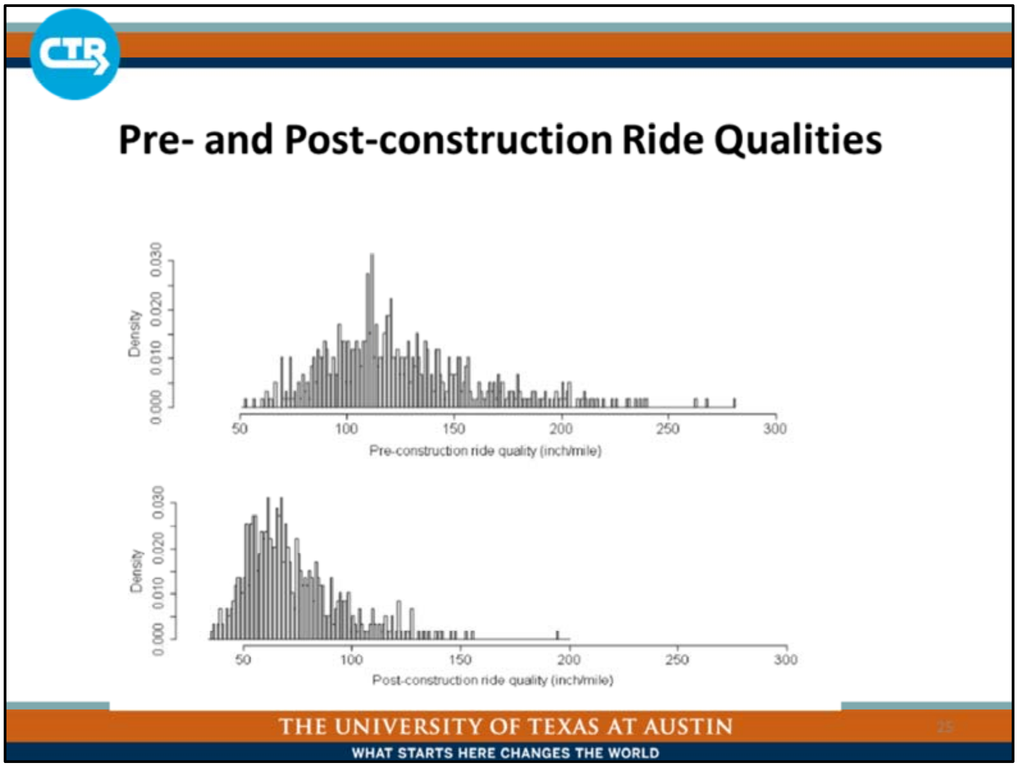
- A statistical model development exercise was carried out to investigate the relationship between the pavement field performance and the pavement specific construction attributes such as post-construction ride quality, drop in IRI, volumetric properties (QC/QA), traffic, etc.
- Pavement deterioration was quantified as the deterioration rate of pavement in terms of ride quality change (i.e., drop IRI/year).
- The initial IRI after the construction is influenced by the construction quality, road geometric features, material properties, and the pre-existing road condition.
- Asphalt overlays with Type D mixes are likely associated with smoother surface finishes with lower initial ride quality (as compared with Type C).
- A mixture with smaller aggregates is likely more workable and allows for better compaction, thereby resulting in a smoother post-construction surface.
- Facilities with lower posted speed limits (less than 45 mph) are likely to be associated with higher initial pavement roughness. On pavement sections with lower posted speed limits it is typically harder to achieve smoother finishes probably due to inherent geometric characteristics. Moreover, the measurement of the roughness using inertial profilers would be slightly biased toward higher side on the pavements with lower posted speed limits.
- Short-pavement projects are likely result in a higher post-construction surface roughness.
- Pavements carrying higher loads are likely associated with lower initial ride quality. Pavements carrying higher traffic loads are typically structurally sound and well-maintained pavements, which enhances the ease of achieving a smoother post-construction surface in a surface overlay project.
- On the other hand, pavements carrying higher traffic volumes are likely to be associated with higher initial ride quality after an overlay.
- The model suggests that pavements with higher annual maintenance costs (per unit length) are likely to be associated with higher initial ride quality following an overlay construction project. Higher maintenance costs may indicate frequent issues with the pavement surface, which may lead to increased difficulty in delivering a post-construction smoother surface.



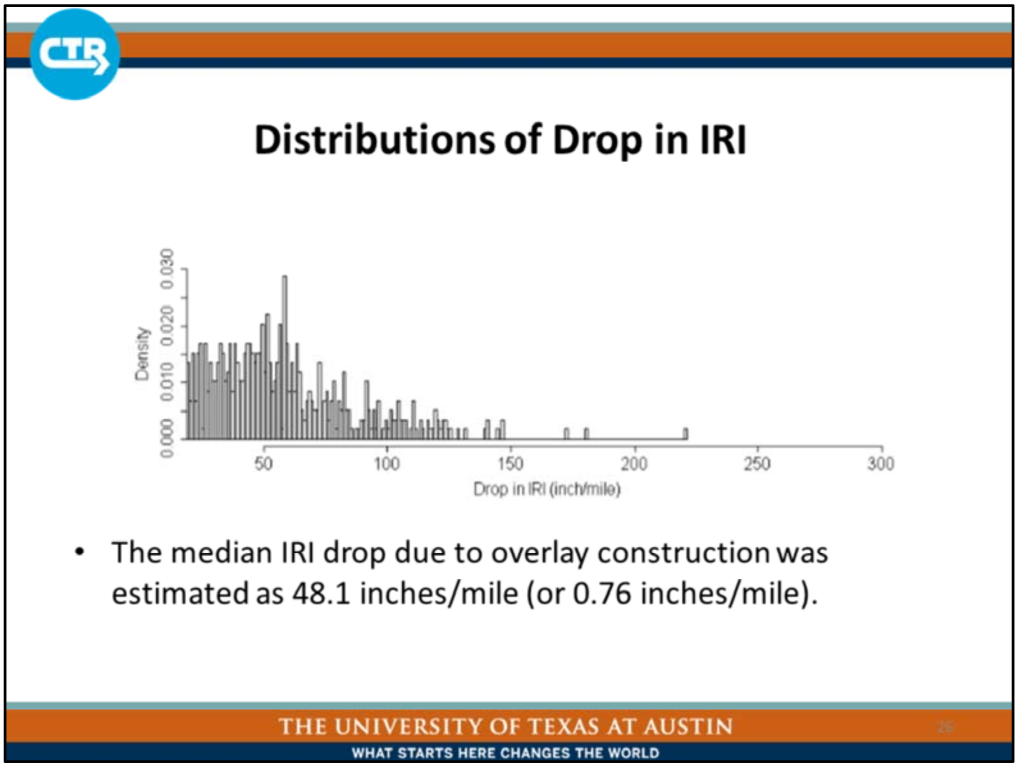
- Data suggests that both the initial IRI post-construction, as well as the drop in IRI that is attributable to construction activity, influence the future performance of the pavement.
- Pavements with higher ride quality increase traffic dynamic loads, thereby resulting in faster deterioration rates over the time.
- The model indicates that pavement constructions with higher drop in IRI relative to the pre-existing surface are associated with higher future deterioration rates as indicated by the positive coefficient on the respective variable.
- Pavements that required a significant effort in reducing the pre-existing surface roughness are likely the pavements with relatively moderate to poor structural condition. A mere surface project may temporarily reduce the pavement smoothness but the underlying pavement will likely witness a higher deterioration over time.
- It is important to recognize the additional effort of the contractor in reducing the surface roughness of such pavements.
- Two overlay construction jobs delivering equivalent initial IRI should not always be rewarded the same; the pre-existing conditions and thereby the effort to bring down the initial IRI could be significantly different.
- Drop in IRI represents the contractor’s effort in reducing the road roughness.
- The findings of this study confirm that a pay adjustment system that uses both the initial IRI and the drop in IRI would render a rational performance-related pay adjustment specification.
- Pavement construction that involves a significant effort in reducing the roughness (of the pre-existing surface) while delivering a smoother finished pavement should be rewarded for the expected superior pavement performance.



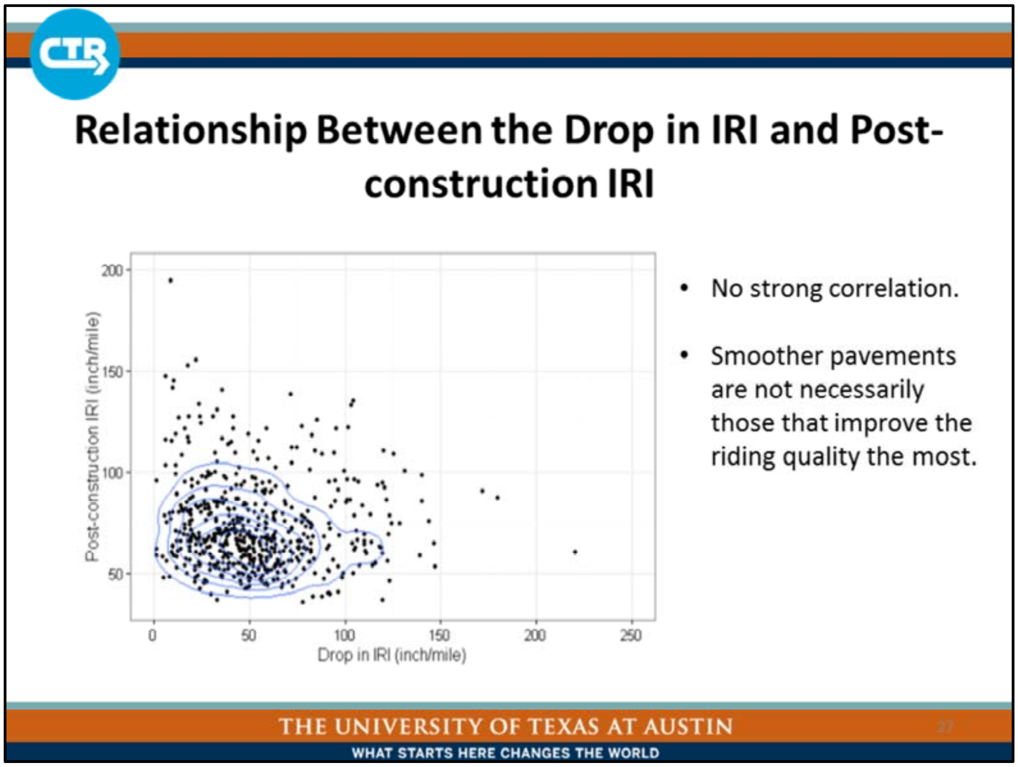
- Empirical findings are important and indicate the overall economic value of building smoother pavement structures. The findings confirm that a pay adjustment system that uses both the initial IRI and the drop in IRI is required to account the true effort of contractors.
- Analysis of IRI data was intended to investigate the distributions of the pre- and post-construction IRI values to understand the typical ride quality provided by contractors in Texas.
- From the data shown in the following slides, the quartiles of the distributions were calculated. These quartiles were used to identify preliminary thresholds for utilizing in the proposed ride specification.
- About 25% of the contractors are delivering very smooth surfaces below 57.5 inches/mile (or 0.9 m/km).
- Another 25% of the projects were delivered with slightly rough surfaces, that is, rougher than 83.5 inches/mile (1.3 m/km).
- The median post-construction roughness is 67.5 inches/mile (or 1.07 m/km). It is relatively common to deliver a smoother pavement surface by resurfacing a smoother pre-existing surface. Therefore, the pre-existing ride quality before construction is equally important to assess the true quality of the construction project.
- In Texas, about 25% of the pavements were smoother than 100 inches/mile (1.6 m/km), while another 25% of the pavements were rougher than 144 inches/mile (2.3 m/km) prior to construction.
- The median pre-existing roughness was estimated as 118 inches/mile (1.9 m/km).



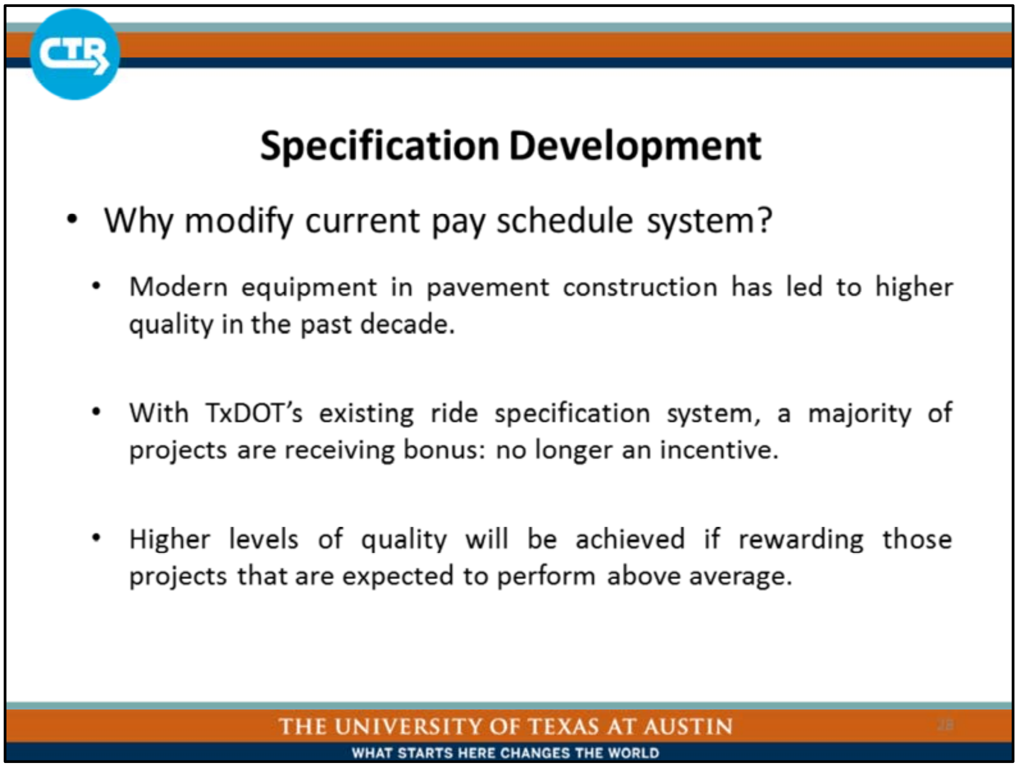
- Pre-construction ride quality is more spread out than the post-construction ride quality.
- Pavements deteriorate under a wide variety of distress mechanisms leading to a wide variety of the pre-construction ride qualities.
- The post-construction ride quality is generally controlled by the ride specification; therefore, it is relatively more uniform as represented by a lower spread of the distribution (i.e., lower standard deviation).



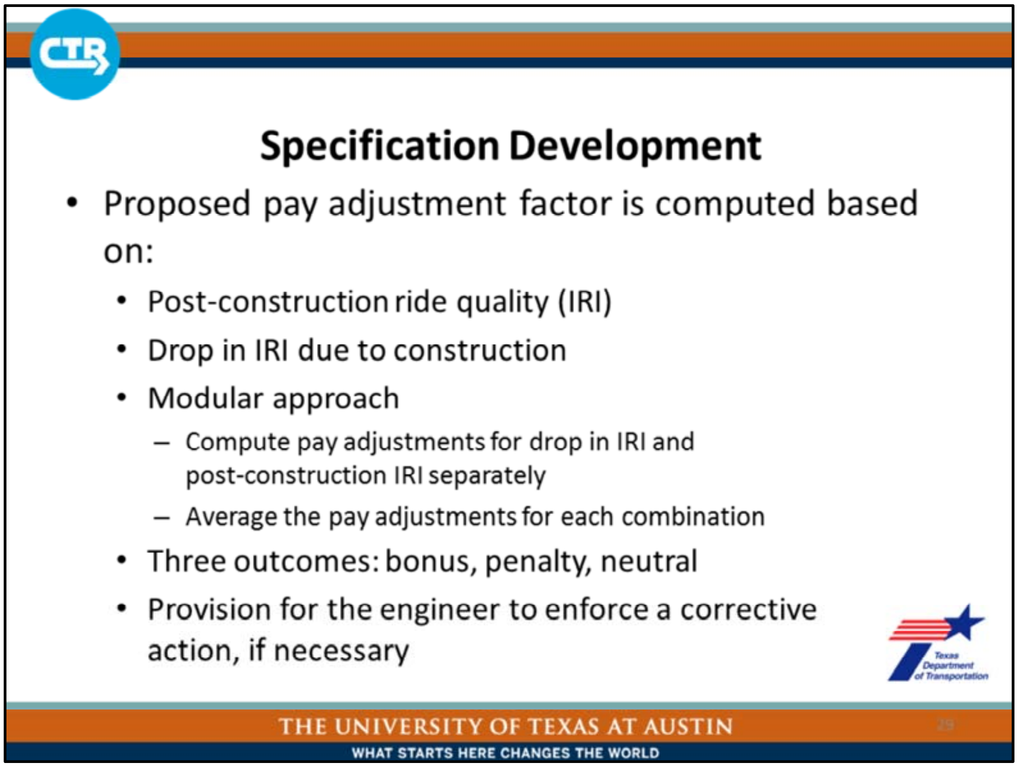
- The quartiles of the distribution of the drop in IRI were also estimated.
- About 25% of the projects reduced IRI by 30 inches/mile (or 0.47m/km); on the other hand, a few projects reduced IRI by more than 68.5 inches/mile (or 1.08 m/km).
- The median IRI drop due to overlay construction was estimated as 48.1 inches/mile (or 0.76 m/km).
- The new ride specification should reward projects whose quality is above average while not necessarily rewarding marginal improvements over a pre-existing smooth pavement.



- This figure shows scatter plot between drop in IRI and the post-construction IRI along with a bivariate density contours.
- The plot suggests no strong correlation between the IRI drop and the post-construction IRI.
- The findings highlight that the projects resulting in smoother pavements are not necessarily those that improve the riding quality the most.



- Depending on the pre-existing pavement conditions, a project may only marginally improve ride quality but still receive a bonus as per the current specification. The relationship shown in the previous slide further emphasizes the need to revise the existing ride specification to incorporate the drop in IRI due to construction.
- The current TxDOT specification was developed based on the historical data reflecting local contractor's capabilities in delivering smoother pavements.
- According to the current pay adjustment system, the reward/penalty to a contractor is based on the offset to the average contractor's performance. Due to the improved quality control with the advent of modern equipment in pavement construction, the average performance of contractors has improved in the past decade.
- It is important to update the current system so it works as an incentive for maintaining higher levels of quality while only rewarding those projects that are expected to perform above average.



- The proposed ride specification computes the pay adjustment in a modular fashion. For each pair of initial IRI and the drop, a pay adjustment is assessed by averaging the individual pay adjustments corresponding to the initial IRI and the drop. The individual pay adjustments are designed to be proportional to the respective ride measure (initial IRI or drop), within the thresholds.

Initial IRI \ IRI drop	0 to 32 inch/mile or < 0.5 m/km	32 to 55 inch/mile or 0.5 to 0.87 m/km	55 to 75 inch/mile or 0.87 to 1 m/km	75 to 95 inch/mile or 1 to 1.5 m/km	>95 inch/mile or > 1.5m/km
> 95 inch/mile or > 1.5m/km	Corrective action	Corrective action	Corrective action	No bonus/penalty or Corrective action	No bonus/penalty or Corrective action
75 to 95 inch/mile or 1 to 1.5 m/km	0.5*(Penalty.IRI + Penalty.Drop)	0.5*(Penalty.IRI + Penalty.Drop)	0.5*(Penalty.IRI + Zero.Drop)	0.5*(Penalty.IRI + Bonus.Drop)	0.5*(Penalty.IRI + Max.Bonus.Drop)
55 to 75 inch/mile or 0.87 to 1 m/km	0.5*(Zero.IRI + Penalty.Drop)	0.5*(Zero.IRI + Penalty.Drop)	0.5*(Zero.IRI + Zero.Drop)	0.5*(Zero.IRI + Bonus.Drop)	0.5*(Zero.IRI + Max.Bonus.Drop)
32 to 55 inch/mile or 0.5 to 0.87 m/km	0.5*(Bonus.IRI + Penalty.Drop)	0.5*(Bonus.IRI + Penalty.Drop)	0.5*(Bonus.IRI + Zero.Drop)	0.5*(Bonus.IRI + Bonus.Drop)	0.5*(Max.Bonus.IRI + Max.Bonus.Drop)
< 32 inch/mile or < 0.5 m/km	0.5*(Max.Bonus.IRI + Penalty.Drop)	0.5*(Max.Bonus.IRI + Penalty.Drop)	0.5*(Max.Bonus.IRI + Zero.Drop)	0.5*(Max.Bonus.IRI + Bonus.Drop)	0.5*(Max.Bonus.IRI + Max.Bonus.Drop)

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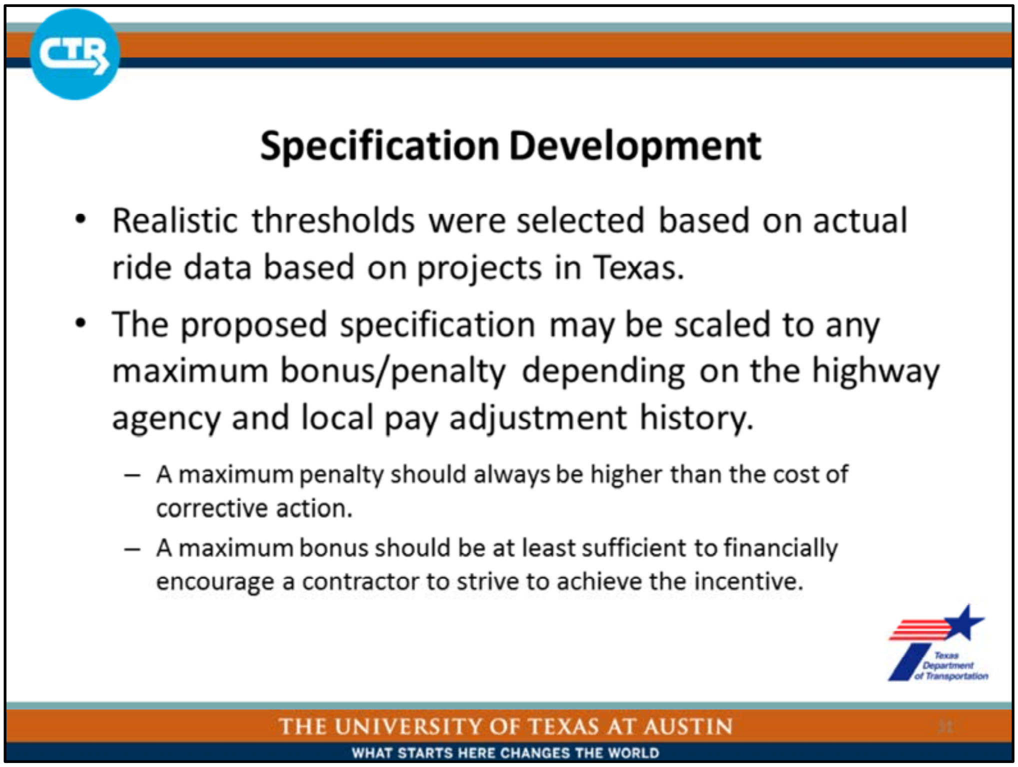
- This table shows the proposed ride specification that incorporates IRI drop and as-constructed IRI (initial IRI). Each cell describes the corresponding total pay adjustment.
- Red cells include relatively rougher pavements with minimal ride improvement from the pre-existing pavement surface.
- Green cells include relatively smoother pavements despite starting from a relatively rougher pre-existing pavement
- The bonus and penalty in the left-bottom and top-right regions are governed by the penalty and bonus equations, which may result in either a bonus or penalty.
- Pavements smoother than 32 inches/mile (or 0.5 m/km) receive a maximum bonus with respect to initial IRI; however, the overall pay adjustment also depends on the drop in IRI relative to the pre-existing ride quality.
- Similarly, projects are rewarded a maximum bonus with respect to their efforts in significantly reducing the IRI of the pre-existing pavement by over 95 inches/mile (or 1.5 m/km); however, the overall pay adjustment also depends on the ride quality of final delivered pavement.
- Corrective action may be required on newly overlaid pavements rougher than 95 inches/mile (or 1.5 m/km) depending on the pre-existing ride quality prior to the construction.
- The engineer may choose to waive the corrective action despite delivering a pavement rougher than 95 inches/mile in the case of a significant ride improvement from pre-construction ride quality.



