STATE OF FLORIDA

Assessing the Appropriate Construction Quality Index for Florida

Contract No. PR608014

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STATE MATERIALS OFFICE

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The opinions, findings and conclusions expressed in this publication are those of the authors and do not necessarily reflect those of the State of Florida Department of Transportation.

SI (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
ILLUMINATION				
lx	lx	lx	lx	lx
cd/m^2	cd/m^2	cd/m^2	cd/m^2	cd/m^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
FORCE and PRESSURE or STRESS				
N	newtons	0.225	pound force	lbf
kPa	kilopascals	0.145	pound force per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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16. Abstract

All Florida Department of Transportation (FDOT) pavement projects are accepted in accordance with one or more construction specifications. The purposes of these specifications are to provide guidance and establish minimum requirements that enable a quality product to be built. The final product must meet the expectations of the designer to protect public safety and provide the expected level of service.

Researchers have found that owners and contractors agree that low-quality construction work often is treated no differently than high-quality construction work. However, these beliefs are based, at least in part, on subjective opinions and not on objective measures of construction quality.

By adopting a construction quality index (CQI)—a rational measure of the overall quality of a constructed facility can be calculated by determining the quality of the individual components and linking them together to obtain a composite quality index for the job. The CQI can be used to rate the quality of the product produced by the contractor, to determine the contractor's compensation, or to lower or eliminate a contractor's qualification status.

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1 Introduction

1.1 Background

State highway agencies (SHAs) are developing strategies that improve the quality of the transportation infrastructure while coping with changes in business models and reductions in agency personnel. Changes in policy regarding the use of contractor-conducted testing in quality assurance decisions and a continuing reduction in agency personnel have increased the need for quality-driven contractors. This change, coupled with more agencies adopting performance-based and performance-related specifications, places more requirements on contractors to know and use quality management in their field operations. With more contractors providing the quality control (QC) function, the agency's role has changed to a quality assurance (QA) role. There is a need for rational, comprehensive methods to evaluate a contractor's end-product from a quality perspective; thus, there is a need for examining quality performance measurement techniques and approaches.

All Florida Department of Transportation (FDOT) projects are accepted in accordance with one or more construction specifications. The purposes of these specifications are to provide guidance and establish minimum requirements that enable a quality product to be built. The final product produced must meet the expectations of the designer to protect public safety and provide the expected level of service.

Researchers have found that owners and contractors agree that low-quality construction work often is treated no differently than high-quality construction work. For example, assume that Contractor A produces a product that nominally meets the minimum requirements of the specification with considerable variability in quality, while Contractor B produces the same product with higher quality materials and exercises superior quality control (less variability in product quality). Clearly, Contractor B's product is superior to Contractor A's product. This observation gives rise to a number of salient questions:

- How can the differences in construction quality be quantified objectively?
- How can quality indicators required by the specifications and stored in FDOT's LIMS be linked rationally to formulate quality discriminators?
- What acceptance quality characteristics are most important in determining contractor quality?
- What is the relationship between contractor quality and performance of constructed facilities?
- How can the various components of a pavement construction project be combined to develop an overall indicator of construction quality?
- Can concepts from performance-related specifications be used to assess construction quality?

Some of these questions can be answered by adopting a construction quality index (CQI)—a rational measure of the overall quality of a constructed facility, calculated by determining the quality of the individual components and linking them together to obtain a composite quality index for the job. The CQI can be used to rate the quality of the product produced by the contractor, to determine the contractor's compensation, or to lower or eliminate a contractor's qualification status.

1.2 Objective

The objective of this research was to develop a practical and effective pavement CQI. The CQI should be implemented without substantial modification to the Department's current test and measurement system. As a minimum, the CQI should address material, structural, and pavement smoothness characteristics. It should be applicable for both new and rehabilitation projects. Soils, bound and unbound granular base materials, asphalt, and concrete should be considered.

FDOT's goal is for the CQI to be used as an objective tool to evaluate the quality of pavement construction. Its formulation must be objective, that is, it must be based upon quality characteristics that are explicitly addressed in the construction specifications and directly within the control of the contractor.

The CQI formulation must be transparent and easily understood. This can be accomplished by applying concepts consistent with those already used by the Department and familiar to the contractor such as percent within limits. To the greatest extent possible, the CQI should use data from the Laboratory Information Management System (LIMS), which serves as the Department's enterprise database system for all construction quality data.

1.3 Scope

In keeping with a straightforward approach, the CQI only addresses quality factors for the major components of pavement construction, such as:

- Rigid (PCC) pavements
- Flexible pavements
- Base course
- Subgrade
- Embankment

Other aspects of contractor performance (e.g., financial resources, ownership of equipment or ability to lease equipment, adherence to schedule, job safety, past performance) are not included in this CQI formulation.

The CQI model has been formulated in a modular fashion. The model is flexible allowing it to be scaled to all pavement construction projects, from routine mill and overlay rehabilitation to major new highway pavements construction. Additionally, other components of highway construction (such as structures, deep foundations, drainage, signage, etc.) can be added in the future.

Finally, the CQI was developed with a vision for the future, which inevitably will include aspects of mechanistic-empirical (M-E) analysis. However, the research team is aware of on-going research efforts nationally and in Florida to evaluate, revise, validate, and calibrate the new Mechanistic-Empirical Pavement Design Guide (MEPDG). While M-E concepts allow the analyst to directly link fundamental material quality measures to facility performance, we do not believe that the evolution of M-E procedures is sufficiently mature for widespread acceptance of a CQI based solely upon these concepts. Therefore, our modular approach will facilitate replacing the purely empirically based performance measures with mechanistic-based performance measures in the future. We believe that adopting an M-E based approach before sufficient evaluation, validation, and calibration jeopardizes acceptance of the CQI by skeptics of the MEPDG as it is currently proposed.

2 Literature Review

2.1 Introduction

A survey of SHAs was conducted to determine what their plans or policies are in this area. The results are summarized in the Appendix A. Most SHAs are using subjective measures to pre-qualify contractors.

Hybert (1996) reviewed quality problems in owners that use a contracting process to provide customized, large-scale systems or products. This can be extended to quality problems on many construction projects. He asserts that current bid practices may de-emphasize the importance of partnership between the contractor and owner so that both work toward the same end. Instead, these practices put the contractor and owner in an adversarial relationship, possibly putting one party in a position where it needs to take drastic measures to recover. Too often, contractors are winning contracts by underbidding, exaggerating delivery capabilities, underestimating the project risks, or under-solving the technical problems, just to get a lower price than their competitors. They are also rewarded by change orders for their ability to argue specification interpretation issues.

The concept of teaming or partnering (in a non-legal sense) stresses having fewer suppliers and working closely with them so they understand the customer's needs well. This way, both the customer and the supplier have a stake in each other's success. There are risks to both parties in a teaming approach, since it requires mutual trust. Teaming can reduce the need for costly risk management tactics (change orders, claims, using the specifications as a shield to avoid work requirements, etc.).

2.2 Performance-Related Specifications

Transportation agencies are switching from end-result specifications (ERS) that define end product quality to performance-related specifications (PRS) that specify quality in terms of desired long term performance. PRS describe the desired levels of key construction quality characteristics that correlate with engineering properties and apply mathematical models to predict future pavement performance.

The FWHA (2001) listed the following benefits of using PRS:

- Establishes a direct relationship between quality characteristics and product performance
- Identifies an optimum level of quality
- Provides a rational basis to set the appropriate level of penalty/bonus for inferior/superior quality
- Provides a critical link between construction and engineering management systems.

Also, PRS help transportation agencies forecast future performance, maintenance requirements, and life-cycle costs.

An assumption that legitimate mathematical relationships have been established between characteristics measured at the job site and the expected performance of the construction activity is required in order to determine an appropriate amount of pay reduction/addition as penalties/bonuses of inferior/superior construction quality. However, for most factors, there are no such convenient or simple relationships. Therefore, a method to develop the required relationships is required.

A comprehensive approach for the development of performance models for network-level Pavement Management System (PMS) using Long Term Pavement Performance (LTPP) data was presented by Bekheet et al. (2005). Conventionally, historical performance and inventory data have been used for developing these pavement performance models. However, historical data may not be appropriate to use because field data collection equipment has been continually improved, and inventory records may be incomplete.

As an alternate reliable source of data for developing pavement performance models, the LTTP was used. Once base pavement performance models have been developed, they can be adapted to agency-specific experience and data to render agency-specific models. (Bekheet et al. 2005)

Buttlar and Harrell (1998) reported the SHAs' efforts to develop an implement end-result and performance-related specifications (ERS/PRS) in Illinois. They stated that PRS provided the ultimate method of compensation for a delivered product even though such a system could be challenging to develop. They suggested development and implementation of a specification that combined elements of ERS and PRS considering the existing technology level, available materials, and test equipment. As key steps for developing the combination specification, the authors presented the following:

1. Make an initial move to statistical quality QC/QA.
2. Develop a comprehensive ERS to consider all relevant quality characteristics.
3. Monitor and foster development of primary and secondary prediction relationships.
4. Develop performance-related pay factors.
5. Compare performance-related pay factors with ERS pay factors, which were developed based upon experience.
6. Periodically repeat steps 3, 4, and 5 to move from ERS to PRS.

Noureldin (1997) presented an approach to estimate the deviation from pavement performance life caused by any deviation in the as-built characteristics from the as-designed characteristics. The deviations can be used to set up the basis for measuring the rational pay adjustment. To get the estimation, key quality control aspects in asphalt pavement construction such as asphalt content, aggregate characteristics, pavement layer thickness and their degree of compaction, and initial pavement smoothness are quantified using a partial derivatives approach. While Noureldin's approach is generally applicable, his published relationships are only valid for one particular scenario in Saudi Arabia.

Weed (1998) proposed a method for developing pay schedules based upon the need for a rational method to relate as-built quality to expected performance and ultimate value as the basis for reliable and defensible pay schedules. The pay factor in the method can be expressed as a monetary value rather than as a percentage of the bid price of the pavement. This method is believed to more appropriately reflect the true value of departures from the design level of quality since the actions upon which the pay reduction is based are not a function of the thickness of the pavement layer itself or bid price.

In order to develop mathematical models to predict pavement performance, analytical data and survey data can be used and several examples are shown. Then, the models were combined with other models which relate expected life to present value to obtain rational and practical pay schedules.

In a later work Weed (2000) presented a method for combining the effects of multiple deficiencies. Air voids and thickness of HMA pavement are factors used to decide if a lot of HMA pavement is rejectable or not. In the current New Jersey DOT specification for HMA pavement, the rejectable quality level (RQL) for both air voids and thickness is 75 (in terms of percent defective), which means that if any one RQL of the two characteristics is more than 75, then the agency reserves the right to order removal and replacement of the deficient pavement. This might not consistently distinguish poor quality pavement from acceptable quality pavement, because a pavement job with two items rated as having poor quality levels but each barely within the acceptable range may be a worse case than the another pavement job with an excellent quality level for one characteristic but a quality level above the RQL in another characteristic. To determine an appropriate method to assess the combined effect of deficiencies in air voids and thickness, survey data were used. Based on the performance model with combined effects, several pay equations were presented.

Weed and Tabrizi (2005) explained the development of a statistical acceptance procedure for hot-mix asphalt pavement smoothness using the international roughness index. As procedural steps, Weed and Tabrizi (2005) suggested the following.

- Select a quality characteristic that relates to performance
- Select a statistical quality measure upon which acceptance will be based
- Select an appropriate mathematical form for the performance model
- Obtain data to calibrate the performance model
- Apply life-cycle-cost analysis to determine appropriate pay levels
- Convert this information into an appropriate pay schedule
- Define lot size and sample size
- Finalize the prototype specification

A rational and feasible method for quantitatively formulating pay factors was described by Monismith et al. (2004) for asphalt concrete construction. Performance models were developed for fatigue and rutting based on the analysis of accelerated pavement tests from the Caltrans Heavy Vehicle Simulator (HVS) and the WesTrack accelerated pavement performance test program.

The development of pay factors in the research considers the economic impacts to the highway agency. The amount of penalty/bonus was sought under the assumption that the penalty should be the extra cost to the agency and the bonus should not be greater than the added savings to the agency.

For new construction, these costs/savings to the agency are related mainly to prospective pavement rehabilitation. Inferior construction amplifies the present worth of future rehabilitation costs; contrarily, superior construction decreases the present worth of the costs. Differences in the present worth of future rehabilitation costs between as-built and as-designed are applicable to set the appropriate level of penalty/bonus for inferior/superior pavement construction quality. However, the authors admitted that penalties/bonuses might be too low because only the first rehabilitation cycle was considered in their performance model. The performance-based approach highlights the importance of uniformity in both materials and placement and the importance of sticking to the design target value.

Killingsworth (2004) argued that of 13 factors analyzed only five proved to have a significant influence on the overall performance of HMA pavement and should be included in performance-related HMA construction specifications. The selected factors are segregation, initial ride quality, in-place pavement density, density at longitudinal joints, and permeability. These quality characteristics of as-produced and as-constructed hot mix asphalt directly affect as-designed performance quality and life. Practical test methods for measuring these five quality characteristics, specification criteria, and threshold values are suggested for PRS.

Whiteley et al. (2005) developed a method for obtaining pay factors based on pavement life cycle cost (LCC) by establishing the relationship between design life and LCC, as well as between LCC and pay factors. The following are results of the research:

- Overlay thickness increases result in increased pavement service life.
- More than 80 percent of the contribution to the variance in pavement service life predictions are made by overlay thickness whereas less than 20 percent of the variance are contributed by combined variables of accumulated ESALs after eight years and total prior cracking.
- Regardless of overlay thickness distribution type, the resulting life cycle costs show a normal distribution.
- The pay factor values presented in the research shows that disincentives for inferior performance are greater than incentives for superior performance.

2.3 Analytical Hierarchical Process

The Analytic Hierarchy Process (AHP) is comprehensive, logical, and structured decision making process to help decision makers set priorities and make the best decision when both qualitative and quantitative aspects of a decision need to be considered (Saaty 1980). The AHP is designed to consider a variety of tangible and intangible strategic goals and manage conflicting stakeholders.

The AHP relies on three fundamental assumptions:

- Preferences for different alternatives depend on separate criteria which can be reasoned about independently and given numerical scores.
- The score for a given criteria can be calculated from sub-criteria. That is, the criteria can be arranged in a hierarchy, and the score at each level of the hierarchy can be calculated as a weighted sum of the lower level scores. The model can be as many levels deep as necessary to model the information appropriately.
- At a given level, suitable scores can be calculated from only pair wise comparisons.

The decision problem may involve social, political, technical, and economic factors. Complex decisions are approached by decomposing the problem in a hierarchical structure involving goals, criteria, and alternatives. A series of one-on-one comparisons are made, and the results are synthesized to determine the priorities of the alternatives with respect to each criterion and the weights of each criterion with respect to the goal. For each pairing, participants are asked to rank, on a scale from -9 to +9, how important that criterion is compared with the other one. The mathematical model calculates a relative weight for each criterion, and the summation is normalized to 100 percent. The incorporation of all relevant decision criteria and their pair-wise comparison allows the decision maker to determine the trade-offs among objectives. This procedure recognizes and incorporates the knowledge and expertise of the participants by making use of their subjective judgments.

The AHP has been used within transportation engineering by Smith and Tighe (2006) as a tool for infrastructure management. Specific examples cited by Smith and Tighe include the use of AHP to compare fast tract concrete repair products based on priorities set by an agency and use of AHP to compare maintenance, rehabilitation, and reconstruction strategies for asphalt pavements. Smith, et al., (1995) used the AHP to characterize bridge material selection decisions of stakeholders, specifically as it relates to using timber as a bridge material.

Acceptance Quality Characteristics

An acceptance quality characteristic (AQC) is defined by FHWA (1999) as an inherent measurable pavement characteristic that significantly affect pavement performance, is under the direct control of the contractor, and is measurable at or near the time of construction. The AQC for this project were selected to be identical to those currently used by FDOT for acceptance of pavement materials at the mine, plant or roadway based upon the FDOT *2007 Standard Specifications for Road and Bridge Construction*. These are listed in Appendix B.

