DEVELOPMENT OF A CONSTRUCTION QUALITY INDEX AND AN INTEGRATED CONSTRUCTION QUALITY INDEX TO EVALUATE THE QUALITY OF PAVEMENT CONSTRUCTION PROJECTS

By

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To my Wife

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LIST OF ABBREVIATIONS

AHP	Analytic hierarchy process.
ANP	Analytic network process.
AQC	Acceptable quality characteristics.
CQI	Construction quality index.
ERS	End-result specifications.
HMA	Hot mixed asphalt.
ICQI	Integrated construction quality index.
LBR	Lime bearing ratio.
LCC	Life-cycle cost.
LIMS	Laboratory information management system.
LSL	Lower specification limit.
LTPP	Long-term pavement performance.
MEPDG	Mechanistic-empirical pavement design guide.
PD	Percent defective.
PMS	Pavement management system.
PRS	Performance-related specifications.
PWL	Percent within limits
QA	Quality assurance.
QC	Quality control.
RAP	Recycled asphalt pavement.
RQL	Rejectable quality level.
SHA	State highway agency.
USL	Upper specification limit.

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Using some type of evaluation process to rate contractors is definitely the current national trend. In the past, several actions by state highway agencies have been taken to develop some kind of rational system of rating the quality of highway construction projects and to utilize these ratings for contractor qualification or bidding purposes. However, setting contractors' bidding limits is the most substantial use of quality ratings while some states do not use them for anything, and some states do not even rate the quality of their projects. The subjectivity is one of the main complaints against current systems. The Construction Quality Index (CQI) and the Integrated Construction Quality Index (ICQI) are ratings of the quality of materials and workmanship on highway projects that, unlike current quality rating models used by state highway agencies, is totally objective.

The CQI/ICQI model tended to assign quality index values consistent with the owner's level of satisfaction with the limited data procured through the LIMS database. FDOT was asked to provide 105 projects to the research team along with an associated "rating" for each project. The projects submitted by FDOT were to be ones that had data entered into the LIMS database.

For the projects that met the criteria for inclusion, the CQI model showed positive results, rendering higher CQI for projects rated "good" by FDOT. The results were clearer when the projects were put into two categories; good and poor. Because the rating by FDOT is a criterion of the model, having a consistent and precise rating is essential for successful application of the CQI model.

There is a tendency that better rated projects by FDOT produce higher ICQI. The mean value of ICQI for projects rated "good" by FDOT construction and materials personnel was higher than the other ICQI mean values for projects rated "average" or "poor." The same relationship can be seen between "average" and "poor."

CHAPTER 1
INTRODUCTION

1.1 Background

In 1992, construction was one of the largest industries in the United States, constituting approximately 7.9 percent of the Gross National Product (GNP) (MacAuley et al. 1993). Comparing the post-World War II peak of 11.9 percent of GNP attained in 1966, this 7.9 percent seems low even though the construction industry tends to fluctuate widely according to variations in the economy or the cycle of the seasons. However, this measure does not illustrate the importance of construction in the economy because the above data only represents new construction. Several types of construction activity that are not included in new construction data, for example, maintenance and repair, commercial/industrial renovation, and hazardous waste cleanup, are also a big part of the U.S. industry. With the start of the new century, various construction agencies have already begun searching for cost-effective and labor-effective management practices.

State Highway Agencies (SHAs) have been seeking to develop mechanisms that elevate the quality of the transportation infrastructure and reduce project cost and agency personnel. As one of the alternative ways to shave project costs and reduce agency personnel, policy changes concerning the use of contractor-conducted testing in quality assurance decisions have been made by SHAs, which has reinforced the importance of quality-driven contractors. These policy changes forced contractors to implement more requirements in handling quality management in their field operations. As more contractors administered the quality control (QC) service, the SHAs do not do QC any more, thus a quality assurance (QA) remains as their role. Within this quality assurance process, a need arose for comprehensive evaluation methods for contractors' quality control processes, which led to a need for researching quality performance measurement techniques and approaches.

All SHAs accept their projects in accordance with one or more construction specifications that contain guidance and minimum requirements that contractors should follow. Theoretically, when contractors comply with the specifications, the final product must provide the expected level of service for the expected periods of time.