- The maximum bonus and penalty corresponding to initial IRI, as well as the drop in IRI, are set to $1.00.
- The proposed specification shall be scaled to any maximum bonus/penalty depending on the highway agency and local pay adjustment history.
- The maximum bonus and penalty play a vital role and should be set to reasonable values according to the general principles in the following slide. The maximum bonus should be at least sufficient to financially encourage a contractor to strive to achieve the incentive.

- **Bonus equations:**

  Based on drop (Bonus.Drop) ($): 0.05*Drop – 3.75

  Based on initial IRI (Bonus.IRI) ($): -0.0435*IRI + 2.391

  Max.Bonus.Drop = $1

  Max.Bonus.IRI = $1

- **Penalty equations:**

  Based on IRI drop (Penalty.Drop) ($): 0.0182*Drop – 1

  Based on initial IRI (Penalty.IRI) ($): -0.05*IRI + 3.75

  Max.Penalty.Drop = -$1

  Max.Penalty.IRI = -$1

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- The bonus/penalty in the other cells is governed by the bonus/penalty equations presented in the table.
- The equations ensure the pay adjustment will vary linearly between the respective thresholds.
- The proposed specification shall be scaled to any maximum bonus/penalty depending on the highway agency and local pay adjustment history.

Distribution of the 565 Projects Evaluated

Initial IRI \ IRI drop	0 to 32 inch/mile or < 0.5 m/km	32 to 55 inch/mile or 0.5 to 0.87 m/km	55 to 75 inch/mile or 0.87 to 1.2 m/km	75 to 95 inch/mile or 1.2 to 1.5 m/km	>95 inch/mile or > 1.5m/km
> 95 inch/mile or > 1.5m/km	6%	4%	1%	1%	2%
75 to 95 inch/mile or 1 to 1.5 m/km	7%	6%	4%	1%	3%
55 to 75 inch/mile or 0.87 to 1 m/km	11%	15%	9%	5%	4%
32 to 55 inch/mile or 0.5 to 0.87 m/km	4%	7%	6%	2%	2%
< 32 inch/mile or < 0.5 m/km	0%	0%	0%	0%	0%

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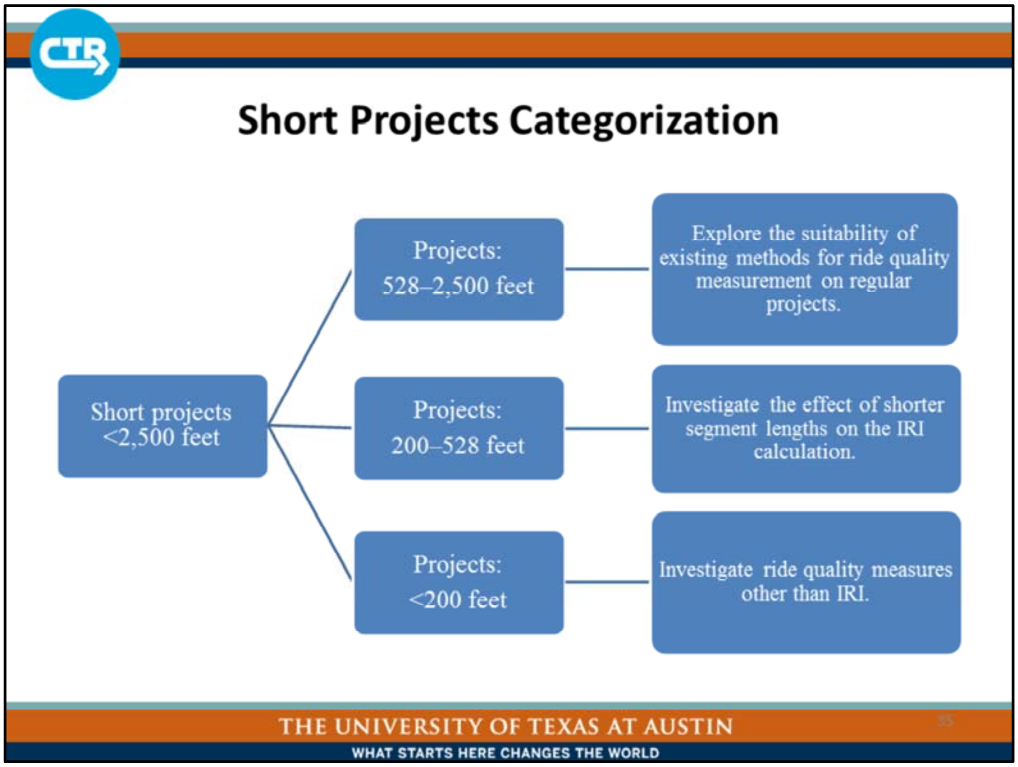
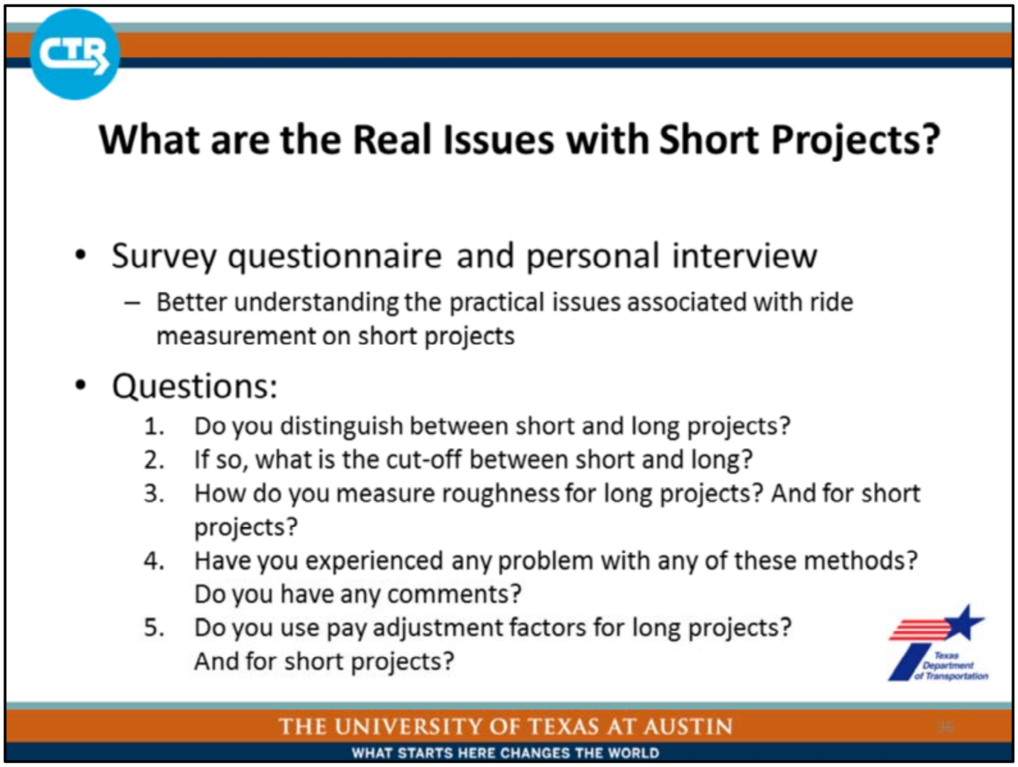
- About 36% of the hot-mix pavements were rougher than 75 inches/mile (or 1.2 m/km). The existing specification using only initial IRI penalizes these projects equally for delivering a rougher pavement. However, about 22% of these projects actually improved the ride quality of pre-construction surface by more than 75 inches/mile (or 1.2 m/km).
- The proposed specification addresses the issue by adding a bonus for the significant ride improvement (drop in IRI), thereby reducing or nullifying the overall penalty.
- Similarly, about 64% of the projects were smoother than 75 inches/mile (or 1.2 m/km) and receiving a bonus. However, about 56% of these projects achieved smoother finished surface due to a smooth pre-existing pavement, marginally improving the ride quality (with drop in IRI less than 55 inches/mile).
- The proposed specification also addresses the issue by adding a penalty for marginal ride improvement (drop in IRI), thereby reducing or nullifying the overall bonus.
- The proposed specification is more rational and acknowledges the contractors' efforts to achieve high quality and long-lasting pavements.
- Implementing the proposed specification is expected to financially motivate contractors to deliver smoother pavements while significantly improving the ride quality of existing pavements.

Part 2

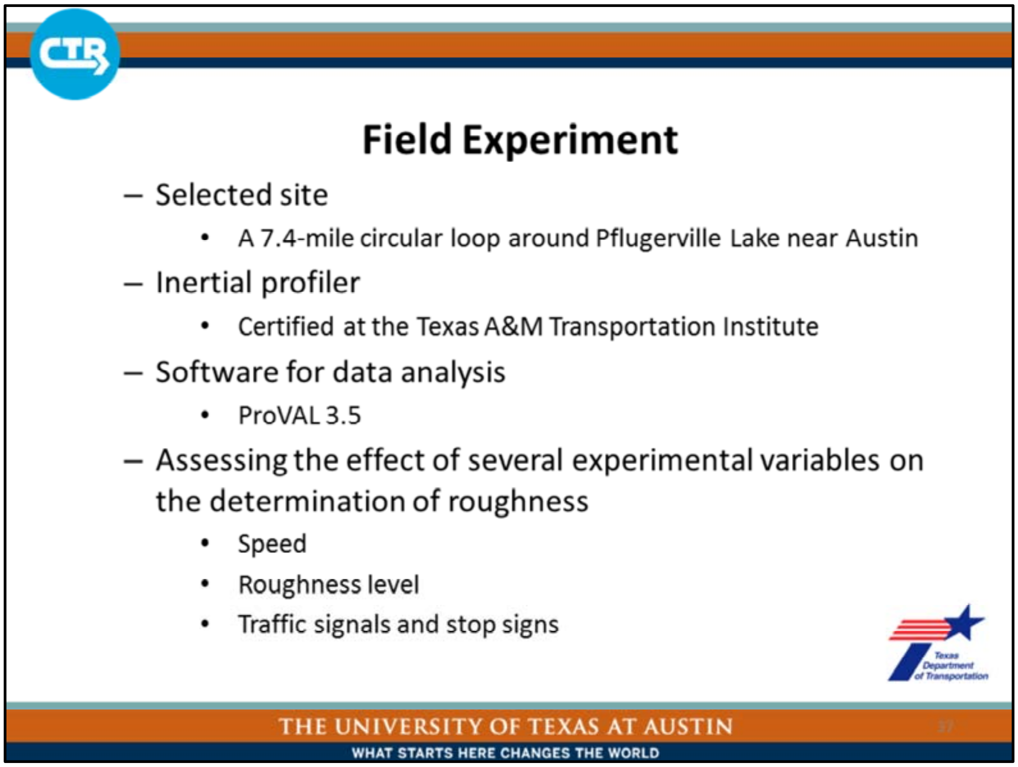
Short Projects



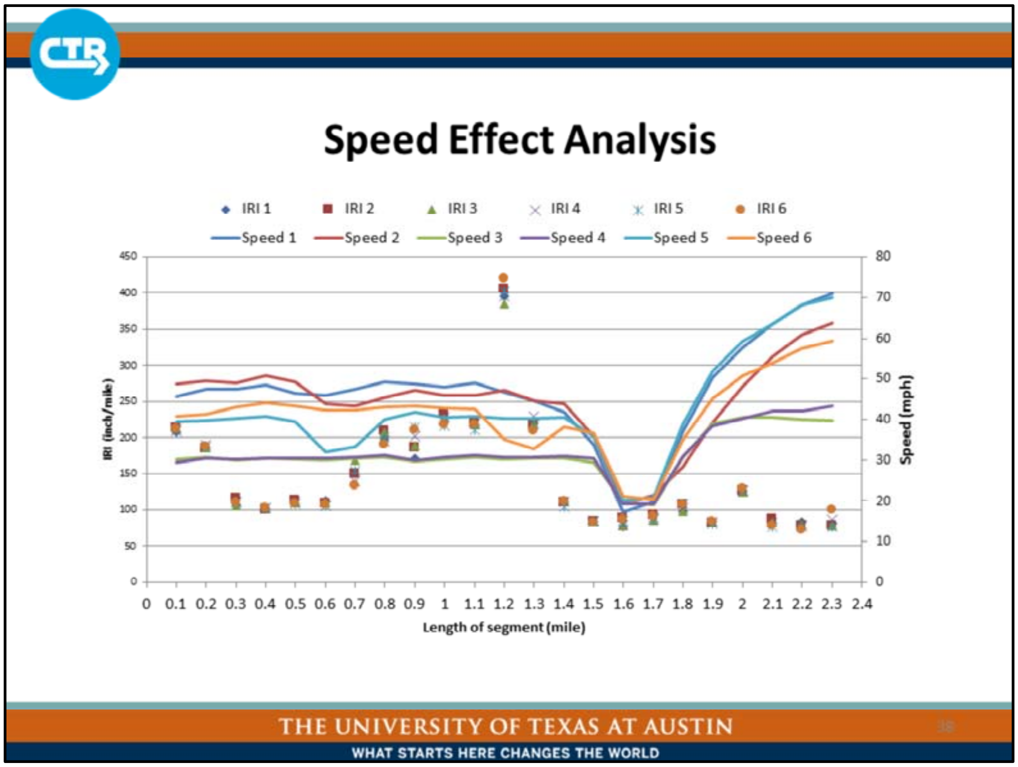
- According to the current TxDOT specification, projects with lengths of less than 2,500 feet are called short projects. The research team categorized the short projects in three groups:
    - Projects with lengths between 528 and 2,500 feet
    - Projects with lengths between 200 and 528 feet
    - Projects with lengths shorter than 200 feet
- It should be mentioned that 528 feet is the common length to summarize IRI. For the project lengths of less than 528 feet , the effect of shorter profiler length must be evaluated by the respective agency.
- It is recommended that 200 feet be the minimum length required to measure IRI values.



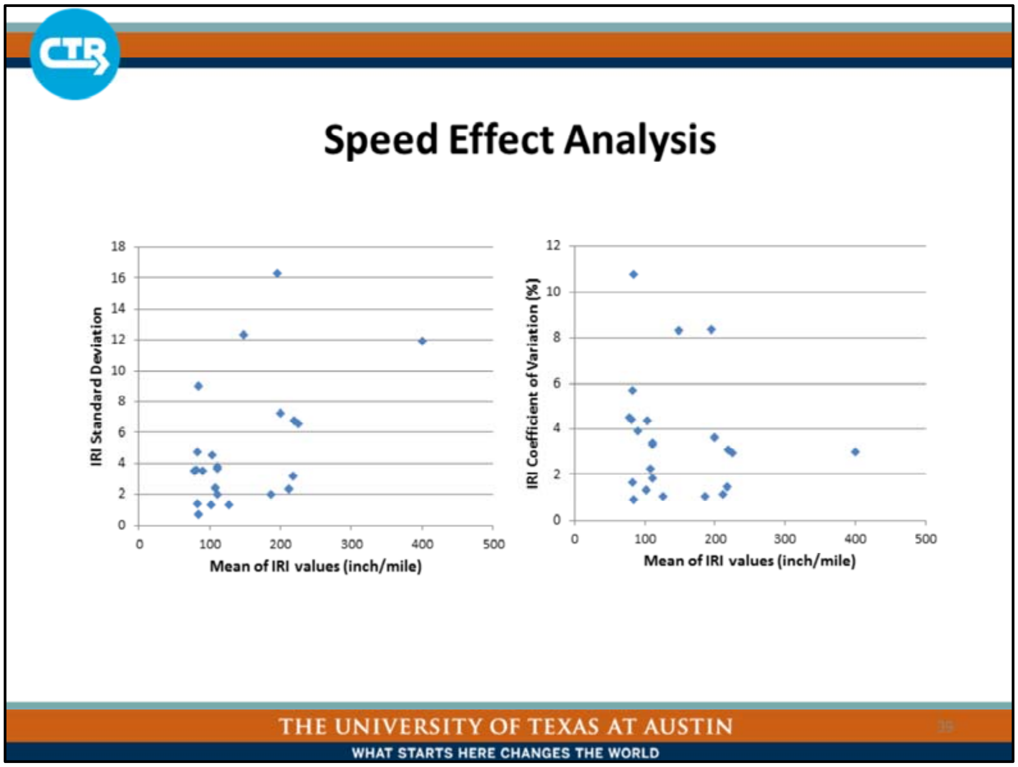
- An electronic message was sent to several TxDOT construction engineers to obtain their responses on the above questions pertaining to ride quality on short and long projects.
- In addition, the research team met with Dr. Magdy Mikhail, Mr. Jeff Howdeshell, Dr. Robin Huang, and Dr. Feng Hong of TxDOT to ask the same questions and gather more practical information about the operation of the inertial profiler and field experiences.
- The survey questionnaire and interviews were aimed at better understanding the practical and other perceived issues associated with ride measurement on short projects.



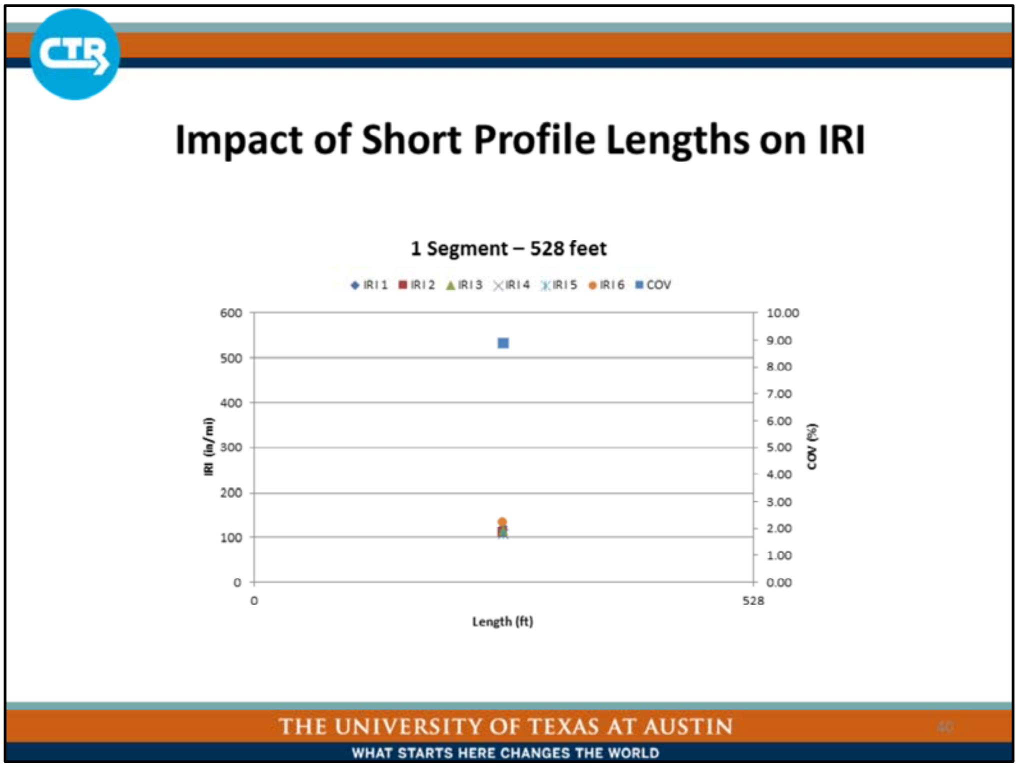
- A field experiment was carried out to assess the effect of several experimental variables on the determination of roughness. Some of the variables assessed included: speed, roughness level, and number of stops.
- A 7.4-mile circular loop on East Pflugerville Parkway, Texas State Highway 130 (SH 130), Cameron Road, and Weiss Lane around Pflugerville Lake, near Austin, was selected.
- This loop was chosen because of the several traffic signals, stop signs, and a sharp turn on the route.
- Speed changes (braking and acceleration) can cause the accelerometer to tilt which may have an effect on the profile data. Therefore, the data collected on this loop helped researchers to study the effect of speed changes on IRI values.
- Another advantage of this loop is that all segments are paved with asphalt so it is a relatively homogeneous surface.
- The loop was driven six times at different speeds ranging from 30 to 70 mph.