3 Model Formulation and Implementation

3.1 Model Formulation

3.1.1 Model Concept

The values of the AQCs will be stochastic. We will assume that the results of tests to measure and AQC will be normally distributed with a calculable mean and standard deviation. If we know the mean and standard deviations of the various AQCs, we could use a mechanistic-empirical model in a Monte Carlo simulation process to depict a distribution of pavement life as depicted in Figure 3-1.

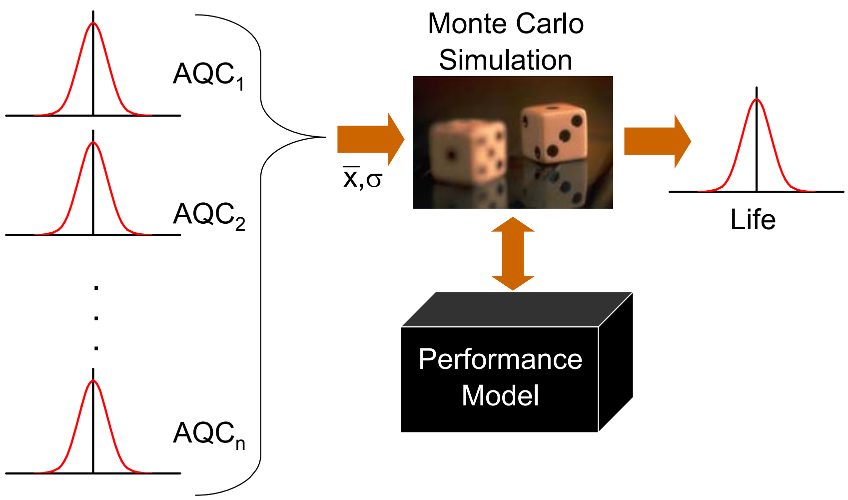

Figure 3-1. Ideal concept for CQI formulation

The performance model would need to be able to accept the inputs from the Monte Carlo driver, calculate the pavement response, and predict the pavement life. One such model potentially capable of performing these calculations is the Mechanistic-Empirical Pavement Design Guide (MEPDG) currently under review by AASHTO. However, the MEPDG must be calibrated for local conditions. There are advantages to this approach, the most notable of which is that it is based upon a rigorous analytical approach using the best available technology. However, there are also significant disadvantages:

- the model must be calibrated for local conditions
- the analytical models in the MEPDG are currently undergoing review and revision
- the computational requirements are quite large.

For these reasons, the current CQI formulation is based upon a much simpler approach described in the following paragraphs.

The diagram in Figure 3-2 shows a conceptual pavement system consisting of a series of *n* layers. Note that the model formulation does not require that all existing layers in the pavement system be a part of the construction project. For example, a typical flexible pavement resurfacing project may involve rehabilitation of the friction course (Layer 1) and a portion of the structural course (Layer 2). In this case, the maximum number of layers considered in the CQI is two, and all other layers are not considered in the calculations.

Figure 3-2. Schematic of a pavement structure with *n* layers

The general form of the CQI for a layered pavement system is given by

$$CQI = \sum_{\text{layers}} W_{layer} \times CQI_{layer} \qquad \text{(Equation 3-1)}$$

where W_{layer} = weighting factor for layer i
CQI_{layer} = construction quality index for layer i

For each layer, the CQI is based upon the sum of the Acceptance Quality Characteristics (AQC) for each layer times a weighting factor:

$$CQI_{layer} = \sum_{AQC} w_{ACQ} \times cqi_{AQC} \qquad \text{(Equation 3-2)}$$

where w_{AQC} = weighting factor for AQC_i
cqi_{AQC} = construction quality index for AQC_i

Finally, the construction quality index for each AQC is given by

$$(cqi)_{AQC} = (PWL)_{AQC} \qquad \text{(Equation 3-3)}$$

where $(PWL)_{AQC}$ is the percent within limits. $(PWL)_{AQC}$ is calculated based upon statistical principles assuming that random samples are taken from a normally-distributed population using the procedures outlined in *Evaluation Procedures For Quality Assurance Specifications* (Burati et al. 2004).

A *Q* statistic is determined from the difference between the sample mean ($\overline{X}$) and lower specification limit (*LSL*) or upper specification limit (*USL*) divided by the sample's standard deviation (*s*):

$$Q_L = \frac{\overline{X} - LSL}{s} \quad \textit{and} \quad Q_U = \frac{USL - \overline{X}}{s} \qquad \text{(Equation 3-4)}$$

The *Q* statistic is a quality index for its specification limit. For one-sided limits, the appropriate *Q* value is calculated and cross-referenced in the PWL table (Appendix C) to find the PWL of that sample. Two-sided limits require both *Q* values to be calculated and cross-referenced in the table. The two-sided percent within limits is then given by the following relationship:

$$PWL_T = PWL_U + PWL_L - 100 \qquad \text{(Equation 3-5)}$$

3.1.2 Model Weighting Factors

A series of expert panel meetings were conducted in Gainesville, Orlando, and Tallahassee to solicit input from the Department, construction industry, academia, and consultants. The forms that were used in the meetings for flexible and rigid pavements are reproduced in Appendix D. The instructions given to the panel meetings were simple:

- Each response only represents your opinion concerning the relative importance of the pair of items on a single line.
- Fill out all portions of the form for which you feel qualified to have an opinion
- Fill out the forms without discussion or collaboration with your neighbor.

The results of the survey are recapitulated in Appendix E for flexible and rigid pavements, respectively. The average values were used to in the SuperDecisions software to determine the weighting factors for the CQI relationships. These weighting factors for flexible pavement are presented in Table 3-1 and for rigid pavements in Table 3-2. Note that the sum of the weighting factors in each case sum to unity.

There are plausible scenarios, typically for rehabilitation projects, in which one or more layers of the system will not be a part of the construction project. For example, in projects where an existing pavement is being rehabilitated by milling and overlaying, it is possible that only the structural Superpave and friction course layers will be constructed in the project, all other layers remaining undisturbed from previous construction projects. In such cases, revised layer weighting factors are calculated by weighting their respective contribution to the project as shown in Table 3-3.

3.1.3 Adaptation of the Model for More than One Superpave Mix

For construction projects with Superpave layers, often the project may involve several mixes with different target values for the certain AQCs. In this case the model was adapted as follows:

$$CQI_{SP} = \sum t_i \left(CQI_{mix}\right)_i \qquad \text{Equation 3-6}$$

where t_i is a tonnage weighting factor given by

$$t_i = \frac{\text{tons of mix i}}{\text{total tons of Superpave}} \qquad \text{Equation 3-7}$$

For example, suppose a construction project used three Superpave mixes, designated by SP1, SP2, and SP3. A total of 20,000 tons were placed on the example project: 4,000 tons of SP1, 10,000 tons of SP2, and 6,000 tons of SP3. Table 3-4 presents the calculation of the layer CQI for this example.

3.2 <u>Model Implementation</u>

The CQI model was implemented in the Microsoft Windows® operating system as a stand-alone application called *CQI Calculator*. The application runs from one window and displays several screens to simplify and organize data entry. Data can be easily imported or exported from text files, and reports in HTML format can be produced from the input data. At the current time, the application cannot read input files directly from LIMS. Appendix F presents a User's Guide for *CQI Calculator.*

Table 3-1. Flexible Pavement Weighting Factors

Pavement Component	**Weighting Factor, W_{layer}**
Embankment	0.046
Stabilized Subgrade	0.074
Base Course	0.175
SuperPave	0.400
Friction Course	0.305
Embankment	**Weighting Factor, w_i**
Density	1.000
Stabilized Subgrade	**Weighting Factor, w_i**
Density	0.617
LBR	0.383
Base	**Weighting Factor, w_i**
Density	1.000
SuperPave	**Weighting Factor, w_i**
Passing #200	0.089
Passing #8	0.089
Air Voids	0.269
Asphalt Content	0.237
Density	0.316
FC-5	**Weighting Factor, w_i**
Passing #8	0.096
Passing #4	0.107
Passing 3/8"	0.151
Asphalt Content	0.333
Ride Number	0.313
FC-9.5	**Weighting Factor, w_i**
Passing #200	0.073
Passing #8	0.073
Air Voids	0.241
Asphalt Content	0.200
Density	0.198
Ride Number	0.215
FC-12.5	**Weighting Factor, w_i**
Passing #200	0.073
Passing #8	0.073
Air Voids	0.241
Asphalt Content	0.200
Density	0.198
Ride Number	0.215

Table 3-2. Rigid Pavement Weighting Factors

Pavement Component	**Weighting Factor, W_{layer}**
Embankment	0.075
Stabilized Subgrade	0.099
Base Course	0.212
PCC	0.614
Embankment	**Weighting Factor, w_i**
Density	1.000
Stabilized Subgrade	**Weighting Factor, w_i**
Density	0.617
LBR	0.383
CTPB	**Weighting Factor, w_i**
Cement Factor	0.260
Gradation	0.327
Water-cement ratio	0.413
ATPB	**Weighting Factor, w_i**
Binder Content	0.333
Gradation	0.667
PCC	**Weighting Factor, w_i**
Air Content	0.039
Slump	0.058
Water-cement Ratio	0.133
Compressive Strength	0.176
Thickness	0.266
Profile Index	0.328

Table 3-3. Example Calculation of Revised Layer Weighting Factors

Layer	**Layer Weighting Factor**	**Calculation of Revised Layer Weighting Factor**
Friction Course	$W_{FC} = 0.305$	$W_{FC\ revised} = 0.305/0.705 = 0.433$
Superpave	$W_{SP} = \underline{0.400}$	$W_{SP\ revised} = 0.400/0.705 = \underline{0.567}$
Total	**0.705**	**1.000**

Table 3-4. Example Calculation for Multiple Superpave Mixes

Mix	**Tons Produced**	**Mix CQI**	**Calculation of t_i**	**Calculation of CQI_{SP}**
SP1	4,000	0.958	t_{SP1} = 4,000/20,000 = 0.200	CQI_{SP1} = 0.200×0.958 = 0.192
SP2	10,000	0.923	t_{SP2} = 10,000/20,000 = 0.500	CQI_{SP2} = 0.500×0.923 = 0.462
SP3	6,000	0.976	t_{SP3} = 6,000/20,000 = 0.300	CQI_{SP3} = 0.300×0.976 = 0.293
Total	**20,000**			**CQI_{SP} = 0.947**

4 Model Validation

4.1 Introduction

In order to validate the CQI, the research team asked FDOT Construction and Materials officials to provide projects for the team to study. It was requested that the projects be recent enough to be relevant (having used current methods like SuperPave), but old enough that sufficient post-construction testing would have been performed. The most important requirement was for the projects to have their relevant data stored in the LIMS database. It was also requested that FDOT provide a “level of satisfaction,” or “rating” of each project provided.

FDOT supplied 18 projects for review. This was thought to be a sufficient number both by the research team and the FDOT project managers. The projects consisted of 12 flexible paving projects and six rigid paving projects. Details of these projects can be seen in Table 4-1.

Table 4-1. All Projects Identified as Validation Candidates

Project Number	Pavement Type	Project Location	FDOT Ratings
20794725201	Flexible	SR 21 from Melrose to Keystone Heights	Good
20795625201	Flexible	SR 100, US 301 Union County Line	Poor
20795635201	Flexible	SR 100	No Data
20820025201	Flexible	SR 16	Poor
20822645201	Flexible	SR 21 from Putnam C/L to SR 100	Good
20916635201	Flexible	SR 152	Poor
20969225201	Flexible	SR134	Poor
20999915201	Flexible	SR20 from Rowland Ave. to Francis/Radcliff Rd.	Poor
21000415201	Flexible	SR 20 from Francis to SR 19	No Data
21025315201	Flexible	SR 207 from CR 305 to West of I-95	Poor
21037425201	Flexible	SR 500	Good
21325125201	Flexible	I-295 from I-95 to Buckman Bridge	Good
20960015201	Rigid	SR 9A	Good
21327115201	Rigid	I-95 from I-295 to Nassau C/L	Good
21327315201	Rigid	I-95 from Heckscher Dr. to SR 9A	No Data
25840115201	Rigid	SR 400	Good
25864215201	Rigid	I-275 from Floribraska Ave. to Hillsborough Ave.	Good
25866015201	Rigid	I-275 from Hillsborough Ave. to Yukon St.	Good

The team had significant problems in the procuring of the data from LIMS. It took months to gain access to LIMS, and once the data was available, it became apparent that large portions of important data had not been entered into the database.

4.2 Project Descriptions

Each pavement system consists of several layers with different functions and materials. Possible flexible pavement layers include embankment, subgrade, base, Superpave, and friction courses. Possible rigid pavement layers include embankment, subgrade, base, and concrete pavement.

4.2.1 Project Number 20794725201

This project consisted of 3.56 miles of asphalt resurfacing (2 lanes) constructed in District 2 on SR 21 from Melrose to Keystone Heights. LIMS contained data for three layers of construction: embankment, Superpave, and FC-12.5 (no ride number). Test results were found for eight samples on the embankment and 55 samples for the paving (Superpave and friction course).

4.2.2 Project Number 20795625201

This project consisted of 10.543 miles of 2-lane asphalt resurfacing on SR 100 from US 301 to the Union County line in District 2. LIMS contained data for four layers of construction: embankment, base, Superpave, and FC-12.5. Test results were found for four samples on the embankment, 47 samples for the base, and 78 samples for the paving (Superpave and friction course).

4.2.3 Project Number 20820025201

This project was constructed on SR 16 in District 2 and was an asphalt resurfacing (2 to 4 lanes) project with a length of 10.583 miles. LIMS contained data for four layers of construction: embankment, base, Superpave, FC-9.5, and FC-12.5 (no ride numbers on the friction course). Test results were found for 25 samples on the embankment, and 129 samples for the paving (Superpave and friction course).

4.2.4 Project Number 20822645201

This was an asphalt widening and resurfacing (2 lanes) project with a length of 2.381 miles on SR 21 from the Putnam County line to SR 100 in District 2. LIMS contained data for one layer of construction: embankment. Test results were found for eight samples on the embankment.

4.2.5 Project Number 20916635201

This project was constructed in District 2 on SR 152 and was an asphalt widening and resurfacing (4 lanes) project with a length of 1.336 miles. LIMS contained data for three layers of construction: embankment, Superpave, and FC-9.5 (no ride number). Test results were found for four samples on the embankment, and 42 samples for the paving (Superpave and friction course).

4.2.6 Project Number 20969225201

This project was constructed in District 2 (SR 134) and was an asphalt widening and resurfacing (4 to 6 lanes) project with a length of 4.703 miles. LIMS contained data for two layers of construction: Superpave and FC-12.5 (no ride number). Test results were found for 82 samples for the paving (Superpave and friction course).

4.2.7 Project Number 20999915201

This project was constructed in District 2 (SR20 from Rowland Ave. to Francis/Radcliff Rd.) and was a project to add lanes and perform reconstruction (2 lanes added to 2 lane road) with a length of 4.412 miles. LIMS contained data for two layers of construction: Embankment and Subgrade. Test results were found for 104 samples for the Embankment and Subgrade.

4.2.8 Project Number 21025315201

This project was constructed in District 2 (SR 207 from CR 305 to West of I-95) and was a project to add lanes and perform reconstruction (2 lanes added to 2-lane road) with a length of 3.736 miles. LIMS contained data for one layer of construction (subgrade). Test results were found for 34 samples for the subgrade (only LBR).

4.2.9 Project Number 21037425201

This project was constructed in District 2 (SR 500) and was an asphalt resurfacing (5 lanes) project with a length of 1.03 miles. LIMS contained data for two layers of construction: Superpave and FC-12.5 (no ride number). Test results were found for 13 samples for the paving (Superpave and friction course).

4.2.10 Project Number 21325125201

This project was constructed in District 2 (I-295 from I-95 to Buckman Bridge) and was an asphalt resurfacing (6 and 8 lanes) project with a length of 4.857 miles. LIMS contained data for two layers of construction: Superpave and FC-12.5 (only ride number). Test results were found for 98 samples for the paving (Superpave and friction course). However, since the only test results found for the FC-12.5 were for ride quality, it was determined that this project, for the purposes of this research only had results from one layer – Superpave.