In many cases, low-quality work and high-quality work are treated the same as long as they meet the requirements of the specifications. The current approach for evaluating the quality of pavement projects is generally based on engineering judgment. Various material properties, such as the percentage of laboratory density, the limerock-bearing ratio, the asphalt binder content, and gradation, are used for evaluating pavement construction. It is generally believed that these properties should be related to the quality of the pavement construction; however, no fundamental engineering properties are used to connect the components of the pavement system to evaluate the pavement system performance.

Many researchers recently have emphasized the development of a Construction Quality Index (CQI). The CQI supplies a rational means for measuring the overall quality of a constructed structure by determining the quality of the individual components and combining them as a system to obtain a composite quality index. The CQI value can be used either to determine the contractor's compensation according to the quality level or to determine the contractor's qualification status as a contractor rating system.

1.2 Objective

The primary purpose of this research was to develop two practical and objective models to evaluate the quality of pavement construction. One model generates CQI, and the other model produces integrated construction quality index (ICQI), including aspects of mechanistic-empirical analysis. The CQI/ICQI were implemented without substantial modification to FDOT's current test and measurement system. The CQI/ICQI include material, structural, and pavement smoothness characteristics and are applicable for both new and rehabilitation projects. Soils, bound and unbound granular base materials, and asphalt were considered. Concrete materials for concrete pavement projects were not considered in validating the models because of the limited number of concrete pavement projects and significant problems in the procuring of the data.

The goal of the developed CQI/ICQI was to be able to use it as an objective tool for evaluating the quality of pavement construction. The formulation and data set used to develop the CQI/ICQI model 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.

In order to be transparent and stick to the specifications, the CQI model was applied using the percent within limits (PWL) concept, which already has been used by FDOT and is familiar to the contractor. In general terms, the PWL determines whether the CQI for a project is good or bad. The PWL for each quality characteristic were multiplied by weighting factors. In the CQI model, the analytic hierarchy process (AHP) was applied to obtain weighting factors for each factor (acceptance quality characteristics) and each layer of the pavement system. Acceptance quality characteristics such as #200 sieve passing rate and asphalt content from specifications were considered as factors of the model, but interactions between the factors were not considered.

In the ICQI model, the mechanistic-empirical model and statistical (regression) analysis were used to generate ICQI. The same factors (acceptance quality characteristics) in the CQI model were initially considered for development of the ICQI model, but the mechanistic-empirical pavement design guide had different acceptance quality characteristics from the CQI model to predict future pavement performance. Data for the different acceptance quality characteristics of the mechanistic-empirical pavement design guide was stored in FDOT's database system, and the acceptance quality characteristics from the pavement design guide were used to generate the ICQI model.

The factors (acceptance quality characteristics from the pavement design guide) were considered as independent variables, and a modified output from the mechanistic-empirical model was used as a dependent variable of the regression model in developing the ICQI model. Interactions between the factors in each layer of the pavement system were analyzed in the ICQI model; however, weighting factors for each layer of the pavement system were obtained from the AHP.

For validation purposes, personnel from asphalt paving construction projects were asked to provide FDOT Construction and Materials officials with their ratings for the projects. Once the CQI and ICQI were developed and generated the scores for the projects, they were compared to the FDOT ratings under the assumption that FDOT ratings were the correct evaluations for the quality of the projects. Even though the mechanistic-empirical model can produce a variety of output, such as expected distresses according to pavement system ages, the generated output cannot represent a project but, rather, only represent one sample in this research. Therefore, when comparing a project's quality rating, the mechanistic-empirical model was not used. It was used to develop the ICQI.

To the greatest extent possible, the CQI/ICQI should use data from the Laboratory Information Management System (LIMS) because it is FDOT's enterprise database system, which, theoretically, contains all construction quality data and is available to general LIMS users.

1.3 Scope

In order to achieve the objective of this research, the detailed scope of this study was as follows:

- To collect data related to major components of asphalt pavement construction
- To identify the factors that influence the performance of asphalt pavement construction
- To identify interactions between the factors that influence the performance of asphalt pavement construction
- To measure and analyze the effects of construction quality characteristics on pavement project performance
- To validate CQI and ICQI with FDOT ratings

In keeping with a straightforward approach, the CQI/ICQI only focuses on quality factors for the major components of asphalt pavement construction such as Superpave (asphalt), base course, subgrade, and embankment. Other aspects of contractor performance typical in the current rating system (e.g., financial resources, ownership of equipment or ability to lease equipment, adherence to schedule, job safety, and past performance) are not included in the CQI/ICQI formulation.