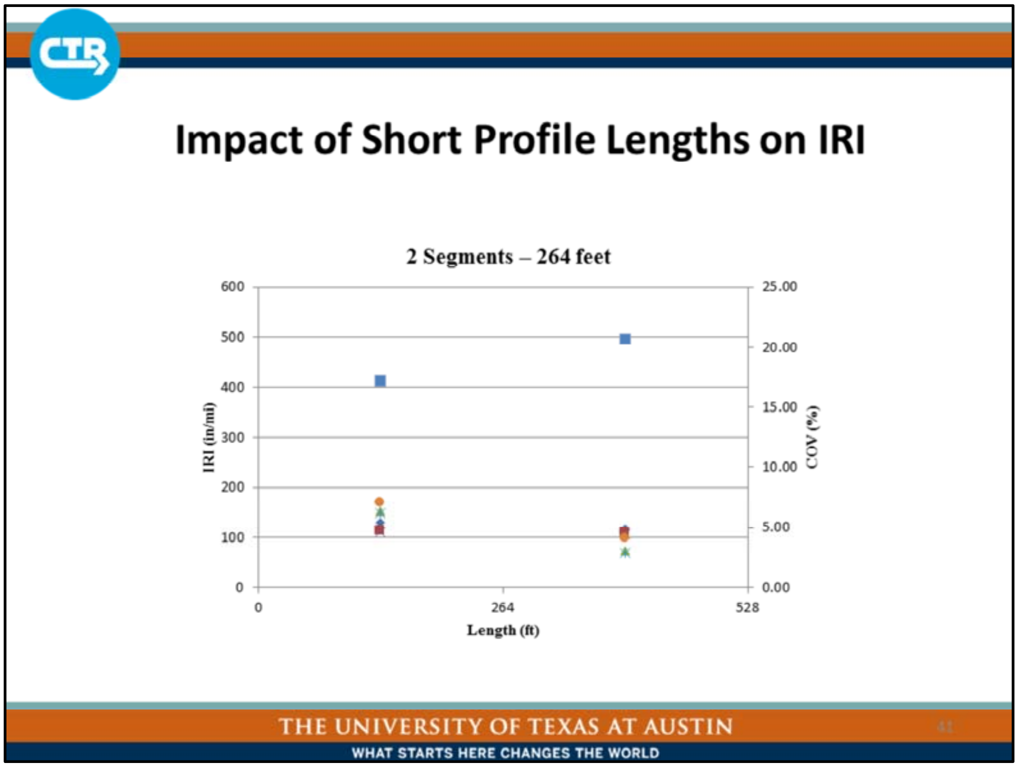
- This slide presents the plot of the IRI values versus vehicle speed over a portion of the studied loop.
- In this graph, continuous curves represent the speed of the vehicle and dots represent the six measured IRI values on every 528-foot (0.1 mile) test segment.
- The graph shows that on most of the segments, identical IRI values were obtained regardless of speed of operation.



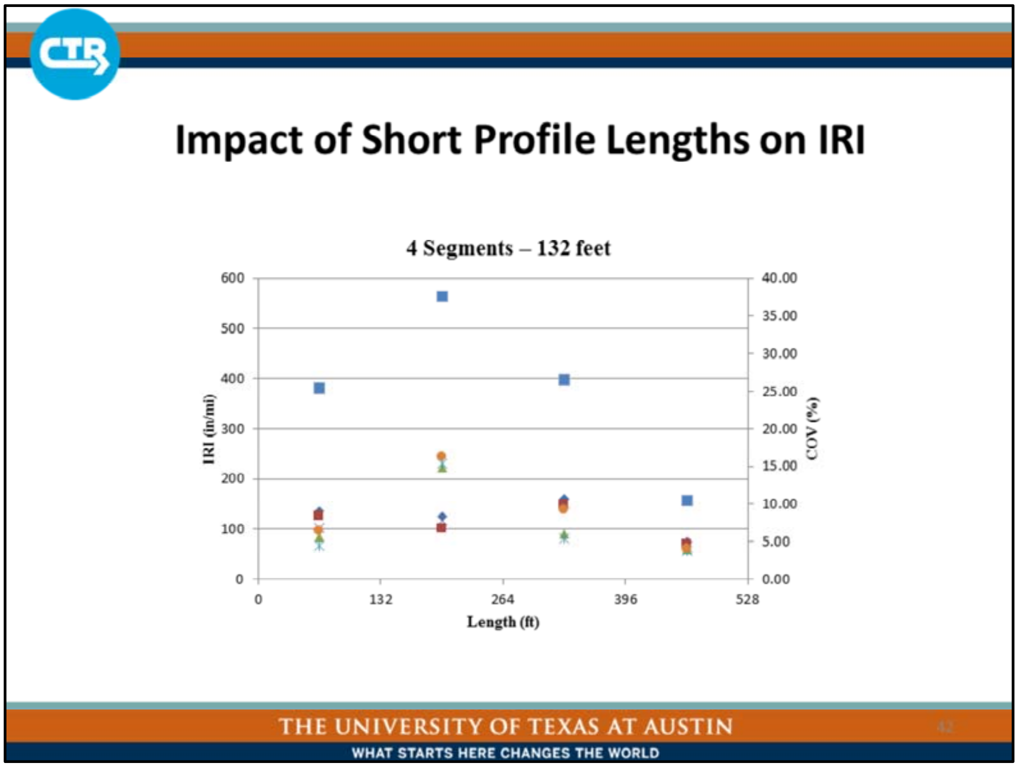
- The research team calculated mean, standard deviation (STD), and coefficient of variation (COV) of the six IRI values at every 0.1-mile segment.
- These figures show the plots of IRI standard deviations versus IRI mean values and IRI coefficient of variations versus IRI mean values.
- As shown in the plot of STD versus mean values, the data are randomly distributed and there is no clear relationship between STD and mean values.
- Likewise, no obvious relationship could be found between COV and IRI data.
- This indicates that the standard deviation and coefficient of variation are not proportional to the roughness mean values.
- This analysis demonstrates that the IRI variations in some segments are related to other factors that require further investigation.



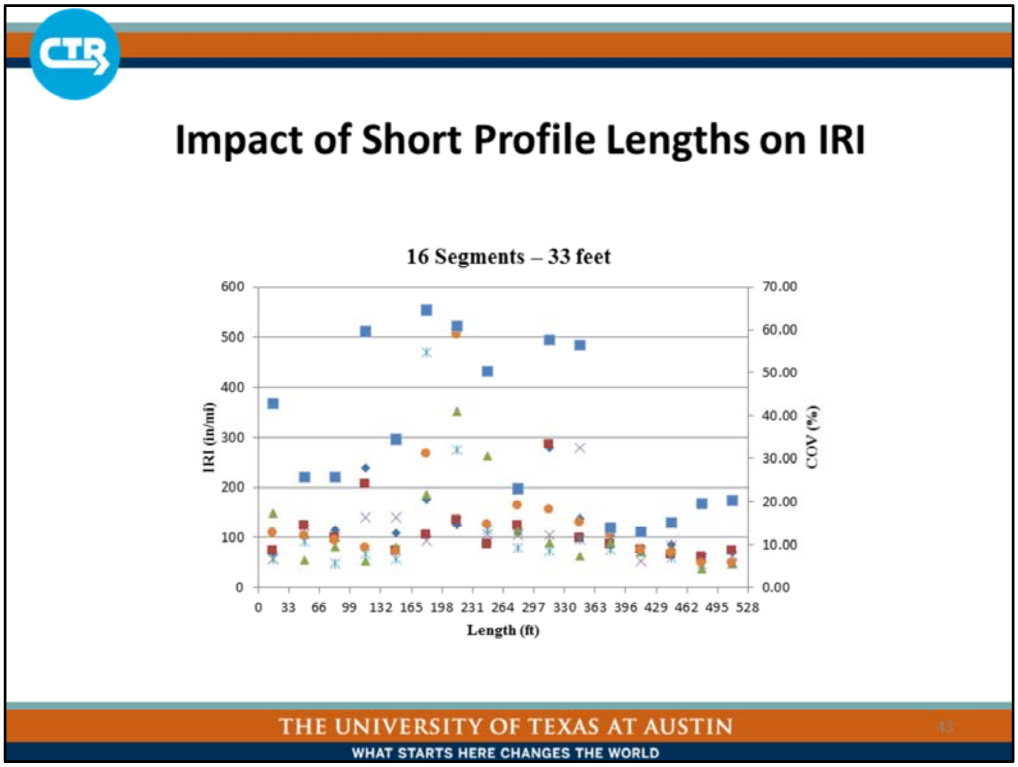
- A comparative statistical analysis was performed to investigate the influence of the shorter profile length on the IRI values.
- A random 528-foot segment was selected and five different base lengths were considered for this analysis: 528, 264, 132, 33, and 16 feet.
- As mentioned earlier, IRI algorithm should be initiated before the target section in order to be stable. Otherwise, the IRI results are not consistent or reliable. Therefore, a pre-section was considered in this analysis.
- This slide (and the following) illustrate the IRI values for these five base lengths. It should be pointed out that the IRI values corresponding to the pre-section are discarded when the IRI calculation is completed.
- Once the IRI values were obtained for six profiles, the research team calculated the COV of six IRI values. COV represents the degree of variation between IRI values for six runs on each segment. COVs are provided in these plots for each segment.
- The analysis showed that as the profile length decreases, the variation between IRI results obtained through six runs increases. This indicates that the repeatability of IRI algorithm decreases with decreasing the profile length.



- Same notes as before apply here.



- Same notes as before apply here.



- Same notes as before apply here.

Impact of Short Profile Lengths on IRI

- The average of IRI is unbiased.
- Standard deviation changes significantly.

Length (ft)	IRI (in./mi)	StDev (in./mi)
528	113.33	0
264	113.32	7.7
132	113.32	18.86
33	113.28	28.77
16	114.5	33.63

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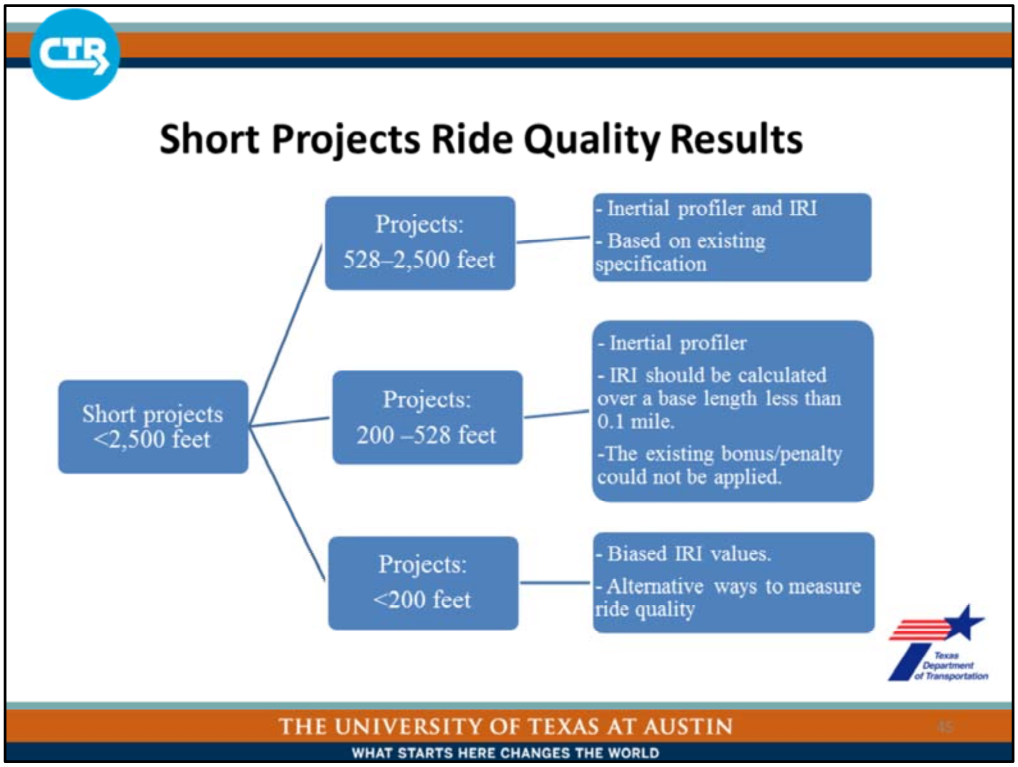
- The IRI values corresponding to different base lengths were calculated for one of the runs.
- For this segment, IRI528 is about 113.33 inches/mile. When the IRI is calculated over shorter segment lengths, the average of IRI values calculated on the segment does not change noticeably and is very close to the IRI528, whereas the standard deviation of IRI values increases as the segment length decreases. The maximum standard deviation can be observed for the 16-foot segment length. This analysis indicates that the average IRI for shorter sections is unbiased; however, its standard deviation changes significantly. Over shorter segments, localized roughness such as cracking and bumps affect the IRI values and magnify them.



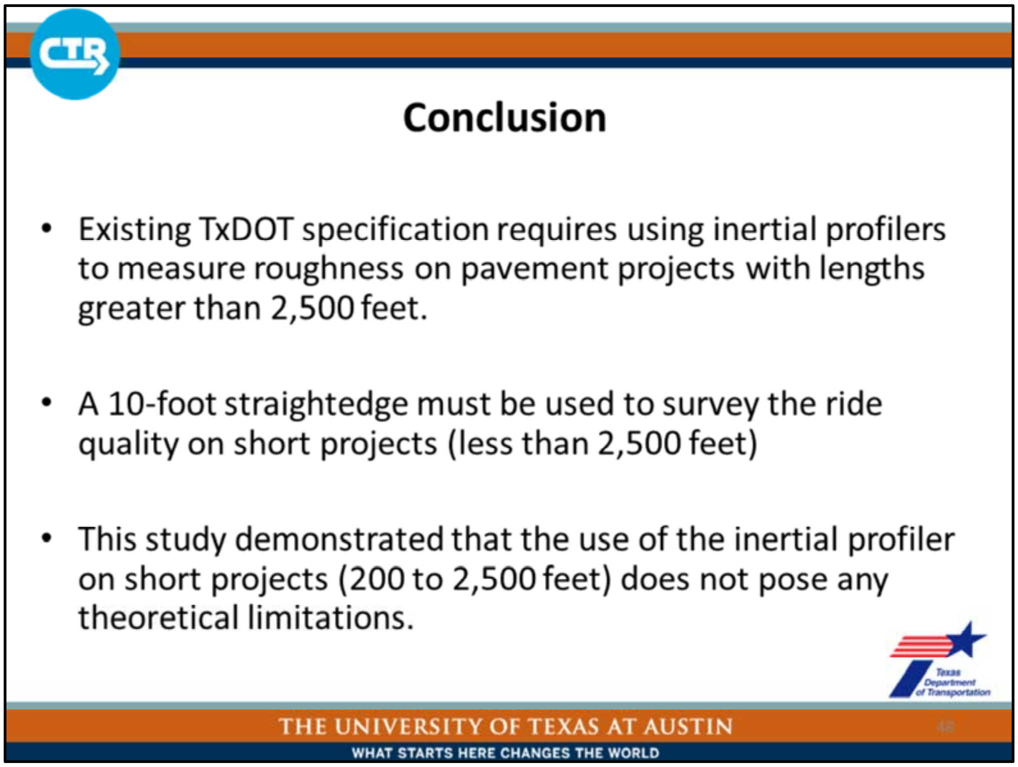
- Based on the previous analysis, it is recommended that the inertial profiler calibrated and operated according to the existing Tex-1001-S specification could be used on short projects spanning between 528 feet and 2500 feet without further theoretical considerations.
- The utilization of the 10-foot straightedge should be only consider if practical or economic considerations renders the use of the inertial profiler unacceptable.
- In the case of projects with length between 200 and 528 feet the inertial profiler can also be used but the IRI should be averaged over a base length of less than 0.1 mile.
- In this case, the maximum value of the IRI increases when the IRI is summarized over a shorter base length. In fact, the IRI value accumulated over a very short base length is greatly affected by localized roughness (i.e., bumps and dips).
- Localized roughness such as bumps and dips increase the IRI values. The effect of localized roughness is reduced when the IRI is averaged over a longer distance.
- It should be stated that the shorter base length increases the variation of IRI values. However, it is not the mean value that is affected but it is the variability and the reliability of the obtained IRI.
- Therefore, the IRI obtained for these projects will not be biased but will be more variable and therefore the same bonus/penalty specification could not be applied.

Conclusion

- Existing TXDOT ride specification is based on as-constructed ride quality measured immediately after the overlay construction.
- Literature review highlights the importance of incorporating the pre-existing ride quality into the ride specification.
- Analysis of data from projects in Texas suggests that projects delivered with better ride quality are not necessarily significantly in improving the IRI from the pre-existing surface.

Conclusion

- Statistical analysis showed that both drop in IRI and post-construction IRI are directly related to the pavement performance and deterioration rate.
- The proposed ride specification computes the pay adjustment according to a combination of as-constructed IRI and a drop in IRI.
- The revised system acknowledges the contractors' true efforts and financially motivates the contractors.


Conclusion
Existing TxDOT specification requires using inertial profilers to measure roughness on pavement projects with lengths greater than 2,500 feet.
A 10-foot straightedge must be used to survey the ride quality on short projects (less than 2,500 feet)
This study demonstrated that the use of the inertial profiler on short projects (200 to 2,500 feet) does not pose any theoretical limitations.
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0-6853-P3

STUDENT'S GUIDE

Research Supervisor:
Dr. Jorge Prozzi

TxDOT Project 0-6853: Improvements to Ride Specifications

AUGUST 2016; PUBLISHED MARCH 2017

Performing Organization: Center for Transportation Research The University of Texas at Austin 1616 Guadalupe, Suite 4.202 Austin, Texas 78701	**Sponsoring Organization:** Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, Texas 78763-5080
Performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.	

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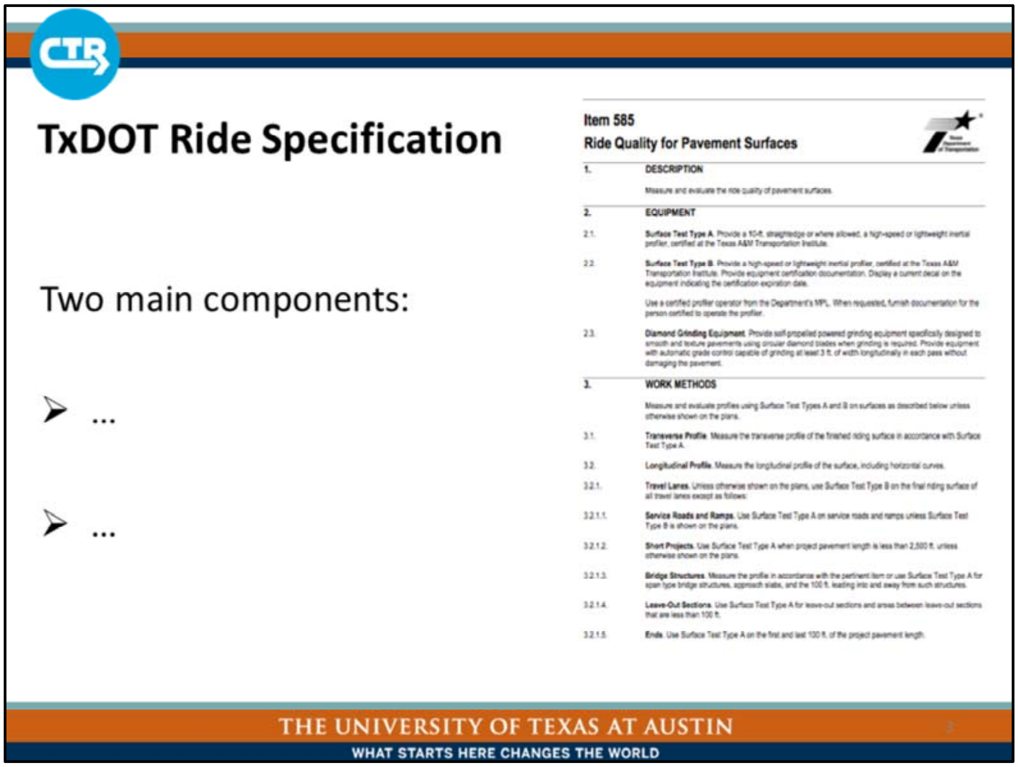
CENTER FOR TRANSPORTATION RESEARCH

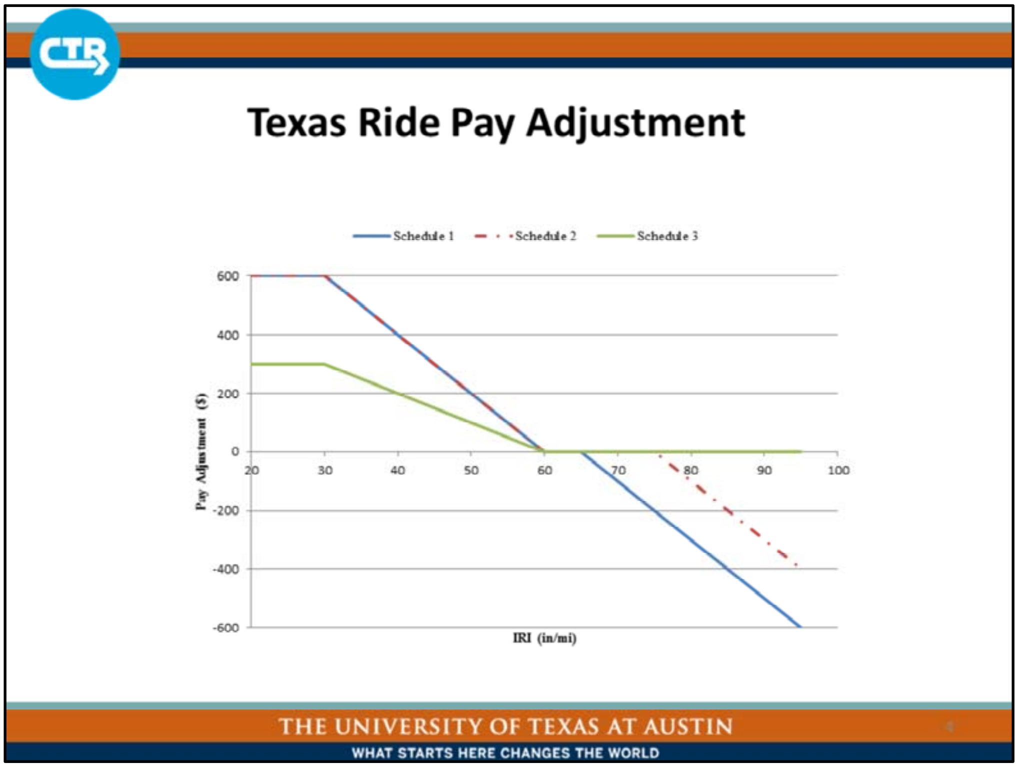
TXDOT Project No. 0-6853
Improvements to Ride Specification
Student's Guide (P3)