4.2.11 Project Number 20960015201

This project was constructed in District 2 (SR 9A) and was a new PCC construction (6 lanes) project with a length of 1.515 miles. LIMS contained data for two layers of construction: embankment and PCC (no ride number). Test results were found for 33 samples for the PCC and 111 for the embankment.

4.2.12 Project Number 21327115201

This project was constructed in District 2 (I-95 from I-295 to Nassau County Line) and included adding lanes and PCC reconstruction. The project had a length of 7.924 miles. LIMS contained data for only the ride numbers for the PCC).

4.2.13 Project Number 25840115201

This project was constructed in District 7 (SR 400) and included reconstruction and adding four lanes to a four-lane road using PCC construction. The project had a length of 2.759 miles. LIMS contained data for four layers of construction: embankment, subgrade, base, and PCC (no ride number). Test results were found for 238 samples for the PCC, 45 for the embankment, seven for the subgrade, and eight for the base.

4.2.14 Project Number 25864215201

This project is a PCC rehabilitation currently being constructed in District 7 (I-275 from Floribraska Ave. to Hillsborough Ave.). The project has a length of 1.784 miles. LIMS contains data for two layers of construction: embankment and PCC (no ride number).

4.2.15 Project Number 25866015201

This project is a PCC resurfacing project currently being constructed in District 7 (I-275 from Hillsborough Ave. to Yukon St.). The project has a length of 2.506 miles. LIMS contains data for two layers of construction: embankment and PCC (no ride number).

4.3 Validation Process

The available data for each project were fed into the CQI model. As explained in Chapter 3, a project's CQI is the sum of each layer's CQI of the project. Each layer of the pavement system has its weight and the sum of the layer's weights is 100 percent, or 1.00.

Of course, all projects do not have data for every possible layer. Such projects can be divided into two scenarios: type of construction and missing data in LIMS. For example, in resurfacing-type construction, layers of embankment, subgrade, or base do not exist. Unfortunately, for several projects, it is clear that some data are missing or irretrievable from LIMS.

Therefore, when there are missing layers, a weight correction of the layers with data should be considered. In order to make the sum of remaining layers' weights 100 percent or 1.00, when there are missing layers, the missing layers' weights are divided and added to the remaining layers' weights by the proportion of the remaining layers' weights. This rule is equally applied at the parameter level, too. For example, if a "ride number" is the only parameter for a friction course layer, then the ride number CQI represents the CQI for the entire friction course. This arrangement is not ideal, but it is the best that can be accomplished when key data is missing from the LIMS database.

When there are multiple design mixes for a single layer, their weights are proportioned by tonnage.

Though the model is programmed to render the best-possible CQI when data is missing, it is inarguable that having no data for multiple layers of the pavement structure or having extremely low sample numbers hurts the performance of the model. That being a given, the model performed quite well. Table 4-2 shows the results for the projects with data for at least three layers of the pavement structure.

Table 4-2. Projects with at Least Three Layers of Data

Project Number	Pavement Type	Project Description	FDOT Rating	CQI
20794725201	Flexible	SR 21 from Melrose to Keystone Heights	Good	0.9402
20795625201	Flexible	SR 100, US 301 Union County Line	Poor	0.9141
20820025201	Flexible	SR 16	Poor	0.8519
20916635201	Flexible	SR 152	Poor	0.8502
25840115201	Rigid	SR 400	Good	0.9356

Table 4-2 shows that for this limited data, the model worked well and that the cutoff between a project rated "good" by FDOT and those rated "poor" by FDOT is somewhere between 0.9141 and 0.9356. Of course, as stated earlier, some projects, such as straight asphalt resurfacing projects have only two layers. Therefore, analysis was done to determine the CQI for any project where data was available for over 50 percent of the layers constructed. Table 4-3 shows results from this analysis.

It is apparent when studying Table 4-3 that one project – either project number 20795625201 (CQI = .9141) or project number 21037425201 (CQI = .8947) is keeping the model from being completely accurate, at least in assigning all FDOT-rated "good" projects a higher CQI than any FDOT-rated "poor" projects. This brings up a second issue that can negatively affect the accuracy of the model – extremely low sample counts. Project number 20795625201 (CQI = .9141) had 129 samples analyzed, the third-most of any project, while project number 21037425201 (CQI = .8947) had only 13, the fewest of any finished project by a wide margin. Only the two projects analyzed had fewer.

Because three projects have such a low sample count, it is reasonable to discontinue using them in the analysis. The three projects dropped from further analysis were the two ongoing projects (Projects numbered 25864215201 and 25866015201) and project number 21037425201.

Table 4-3. Projects with Data from Over 50 Percent of Layers

Project Number	Pavement Type	Max. Possible Layers	No. Layers of Data	No. of Sampl es	FDOT Rating	CQI
20794725201	Flexible	5	3	63	Good	0.9402
20795625201	Flexible	5	4	129	Poor	0.9141
20820025201	Flexible	5	4	154	Poor	0.8519
20916635201	Flexible	5	3	46	Poor	0.8502
20969225201	Flexible	2	2	82	Poor	0.8666
21037425201	Flexible	2	2	13	Good	0.8947
25840115201	Rigid	4	4	335	Good	0.9356
25864215201	Rigid	2	2	8	Good	1.000
25866015201	Rigid	2	2	4	Good	1.000

Table 4-4 shows the results of the analysis of all projects with data from over 50 percent of all layers and without extremely low sample counts. This table, then, best reflects the performance of the model as it should perform under the conditions originally envisioned by the research sponsors and the research team – that of a model working in conjunction with a LIMS database that contains data in sufficient areas and sufficient quantity to effect accurate measurements of the quality of materials and workmanship on any given project.

Table 4-4. Model Performance on All Projects with Sufficient Data

Project Number	Pavement Type	Max. Possible Layers	No. Layers of Data	No. of Samples	FDOT Rating	CQI
20794725201	Flexible	5	3	63	Good	0.9402
20795625201	Flexible	5	4	129	Poor	0.9141
20820025201	Flexible	5	4	154	Poor	0.8519
20916635201	Flexible	5	3	46	Poor	0.8502
20969225201	Flexible	2	2	82	Poor	0.8666
25840115201	Rigid	4	4	335	Good	0.9356

Table 4-4 shows that the model has rendered CQI values that line up with the considered opinion of the owner as to the quality of the project. This, of course, is contingent upon the model being supplied with a reasonable amount of data to work with. It is unfortunate that LIMS, for one reason or another, only supplied sufficient data for one-third of the original 18 projects. The most important result, however, is that no project rated “poor” by FDOT Construction and materials personnel was rated as high as any project rated “good” by those same personnel. As with Table 4.2, the cutoff between a project rated “good” by FDOT and those rated “poor” by FDOT is somewhere between 0.9141 and 0.9356.

4.4 LIMS Issues

The research team experienced difficulty with many aspects of LIMS. First, the team found LIMS to be a difficult system from which to retrieve data. Although many LIMS users have entered data pertaining to their work area (concrete, aggregate, asphalt, etc.), few were able to acquire data for this research from LIMS.

Also, the research team found the LIMS data to be incomplete. Once gaining access to LIMS, the team found that many data had either not been entered into LIMS or had been entered to the wrong place. For instance, for some asphalt paving projects, several key asphalt data were not found when the job status was listed as "Construction Completed." Even when asphalt data were present, there were cases where no asphalt data was found under some asphalt design mix numbers that had been listed for the project.

Even with the help of FDOT personnel, the research team found that LIMS data were hard to match with construction activities. For instance, concrete data are not classified as to whether they are for pavement or structure. So, assumptions had to be made in this regard.

The research team found many cases where the number of samples was so low that it seemed that there were many missing test results. Acceptance quality characteristics with two or fewer data were excluded, because PWL requires at least three sample data by definition. However, many other acceptance quality characteristics had such a small number of sample data that the research team was skeptical of the completeness of the data set. However, in order to perform the research, sometimes these few samples had to represent the acceptance quality characteristic's CQI. In the cases where the sample numbers were so small as to violate the assumptions of the model, the project was not included in the analysis. Therefore, only six of the original 18 projects ended up in the final analysis.

There was also a problem with missing layers and acceptance quality characteristics. For example, a weight for a Ride Number of 0.43 (out of 1.00) was the only test result for the pavement layer of project number 21325125201. Since other parameters for pavement performance were not present, this significantly biased the model for this project. This project was, then, excluded from the final analysis.

Another example of this was a project for which the district was exceedingly proud. This project was project number 20960015201, a rare new construction project, and an even rarer new PCC pavement project. Of course, the district rated the project "good," and, using the data available, the model calculated a CQI of 0.9317, a figure that puts the project where it should be, solidly above all the "poor" projects, and in the range of "good" projects. However, this project was excluded from the final analysis because LIMS only contained data for two of the four layers of construction.

5 Conclusions and Recommendations

5.1 Conclusions

A practical and effective pavement CQI has been developed. The CQI formulation is transparent and easily understood because it relies on concepts consistent with those already used by FDOT and familiar to the pavement contractor. The CQI uses data from the Laboratory Information Management System (LIMS), which serves as the Department's enterprise database system for all construction quality data. The CQI addresses material, structural, and pavement smoothness characteristics and is applicable for both new and rehabilitation projects. Soils, bound and unbound granular base materials, HMA, and PCC are considered.

Because a pavement system is composed of one or more material layers, the CQI formulation is based upon a summation of the CQI of each individual layer multiplied by a weighting factor that takes into account the relative importance of that layer in the overall pavement system performance. The CQI of each layer is similarly determined by summing the products of the percent within limits of each acceptance quality characteristic multiplied by an appropriate weighting factor. All weighting factors were determined from information gathered at expert panel meetings consisting of experts from FDOT, the construction industry, and academia. Other aspects of contractor performance (e.g., financial resources, ownership of equipment or ability to lease equipment, adherence to schedule, job safety, past performance) are not included in this CQI formulation.

The CQI model was formulated in a modular fashion. The model is flexible allowing it to be scaled to all pavement construction projects, from routine mill and overlay rehabilitation to major new highway pavements construction.

The CQI model was implemented in the Microsoft Windows® operating system as a stand-alone application called *CQI Calculator*. The application runs from one window and displays several screens to simplify and organize data entry. Data can be easily imported or exported from text files, and reports in HTML format can be produced from the input data. At the current time, the application cannot read input files directly from LIMS.

FDOT was asked to provide 18 projects to the research team along with an associated subjective quality rating for each project. The projects submitted by FDOT were to be ones that had data entered into the LIMS database. The LIMS database did not contain as much data as had been anticipated by FDOT or the research team. Subsequently, only one-third (six) of the projects submitted by FDOT Construction and Materials personnel contained test results in sufficient quantity, and for enough layers of the pavement structure, to exercise the features of the model.

For the six projects that met the criteria for inclusion, the model was extremely accurate, never rendering a CQI for a project rated “Poor” by FDOT higher than any project the FDOT rated “Good.” The highest FDOT-rated “Poor” project had a CQI of 0.9141, while the lowest FDOT-rated “Good” project had a CQI of 0.9356.

5.2 Recommendations

We recommend that more research be conducted to address legitimate concerns brought on by the limitations of the research before the model is implemented by FDOT. Data from more projects should be entered into the model in order to achieve total validation. Of course, these projects must be ones for which LIMS contains the needed quantity and quality of data over the entire project spectrum. Therefore, we recommend that the CQI for pavements be trial-run on a three to five projects from each District. If sufficient data are available from the Pavement Condition Survey records, the CQI results should be compared with performance data, as well.

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Appendix A. Survey of State Highway Agency Policy and Practice

State or Territory	Contact	Construction Quality Index
Alabama	ALDOT Construction Engineer	None
Alaska	AASHTO Liaison	None
Arizona	Assistant State Engineer	None
Arkansas	State Construction Engineer's Office	None
California	Division of Construction Specialist for Project Progression	None statewide some regions rate for particular jobs
Colorado	Branch Manager of Contracts and Market Analysis Branch	About to start a pilot program
Connecticut	Transportation Engineer 2	Inspectors rate subjectively once a year using attached form if average drops below thresh hold contractor has to come in and have a meeting with DOT
Delaware	Quality Engineer	None
Georgia	State Construction Engineer	None
Hawaii	Engineering Program Manager w/in Construction and Maintenance	None
Idaho	Chief Engineer	None for contractors do rate their consultants
Illinois	Pre-qualification Engineer	Very detailed subjective but does include workmanship and creates coefficient that increases or decreases amount of money company can bid
Indiana	State Construction Engineer	Uses attached form to rate contractors
Iowa	Construction Office Director	Uses a subjective contractor evaluation form that creates a coefficient to decrease or increase bidding capacity
Kansas	Bureau of Construction and Maintenance	Uses a subjective contractor evaluation form that creates a coefficient to decrease or increase bidding capacity
Kentucky		
Louisiana	Chief of Construction Section	None for contractors but do rate plans
Maine	Pre-qualification Coordinator	Uses a subjective contractor evaluation form that is subjectively used to determine how many years of qualification
Maryland	Assistant Construction Engineer	Subjective yearly questionnaire creates a grade depending upon grade retention is held for a variable amount of time
Massachusetts		
Michigan	Construction Contracts Engineer	Subjective sheet have three tier prior to effecting pre-qualification amount
Minnesota	Engineer Senior Administrative	Do not rate contractors rate overall project based upon cost vs. quality
Mississippi	Construction Division Head	None

State or Territory	Contact	Construction Quality Index
Missouri	Senior Information Specialist for Construction Department	Uses a subjective questionnaire that creates a percentage based upon that percentage a contractor can be put on probation or suspended for one year
Montana	Construction Section	
Nebraska	Construction Department	Uses a subjective check list that goes into a weighted data base based on job size data base creates a coefficient that effects the amount that can be bid
Nevada	Chief Construction Engineer	Subjective report that is input into a formula to effect pre-qualification amount
New Hampshire	District Engineer	Subjective form affects pre-qualification amount
New Jersey		
New Mexico	State Construction Engineer	Developing a system, currently have a simple pre-qualification form that is more like an application
New York	Co-Assistant Director of Construction	None, are in the process of trying to create one
North Carolina	State Construction Engineer	Basic pre-qualification safety and environmental index but no performance grade.
North Dakota	Assistant Construction Engineer	Financial pre-qualification no rating system
Ohio	Contractor Pre-qualification	
Oklahoma	State Construction Engineer	Have a subjective form that is saved but not applied to anything currently
Oregon	Contract Administration Engineer	Subjective form just changed to more effective form once contractor drops below set average they are put into a discipline process
Pennsylvania	Contract Evaluation Engineer	Every six months a subjective form is filled out effects amount that can be bid, if scores are extremely low in particular areas can not bid that type of job
Rhode Island		
South Carolina		
South Dakota		
Tennessee	Construction Contracts Officer	Do not currently do anything, hope to by beginning of 2007
Texas	Contract Letting and Processing	Financial pre-qualification no rating system
Utah	Manager Contracts Estimates/Agreements	Subjective form on each job done to let contractor know how they are doing, only used in deciding who to hire for design build jobs
Vermont	Construction Engineer	
Virginia	Contract Engineer Assistant Division Administrator	Subjective for effects pre-qualification only score and safety effect pre-qualification revamping form by end of fall 2006
Washington	Contracts Engineer	

State or Territory	Contact	Construction Quality Index
West Virginia	Construction Engineer	Subjective form effects pre-qualification amount
Wisconsin	Contracts Engineer	
Wyoming	Construction Branch	Subjective form that affects pre-qualification amount
Washington DC	Construction Office	None
Puerto Rico	Area de Construction	Trying to implement but currently have none