The CQI/ICQI models were formulated in a modular fashion. The flexible models enable them to be scaled to all pavement construction projects, from routine mill and overlay rehabilitation to major new highway pavement construction. This means that the CQI/ICQI models should be able to generate "layer-level" CQI/ICQI for each layer of the pavement system, and the sum of the layer-level CQI/ICQI times a weighting factor for each layer makes the project-level CQI/ICQI. By allowing the model to have layer-level CQI/ICQI, any type of layer combination for the pavement system should not be a problem. According to the layer combination, revised weighting factors for each layer are calculated by weighting their respective contribution to the project.

This modular approach leads the ICQI model to consider interactions between factors only within the same layer because the layer-level ICQI should have its own value (score), which is not combined with other factors in other layers.

Because there are not enough concrete pavement projects, and therefore not enough data, to validate the model, concrete pavement has been excluded from the CQI/ICQI.

Finally, the ICQI was developed with mechanistic-empirical (M-E) analysis. The procedures of ICQI development and the generating of ICQI scores from the model were as follows:

- Collect data for acceptance quality characteristics from LIMS
- Generate output (such as expected distresses) from the Mechanistic-Empirical Pavement Design Guide (MEPDG) for each sample
- Determine how to translate expected distresses to pavement performance in MEPDG.
- Develop regression model for each layer using the collected data and the generated output
- Enter the collected data to the layer-level ICQI model to have sample-level ICQI for each sample
- Compute $ICQI_{layer}$ from sample-level ICQI
- Calculate the project-level ICQI by the sum of the layer-level ICQI times a weighting factor for each layer

Even though the MEPDG allows researchers to connect fundamental material quality measures to facility performance, it still needs evaluation, revision, validation, and calibration. For evaluation and calibration, the MEPDG was used to develop ICQI. The result of the ICQI model was compared to the CQI model and FDOT ratings.

CHAPTER 2
LITERATURE REVIEW

2.1 Contractor Evaluation Systems of SHAs

A literature review related to contractor evaluation systems of SHAs, performance-related specifications, analytical hierarchical process, percent within limits, and acceptance quality characteristics was conducted for this research proposal.

When low-quality construction work is treated the same as high-quality work in competitive-bid construction projects, both owners and contractors acknowledge that it is a problem. Hybert (1996) examined quality problems in owners that use a contracting process to provide customized, large-scale systems or products, which can be extended to quality problems on many construction projects. Too often, he found that contractors were 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 then earn extra fees by change orders for their ability to argue specification interpretation issues.

SHAs have expressed this same concern. Since each SHA has its own political and cultural circumstances in dealing with contractor quality, every state's contractor evaluation system should not be the same. However, a survey was conducted concerning their policies to find out whether the methods used by them can be implemented in FDOT. Survey results concerning SHAs' plans or policies of contractor evaluation systems can be seen in Table 2-1.

Table 2-1. Current project rating systems around the U.S.A.

State	State Wide Rating System	Description
Alabama	N	N/A
Alaska	N	N/A
Arizona	N	N/A

Table 2-1. Continued

State	State Wide Rating System	Description
Arkansas	N	N/A
California	N	Some districts informally rate some projects.
Delaware	N	N/A
Georgia	Y	A subjective form is used to affect bidding capacity.
Hawaii	N	N/A
Idaho	N	N/A
Illinois	Y	A subjective form is used to create a performance factor that affects the prequalification amount.
Indiana	Y	A subjective form is used to create a performance factor that affects the prequalification amount.
Iowa	Y	A subjective form is used to create a performance factor that affects the prequalification amount.
Kansas	Y	For work completed by the prime only, a subjective form is used to form a factor that affects bidding capacity.
Kentucky	Y	A subjective form is used to designate a performance level which affects bidding capacity.
Louisiana	N	N/A
Maine	Y	A subjective form is used to create a performance rating that affects the prequalification amount.
Maryland	Y	A subjective form is used, and based upon its score the retainage amount is adjusted. Currently revising their form to make it less subjective.
Massachusetts	Y	A subjective form is used by the prequalification committee in their decision making process. A contractor must have an 80% passing rate.
Michigan	Y	A subjective form is used to affect the prequalification amount. If the contractors' scores are too low, they are given three chances to improve prior to disciplinary action.
Minnesota	N	Trying to become a prequalification state; currently rate particular projects based upon quality vs. cost.
Mississippi	N	N/A