Texas Department of Transportation

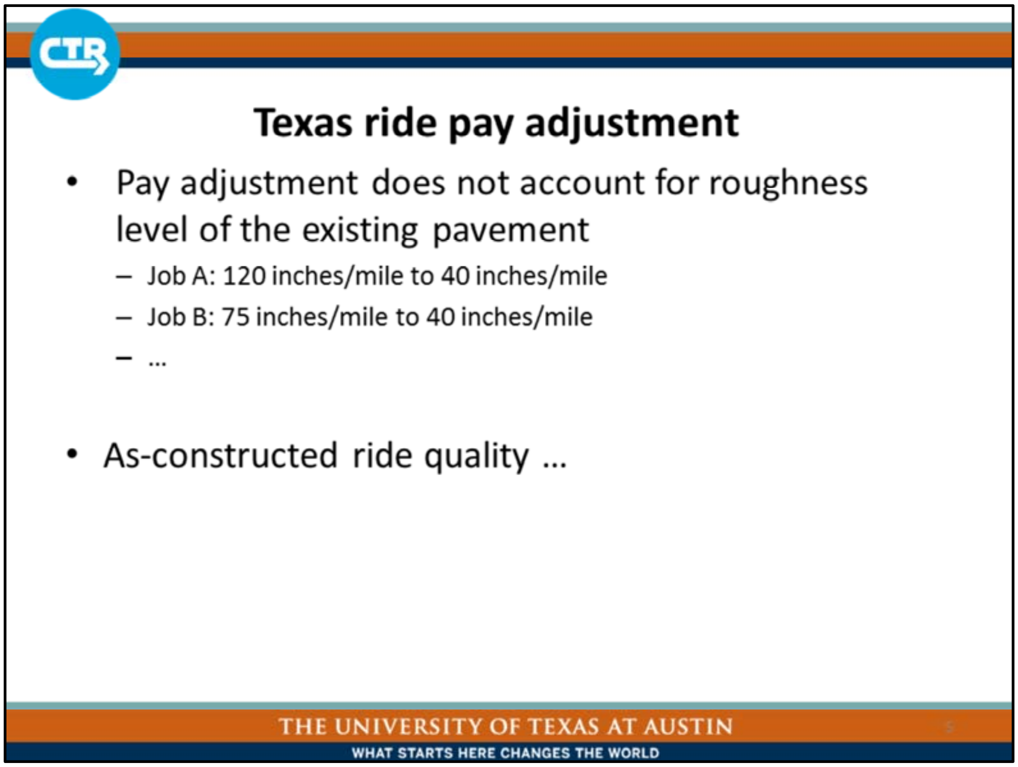
Contents



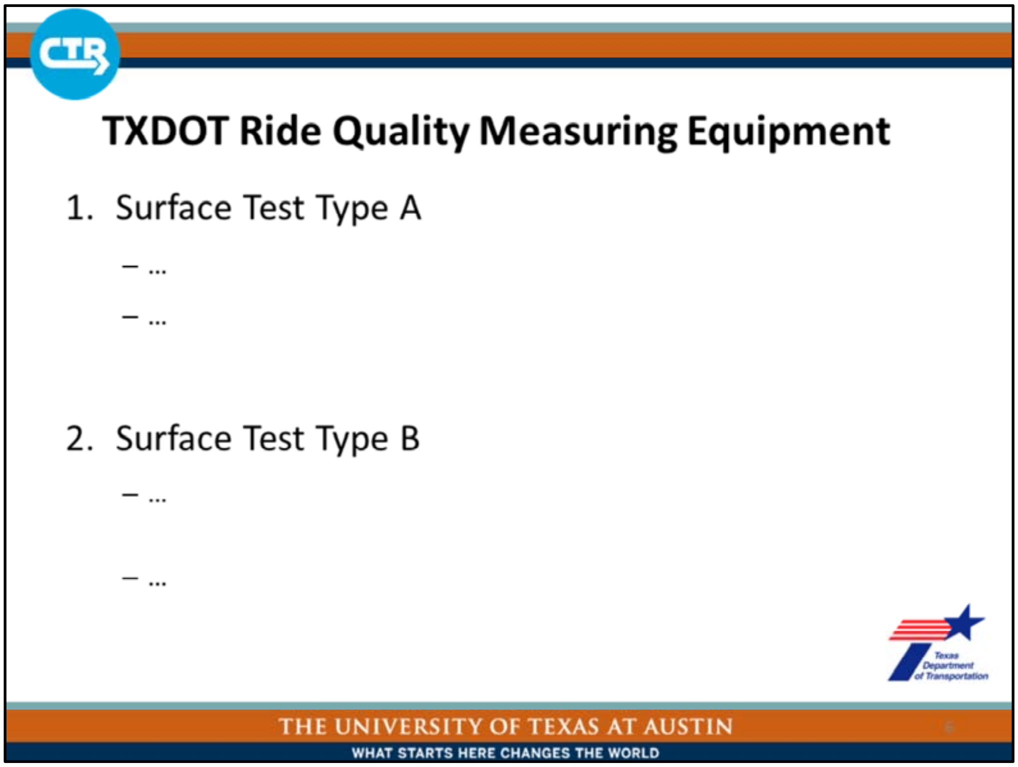
- The student should read Item 585 of TxDOT specification, Ride Quality of Pavement Surfaces.



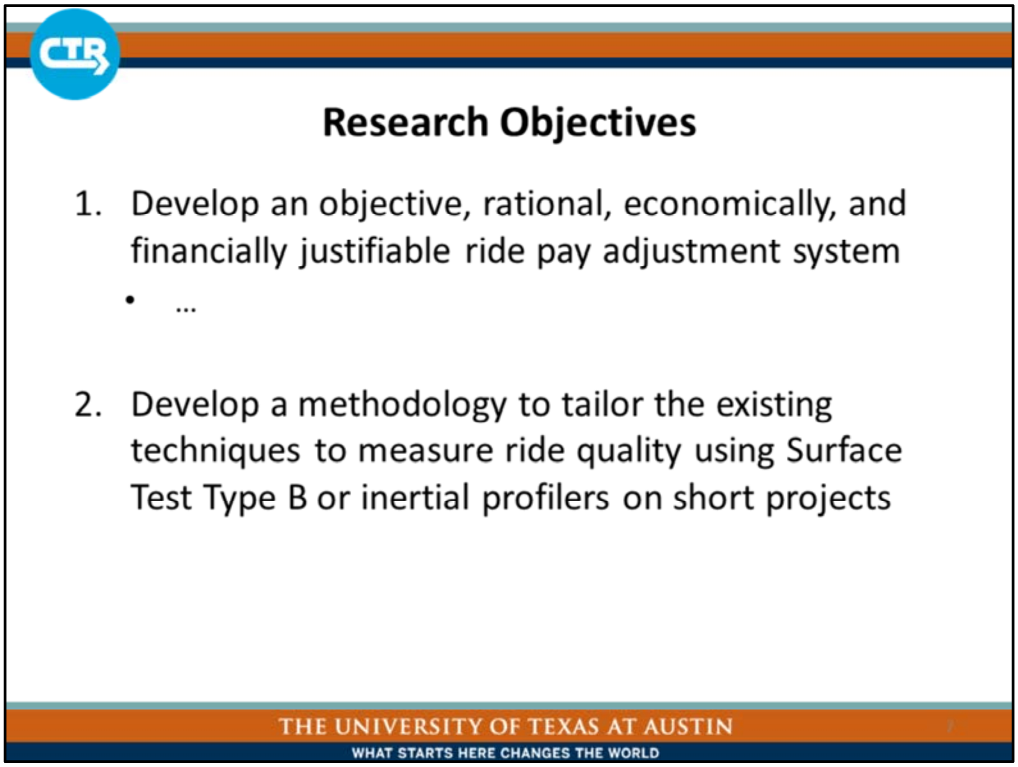
- The student should become familiar with the three pay schedules.
- The student should calculate bonus and penalty for two different examples.



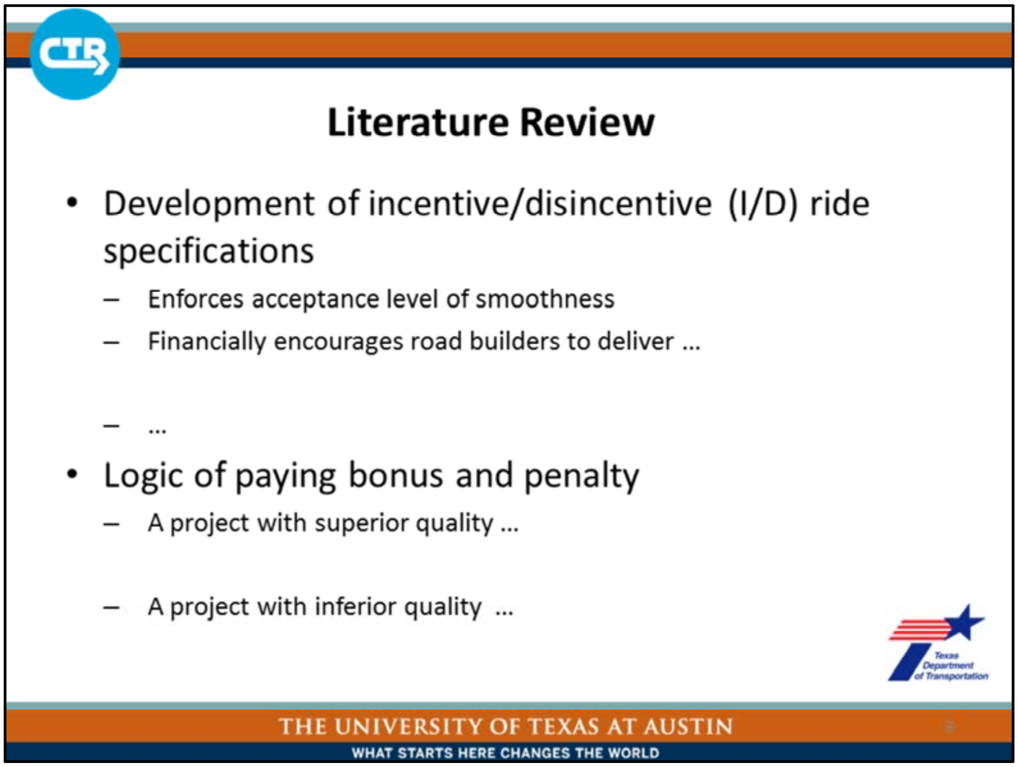
- The student should understand current specifications and the need to include the change in the ride quality from the existing condition to the condition after overlay in the new specification.



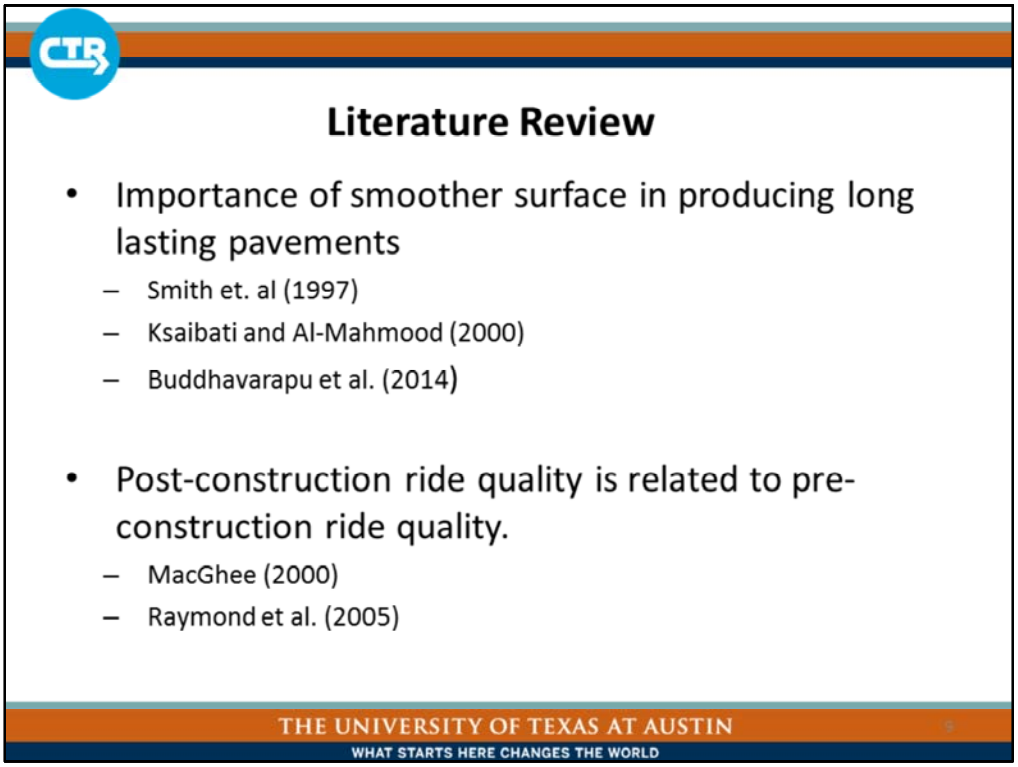
- The student should understand the two types of tests used by TxDOT and their differences.
- The student should discuss advantages and disadvantages.



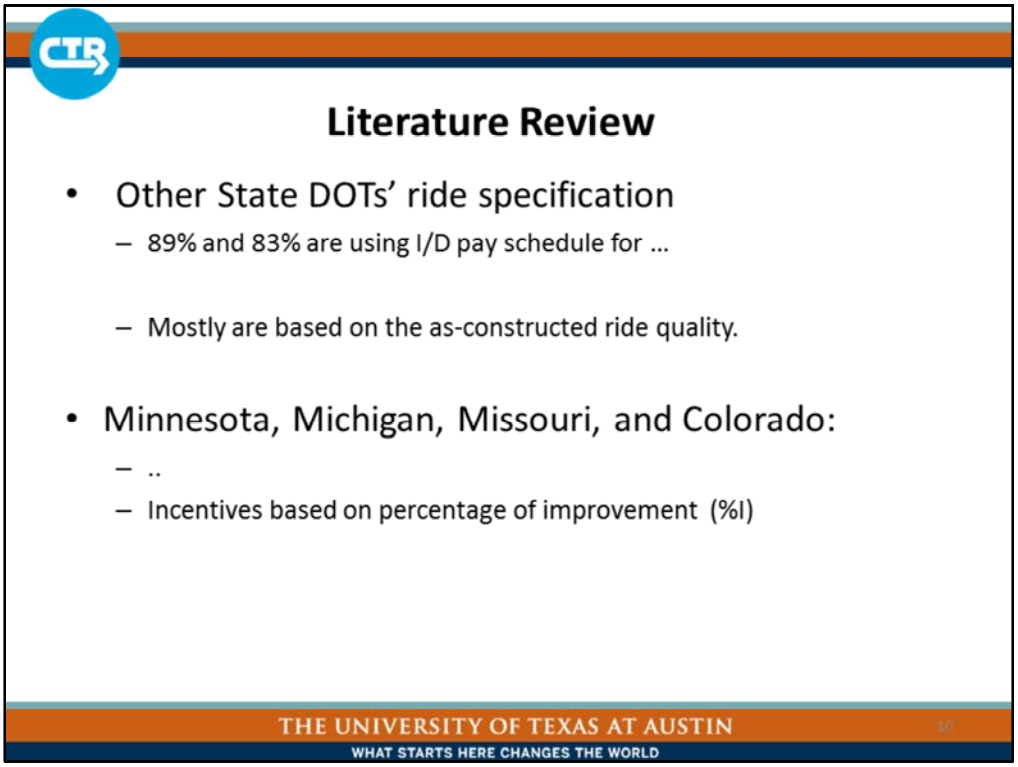
- The student should understand the project objectives.
- The student should understand how TxDOT defines short projects.
- Student reading: Prozzi, J. A., P. Buddhavarapu, S. Kouchaki, and A. de Fortier Smit. “A Proposal for Revising TxDOT Ride Specification to Account for Ride Quality Improvement,” FHWA/TX-16/0-6853-1. Austin, TX: Center for Transportation Research, The University of Texas, August 2016.



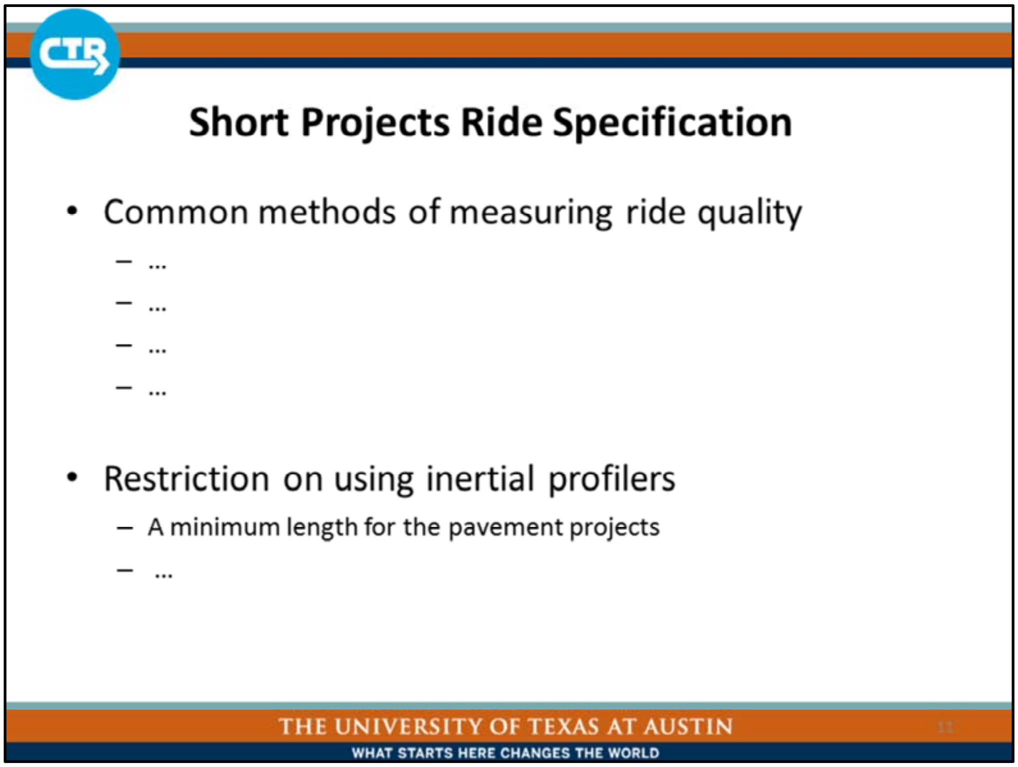
- The student needs to understand the reasoning behind the implementation of incentive/disincentive ride specifications, as well as their basic principles, objectives, and limitations.



- The student should learn:
  - The effect of lower initial roughness on pavement performance
  - The importance of improving existing roughness through overlay construction
- The student should be encouraged to read the relevant references.

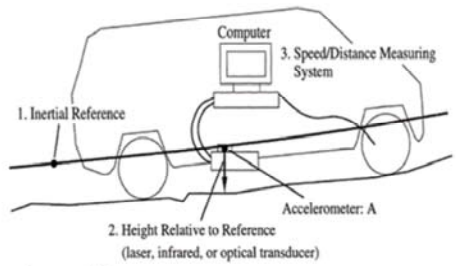


- The student should realize that other state agencies are also applying bonus/penalty specifications.
- The student should realize that several states already incorporate the percentage improvement.
- The student should define percentage improvement.



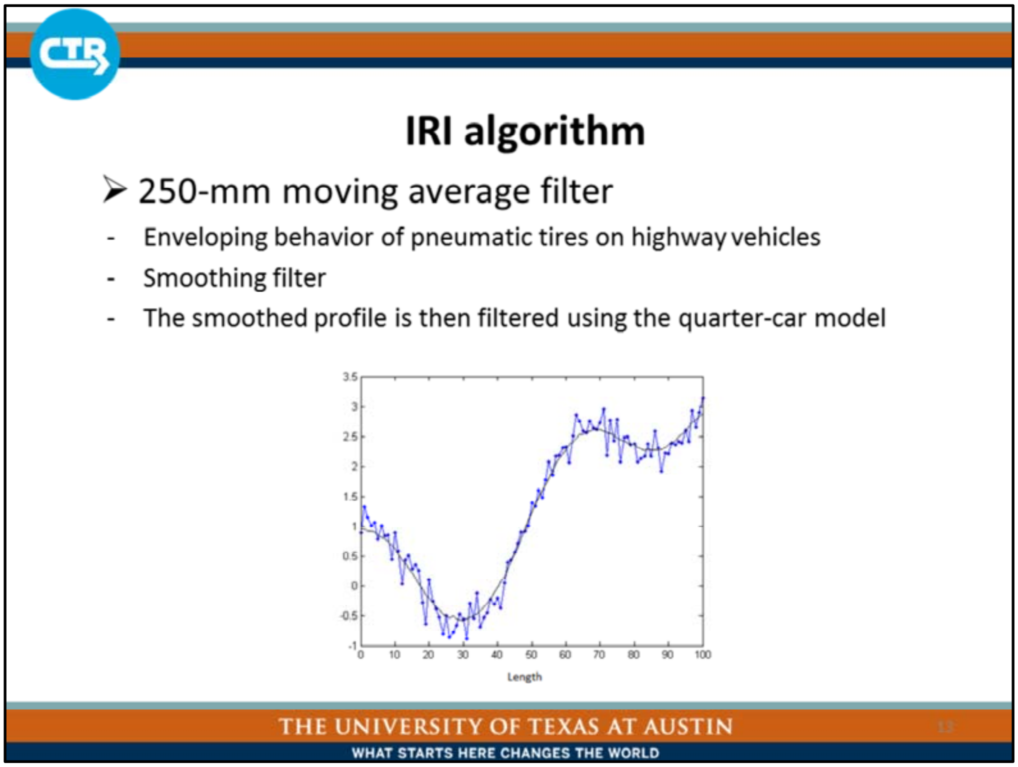
- The student should be familiar with various methods of assessing riding quality.
- The student should discuss restrictions on using inertial profilers and the reasons for such restrictions.