Appendix B. FDOT Pavement Acceptance Quality Characteristics

Table B-1. Acceptance Quality Characteristics for Flexible Pavements

Specification	Layer	AQC	Units	Upper Range	Target	Lower Range
Section 120: Excavation and Embankment	Embankment	Density	Percent Standard Proctor Maximum Density	None	100	0
Section 160: Stabilizing	Stabilized Subgrade	Bearing Value	LBR (soaked)	None	40	5
		Bearing Value	LBR (soaked)	None	35	4
		Bearing Value	LBR (soaked)	None	< 30	2.5
		Bearing Value	LBR = 40 (unsoaked)	None	43	0
		Mixing Depth	inches	2	Per plans	0
		Density	Percent Modified Proctor Density	None	98	0
Section 200: Rock Base	Base Course	Density	Percent Modified Proctor Density	None	98	0
Section 204: Graded Aggregate Base	Base Course	Density	Percent Modified Proctor Density	None	98	0
Section 234: Superpave Asphalt Base	Base Course	Passing No. 8 Sieve	Percent	3.1	Per plans	3.1
		Passing No. 200 Sieve	Percent	1.0	Per plans	1.0
		Asphalt Content	Percent	0.40	Per plans	0.40
		Air Voids (Coarse Mix)	Percent	1.40	4.00	1.40
		Air Voids (Fine Mix)	Percent	1.20	4.00	1.20
		Density (Coarse)	Percent Gmm	1.30	94.50	1.30
		Density (Fine)	Percent Gmm	2.00	93.00	1.20

Table B-1. Acceptance Quality Characteristics for Flexible Pavements (Continued)

Specification	Layer	AQC	Units	Upper Range	Target	Lower Range
Section 283: Reclaimed Asphalt Base	Base Course	Density	Percent Modified Proctor Density	None	95	0
Section 334: Superpave Asphalt Concrete	Structural Course	Passing No. 8 Sieve	Percent	3.1	Per plans	3.1
		Passing No. 200 Sieve	Percent	1.0	Per plans	1.0
		Asphalt Content	Percent	0.40	Per plans	0.40
		Air Voids (Coarse Mix)	Percent	1.40	4.00	1.40
		Air Voids (Fine Mix)	Percent	1.20	4.00	1.20
		Density (Coarse)	Percent Gmm	1.30	94.50	1.30
		Density (Fine)	Percent Gmm	2.00	93.00	1.20

Table B-1. Acceptance Quality Characteristics for Flexible Pavements (Concluded)

Specification	Layer	AQC	Units	Upper Range	Target	Lower Range
Section 337: Asphalt Concrete Friction Courses	FC-5	Asphalt Binder Content	Percent	0.45	Per plans	0.45
		Passing 3/8 in Seive	Percent	6.00	Per plans	6.00
		Passing No. 4 Sieve	Percent	4.50	Per plans	4.50
		Passing No. 8 Seive	Percent	2.50	Per plans	2.50
	FC-9.5	Passing No. 8 Sieve	Percent	3.10	Per plans	3.10
		Passing No. 200 Sieve	Percent	1.00	Per plans	1.00
		Asphalt Content	Percent	0.40	Per plans	0.40
		Air Voids (Coarse Mix)	Percent	1.40	4.00	1.40
		Air Voids (Fine Mix)	Percent	1.20	4.00	1.20
		Density (Coarse)	Percent Gmm	1.30	94.50	1.30
		Density (Fine)	Percent Gmm	2.00	93.00	1.20
	FC-12.5	Passing No. 8 Sieve	Percent	3.10	Per plans	3.10
		Passing No. 200 Sieve	Percent	1.00	Per plans	1.00
		Asphalt Content	Percent	0.40	Per plans	0.40
		Air Voids (Coarse Mix)	Percent	1.40	4.00	1.40
		Air Voids (Fine Mix)	Percent	1.20	4.00	1.20
		Density (Coarse)	Percent Gmm	1.30	94.50	1.30
		Density (Fine)	Percent Gmm	2.00	93.00	1.20
Ride Number	Friction Course	Ride Number		None	5	1

Table B-2. Acceptance Quality Characteristics for Rigid Pavements

Specification	Layer	AQC	Units	Upper Range	Target	Lower Range
Section 120: Excavation and Embankment	Embankment	Density	Percent standard proctor paximum density	None	100	0
Section 160: Stabilizing	Stabilized Subgrade	Bearing Value	LBR (soaked)	None	40	5
		Bearing Value	LBR (soaked)	None	35	4
		Bearing Value	LBR (soaked)	None	< 30	2.5
		Bearing Value	LBR = 40 (unsoaked)	None	43	0
		Mixing Depth	inches	2	Per plans	0
		Density	Percent modified proctor density	None	98	0
Section 287: Asphalt Treated Permeable Base	Permeable Base	Passing Control Sieve[†]	Percent	10	Per plans	10
		Binder Content	Percent	0.5	Per plans	0.45
Section 288: Cement Treated Permeable Base	Permeable Base	Passing Control Sieve[†]	Percent			
		Water-Cement Ratio	None	0.00	0.4	None
		Cement Factor	lb/ft^3	2.00	9.00	2.00
Section 346: Portland Cement Concrete	Pavement Concrete	28-day Comp. Strength	psi	None	3000.00	0.00
		Slump	inches	None	2.00	0.00
		Air Content	Percent	2.50	3.50	2.50
		Water-Cement Ratio	None	0	0.5	None
Section 350: Cement Concrete Pavement	Pavement Concrete	Thickness	inches	None	Per Plans	0
Section 352: Grinding Concrete Pavement	Pavement Concrete	Profile Index *	inches/mile	3	2	2
		Profile Index **	Inches/mile	3	4	4

† For asphalt treated permeable bases with #57 stone, control sieve is 1/2 inch sieve. For asphalt treated permeable bases with #67 stone, control sieve is 3/8 inch sieve.

* For curvature radius ≥ 2000 ft

** For curvature radius ≥ 1000 ft but < 2000 ft

Appendix C. PWL Table

The PWL table gives the percent within limits values for any *Q* value (quality index) and any sample size. These values were obtained through a computer simulation. Using the table avoids complex computations each time the percent within limits is calculated.

To use the table, the quality index must be calculated. A *Q* value is determined from the difference between the sample mean ($\overline{X}$) and the lower or upper specification limit (*LSL* / *USL*) divided by the sample's standard deviation (s):

$$Q_L = \frac{\overline{X} - LSL}{s} \quad and \quad Q_U = \frac{USL - \overline{X}}{s}$$

Two-sided limits require both *Q* values to be calculated. The two-sided percent within limits is then given by the difference between the sum of those two values and one hundred:

$$PWL_T = PWL_U + PWL_L - 100$$

The parameter *n* in the table represents sample size. Once the sample size and the quality index are known, the quality index is found in the column representing the appropriate sample size. The row in which the quality index appears indicates the percent within limits for that quality index. Should the quality index be larger than the first row's value, the percent within limits is recognized as 100%.

	n = 3	n = 4	n = 5	n = 6	n = 7	n = 8	n = 9	n = 10 to 11
100	1.16	1.50	1.79	2.03	2.23	2.39	2.53	2.65
99	-	1.47	1.67	1.80	1.89	1.95	2.00	2.04
98	1.15	1.44	1.60	1.70	1.76	1.81	1.84	1.86
97	-	1.41	1.54	1.62	1.67	1.70	1.72	1.74
96	1.14	1.38	1.49	1.55	1.59	1.61	1.63	1.65
95	-	1.35	1.44	1.49	1.52	1.54	1.55	1.56
94	1.13	1.32	1.39	1.43	1.46	1.47	1.48	1.49
93	-	1.29	1.35	1.38	1.40	1.41	1.42	1.43
92	1.12	1.26	1.31	1.33	1.35	1.36	1.36	1.37
91	1.11	1.23	1.27	1.29	1.30	1.30	1.31	1.31
90	1.10	1.20	1.23	1.24	1.25	1.25	1.26	1.26
89	1.09	1.17	1.19	1.20	1.20	1.21	1.21	1.21
88	1.07	1.14	1.15	1.16	1.16	1.16	1.16	1.17
87	1.06	1.11	1.12	1.12	1.12	1.12	1.12	1.12
86	1.04	1.08	1.08	1.08	1.08	1.08	1.08	1.08
85	1.03	1.05	1.05	1.04	1.04	1.04	1.04	1.04
84	1.01	1.02	1.01	1.01	1.00	1.00	1.00	1.00
83	1.00	0.99	0.98	0.97	0.97	0.96	0.96	0.96
82	0.97	0.96	0.95	0.94	0.93	0.93	0.93	0.92
81	0.96	0.93	0.91	0.90	0.90	0.89	0.89	0.89
80	0.93	0.90	0.88	0.87	0.86	0.86	0.86	0.85
79	0.91	0.87	0.85	0.84	0.83	0.82	0.82	0.82
78	0.89	0.84	0.82	0.80	0.80	0.79	0.79	0.79
77	0.87	0.81	0.78	0.77	0.76	0.76	0.76	0.75
76	0.84	0.78	0.75	0.74	0.73	0.73	0.72	0.72
75	0.82	0.75	0.72	0.71	0.70	0.70	0.69	0.69
74	0.79	0.72	0.69	0.68	0.67	0.66	0.66	0.66
73	0.76	0.69	0.66	0.65	0.64	0.63	0.63	0.63
72	0.74	0.66	0.63	0.62	0.61	0.60	0.60	0.60
71	0.71	0.63	0.60	0.59	0.58	0.57	0.57	0.57
70	0.68	0.60	0.57	0.56	0.55	0.55	0.54	0.54
69	0.65	0.57	0.54	0.53	0.52	0.52	0.51	0.51
68	0.62	0.54	0.51	0.50	0.49	0.49	0.48	0.48
67	0.59	0.51	0.47	0.47	0.46	0.46	0.46	0.45
66	0.56	0.48	0.45	0.44	0.44	0.43	0.43	0.43
65	0.52	0.45	0.43	0.41	0.41	0.40	0.40	0.40
64	0.49	0.42	0.40	0.39	0.38	0.38	0.37	0.37
63	0.46	0.39	0.37	0.36	0.35	0.35	0.35	0.34
62	0.43	0.36	0.34	0.33	0.32	0.32	0.32	0.32
61	0.39	0.33	0.31	0.30	0.30	0.29	0.29	0.29
60	0.36	0.30	0.28	0.27	0.27	0.27	0.26	0.26

59	0.32	0.27	0.25	0.25	0.24	0.24	0.24	0.24
58	0.29	0.24	0.23	0.22	0.21	0.21	0.21	0.21
57	0.25	0.21	0.20	0.19	0.19	0.19	0.18	0.18
56	0.22	0.18	0.17	0.16	0.16	0.16	0.16	0.16
55	0.18	0.15	0.14	0.14	0.13	0.13	0.13	0.13
54	0.14	0.12	0.11	0.11	0.11	0.11	0.10	0.10
53	0.11	0.09	0.08	0.08	0.08	0.08	0.08	0.08
52	0.07	0.06	0.06	0.05	0.05	0.05	0.05	0.05
51	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

PWL	*n* = 12 to 14	*n* = 15 to 18	*n* = 19 to 25	*n* = 26 to 37	*n* = 38 to 69	*n* = 70 to 200	*n* = 201 to ∞
100	2.83	3.03	3.20	3.38	3.54	3.70	3.83
99	2.09	2.14	2.18	2.22	2.26	2.29	2.31
98	1.91	1.93	1.96	1.99	2.01	2.03	2.05
97	1.77	1.79	1.81	1.83	1.85	1.86	1.87
96	1.67	1.68	1.70	1.71	1.73	1.74	1.75
95	1.58	1.59	1.61	1.62	1.63	1.63	1.64
94	1.50	1.51	1.52	1.53	1.54	1.55	1.55
93	1.44	1.44	1.45	1.46	1.46	1.47	1.47
92	1.37	1.38	1.39	1.39	1.40	1.40	1.40
91	1.32	1.32	1.33	1.33	1.33	1.34	1.34
90	1.26	1.27	1.27	1.27	1.28	1.28	1.28
89	1.21	1.22	1.22	1.22	1.22	1.22	1.23
88	1.17	1.17	1.17	1.17	1.17	1.17	1.17
87	1.12	1.12	1.12	1.12	1.12	1.13	1.13
86	1.08	1.08	1.08	1.08	1.08	1.08	1.08
85	1.04	1.04	1.04	1.04	1.04	1.04	1.04
84	1.00	1.00	1.00	1.00	0.99	0.99	0.99
83	0.96	0.96	0.96	0.96	0.95	0.95	0.95
82	0.92	0.92	0.92	0.92	0.92	0.92	0.92
81	0.89	0.88	0.88	0.88	0.88	0.88	0.88
80	0.85	0.85	0.85	0.84	0.84	0.84	0.84
79	0.82	0.81	0.81	0.81	0.81	0.81	0.81
78	0.78	0.78	0.78	0.78	0.77	0.77	0.77
77	0.75	0.75	0.75	0.74	0.74	0.74	0.74
76	0.72	0.71	0.71	0.71	0.71	0.71	0.71
75	0.69	0.68	0.68	0.68	0.68	0.68	0.67
74	0.66	0.65	0.65	0.65	0.65	0.64	0.64
73	0.62	0.62	0.62	0.62	0.62	0.61	0.61
72	0.59	0.59	0.59	0.59	0.59	0.58	0.58
71	0.57	0.56	0.56	0.56	0.56	0.55	0.55
70	0.54	0.53	0.53	0.53	0.53	0.53	0.52
69	0.51	0.50	0.50	0.50	0.50	0.50	0.50
68	0.48	0.48	0.47	0.47	0.47	0.47	0.47
67	0.45	0.45	0.45	0.44	0.44	0.44	0.44
66	0.42	0.42	0.42	0.42	0.41	0.41	0.41
65	0.40	0.39	0.39	0.39	0.39	0.39	0.39
64	0.37	0.36	0.36	0.36	0.36	0.36	0.36
63	0.34	0.34	0.34	0.34	0.33	0.33	0.33
62	0.31	0.31	0.31	0.31	0.31	0.31	0.31
61	0.29	0.29	0.28	0.28	0.28	0.28	0.28
60	0.26	0.26	0.26	0.26	0.26	0.25	0.25
59	0.23	0.23	0.23	0.23	0.23	0.23	0.23
58	0.21	0.21	0.20	0.20	0.20	0.20	0.20
57	0.18	0.18	0.18	0.18	0.18	0.18	0.18
56	0.16	0.15	0.15	0.15	0.15	0.15	0.15
55	0.13	0.13	0.13	0.13	0.13	0.13	0.13
54	0.10	0.10	0.10	0.10	0.10	0.10	0.10
53	0.08	0.08	0.08	0.08	0.08	0.08	0.08
52	0.05	0.05	0.05	0.05	0.05	0.05	0.05
51	0.03	0.03	0.03	0.03	0.03	0.03	0.02
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix D. Expert Panel Meeting Forms

FDOT CONSTRUCTION QUALITY INDEX
EXPERT PANEL RATING SHEET
FLEXIBLE PAVEMENT

Name: ________________________________

Location: ________________________________

Date: ________________________________

Affliation:

- ☐ **Florida Department of Transportation**
- ☐ **Construction Industry**
- ☐ **Consultant**
- ☐ **Academia**
- ☐ **Other** ________________________________

Concerning: **Flexible Pavement System Components**

Which factor has the greater influence on quality?

Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor
Embankment																		Stablized Subgrade
Embankment																		Base
Embankment																		Superpave
Embankment																		Friction Course
Stablized Subgrade																		Base
Stablized Subgrade																		Superpave
Stablized Subgrade																		Friction Course
Base																		Superpave
Base																		Friction Course
Superpave																		Friction Course

Concerning: **Stablized Subgrade**

Which factor has the greater influence on quality?

Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor
Density																		LBR
Density																		Thickness
LBR																		Thickness

Concerning: **Base**

Which factor has the greater influence on quality?

Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor
Density																		Thickness

Concerning: **SuperPave**

Which factor has the greater influence on quality?

Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor
Air Voids																		Passing #200
Air Voids																		Asphalt Content
Air Voids																		Thickness
Air Voids																		Roadway Density
Passing #200																		Asphalt Content
Passing #200																		Thickness
Passing #200																		Roadway Density
Asphalt Content																		Thickness
Asphalt Content																		Roadway Density
Roadway Density																		Thickness

CONTINUED ON NEXT PAGE

FDOT CONSTRUCTION QUALITY INDEX
EXPERT PANEL RATING SHEET

FLEXIBLE PAVEMENT

Concerning: **FC-5**

Which factor has the greater influence on quality?

Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor
Binder Content																		Passing 3/8 in.
Binder Content																		Passing #4
Binder Content																		Passing #8
Binder Content																		Ride Number
Passing 3/8-in.																		Passing #4
Passing 3/8-in.																		Passing #8
Passing 3/8-in.																		Ride Number
Passing #4																		Passing #8
Passing #4																		Ride Number
Passing #8																		Ride Number

Concerning: **FC-9.5/FC-12.5**

Which factor has the greater influence on quality?

Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor
Air Voids																		Passing #200
Air Voids																		Asphalt Content
Air Voids																		Thickness
Air Voids																		Roadway Density
Air Voids																		Ride Number
Passing #200																		Asphalt Content
Passing #200																		Thickness
Passing #200																		Roadway Density
Passing #200																		Ride Number
Asphalt Content																		Thickness
Asphalt Content																		Roadway Density
Asphalt Content																		Ride Number
Ride Number																		Roadway Density
Ride Number																		Thickness
Roadway Density																		Thickness

FDOT CONSTRUCTION QUALITY INDEX

EXPERT PANEL RATING SHEET

RIGID PAVEMENT

Name: ______________________________

Location: ______________________________

Date: ______________________________

Affliation:

- ☐ **Florida Department of Transportation**
- ☐ **Construction Industry**
- ☐ **Consultant**
- ☐ **Academia**
- ☐ **Other** ______________________________

Concerning: **Rigid Pavement System Components**

Which factor has the greater influence on quality?

Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor
Embanmkent																		Stabilized Subgrade
Embankment																		Treated Permeable Base
Embankment																		PCC
Stabilized Subgrade																		Treated Permeable Base
Stabilized Subgrade																		PCC
Treated Permeable Base																		PCC

Concerning: **Stabilized Subgrade**

Which factor has the greater influence on quality?

Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor
Density																		LBR
Density																		Thickness
LBR																		Thickness

Concerning: **Cement Treated Permeable Base**

Which factor has the greater influence on quality?

Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor
Gradation																		Water-Cement Ratio
Gradation																		Cement Factor
Water-Cement Ratio																		Cement Factor

Concerning: **Asphalt Treated Permeable Base**

Which factor has the greater influence on quality?

Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor
Asphalt Binder Content																		Gradation

Concerning: **PCC**

Which factor has the greater influence on quality?

Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor
Air Content																		Compressive Strength
Air Content																		Profile Index
Air Content																		Slump
Air Content																		Thickness
Air Content																		Water-Cement Ratio
Compressive Strength																		Profile Index
Compressive Strength																		Slump
Compressive Strength																		Thickness
Compressive Strength																		Water-Cement Ratio
Profile Index																		Slump
Profile Index																		Thickness
Profile Index																		Water-Cement Ratio
Slump																		Thickness
Slump																		Water-Cement Ratio
Thickness																		Water-Cement Ratio

Appendix E. Tabulation of Results from Expert Panel Meetings

FDOT CONSTRUCTION QUALITY INDEX

FLEXIBLE PAVEMENT

	Construction Industry								FDOT									Academia			Other	GRAND MEAN
- +	1	2	3	4	5	6	7	AVG	8	9	10	11	12	13	14	15	AVG	17	18	AVG	19	
Flexible Pavement System Components																						
Embankment vs. Stabilized Subgrade	1	2	3	3	3	0	0	1.71	5	1	2	2	7	4	0	2	2.88	7	2	4.50	(4)	2.22
Embankment vs. Base	2	2	6	8	1	1	0	2.86	6	2	2	6	8	6	0	6	4.50	7	6	6.50	4	4.06
Embankment vs. Superpave	3	4	8	6	8	(1)	0	4.00	6	3	2	8	8	7	(3)	7	4.75		3	3.00	4	4.29
Embankment vs. Friction Course	0	4	8	6	8	(2)	0	3.43	6	4	6	8	8	8	(4)	5	5.13	4	0	2.00	4	4.06
Stabilized Subgrade vs. Base	1	2	5	8	8	0	0	3.43	4	1	2	3	6	1	0	2	2.38	1	5	3.00	4	2.94
Stabilized Subgrade vs. Superpave	2	2	8	6	8	(1)	0	3.57	4	2	2	8	7	3	(3)	5	3.50		4	4.00	4	3.59
Stabilized Subgrade vs. Friction Course	0	2	8	6	8	(2)	0	3.14	3	3	6	8	7	3	(4)	6	4.00	4	1	2.50	4	3.50
Base vs. Superpave	1	2	8	(4)	8	(2)	0	1.86	4	2	2	6	5	0	(3)	5	2.63		0	0.00	4	2.24
Base vs. Friction Course	0	2	8	(4)	8	(2)	0	1.71	3	3	6	6	6	0	(7)	3	2.50	1	(6)	(2.50)	0	1.50
Superpave vs. Friction Course	(1)	(1)	(6)	(4)	0	(3)	0	(2.14)	(3)	4	0	2	2	4	(4)	2	0.88		(3)	(3.00)	0	-0.65
Stabilized Subgrade																						
Density vs. LBR	2	1	(5)	4	(1)	0	0	0.14	(7)	0	0	(1)		0	(7)	2	(1.86)	6	0	3.00	0	-0.35
Density vs. Thickness	1	0	(2)	(4)	(1)	2	2	(0.29)	(1)	0	(2)	4		(5)	(7)	(1)	(1.71)	6	0	3.00	(4)	-0.71
LBR vs. Thickness	0	0	2	(4)	1	1	2	0.29	8	0	(2)	5		(4)	7	(1)	1.86	0	3	1.50	4	1.29
Base																						
Density vs. Thickness	0	0		4	(8)	2	1	(0.17)	(3)	0	0	2		(3)	(6)	2	(1.14)	5	(2)	1.50	(4)	-0.63
Superpave																						
Air Voids vs. Passing #200	(4)	0	0	0	(8)	0	1	(1.57)	1	(3)	(2)	(5)	(8)	(3)	0	(5)	(3.13)	0	3	1.50	(4)	-2.06
Air Voids vs. Asphalt Content	2	0	0	0	(2)	0	1	0.14	2	0	(2)	(2)	(3)	(1)	0	1	(0.63)	0	3	1.50	(1)	-0.11
Air Voids vs. Thickness	4	1	1	3	(8)	2	1	0.57	0	1	0	0	(2)	(2)	0	(2)	(0.63)	(3)	2	(0.50)	0	-0.11
Air Voids vs. Roadway Density							1									(1)	(1.00)					0.00
Passing #200 vs. Asphalt Content	4	0	2	(2)	5	1	(1)	1.29	2	2	0	0	8	5	3	2	2.75	0	0	0.00	1	1.78
Passing #200 vs. Thickness	8	1	(2)	3	(6)	2	(1)	0.71	(1)	3	2	2	8	3	3	3	2.88	0	1	0.50	(2)	1.50
Passing #200 vs. Roadway Density							(1)									4	4.00					1.50
Asphalt Content vs. Thickness	8	1	(1)	3	(8)	2	0	0.71	(1)	0	2	1	0	0	0	2	0.50		1	1.00	(3)	0.41
Asphalt Content vs. Roadway Density							0									2	2.00					1.00
Roadway Density vs. Thickness							0									1	1.00					0.50
FC-5																						
Binder Content vs. Passing 3/8 in.	(3)	(2)	(1)	2	(4)	(1)	0	(1.29)	(6)	0	0	(2)	(5)	0	(4)	(4)	(2.63)	(1)	(2)	(1.50)	(4)	-2.06
Binder Content vs. Passing #4	(6)	(2)	(1)	2	(4)	(1)	0	(1.71)	(6)	(1)	0	(3)	(5)	0	(4)	(5)	(3.00)	(1)	(2)	(1.50)	(4)	-2.39
Binder Content vs. Passing #8	(5)	(2)	(1)	2	(1)	(1)	0	(1.14)	(2)	(3)	0	(4)	(6)	0	(4)	(6)	(3.13)	(1)	(2)	(1.50)	(4)	-2.22
Binder Content vs. Ride Number	0	(2)	(4)	8	(4)	0	0	(0.29)	(2)	0	1	0	(2)	(2)	0	(2)	(0.88)	5	0	2.50	0	-0.22
Passing 3/8 in. vs. Passing #4	(2)	0	1	2	0	0	0	0.14	0	(3)	0	(2)	(1)	(2)	(4)	(4)	(2.00)		0	0.00	4	-0.65
Passing 3/8 in. vs. Passing #8	(2)	1	1		4	0	0	0.67	5	(4)	0	(1)	(4)	(2)	(4)	(6)	(2.00)		0	0.00	4	-0.50
Passing 3/8 in. vs. Ride Number	3	0	(4)	8	0	1	0	1.14	4	0	1	0	3	(1)	0	2	1.13	5	2	3.50	4	1.56
Passing #4 vs. Passing #8	0	1	1	2	4	0	0	1.14	5	(3)	0	0	(4)	(2)	(4)	(3)	(1.38)		0	0.00	0	-0.18
Passing #4 vs. Ride Number	3	0	(4)	8	(3)	1	0	0.71	4	2	1	0	3	(1)	4	2	1.88	5	2	3.50	(3)	1.33
Passing #8 vs. Ride Number	3	0	(4)	8	(3)	1	0	0.71	(1)	5	1	0	7	0	4	3	2.38	5	2	3.50	(3)	1.56
FC-9.5 and FC-12.5																						
Air Voids vs. Passing #200	(3)	0	0	0	(6)	0	0	(1.29)	1	(3)	0	(4)	(8)	(3)	0	(5)	(2.75)	(2)	2	0.00	(3)	-1.89
Air Voids vs. Asphalt Content	0	0	0	2	(2)	1	0	0.14	2	0	0	(1)	(3)	(2)	0	1	(0.38)	0	2	1.00	(1)	-0.06
Air Voids vs. Thickness	3	1	1	5	(6)	1	0	0.71	2	1	1	0	(2)	(2)	0	(2)	(0.25)	0	2	1.00	(3)	0.11
Air Voids vs. Roadway Density							0									(2)	(2.00)					-1.00
Air Voids vs. Ride Number	0	(2)	(4)	8	(6)	1	0	(0.43)	4	1	1	0	(3)	(2)	0	(2)	(0.13)	7	2	4.50	(3)	0.11
Passing #200 vs. Asphalt Content	2	0	1	1	3	1	0	1.14	3	2	0	0	8	2	2	2	2.38	0	0	0.00	2	1.61
Passing #200 vs. Thickness	4	1	(1)	5	(2)	1	0	1.14	3	3	1	0	8	2	0	2	2.38	7	0	3.50	(1)	1.83
Passing #200 vs. Roadway Density							0									2	2.00					1.00
Passing #200 vs. Ride Number	4	(1)	(4)	8	(1)	1	0	1.00	5	4	1	0	8	1	2	2	2.88	7	2	4.50	(1)	2.11
Asphalt Content vs. Thickness	0	1	(2)	5	(6)	0	0	(0.29)	(1)	0	0	0	0	0	0	(2)	(0.38)	0	0	0.00	(2)	-0.39
Asphalt Content vs. Roadway Density							0									2	2.00					1.00
Asphalt Content vs. Ride Number	1	(1)	(4)	8	(6)	1	0	(0.14)	(2)	0	1	0	0	0	0	1	0.00	7	0	3.50	(1)	0.28
Ride Number vs. Roadway Density							0									1	1.00					0.50
Ride Number vs. Thickness	2	1	4	(8)	(1)	0	0	(0.29)	(2)	0	(1)	0	0	1	0	(1)	(0.38)	(7)	2	(2.50)	(4)	-0.78
Roadway Density vs. Thickness							0									(1)	(1.00)					-0.50

FDOT CONSTRUCTION QUALITY INDEX
RIGID PAVEMENT

- +	Construction Industry						FDOT							Academia			Other	GRAND MEAN
	1	2	3	4	5	AVG	6	7	8	9	10	11	AVG	12	13	AVG	14	
Rigid Pavement System Components																		
Embankment vs. Stabilized Subgrade	2	3	3	(1)	0	1.40	4	2	3	2	(6)	4	1.50	4	0	2.00	(5)	1.07
Embankment vs. Treated Permeable Base	2	8	3	0	0	2.60	4	4	3	4	(6)	7	2.67	4	1	2.50	(5)	2.07
Embankment vs. PCC	2	8	8	0	0	3.60	8	8	7	5	0	3	5.17	3	1	2.00	4	4.07
Stabilized Subgrade vs. Treated Permeable Base	1	8	0	1	0	2.00	1	0	0	1	4	7	2.17	0	6	3.00	0	2.07
Stabilized Subgrade vs. PCC	1	8	8	0	0	3.40	5	8	7	2	6	1	4.83	0	6	3.00		4.00
Treated Permeable Base vs. PCC	(1)	8	8	0	0	3.00	3	7	7	1	6	(1)	3.83	0	1	0.50	4	3.07
Stabilized Subgrade																		
Density vs. LBR	2	1	4	(1)	0	1.20	(8)	(1)	2	0	(7)	(5)	(3.17)		7	7.00	0	(0.46)
Density vs. Thickness	0	0	(4)	0	0	(0.80)	(2)	0	(2)	0	(7)	(5)	(2.67)		7	7.00	(4)	(1.31)
LBR vs. Thickness	0	0	(4)	1	0	(0.60)	8	2	(5)	0	7	3	2.50		1	1.00	4	1.31
Cement Treated Permeable Base																		
Gradation vs. Water-Cement Ratio	0	3	(4)	2	2	0.60	3	(2)	1	2	(4)	(7)	(1.17)	0	7	3.50		0.23
Gradation vs. Cement Factor	0	5	2	1	2	2.00	3	(1)	2		0	(6)	(0.40)	0	7	3.50		1.25
Water-Cement Ratio vs. Cement Factor	0	4	0	0	1	1.00	1	(1)	0		4	1	1.00	0	(7)	(3.50)		0.25
Asphalt Treated Permeable Base																		
Asphalt Binder Content vs. Gradation	0	(4)	4		2	0.50	3			0	0	7	2.50	0	7	3.50	0	1.73
PCC																		
Air Content vs. Compressive Strength	3		8	1	0	3.00	8	0	2	(2)	5	7	3.33	0	7	3.50	4	3.31
Air Content vs. Profile Indedx	3		8	0	0	2.75	8	5	2		8	7	6.00	0		0.00	4	4.09
Air Content vs. Slump	3		(2)	0	0	0.25	3	(5)	2		5	7	2.40	(2)	7	2.50	0	1.50
Air Content vs. Thickness	3		8	2	0	3.25	8	0	2	2	5	7	4.00	3	8	5.50	(2)	3.54
Air Content vs. Water-Cement Ratio	3		2	2	0	1.75	8	(2)	2	2	5	7	3.67	3	7	5.00	6	3.46
Compressive Strength vs. Profile Index	(2)		4	(1)	0	0.25	(2)	0	2		0	3	0.60	0		0.00	4	0.73
Compressive Strength vs. Slump	(2)		(8)	(2)	0	(3.00)	(8)	(3)	(2)		(5)	(6)	(4.80)	(2)	1	(0.50)	(4)	(3.42)
Compressive Strength vs. Thickness	0		0	0	0	0.00	1	0	0	2	0	0	0.50	3	8	5.50	0	1.08
Compressive Strength vs. Water-Cement Ratio	(1)		(8)	(2)	0	(2.75)	0	(3)	1	2	3	(6)	(0.50)	3	1	2.00	1	(0.69)
Profile Index vs. Slump	0		(8)	0	0	(2.00)	(8)	(5)	(2)		(4)	(6)	(5.00)	(2)		(2.00)	(4)	(3.55)
Profile Index vs. Thickness	3		4	2	0	2.25	(1)	0	(2)		0	0	(0.60)	3		3.00	(4)	0.45
Profile Index vs. Water-Cement Ratio	2		(8)	1	0	(1.25)	(1)	(3)	(2)		0	(6)	(2.40)	0		0.00	(4)	(1.91)
Slump vs. Thickness	2		8	2	0	3.00	8	3	1		5	7	4.80	3	8	5.50	4	4.25
Slump vs. Water-Cement Ratio	2		3	0	0	1.25	8	0	2		5	6	4.20	3	8	5.50	4	3.42
Thickness vs. Water-Cement Ratio	(2)		(8)	(2)	0	(3.00)	0	(3)	0	(2)	0	(6)	(1.83)	0	8	4.00	0	(1.15)

Appendix F. CQI Calculation Users Guide

Construction Quality Index Calculator v1.2

User's Guide

Introduction and Installation

This guide will assist in installing, using, and uninstalling the CQI Calculator.