Table 2-1. Continued

State	State Wide Rating System	Description
Missouri	Y	A subjective form is used to rate the contractor. If their average score becomes to low, they can be placed on probation or suspended.
Montana	N	N/A
Nebraska	Y	A subjective form is used to create a rating factor that affects bidding capacity.
Nevada	Y	A subjective form is used to affect prequalification amount.
New Hampshire	Y	A subjective form is used to rate the contractor. This form is then used by the prequalification board along with other information to qualify the contractor.
New Jersey	Y	A subjective form is used to create a factor that affects prequalification amount.
North Carolina	N	Have a safety and environmental index but no performance evaluation.
North Dakota	N	N/A
Ohio	Y	A subjective form is used to affect the financial capacity portion of prequalification.
Oklahoma	Y	A subjective form is filled out for each project; currently the forms are filed away and not used.
Oregon	Y	A subjective form is used for all projects; once the average score drops below a threshold, a discipline process begins.
Pennsylvania	Y	A subjective form is used to create an ability factor that increases or decreases their bidding capacity. If the contractor is sub par in particular types of project, they can be barred from bidding.
Rhode Island	N	N/A
South Carolina	Y	A subjective form is used to create a score for each project. If the contractor's quarterly average drops below the minimum score, they are brought in for a meeting; if no improvement occurs, they are disqualified from bidding. The state is trying to implement more strict standards for important projects.

Table 2-1. Continued

State	State Wide Rating System	Description
South Dakota	N	The state used to have a standard form; due to lack of use only some districts still use the form.
Tennessee	N	Trying to begin an evaluation system by 2007.
Texas	N	N/A
Utah	Y	A subjective form is used to let contractors know where they stand. On design build jobs the contractor with the highest score gets the job.
Vermont	Y	A subjective form is used indirectly by the prequalification board as another source to qualify the contractor.
Virginia	Y	In the process of revamping system, currently the subjective performance rating affects 70% of prequalification amount.
Washington	Y	A subjective form is used to affect bidding capacity.
West Virginia	Y	A subjective form is used to affect bidding capacity.
Wisconsin	Y	A subjective form is used to increase or decrease the prequalification amount.
Wyoming	Y	A subjective form is used to create a rating factor that affects the prequalification amount.
Washington DC	N	N/A
Puerto Rico	N	Wants to implement some evaluation process; however currently can not legally.

Comparing the nationwide interview results of NCHRP 10-54 (Minchin and Smith 2001), the expectation that more states would rate contractors and even several states would facilitate the results of the ratings with a qualification process was not met. Instead, a few states that once rated contractor quality have abandoned their systems.

Currently, 28 states have an evaluation process, and four states are in the final stages of attempting to implement one. Nineteen of the state DOTs use their subjective forms to evaluate contractors affecting either the contractor's bidding capacity or prequalification amount. Other states’ uses for the evaluation scores include, but are not limited to, briefing requirements when the scores drops too low, adjusting the contractor’s retainage, being used by a prequalification committee in their decision-making process, and being placed on probation. Again, no states used objective forms to rate contractors. As a way to be objective, several states’ evaluation forms now have questions that can be answered only with yes or no instead of the traditional scaled responses. However, not a single DOT mentioned trying to include any type of material and workmanship test results. While all forms include a section that contains either workmanship or materials, all are based on whether the workmanship meets specifications, not on numeric test results.

2.2 Performance-Related Specifications

Specifications have been changed by transportation agencies from quality assurance specifications that define end-product quality to performance-related specifications (PRS) that specify quality in terms of desired long-term performance. PRS help transportation agencies forecast future performance, maintenance requirements, and life-cycle costs. PRS describes the desired levels of key construction quality characteristics that have been shown to correlate to engineering properties and applies mathematical models to predict future pavement performance.

The benefits of using PRS include identification of a direct relationship between quality characteristics and product performance, identification of an optimum level of quality, a rational basis upon which to set the appropriate level of penalty/bonus for inferior/superior quality, and a critical link between construction and engineering management systems (FHWA 2001).