Inertial Profiler and IRI Measurements

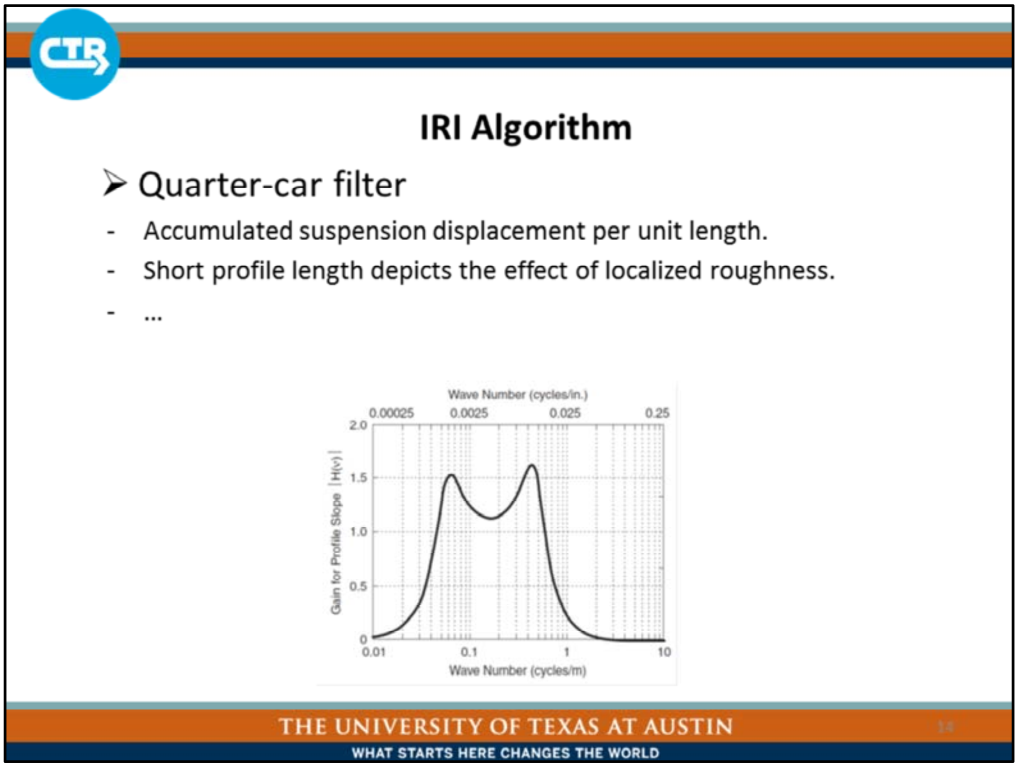


- Longitudinal profile
  - Voltage signals collected using the accelerometer and sensors.
  - Sampled at a given interval distance.
  - TxDOT …
  - The elevation of locations where the signals were sampled.

- The student should understand the three fundamental components of a profiler: accelerometers, proximity sensors, and a distance measuring system.
- This specification is being change to 2 inches.
- Student reading: Sayers, M., and Karamihas, S. “The Little Book of Profiling.” Ann Arbor: The University of Michigan, September 1998.

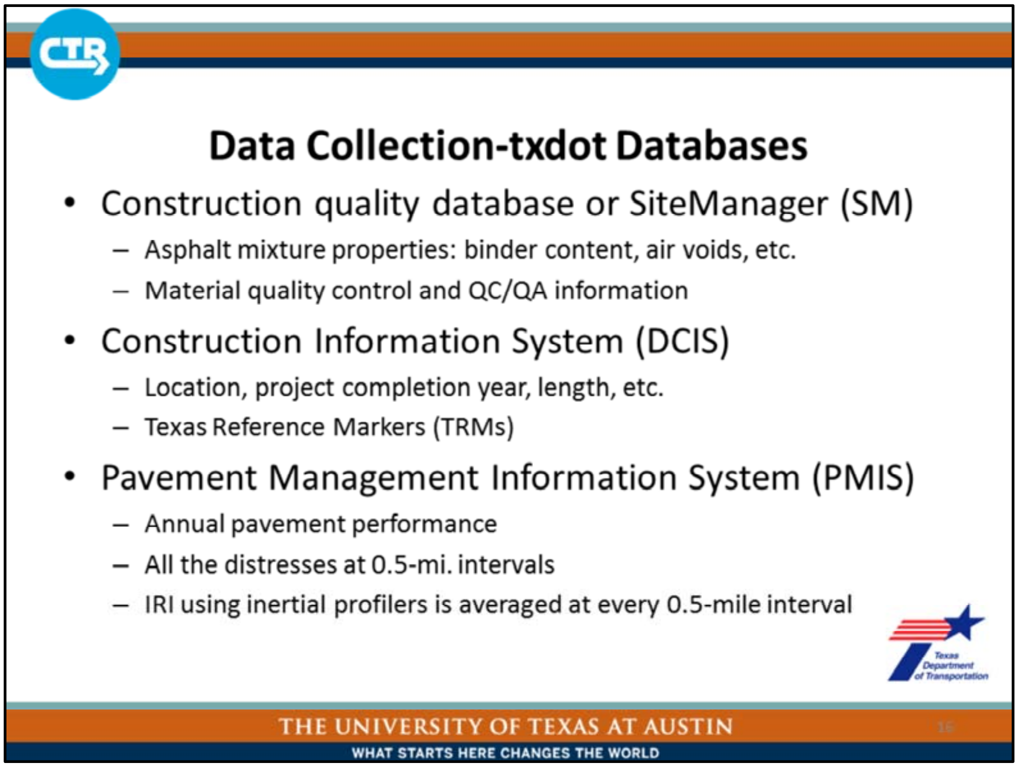


- The student should understand and discuss the need for a 250 mm filter.

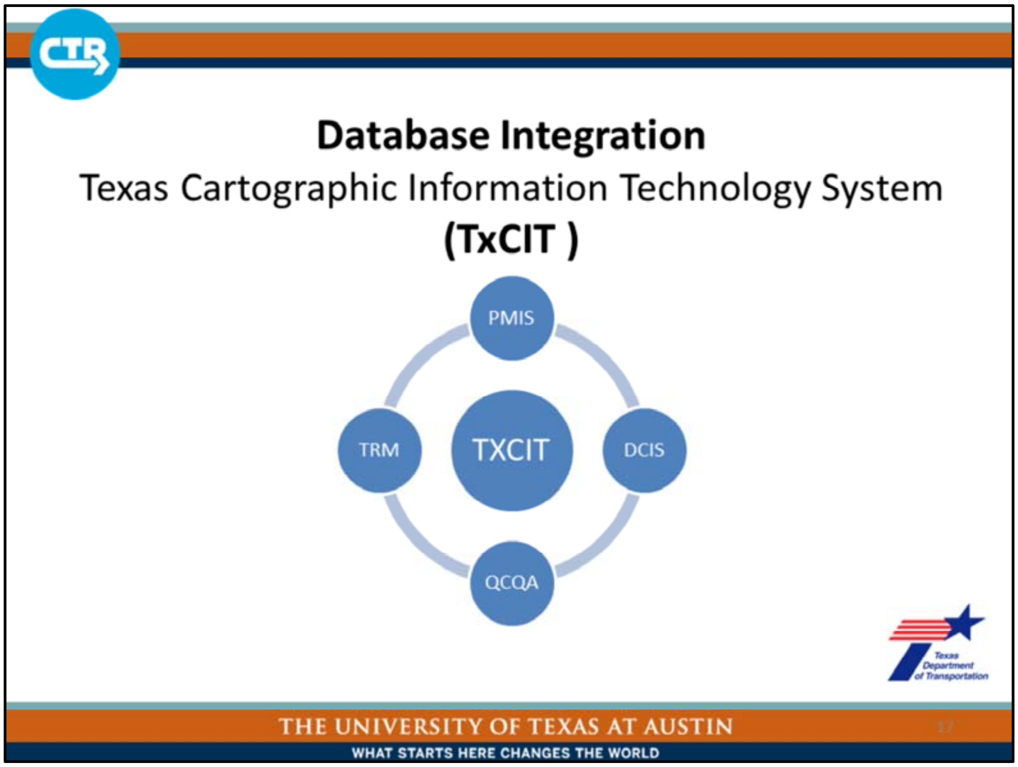


- The student should understand:
  - the quarter-car filter, and
  - the definition of roughness

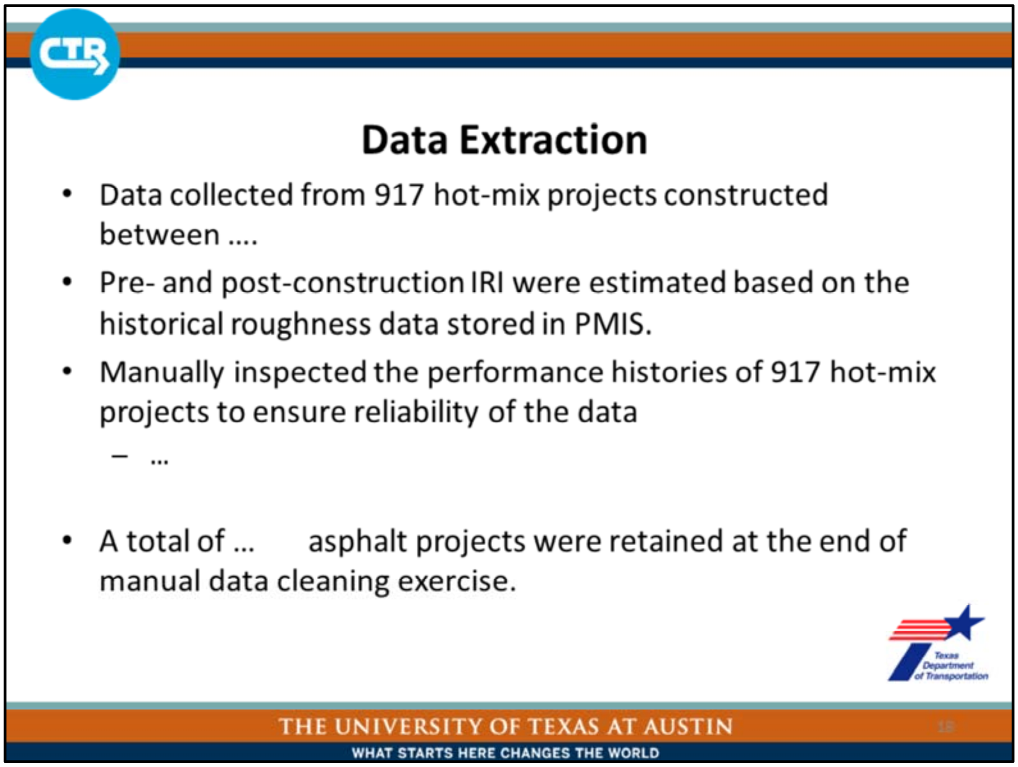
Part 1
Pay Adjustment



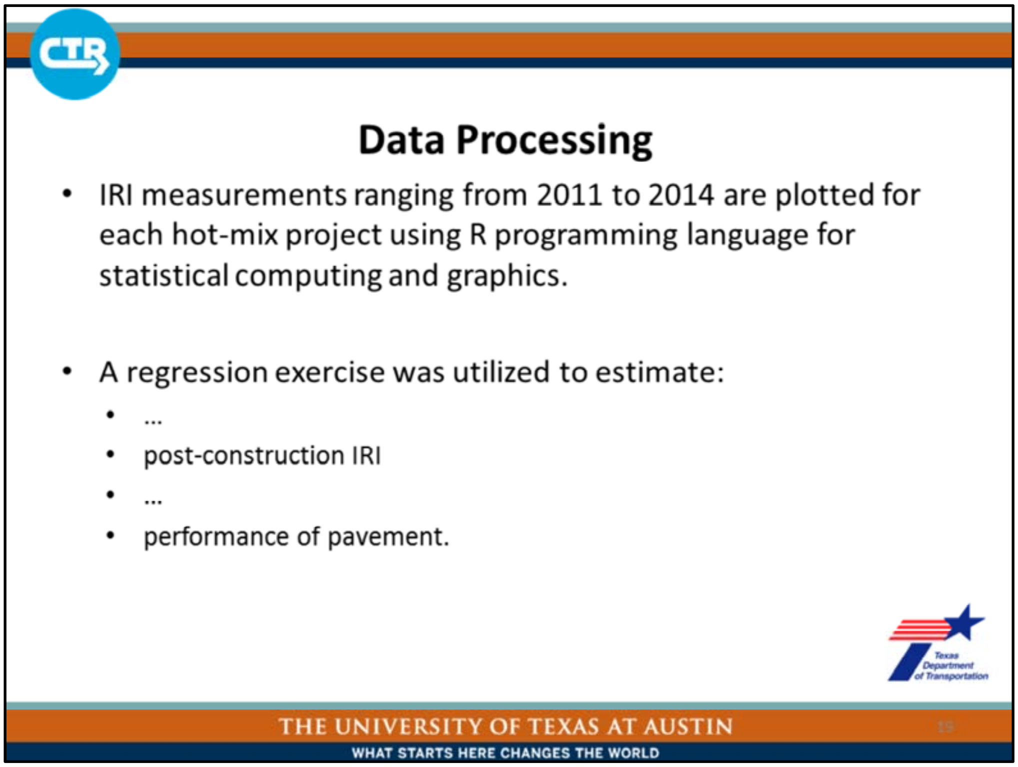
- The student should discuss the various TxDOT databases.
- The student should review the following concepts:
    - distress score (DS)
    - ride score (RS)
    - condition score (CS)



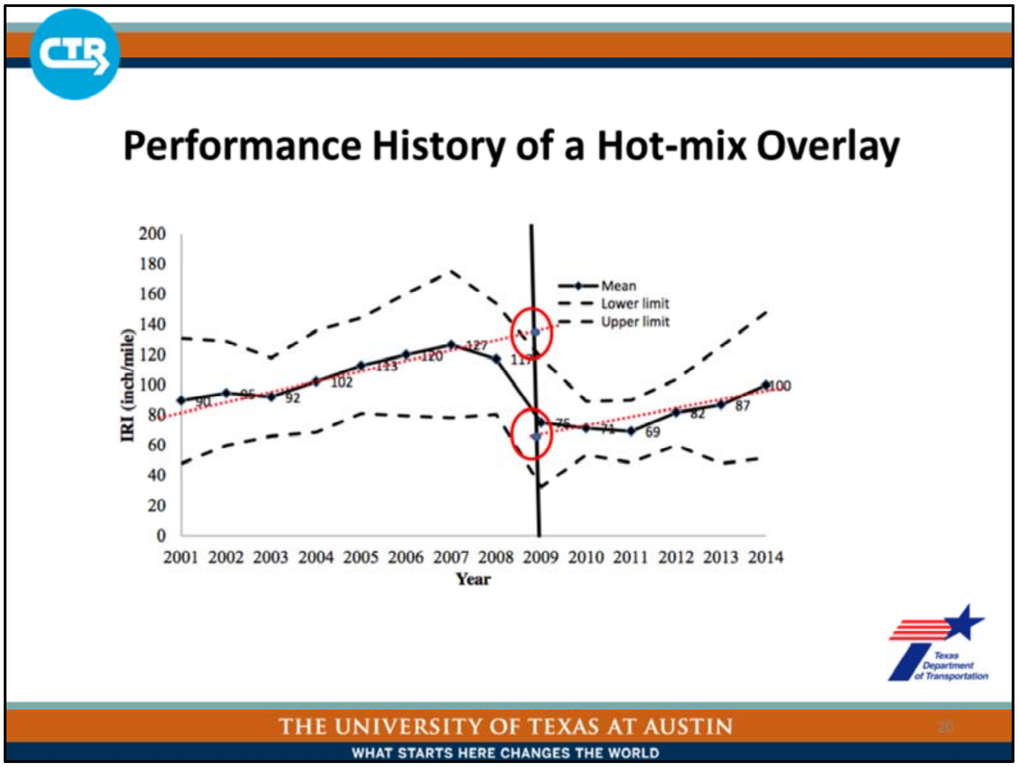
- The student should understand the Texas Cartographic Information Technology System (TxCIT) database



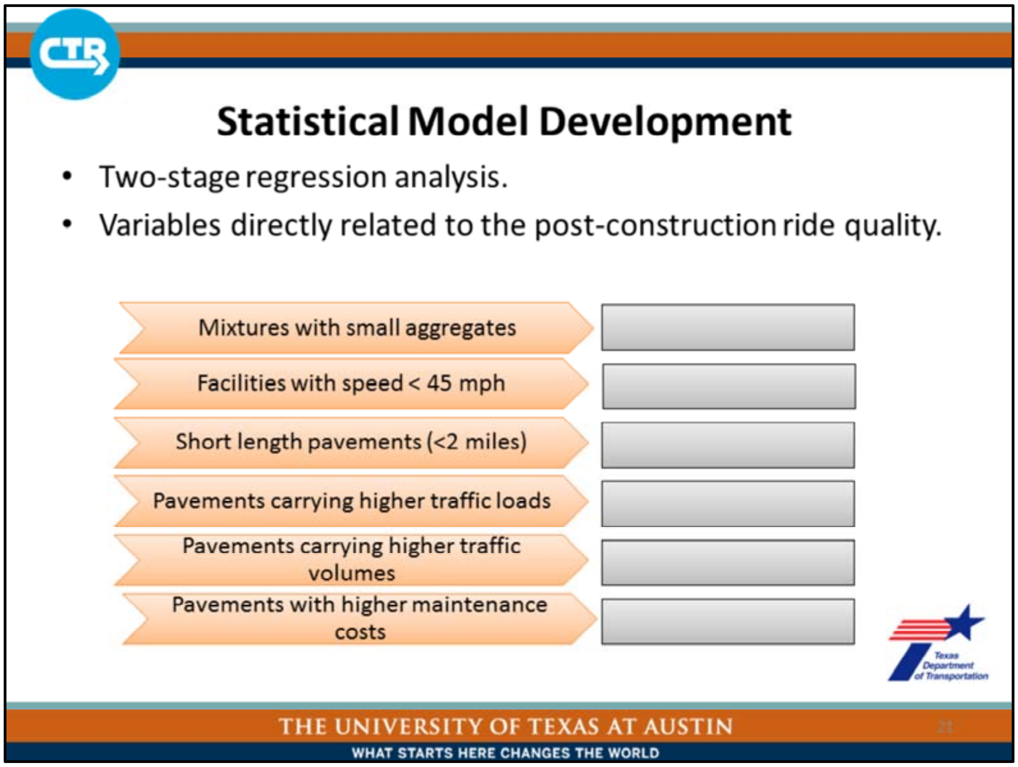
- The student should understand the real issues that involve actual data.
- The student should discuss issues that causes the reduction of the size of the database.



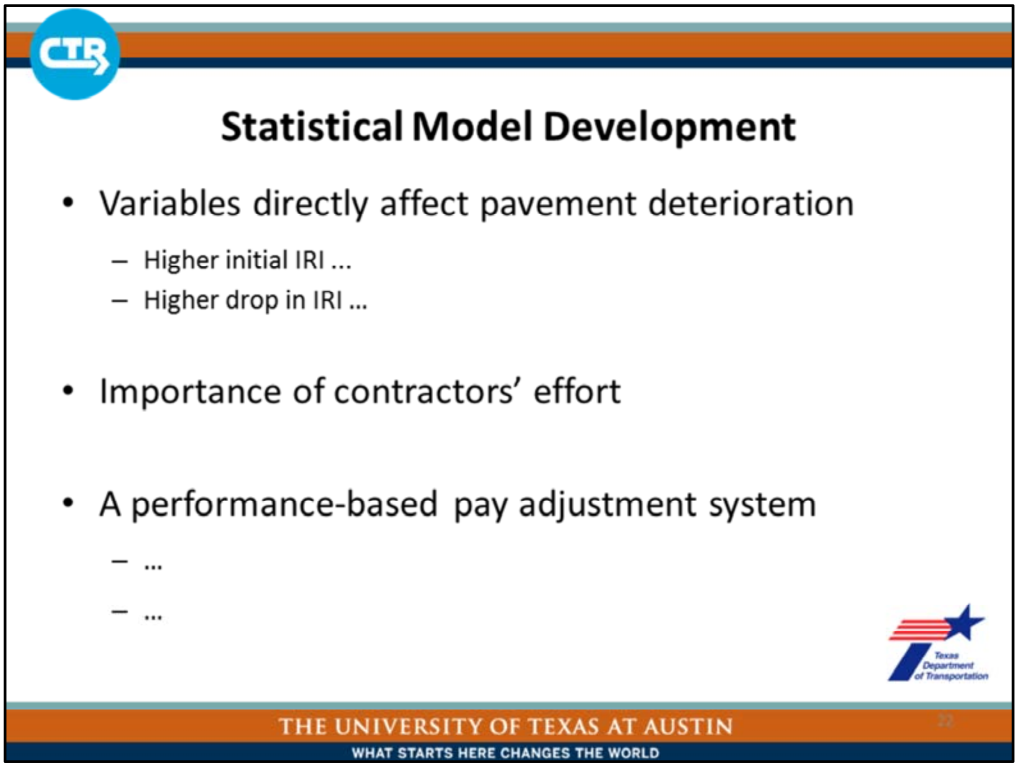
- The student should review the concepts of linear regression and understand its benefits.