The CQI Calculator is designed to organize and evaluate data collected from pavements during construction to give a Construction Quality Index (CQI) that describes how well the pavement adheres to construction standards.

This process uses the concept of percent within limits (PWL) to estimate how many data points will fall within prescribed values given a small sample. The more data points that can be entered, the more accurate the estimate will be. See the file named "PWL.doc" for more information on this process.

Each project is designed for one section of pavement. Depending on the type of pavement, different layers may be added to the project. Finally, depending on which layers are included in the project, different tests will become available. It is not required to have data for every layer and every test, and those not included will not have an effect on the CQI calculation.

The CQI Calculator comes with an installation program for ease of distribution. To install the program, run the "Install.exe" file, select whether shortcuts should be created, and choose an installation directory. The calculator will be registered and an "Uninstall.exe" file will be generated in the selected directory. Running this will completely remove all files associated with the CQI Calculator, including shortcuts and saved projects, and will also remove the registration for it from the system.

To use the CQI Calculator, Java Runtime Environment (JRE) 5 Update 8 or later must be installed. This can be downloaded for free at http://java.sun.com/. Click the "Get Java Software" button to quickly reach the download page.

Once the software is set up, it can be run from the Start Menu if shortcuts were created or by running "CQI.jar" from its installation directory.

CQI Calculator Overview

The CQI Calculator displays a small window that will navigate through the data entry and organization process. An online help screen is available any time by pressing F1 or selecting *Current Screen* from the *Help* menu. This screen will provide assistance with the screen currently displayed in the calculator. Also, a small line of text will appear in the *Status Bar* at the bottom of the main calculator screen. The *Status Bar* explains the calculator's current and completed actions, and may indicate the cause of errors and output files.

The application has a menu bar that is accessible from any screen. The *File* menu allows the project to be saved in its current state by selecting *Save Current Project*, returns to the *Project Selection* screen by selecting *Return to Main Menu*, or closes the application by selecting *Exit*. Note that the application may also be closed by clicking the red X box in the upper right of the screen. Closing the application will lose unsaved work, but returning to the *Project Selection* screen will automatically save any changes that have occurred.

The *Help* menu displays the previously described help screen by selecting *Current Screen* or a small window giving details about the CQI Calculator by selecting *About*.

Project Selection Screen

- ***Overview***

  Also referred to as the *Main Menu*, the *Project Selection* screen organizes and displays all started and completed projects. From this screen, new projects may be started or existing projects may be deleted or edited. Reports may also be generated for a completed project from this screen.

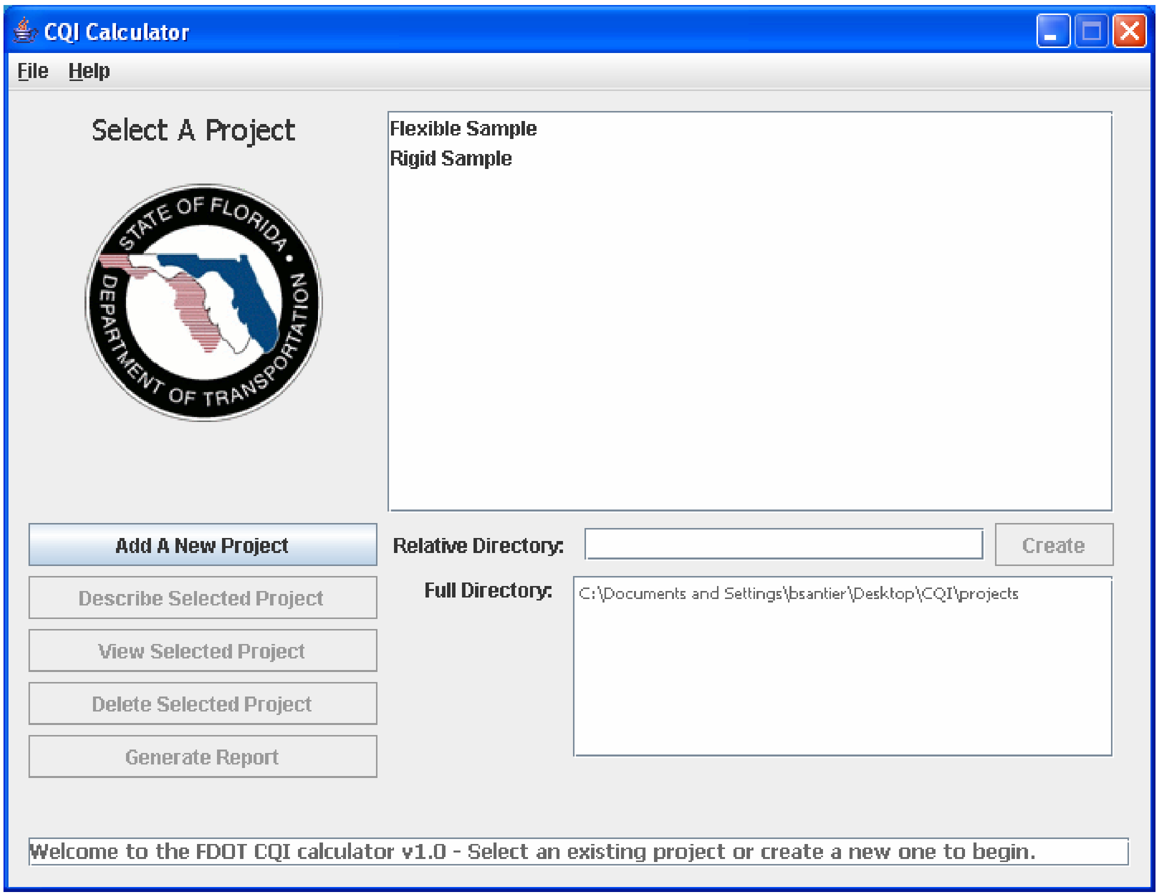

Figure 1: the *Project Selection* screen

- ***Setting the current directory***

  Before the calculator will detect any existing projects, the current directory must be set correctly. This directory is also used when creating new projects and is called the *Full Directory*. The *Full Directory* defaults to the installation directory but can be changed by entering a relative directory in the *Relative Directory* box. Parent directories can also be accessed by entering "..\" in the *Relative Directory* box. See Figure 2 for an example.

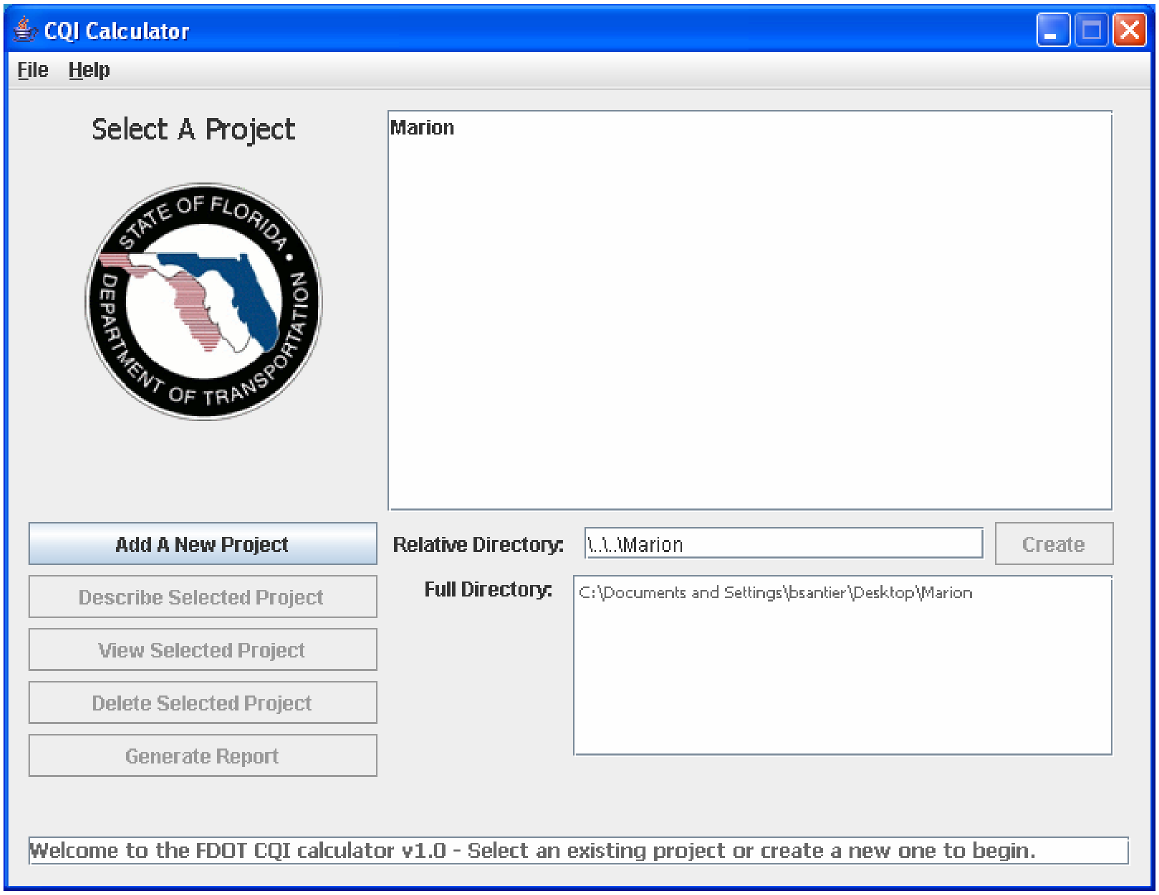

Figure 2: accessing a parent directory

As soon as an acceptable relative directory has been entered, all projects in that directory will be displayed in the selection window. Should the relative directory not exist, "Unrecognized relative directory" will be displayed under the *Full Directory* box and the *Create* button will be enabled. Clicking this button will create the named directory and allow project creation in that directory.

- ***Creating a new project***

  To create a new project in the directory described under the *Full Directory* box, click the *Add A New Project* button. This will automatically begin the editing process for that project by displaying the *Pavement Edit* screen.

- ***Selecting an existing project***

  To select an existing project, ensure that the *Full Directory* is correct and click once on the appropriate project from the selection window. It will be displayed in blue, and the other buttons in the lower left of the screen will be enabled. Also note that the project's calculated CQI will appear just below the FDOT logo. If this value is still undetermined, a square will be displayed instead.

- ***Editing an existing project***

  To change the selected project's basic information, click the *Describe Selected Project* button. The *Project Description Edit* screen will appear. This screen has fields for the project's number, state road identifier, and any additional comments. Enter or edit the information here and click the *Back* button to save changes and return to the *Project Selection* screen.

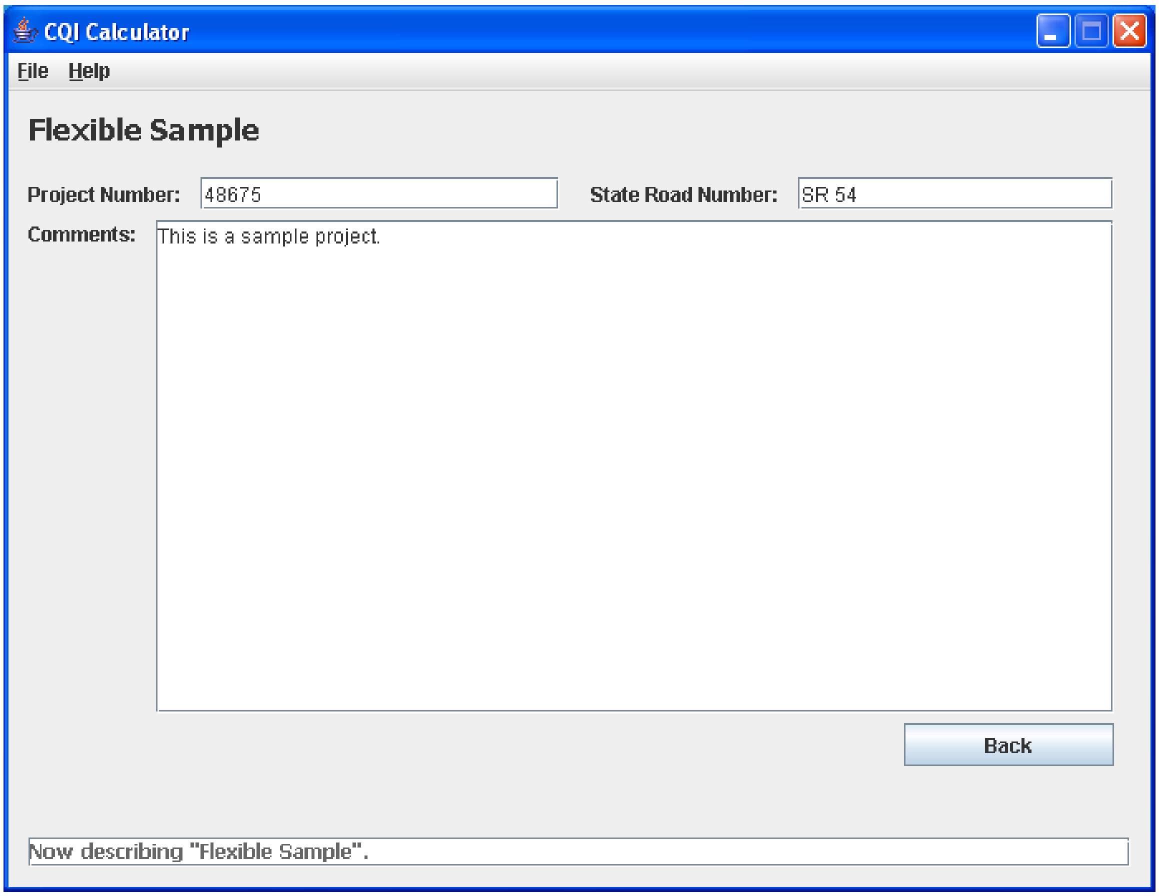

Figure 3: the *Project Description Edit* screen

  To edit the data contained within the selected project, click the *View Selected Project* button. The *Pavement Edit* screen will be displayed for that project.

- ***Deleting an existing project***

  To delete the currently selected project, click the *Delete Selected Project* button. The data files for that project will be removed from disk, but any reports created from that project will not.

- ***Generating a report***

  To generate a printer-friendly report for the currently selected project, click the *Generate Report* button. This will create a .htm file (web page) in the same directory as the project data files that can be viewed with any web browser. The report contains a small graphic depicting the FDOT logo, and must be moved along with the page should the page change directories.

Construction Quality Index Report

Flexible Sample

Date: Tue Jan 30 08:50:07 EST 2007
Project Number: 48675
State Road Number: SR 54
Pavement Type: Flexible
Comments: This is a sample project.

CQI Breakdown:

Layer / Test Name	CQI	Weight	CQI x Weight
Stabilized Subgrade	0.9319	0.0950	0.0885
Density	1.0000	0.6170	
LBR	0.8221	0.3830	
SuperPave	0.8982	0.5135	0.4612
356 [3000.0]	0.8932	0.6000	
Passing #200	0.9555	0.0890	
Passing #8	0.7754	0.0890	
Air Voids	0.8322	0.2690	
Asphalt Content	0.9832	0.2370	
358 [2000.0]	0.9057	0.4000	
Passing #200	0.8106	0.0890	
Passing #8	0.9442	0.0890	
Air Voids	0.8573	0.2690	
Density	0.9628	0.3160	
FC9.5	0.9012	0.3915	0.3528
Passing #200	0.9274	0.2022	
Passing #8	0.8089	0.2022	
Ride Number	0.9236	0.5956	
NB	0.9795	0.5000	
SB	0.8676	0.5000	
Total			0.9025

Figure 4: a sample report

Pavement Edit Screen

- ***Overview***

  The *Pavement Edit* screen describes the project in terms of its name and pavement type, as well as which pavement layers should be included in the analysis of the CQI index. The calculated CQI value of the currently selected layer in the *Layers Used* window is displayed in the top right of the screen.