Buttlar and Harrell (1998) reported the SHA’s efforts to develop and implement end-result specifications (ERS) and performance-related specifications (PRS) in Illinois. Authors of the paper stated that PRS provided the ultimate method of compensation for a delivered product even though such a system could be challenging to develop. They also 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 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.*

An approach was presented to estimate the deviation from pavement performance life due to 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 (Noureldin 1997).

The authors claim that current QC/QA protocols cannot be used to evaluate the overall construction quality of a project and that it is hard to compare the construction quality of different projects or different contractors. An overall CQI is developed using material, thickness, and structural data so that it can evaluate the overall construction quality and facilitate the comparison between different pavement sections and projects (Beckheet et al. 2004).

Because of 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, a method of developing pay schedules was proposed. 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 or bid price (Weed 1998). In his research, analytical data and survey data were used to develop mathematical models for predicting pavement performance. The models were then combined with other models, which relate expected life to present value to obtain rational and practical pay schedules.

Weed (2000) presented a method for combining the effects of multiple deficiencies. Air voids and thickness of hot mixed asphalt (HMA) pavement are factors used to decide whether a large amount of HMA pavement is rejectable. In the current New Jersey Department of Transportation specifications for HMA pavement, the rejectable quality level (RQL) for both air voids and thickness is 75, 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 other 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 for assessing the combined effects of deficiencies in air voids and thickness, survey data were used. Based on the performance model with combined effects, several pay equations were presented.

A rational and feasible method for quantitatively formulating pay factors was described 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 impact 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 increases the present worth of future rehabilitation costs; in contrast, superior construction decreases the present worth of the costs. Differences in the present worth of future rehabilitation costs between as-built and as-designed can be applied in setting the appropriate level of penalty/bonus for inferior/superior pavement construction quality. However, the authors admit 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 adhering to the design target value (Monismith et al. 2004).

Killingsworth argued that of 13 factors analyzed, five were proven 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 (Killingsworth 2004).

Many statistical construction specifications and acceptance procedures define an end result, and according to the end result, bonuses are awarded by many agencies. A significant amount of research was found to improve these procedures and the development of better PRS. 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. For most factors, however, there are no such convenient or simple relationships; therefore, a method for developing the required relationships is necessary.

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 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 alternative 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).

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 the results of the research.

- Overlay thickness increases result in the increase of pavement service life.
- More than 80% of the contribution to the variance in pavement service life predictions is made by overlay thickness, whereas less than 20% of the variance is 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 Analytic Hierarchy Process

The Analytic Network Process (ANP) is structured for the analysis of societal, governmental, and corporate decisions for decision makers. The ANP allows for inclusion of all the factors and criteria that are relevant for making the best decision whether they are tangible or intangible. Both interaction and feedback are allowed to be applied in the ANP. Such feedback is known to take into account the complex effects of interplay in human society, especially when risk and uncertainty are involved (Saaty 1996).

The ANP derives ratio scale priorities for the distribution of influence among the factors and groups of factors in the decision by providing a way to input judgments and measurements. The ANP can be applied to allocate resources according to their ratio scale priorities because the process is based on deriving ratio scale measurements.

An example of applying ANP to the problem of predicting the market share for the biggest three companies in the hamburger fast food industry is shown in Figure 2-1 (Saaty 1999). Clusters of elements form the ANP model, which are connected by their dependence on one another; therefore, decision makers should consider grouping elements that share a set of attributes when identifying clusters. For example, the marketing mix is a cluster whose elements are price, product, promotion, and location. When identifying clusters and their elements, the elements should be similar.

Figure 2-1 below from the research shows the structure of the model described by its clusters and elements and by the connection between them. The flow of influence between the elements is indicated by these connections. The prevailing understanding of the marketplace is diagrammed in the ANP model through the process of analyzing dependencies. A cluster is connected to another cluster when at least one element in it has influence on at least one element