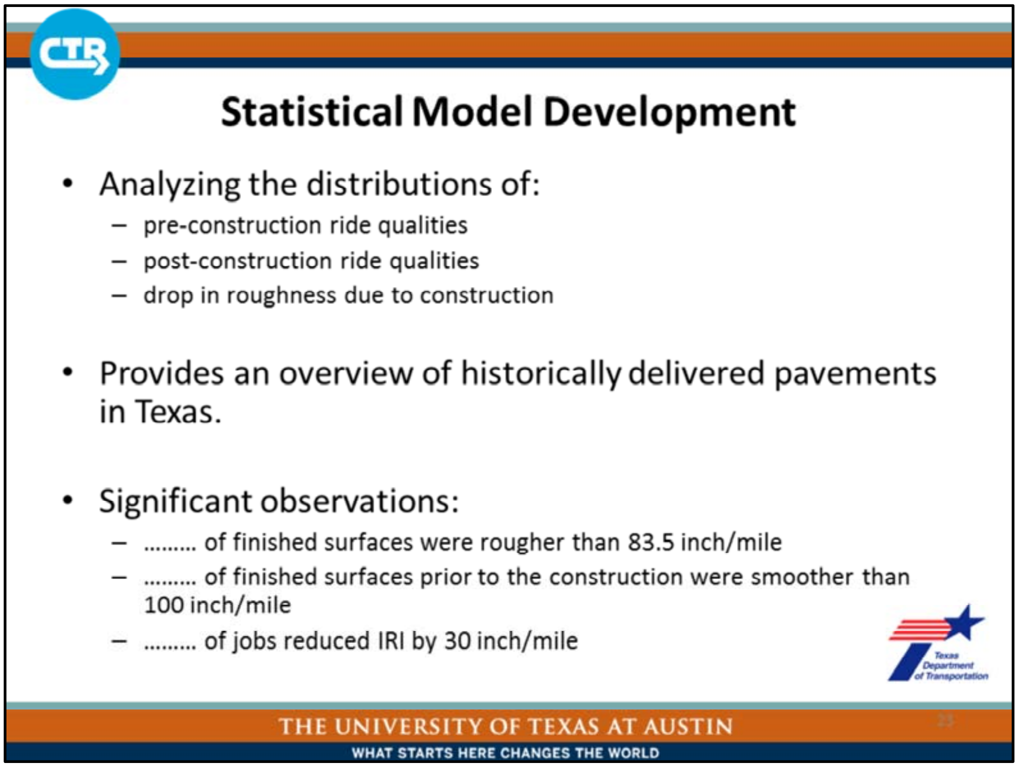
- The students should discuss the following concepts:
    - regression analysis, slope, and intercept
    - mean, standard deviations
    - initial condition and performance



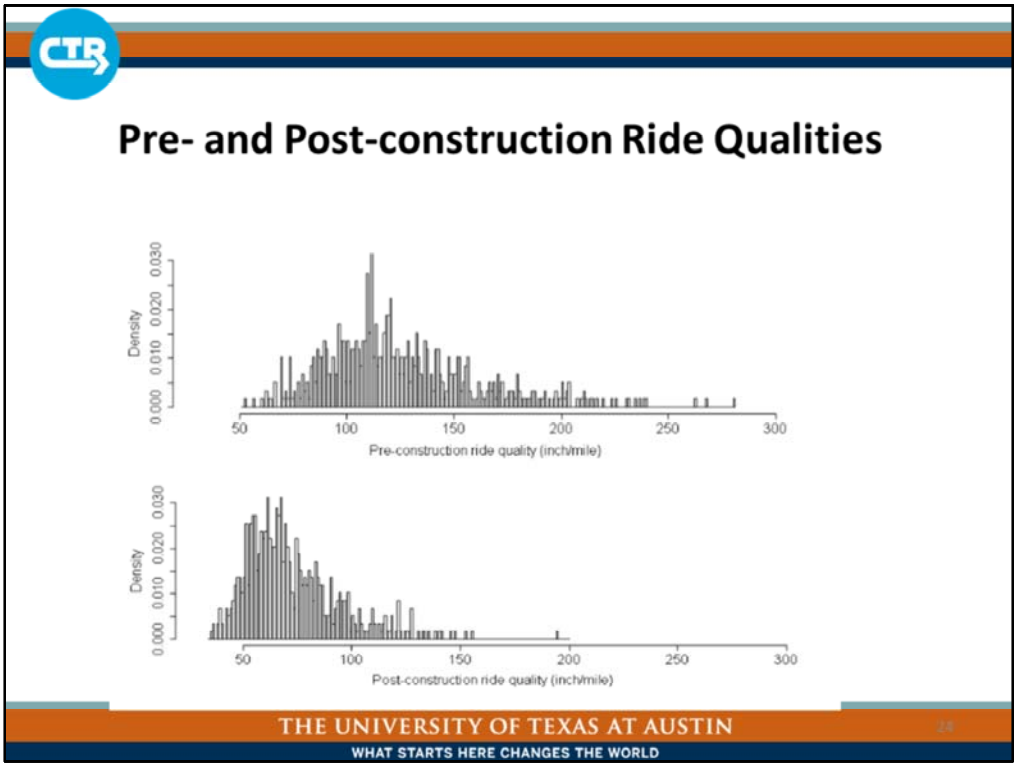
- The student should “critically” discuss the main findings of the regression analysis model.



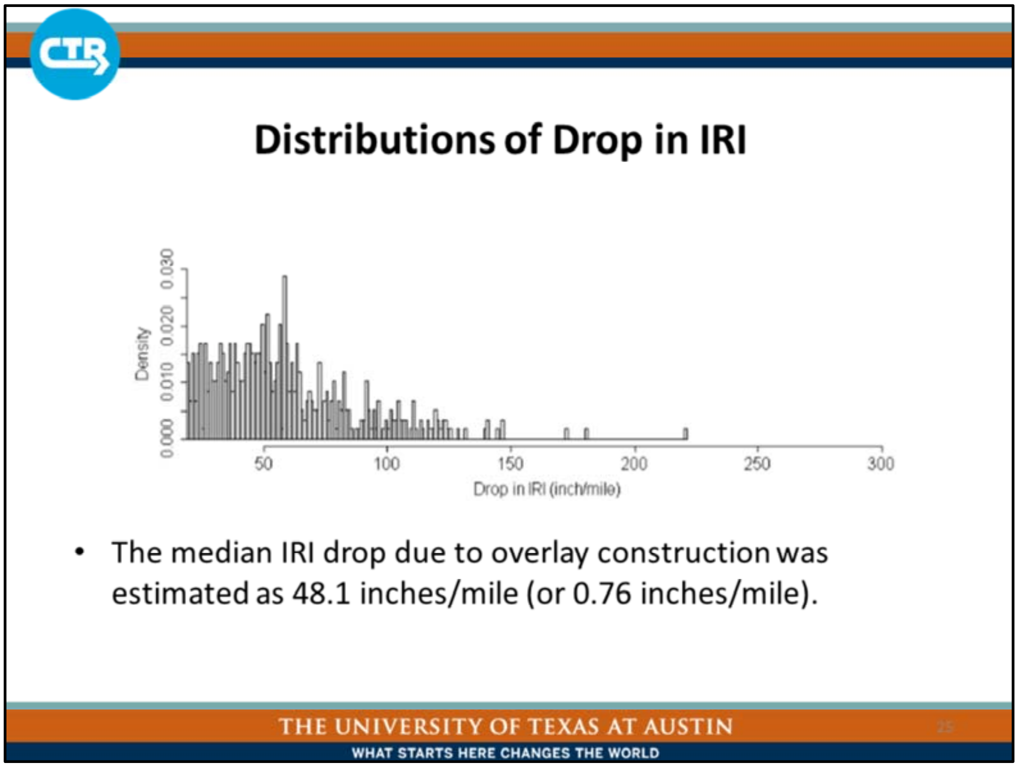
- The student should understand the main findings of the model and discuss its practical implications.



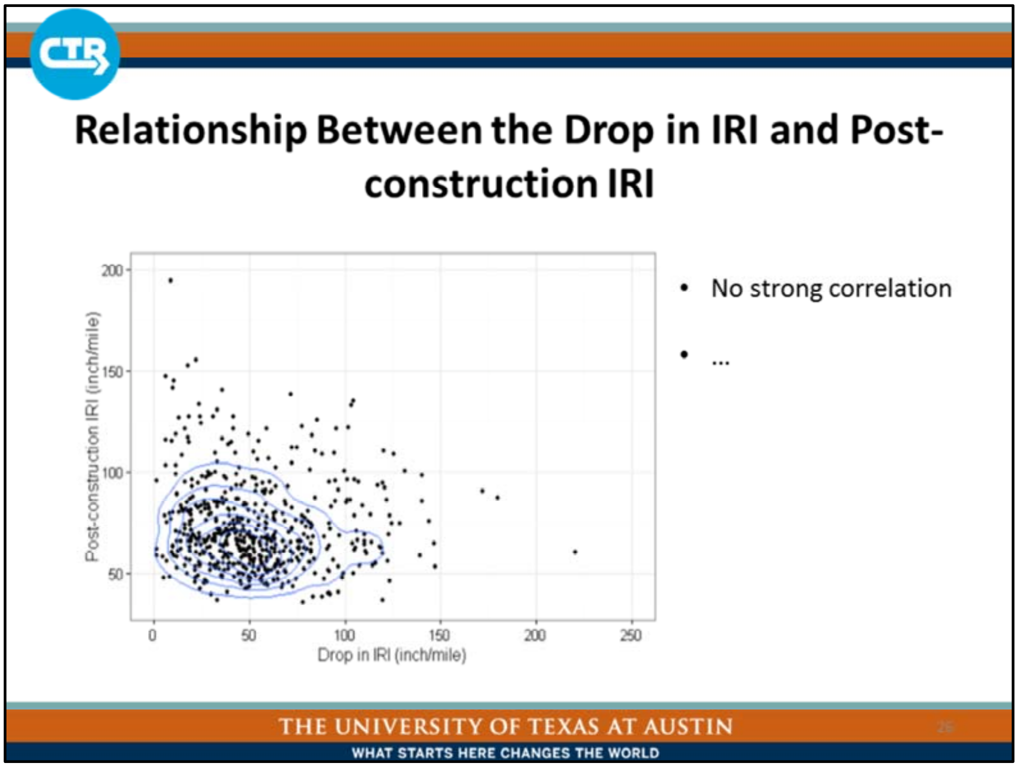
- The student should discuss the concepts of random variables and their distribution.



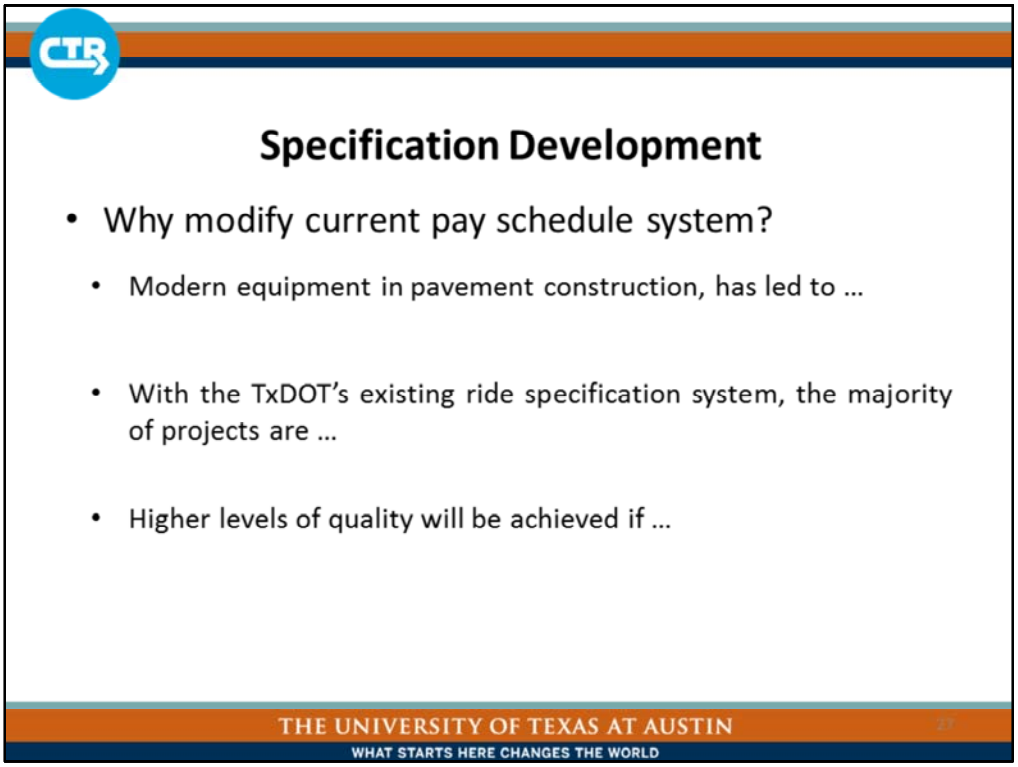
- The student shall compare the distribution of pre- and post-construction IRI distributions:
    - mean?
    - standard deviation?
    - reasons?



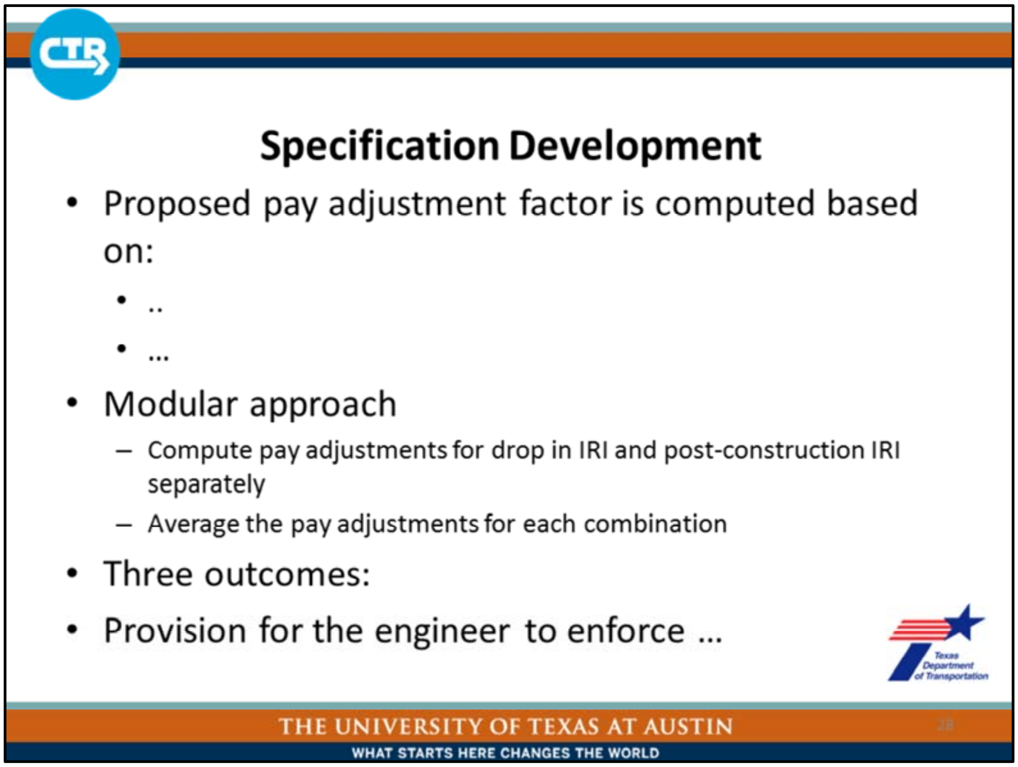
- The student should discuss the concepts of percentiles and quartiles of the distribution: What is the practical meaning?



- The student should discuss the relationship between post-construction IRI and drop in IRI.
- What is the meaning of correlation?
- Correlation vs. cause-effect relation.



- The student should discuss the need (or not) to revise the current TxDOT specification:
    - Discuss current specification and its advantages and disadvantages
    - How would the student improve current specification?



- The student should critically evaluate the proposed specification:
    - logic
    - thresholds

IRI drop / Initial IRI	0 to 32 inch/mile or < 0.5 m/km	32 to 55 inch/mile or 0.5 to 0.87 m/km	55 to 75 inch/mile or 0.87 to 1 m/km	75 to 95 inch/mile or 1 to 1.5 m/km	>95 inch/mile or > 1.5m/km
> 95 inch/mile or > 1.5m/km	Corrective action	Corrective action	Corrective action	No bonus/penalty or Corrective action	No bonus/penalty or Corrective action
75 to 95 inch/mile or 1 to 1.5 m/km	0.5*(Penalty.IRI + Penalty.Drop)	0.5*(Penalty.IRI + Penalty.Drop)	0.5*(Penalty.IRI + Zero.Drop)	0.5*(Penalty.IRI + Bonus.Drop)	0.5*(Penalty.IRI + Max.Bonus.Drop)
55 to 75 inch/mile or 0.87 to 1 m/km	0.5*(Zero.IRI + Penalty.Drop)	0.5*(Zero.IRI + Penalty.Drop)	0.5*(Zero.IRI + Zero.Drop)	0.5*(Zero.IRI + Bonus.Drop)	0.5*(Zero.IRI + Max.Bonus.Drop)
32 to 55 inch/mile or 0.5 to 0.87 m/km	0.5*(Bonus.IRI + Penalty.Drop)	0.5*(Bonus.IRI + Penalty.Drop)	0.5*(Bonus.IRI + Zero.Drop)	0.5*(Bonus.IRI + Bonus.Drop)	0.5*(Max.Bonus.IRI + Max.Bonus.Drop)
< 32 inch/mile or < 0.5 m/km	0.5*(Max.Bonus.IRI + Penalty.Drop)	0.5*(Max.Bonus.IRI + Penalty.Drop)	0.5*(Max.Bonus.IRI + Zero.Drop)	0.5*(Max.Bonus.IRI + Bonus.Drop)	0.5*(Max.Bonus.IRI + Max.Bonus.Drop)

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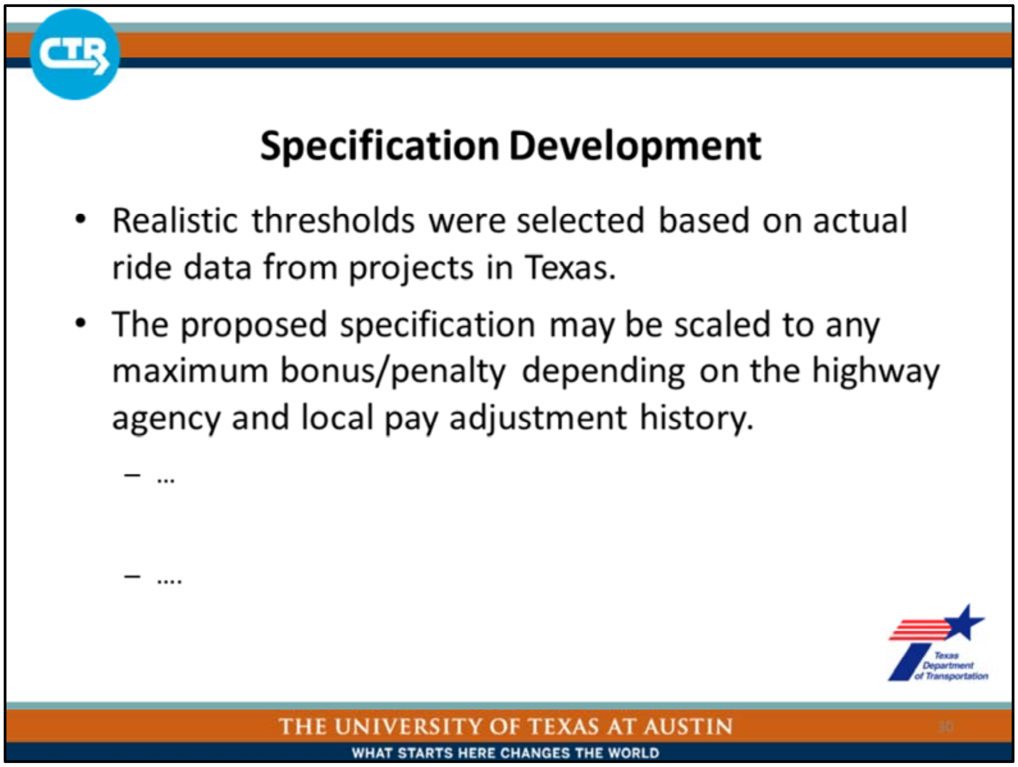
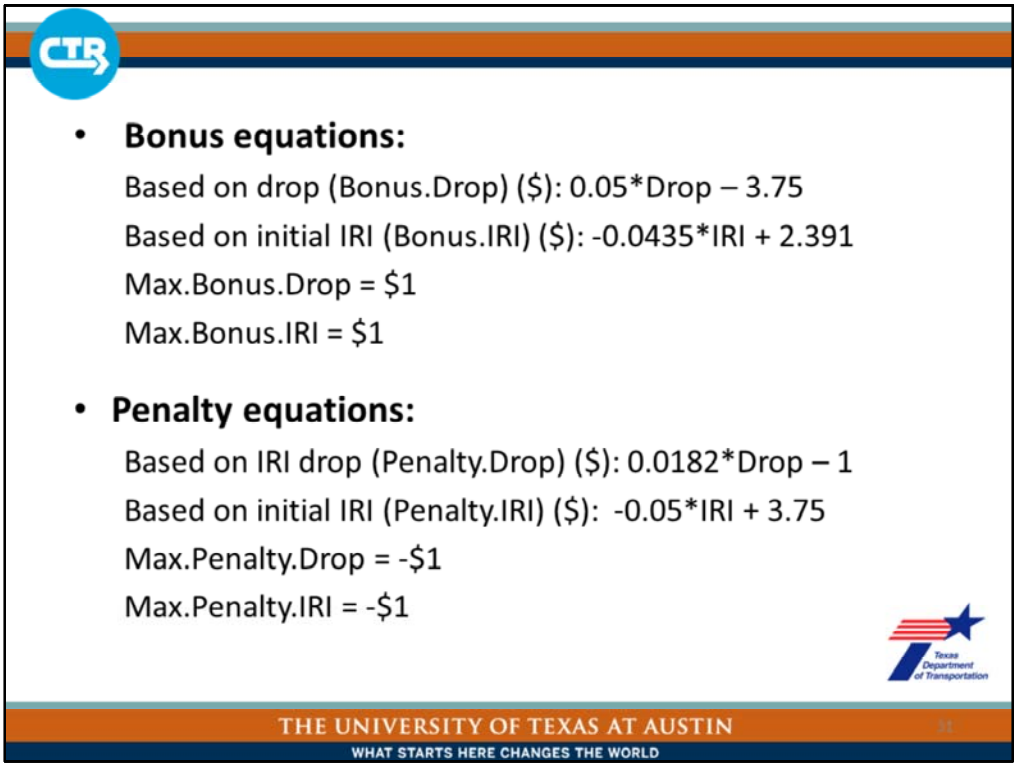
- The student should critically evaluate the proposed specification:
  - logic
  - thresholds
- The student should calculate bonus/penalty for a couple of projects and discuss the outcome.