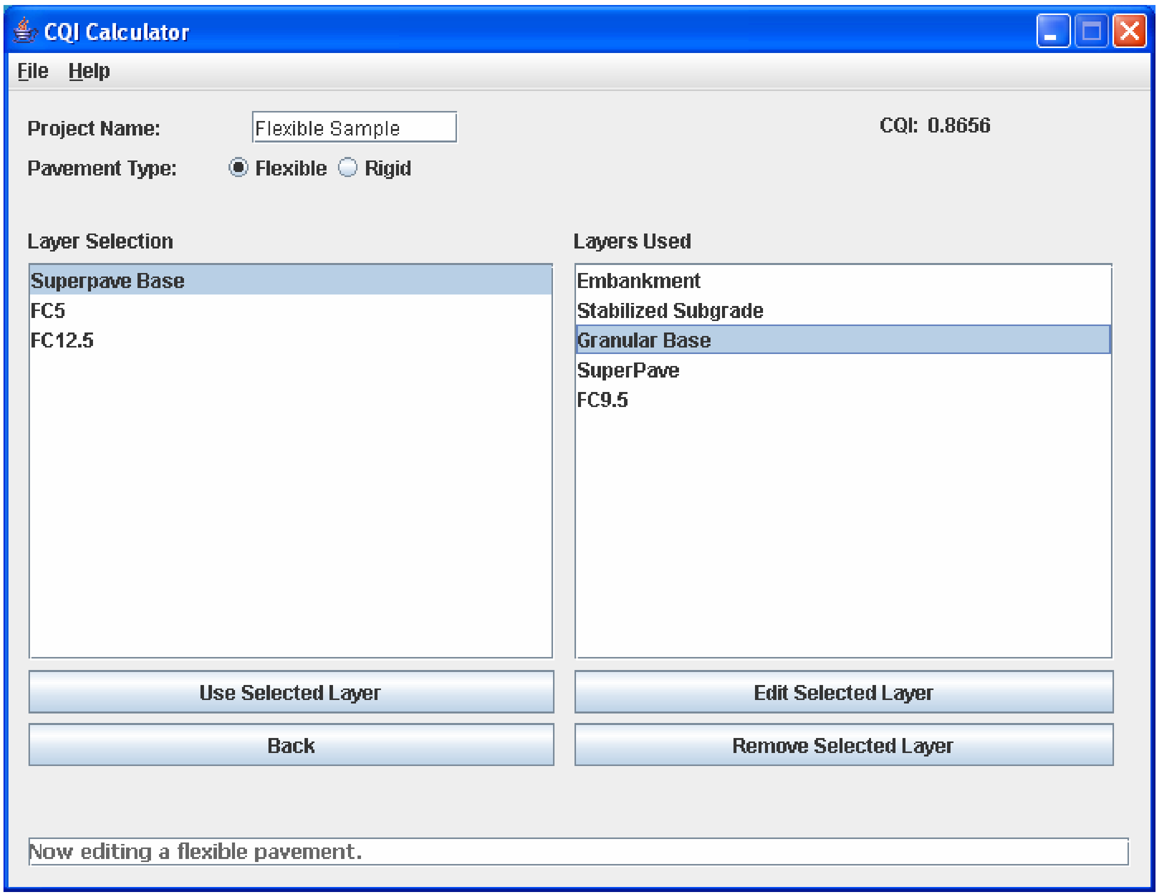

Figure 5: the *Pavement Edit* screen

- ***Changing the project's name***

  To change the current project's name, enter the new name in the *Project Name* text box. This name will be used to refer to the project from the *Project Selection* screen and will be displayed on any generated reports for this project. Changing an existing project's name will not erase the old file with the old name, but will save changes to a new file with the new name.

- ***Selecting a pavement type***

  To change a project's pavement type, click the appropriate *Pavement Type* radio button. This will erase all data previously entered for the project. Note that changing the pavement type changes the list of available layers.

- ***Adding a layer to the project***

  To add a layer for data entry, select the appropriate layer's name in the *Layer Selection* window and click the *Use Selected Layer* button. It will move to the *Layers Used* window. Note that for flexible pavements only one type of friction course may be placed in the *Layers Used* window. Likewise, for rigid pavements, only one type of permeable base may be added.

- ***Removing a layer from the project***

  To move a layer from the *Layers Used* window to the *Layer Selection* window, select it and click the *Remove Selected Layer* button. Although this will ignore that layer in CQI calculations, the data it contains will be saved in the project file should the layer need to be used once more. However, changing the pavement type will clear all data.

- ***Editing a layer***

  To edit the layer currently selected in the *Layers Used* window, click the *Edit Selected Layer* button. The *Layer Edit* screen will appear unless a layer that supports sub layers was selected, in which case the *Multiple Layers Edit* screen will appear.

- ***Returning to the* Select a Pavement *screen***

  Clicking the *Back* button will save the current project to file and return the application to the *Project Selection* main menu.

Layer Edit Screen

- ***Overview***

  The *Layer Edit* screen displays all possible tests the selected layer may include as well as a list of the tests being used in CQI calculations. The calculated CQI for the currently selected test in the *Tests Used* window is displayed in the top right of the screen.

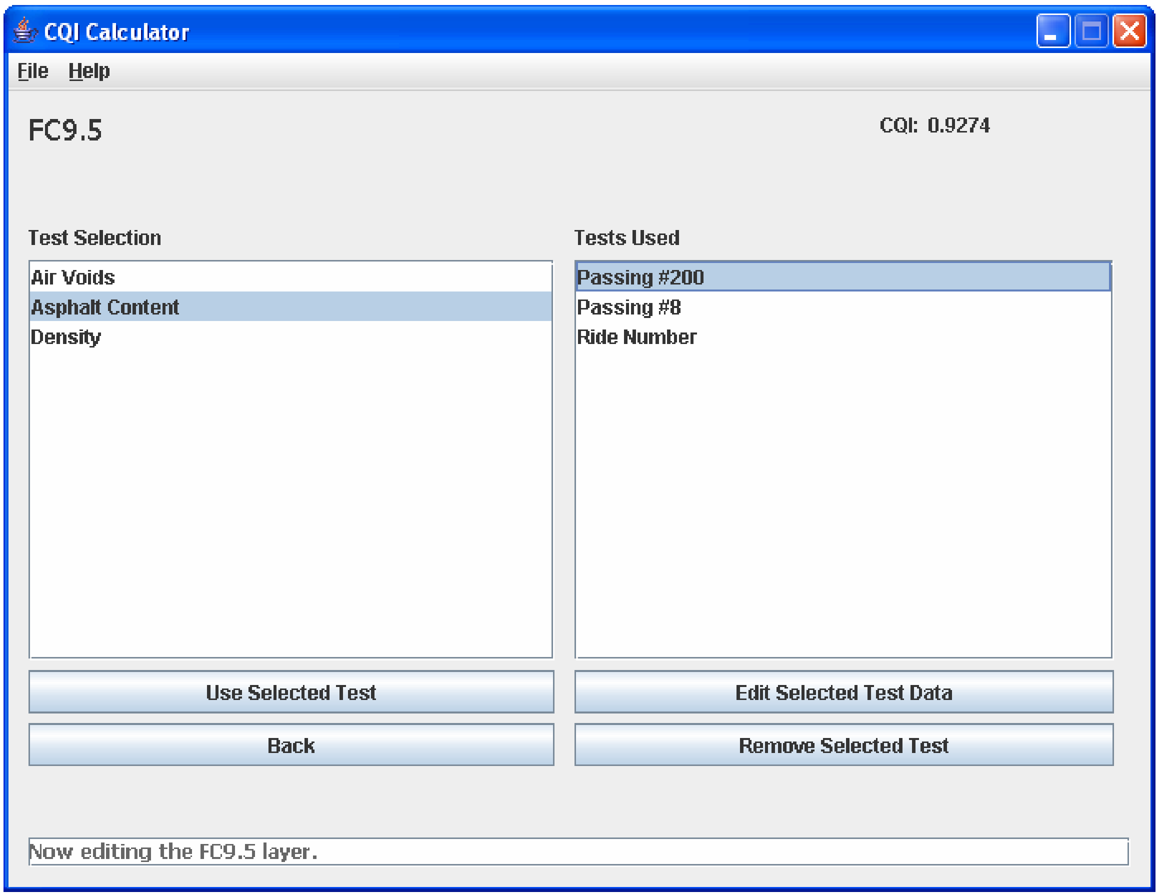

Figure 6: the *Layer Edit* screen

- ***Adding a test to the project***

  To add a test for data entry to the project, select its name in the *Test Selection* window and click the *Use Selected Test* button. The test will move to the *Tests Used* window.

- ***Removing a test from the project***

  To move a test from the *Tests Used* window to the *Test Selection* window, select its name and click the *Remove Selected Test* button. Tests placed in the *Test Selection* window will not be included in CQI analysis, but will retain their data until the pavement type is changed from the *Pavement Edit* screen.

- ***Editing a test's data***

  To enter data for the test selected in the *Tests Used* window, click the *Edit Selected Test Data* button. Unless the Ride Number test was selected, the *Test Data Edit* screen will be displayed. If a Ride Number test was selected, the *Ride Number Test Edit* screen will be displayed.

- ***Returning to the* Pavement Edit *screen***

  To return to the *Pavement Edit* screen, click the *Back* button. Changes will not be saved to file at this step, but will be kept in memory.

Multiple Layers Edit Screen

- ***Overview***

  The *Multiple Layers Edit* screen appears only if a Superpave, friction course, or permeable base layer is selected for editing from the *Pavement Edit* screen. This screen provides support for multiple mixes to be entered into the project, each with a user-defined weight. Layers are displayed in the *Layers Used* window by displaying the mix number followed by the layer's weight in brackets. The calculated CQI of the selected mix will be displayed in the top right of the screen.

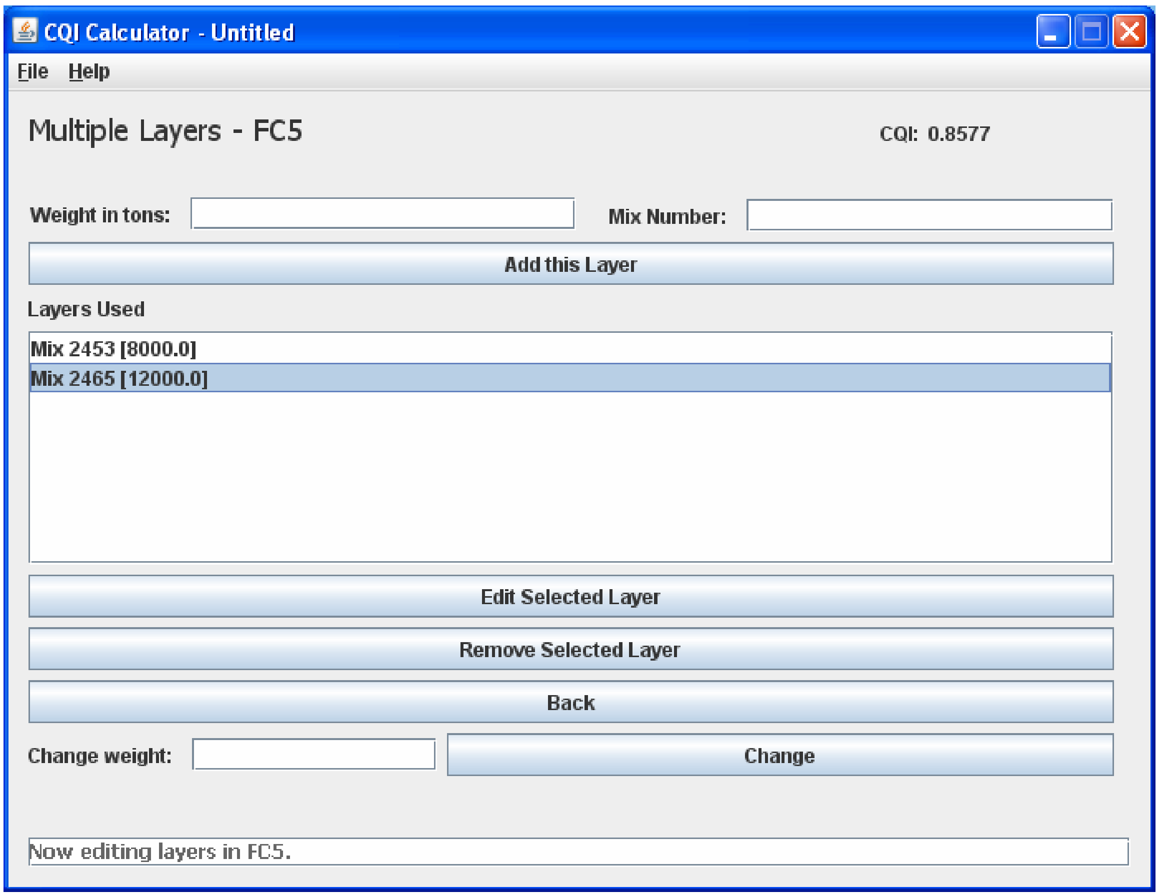

Figure 7: the *Multiple Layers Edit* screen

- ***Adding a layer***

  To add a new layer to the list of used layers, enter the weight of the layer in tons in the *Weight* field. Enter a description of the mix, usually the mix number, in the *Mix Number* field. Finally, click the *Add this Layer* button. The new layer will appear in the *Layers Used* window.

- ***Removing a layer***

  To remove a layer from the *Layers Used* list, select it and click the *Remove Selected Layer* button. This will permanently erase the layer and preclude it from CQI calculations. This change cannot be undone except by loading the project once more from the *Project Selection* screen.

- ***Changing a layer's weight***

  To change the selected layer's weight, enter the new weight in the *Change Weight* text box on the bottom left of the screen. Pressing the *Change* button will set the selected weight to that value. An incorrect input will display an error message in the *Status Bar*.

- ***Editing a layer***

  To further edit the selected Superpave layer, click the *Edit Selected Layer* button. The *Layer Edit* screen will be displayed for that layer.

- ***Returning to the* Pavement Edit *screen***

  To return to the *Pavement Edit* screen, click the *Back* button. This will not save changes to file, but they will be kept in memory.

Ride Number Test Edit Screen

- ***Overview***

  The *Ride Number Test Edit* screen only appears when the Ride Number test is selected for editing from the friction course's *Layer Edit* screen. It allows multiple ride number tests to be included for CQI calculation. Ride number tests are all weighed equally and are usually described by lane designation. The currently selected ride number test's calculated CQI is displayed in the top right of the screen.

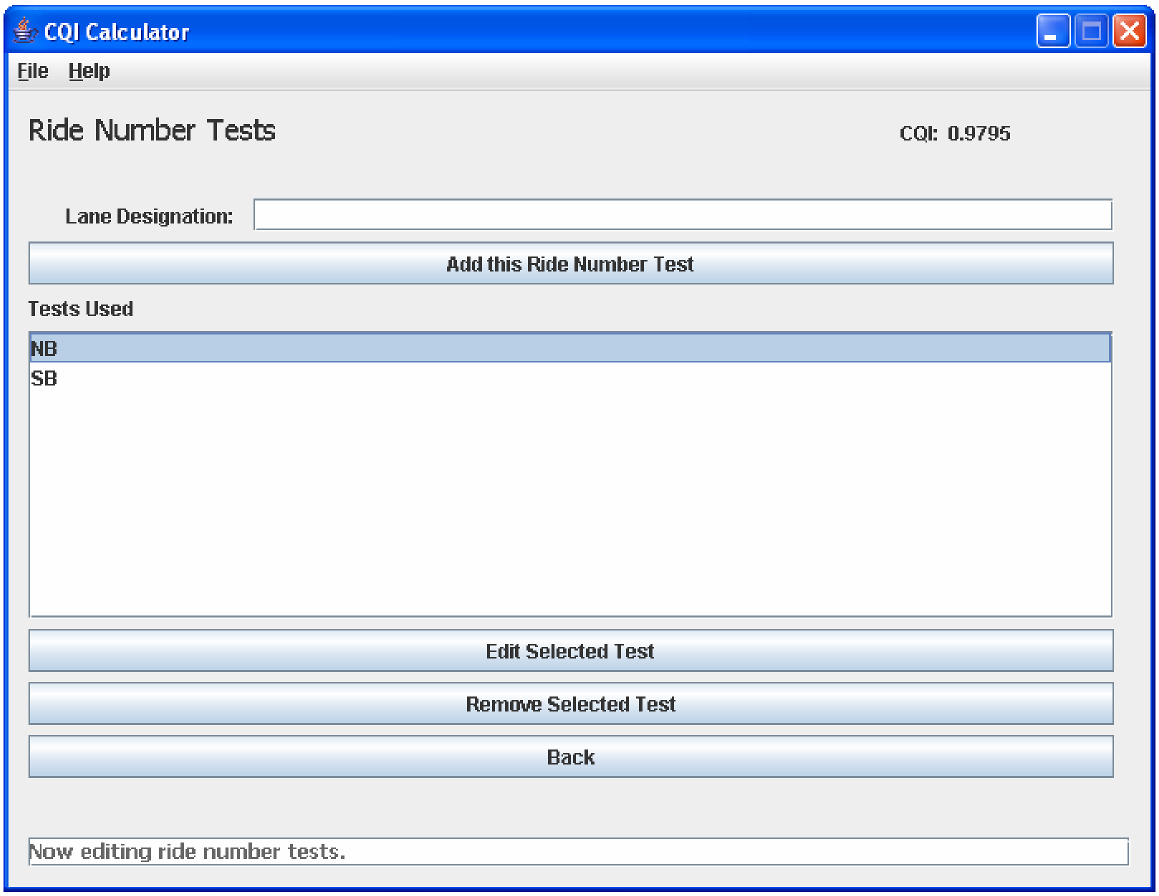

Figure 8: the *Ride Number Test Edit* screen

- ***Adding a ride number test***

  To add a new ride number test, enter the test's description in the *Lane Designation* field and click the *Add this Ride Number Test* button. The test will appear in the *Tests Used* list.