- The student should discuss the principles that need to be applied to determine the dollar value associated with the proposed pay adjustment schedule.



- The student should apply the proposed algorithms to estimate pay adjustment factors for a few projects and compare results with the outcome of current specification.

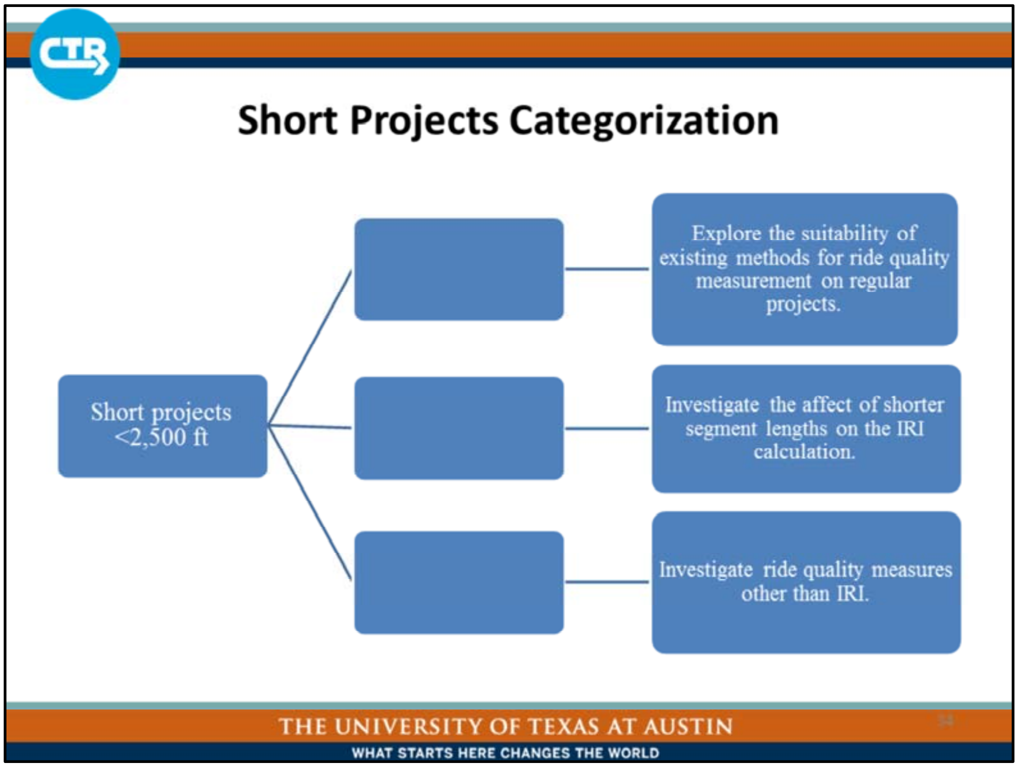
Distribution of the 565 Projects Evaluated

Initial IRI \ IRI drop	0 to 32 inch/mile or < 0.5 m/km	32 to 55 inch/mile or 0.5 to 0.87 m/km	55 to 75 inch/mile or 0.87 to 1.2 m/km	75 to 95 inch/mile or 1.2 to 1.5 m/km	>95 inch/mile or > 1.5m/km
> 95 inch/mile or > 1.5m/km	6%	4%	1%	1%	2%
75 to 95 inch/mile or 1 to 1.5 m/km	7%	6%	4%	1%	3%
55 to 75 inch/mile or 0.87 to 1 m/km	11%	15%	9%	5%	4%
32 to 55 inch/mile or 0.5 to 0.87 m/km	4%	7%	6%	2%	2%
< 32 inch/mile or < 0.5 m/km	0%	0%	0%	0%	0%

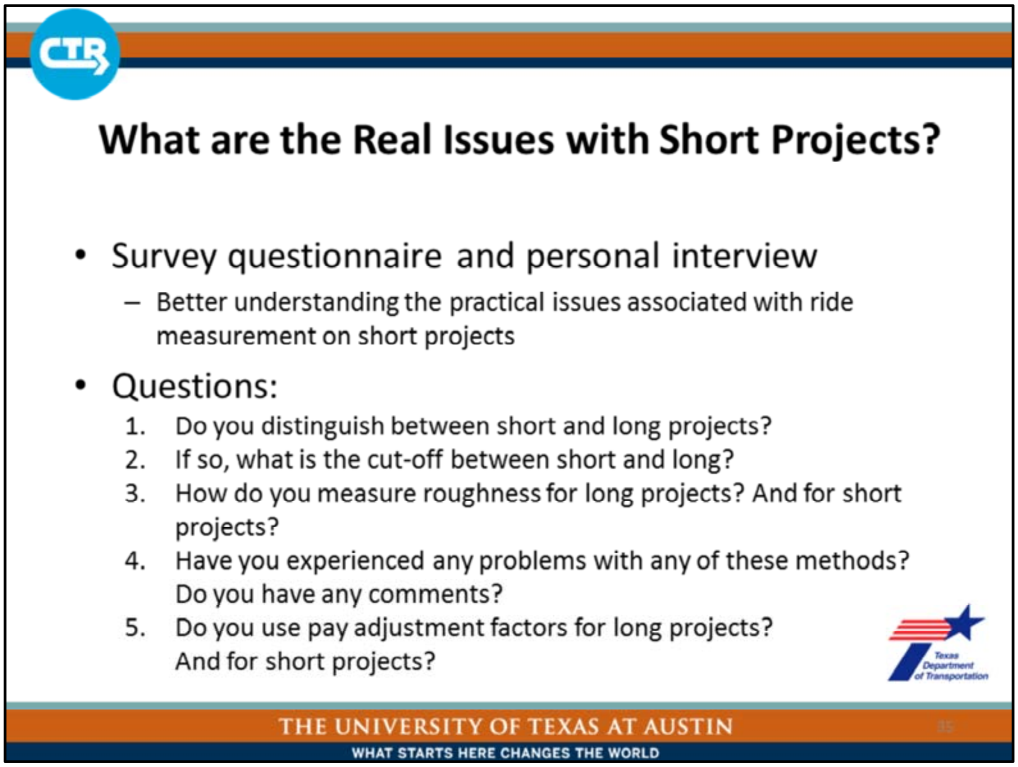
- The student should critically discuss:
    - the reasonableness of the outcome of the specifications
    - the potential acceptability of the proposed schedule by the construction industry

Part 2

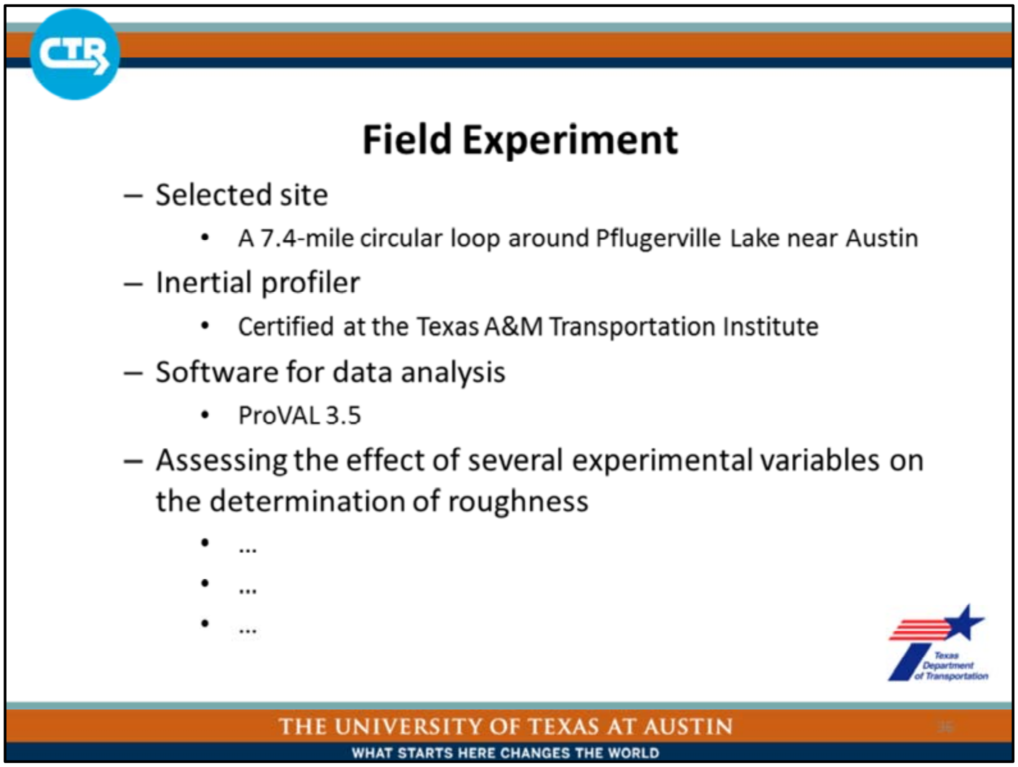
Short Projects



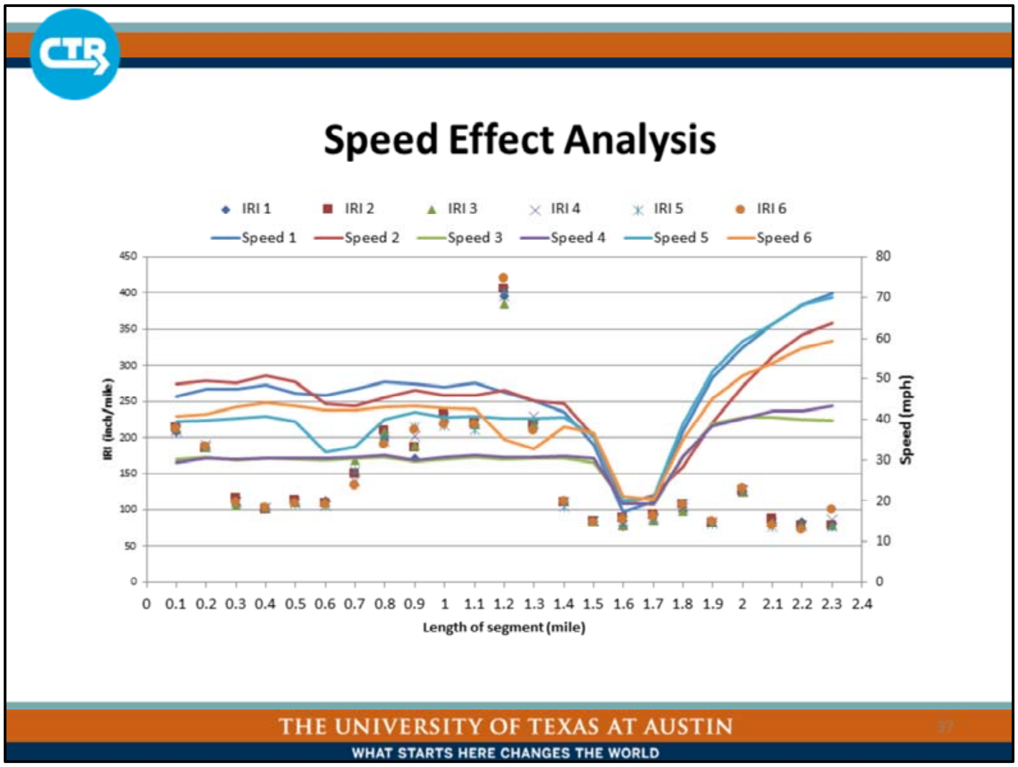
- The student should recall the concepts discussed during the development of the IRI.
- The student should understand the reasoning behind classifying a short project into the following three groups:
    - projects with lengths between 528 and 2,500 feet
    - projects with lengths between 200 and 528 feet
    - projects shorter than 200 feet



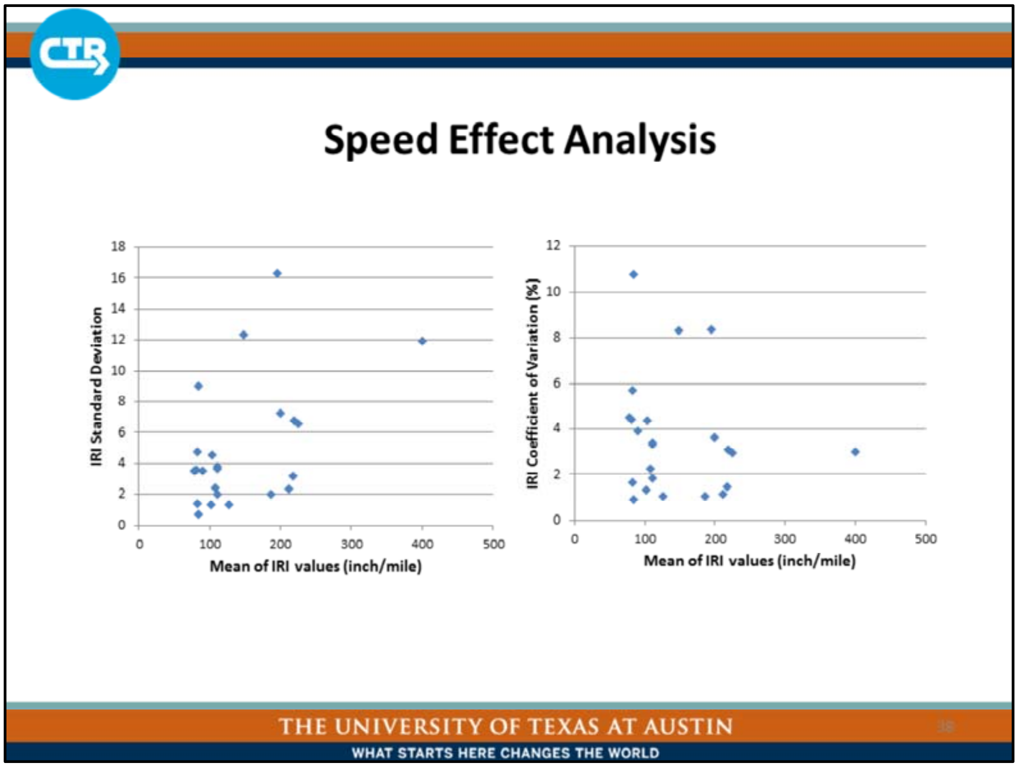
- The student should address the five questions and discuss.



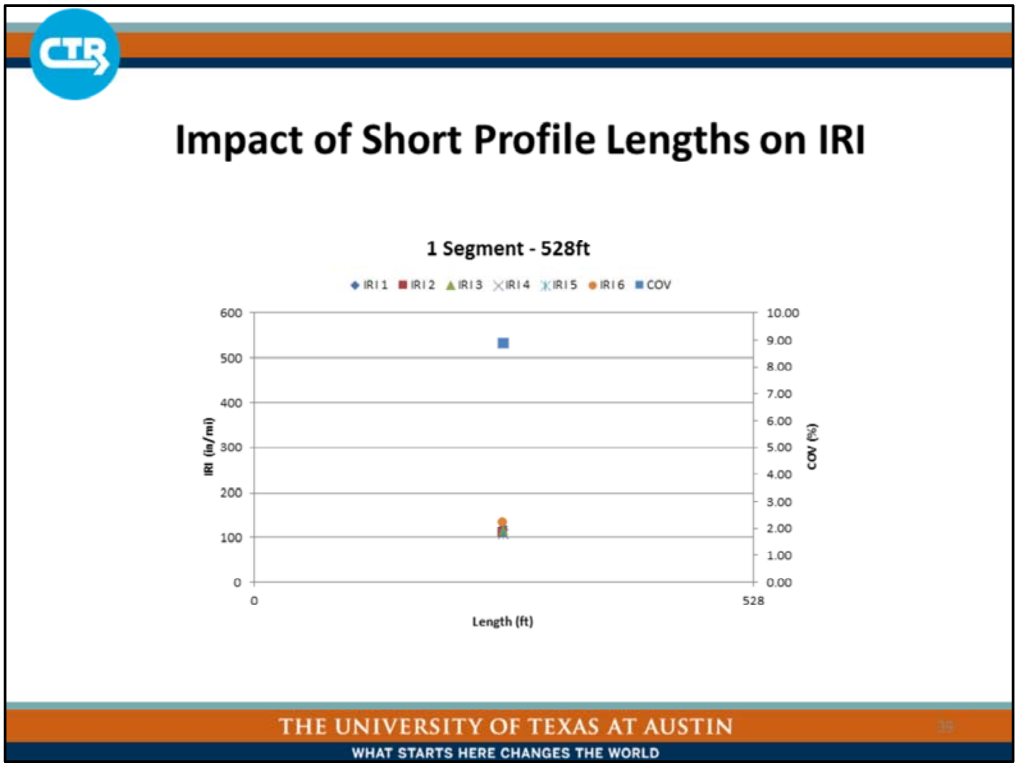
- The student should understand the field experiment and the experimental variables: speed roughness level and number of stops.
- The student shall install ProVAL and become familiar with the software.



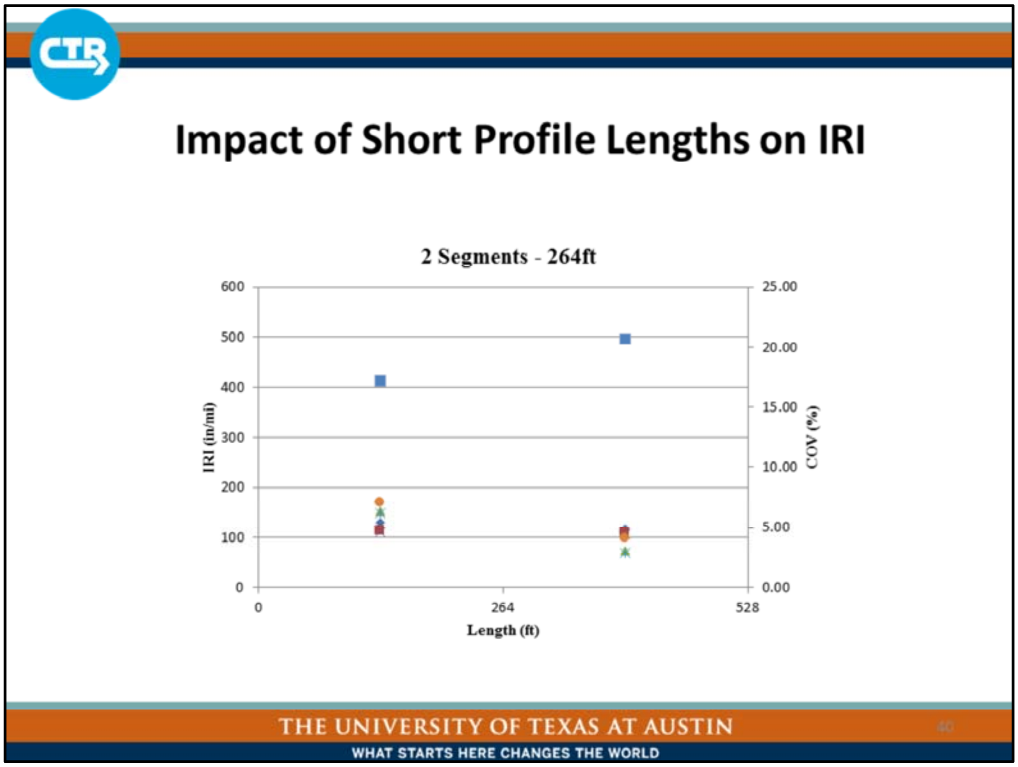
- The student should analyze the relationship between speed and roughness from the experiment and discuss the following:
    - Effect of speed
    - Are the results as expected?
    - What is the most important aspect to take into account in terms of speed?



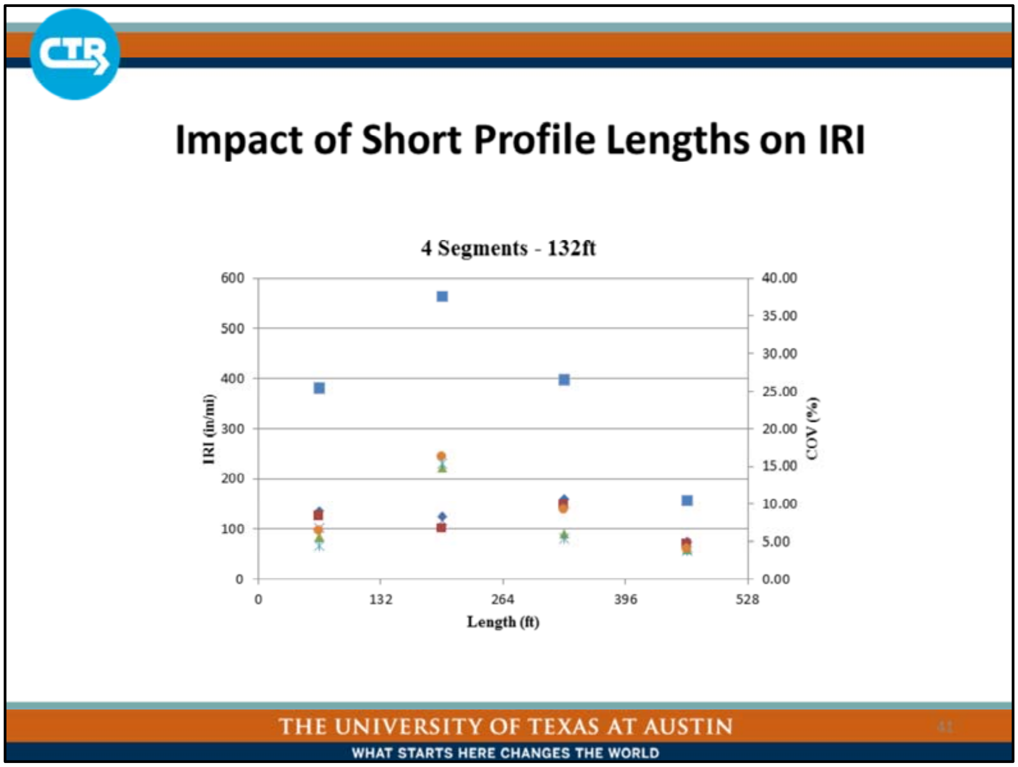
- The student should recall the concepts of mean, standard deviation (STD), and coefficient of variation (COV), and evaluate the correlation based on the two figures.