- ***Removing a ride number test***

  To permanently remove a ride number test from the project, select it and click the *Remove Selected Test* button. This change cannot be undone except by loading the project once more from the *Project Selection* screen.

- ***Editing a ride number test's data***

  To enter data for the currently selected ride number test, click the *Edit Selected Test* button. This will display the *Test Data Edit* screen.

Test Data Edit Screen

- ***Overview***

  The *Test Data Edit* screen holds all of a test's data and specifications for analyzing that data. Data can be imported from text files or entered directly into the list. Data can also be exported to create a text file that can then be imported into another test. Statistical information about the data is shown to the left of the screen as well.

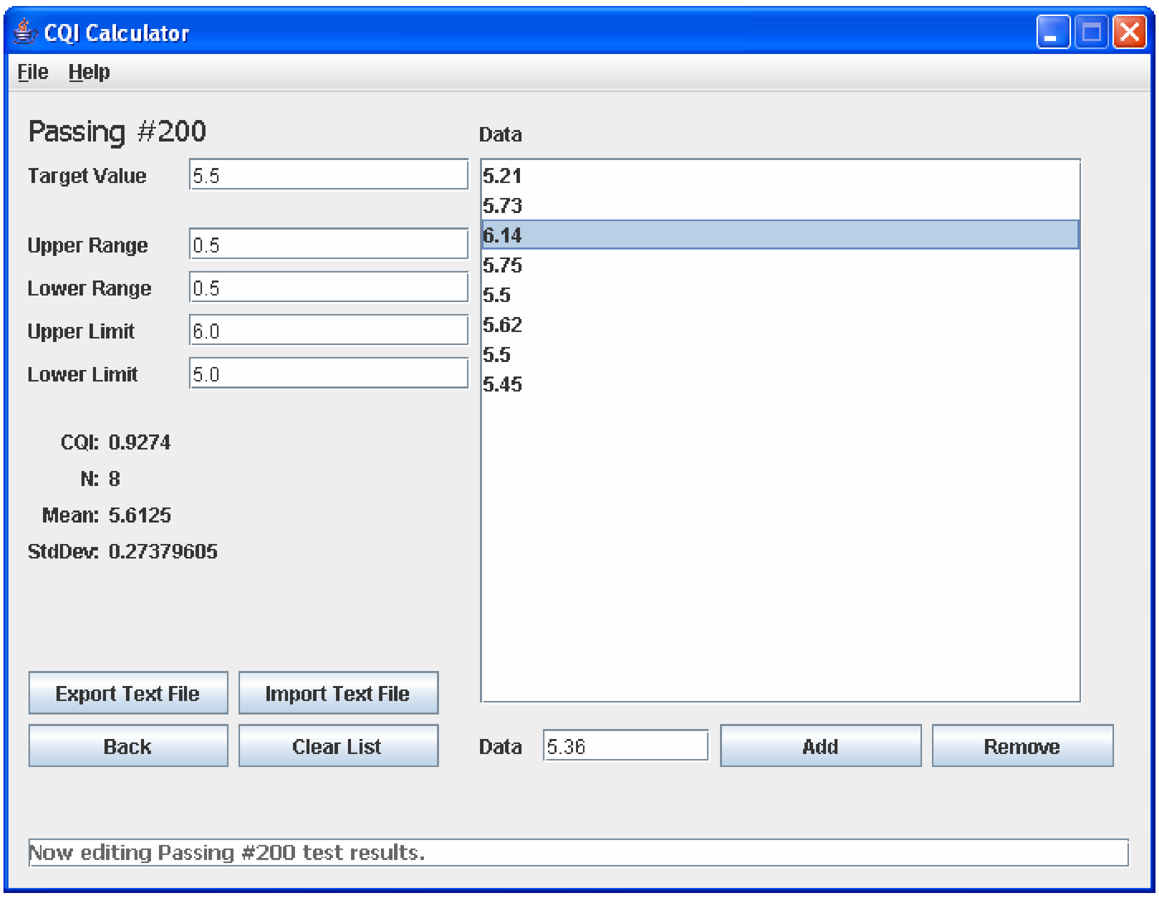

Figure 9: the *Test Data Edit* screen for a double sided limit test

- ***Changing the test's specifications***

  To change the current test's specifications, enter the new values in the fields on the left side of the screen. Changing one field will automatically correct the others. The *Target Value* should be set to the ideal data value. The *Upper* and *Lower Range* fields should then be set such that the entire acceptable range for data is supported. This range is displayed under the *Upper* and *Lower Limit* fields. Note that tests limited only in one direction will have only one field for limits and ranges.

- ***Entering data directly***

To enter data directly into the test, type the number in the *Data* field and click the *Add* button. The data point will appear in the *Data* window.

- ***Removing a data point***

  To remove the currently selected data point, click the *Remove* button. The selected data point will be permanently removed.

- ***Exporting data to a text file***

  To export all of the data that is currently entered in the *Data* window, click the *Export Text File* button. A *Save* window will appear requesting a file name and location. Navigate to the appropriate directory, enter a file name, and click *Save* to export the text file.

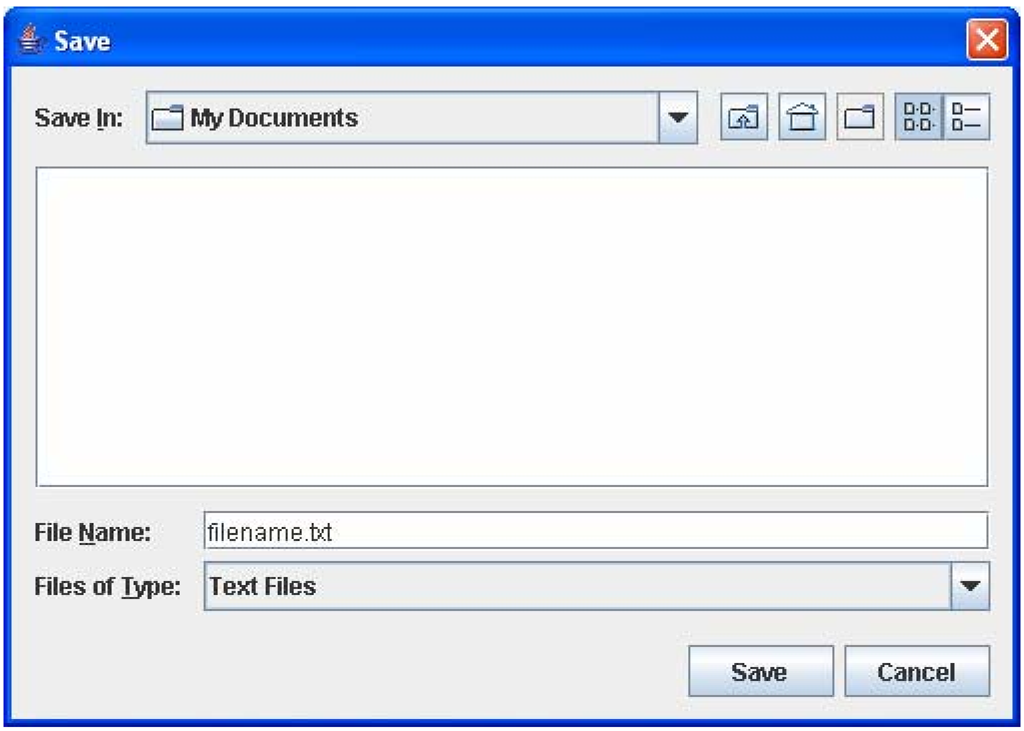

Figure 10: exporting data to a text file

- ***Importing data from a text file***

  Data can be imported from any ASCII file as long as data members are separated by either a comma, tab, or a new line. Combinations of those are also acceptable. Click the *Import Text File* button to open a *Load* window that will ask for a text file to import. Navigate to the appropriate directory, select the data file to load, and click the *Load* button. If the operation was successful, the data will appear in the *Data* window and the message "Successfully loaded all data from [filename]" will appear in the *Status Bar*. Should the operation fail, as many data points as possible will be placed in the *Data* window and the message "Unable to read part of [filename]" will appear in the *Status Bar*. If this occurs, ensure the formatting for that file is correct. Note that importing data will erase all previously entered data points.

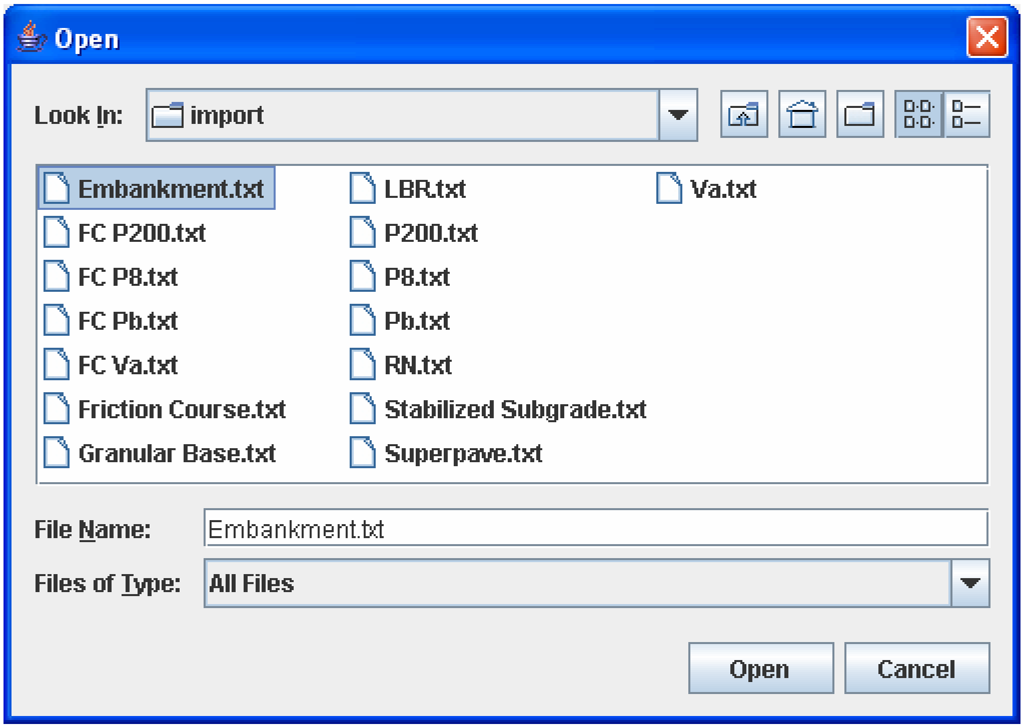

Figure 11: importing data from a text file

- ***Clearing the* Data *list***

  To clear all data points entered for this test, click the *Clear List* button. This will permanently erase all data points.

- ***Returning to the* Layer Edit *screen***

  To return to the *Layer Edit* screen, click the *Back* button. While this will not save any changes to file, the changes will be stored in memory.

- ***Preparing an Excel spreadsheet for importing into the CQI Calculator***

  Excel spreadsheets containing data can be exported for input into the CQI Calculator. All data members must be on the same worksheet and must be the only information on that sheet. If the data is in more than one column, the data will be read from left to right, top to bottom. Select "Save As…" from the *File* menu in Excel and change the file type to "Text (Tab delimited)(.txt)" from the drop-down *Save as type* combo box. Navigate to the appropriate directory and click the *Save* button. Excel will mention that only the active sheet will be saved. Click *OK*. Excel will then mention that this format does not support all formatting. Click *Yes*. The file is now ready to be imported into the CQI Calculator.

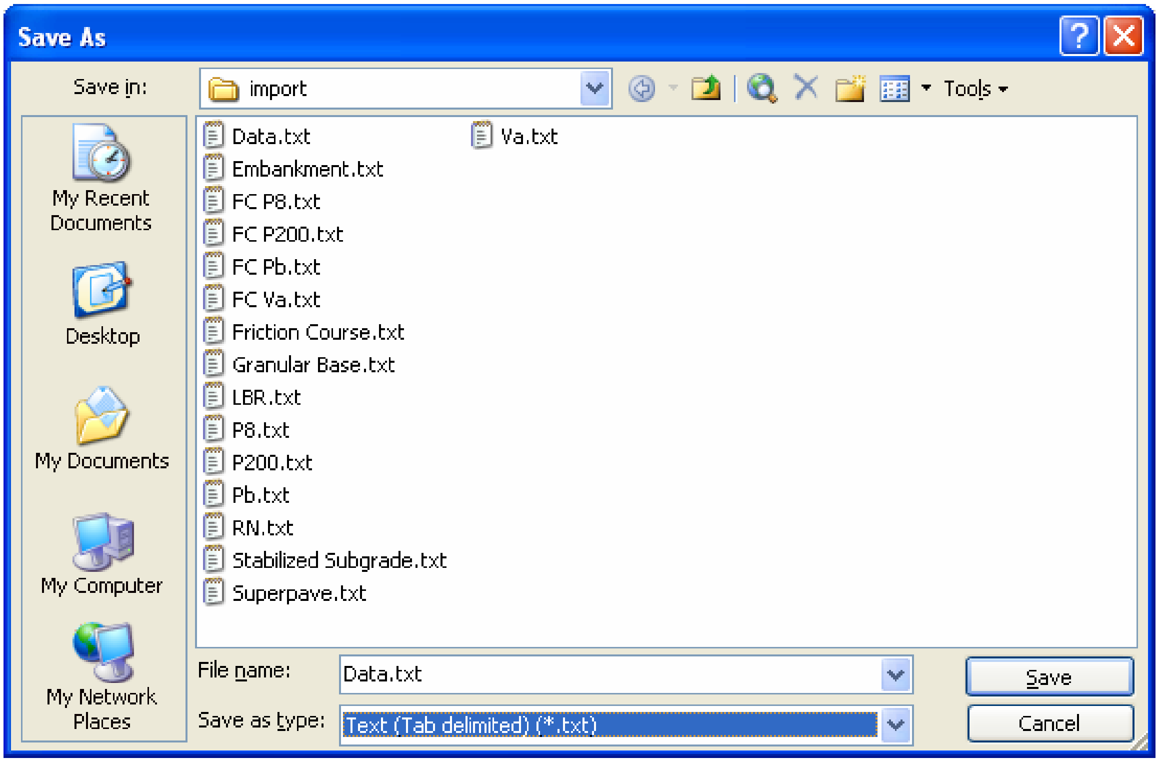

Figure 12: exporting a file from Excel for use in the CQI Calculator

- ***Importing a text file created with the CQI Calculator into Excel***

  To open an exported text file in Excel, right-click its icon and select "Open With" from the pop-up menu. If "Microsoft Office Excel" does not appear in the list, click "Choose Program…" and select Excel from the new window. Click *OK*.