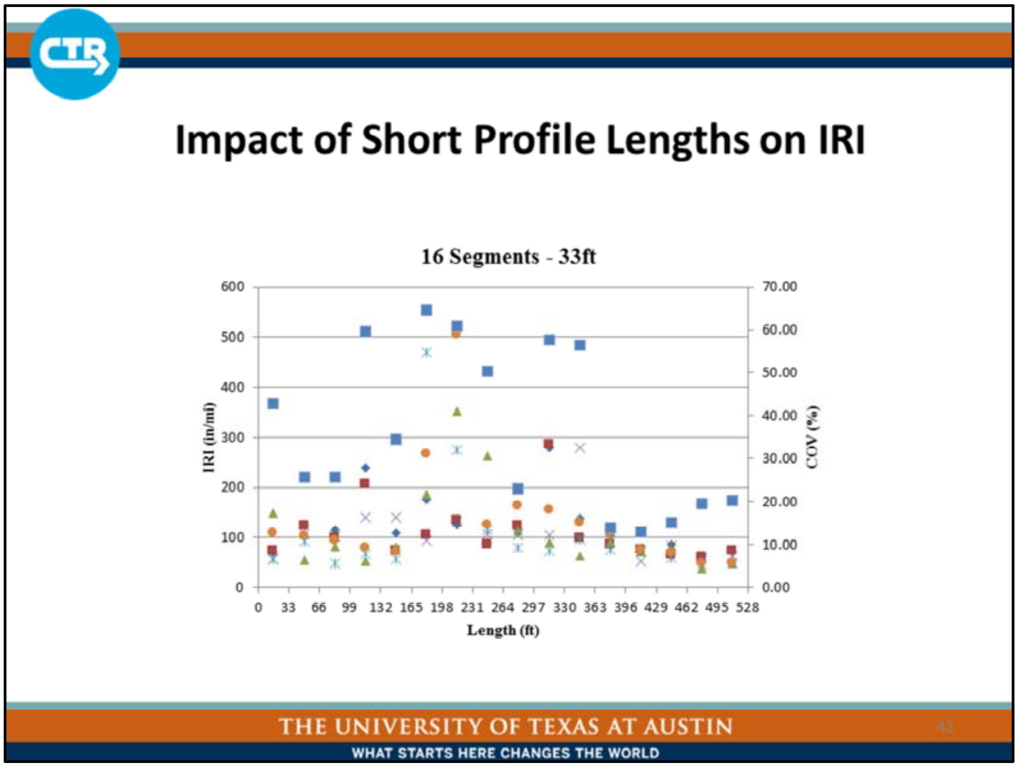
- The student should recall the concepts of the central limit theorem (CLT) and its implication on the estimation of the mean of a distribution as the sample size increases.



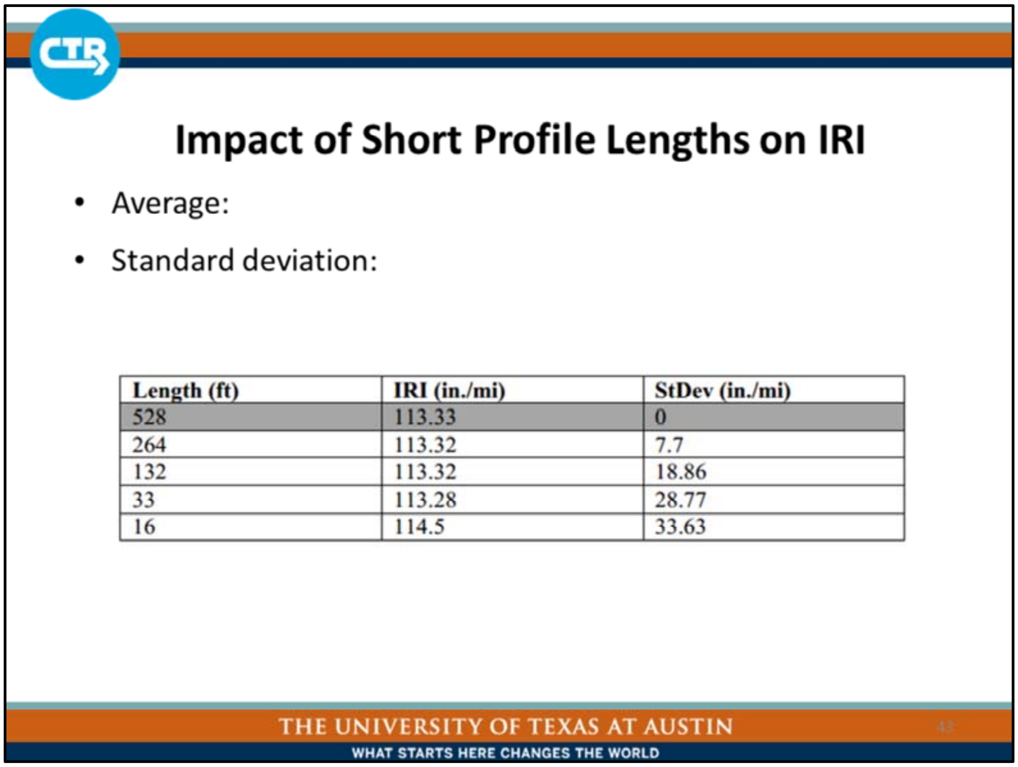
- Same notes as before apply here.



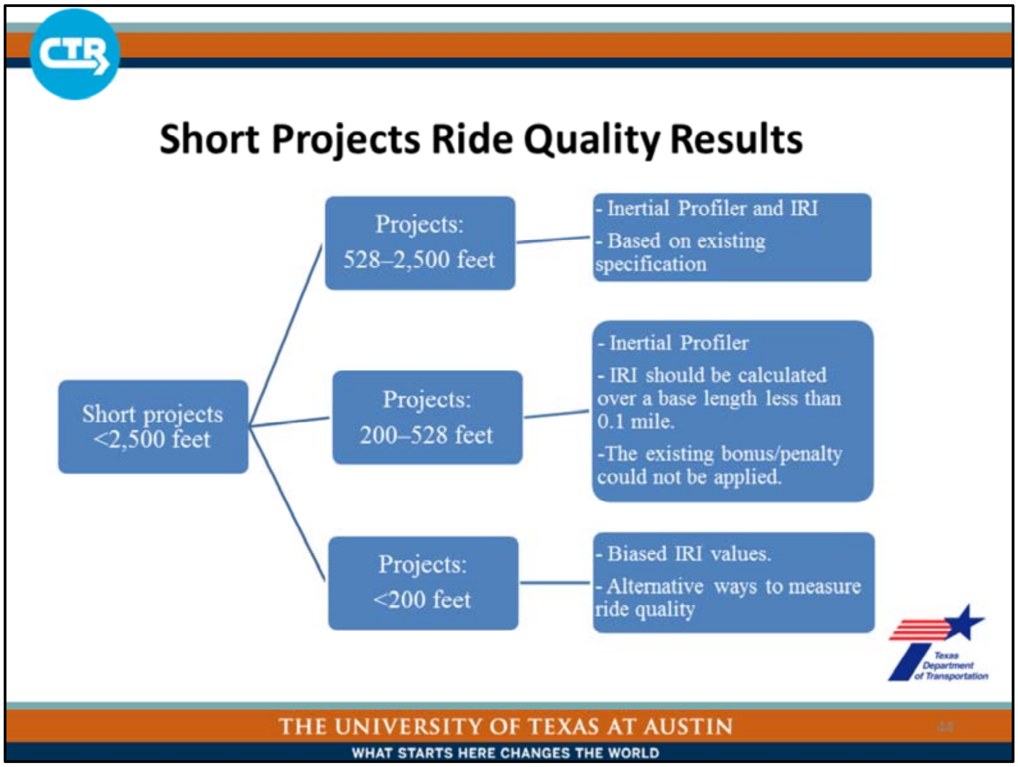
- Same notes as before apply here.



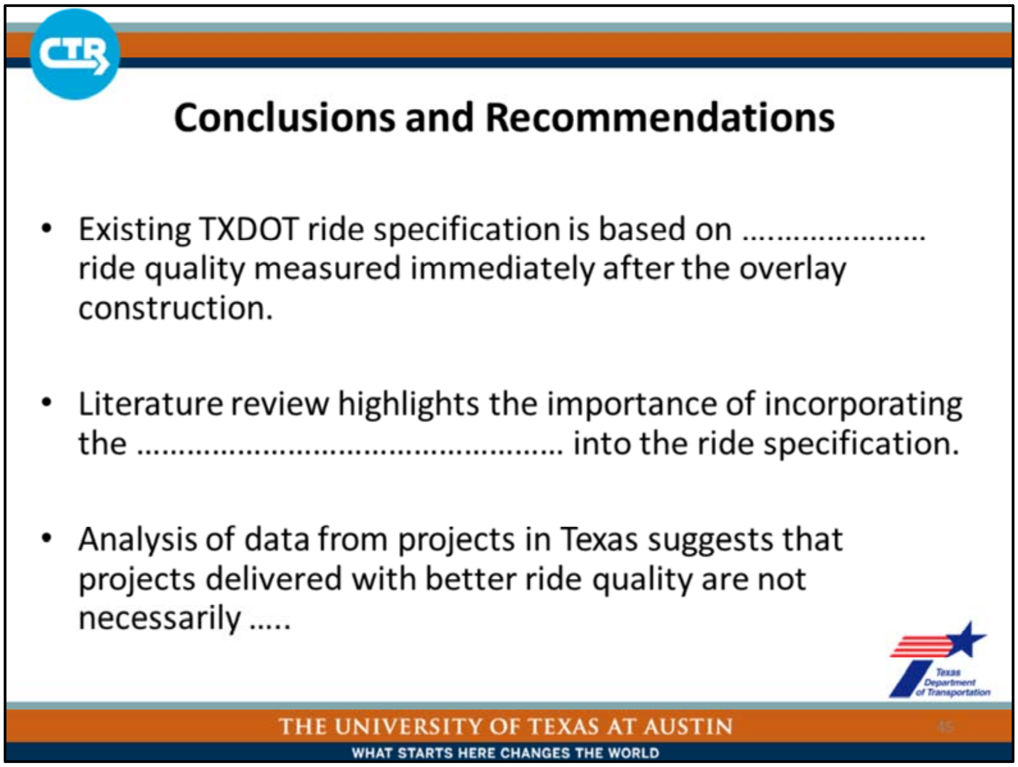
- Same notes as before apply here.



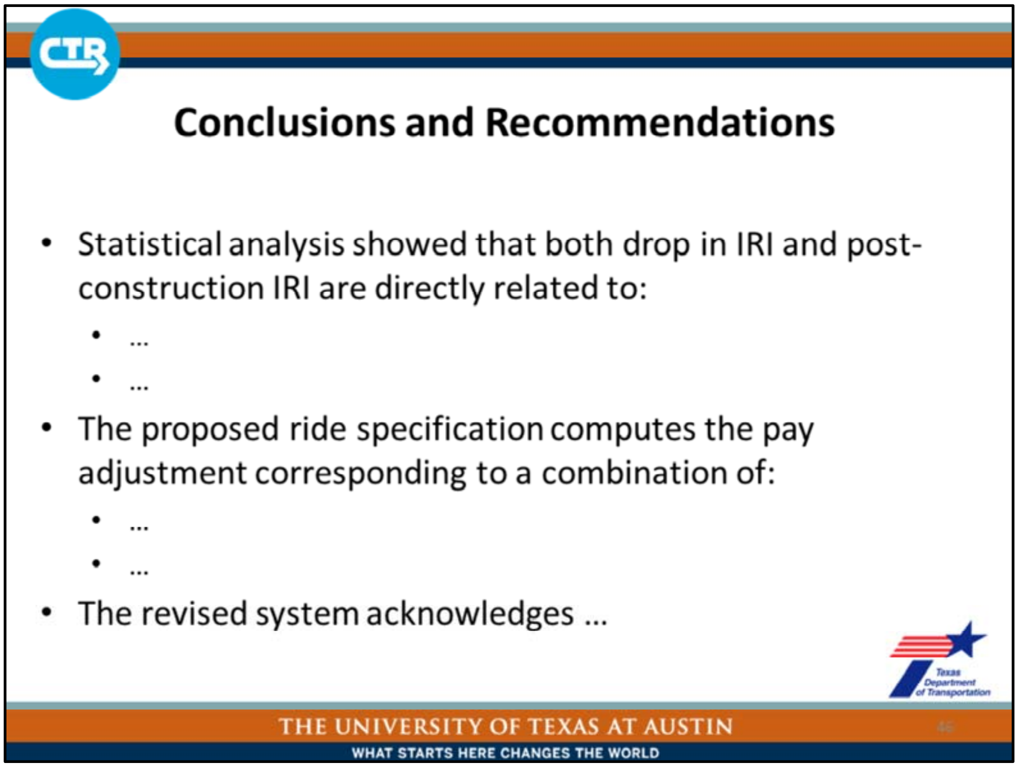
- The student should analyze and discuss the statistics presented in the table.
- The student should answer:
    - What is bias?
    - What is variance?
    - What are the implication in terms of bias and variability?



- The student should critically evaluate the recommendation presented in the table and discuss its practical implications and its potential implementation.



- The student shall discuss the reasonableness of the conclusions and recommendations of the research study.



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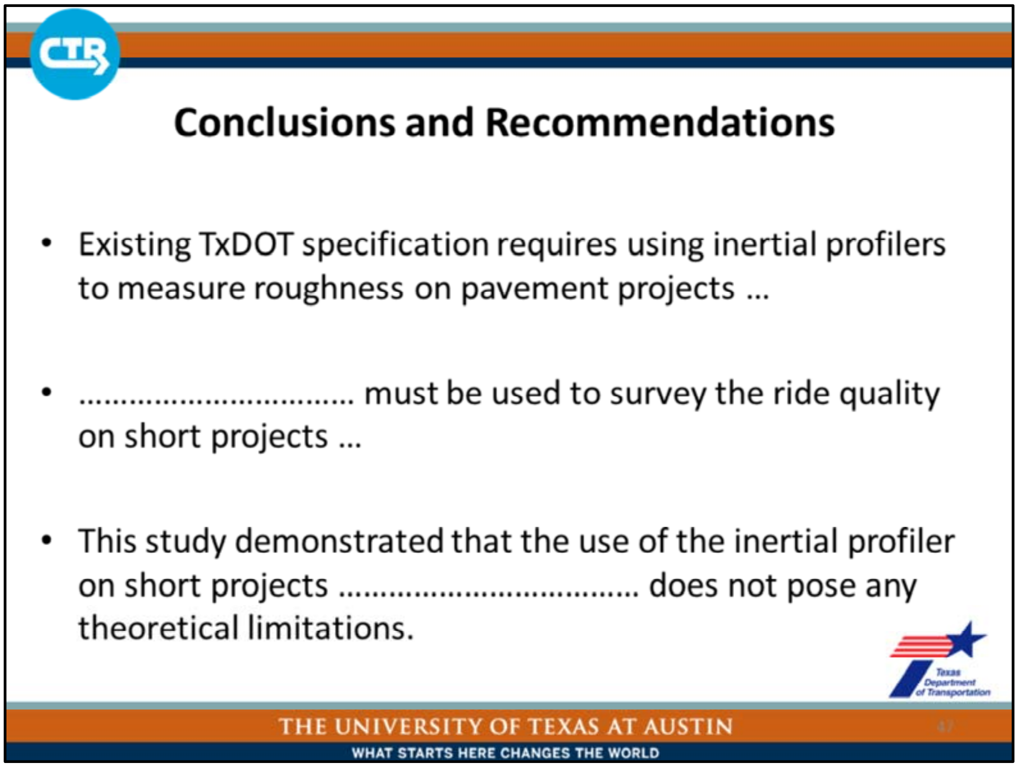

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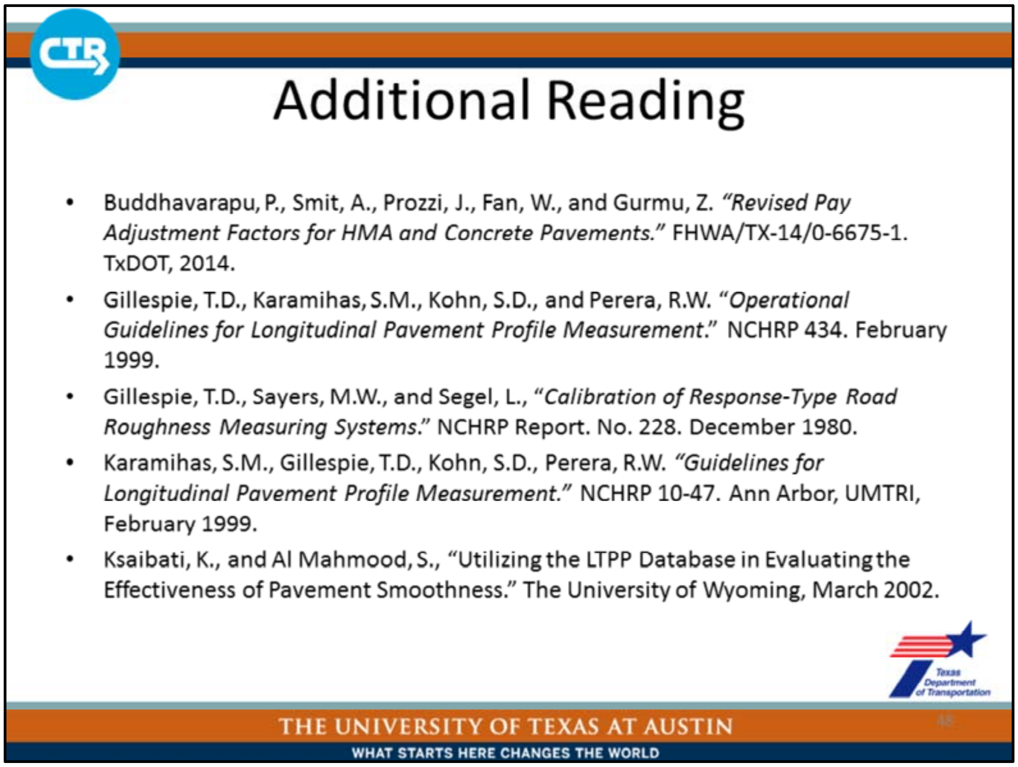

The student is encouraged to read additional bibliography as the recommended above.

Additional Reading

- McGhee, K. *"Factors Affecting Overlay Ride Quality,"* Transportation Research Record: Journal of the TRB, No. 1712. Washington, D.C., 2000 (58–65).
- McGhee, K., and Gillespie, J. *"Impact of a Smoothness Incentive/Disincentive on Hot-Mix Asphalt Maintenance Resurfacing Costs."* FHWA/VTRC 06-R28. Virginia Department of Transportation, 2006.
- Merritt, D.K., Chang, G.K., and Rutledge, J.L. *"Best Practices for Achieving and Measuring Pavement Smoothness: A Synthesis of state-of Practice."* FHWA/LA.14/550. The Transtec Group, Inc., 2014.
- Michigan Department of Transportation, Special Provision for Pavement Ride Quality. 2012.
- Minnesota Department of Transportation, Standard Specification for Construction. Department of St. Paul, Minnesota, 2016.
- Missouri Department of Transportation, Missouri Standard Specification for Highway Construction. 1999.

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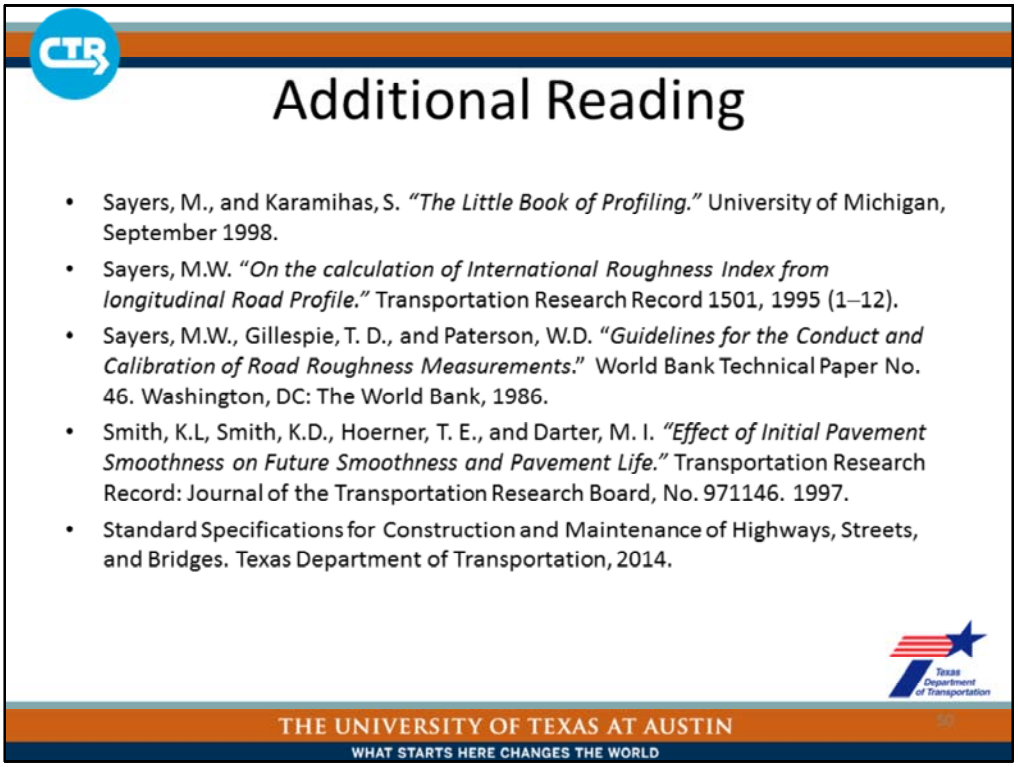

The student is encouraged to read additional reading, such as the sources recommended above.