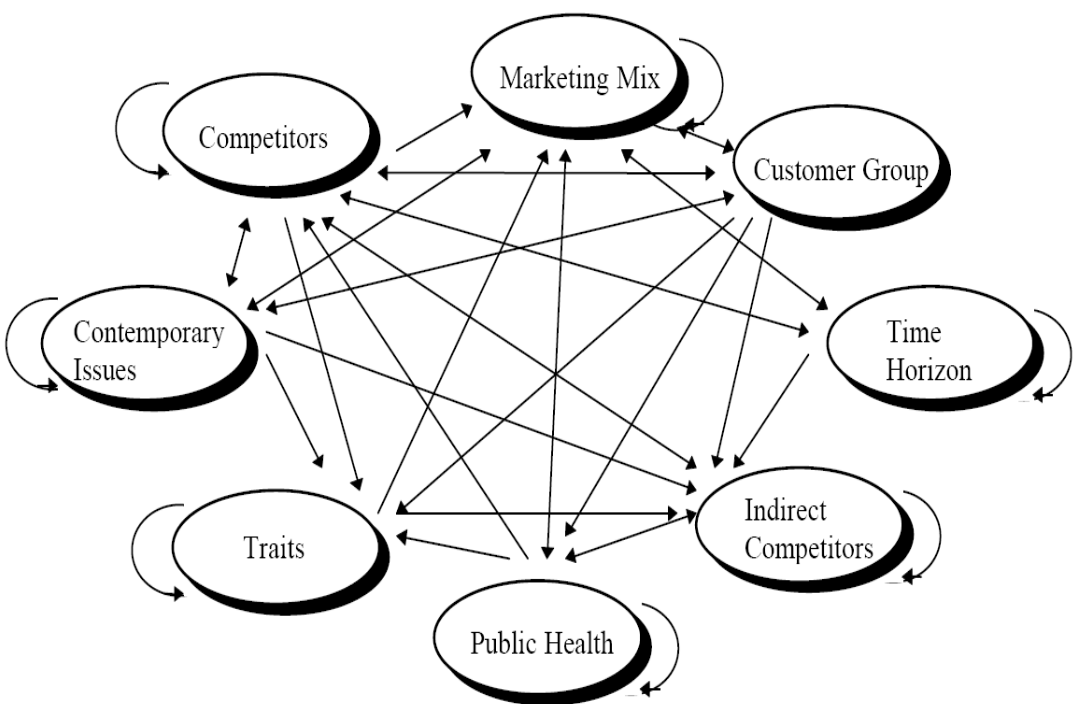


Figure 2-1. Overall goal: market share of competitor group (Saaty 1999)

in another cluster. The elements, themselves, are not displayed in this figure. Except for the customer group cluster, which doesn't have a curving arrow in the figure, inner dependence exists for all other clusters. The connections between elements for the other clusters exist in the same cluster.

With the ANP, the research showed the comparison between the predicted market shares and the actual market shares. The results can be seen in Table 2-2 below. The predicted market shares were close to the actual market shares.

Table 2-2. Predicted and actual market shares (Saaty 1999)

	Market Share	
Company	Predicted %	Actual %
McDonald's	62.9%	58.2%
Burger King	23.9%	28.6%
Wendy's	13.2%	13.2%

Applications of the ANP also can be found in construction performance measurement (Isik et al. 2007). In this paper, Isik et al. present a conceptual performance measurement framework that considers company-level factors (objectives, strategies, and resources), as well as project-level (risks and opportunities) and market-level factors (competition and demand). In order to use the conceptual framework for measuring performance, the ANP was used because authors of the paper regarded the ANP as the best-suited methodology that considers both quantitative and qualitative factors and the interrelations between them. The ANP was the effective tool in those cases in which the interactions among the elements of a system formed a network structure.

The well-known decision theory, the Analytic Hierarchy Process (AHP), is a special case of the ANP. Both the AHP and the ANP derive ratio scale priorities for elements and clusters of elements and make paired comparisons of elements on a common property or criterion. The difference in the AHP is that the elements are organized in a hierarchic decision structure, while the ANP's structure has one or more flat networks of clusters that contain the elements.

As mentioned earlier, the AHP is a special case of the ANP and the decision-making technique developed by Saaty (1980). He claims that AHP is a 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. The AHP is designed to consider a variety of subjective and objective evaluation measures, providing a useful mechanism for inspecting the consistency of the evaluation measures and alternatives. Although there are critics of the method, the general consensus is that the AHP is useful both technically and practically (McCaffrey 2005).

The AHP relies on three fundamental assumptions.

- *Preferences for different alternatives depend on separate criteria that 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 represent the information appropriately.*
- *At a given level, suitable scores can be calculated from only pair-wise comparisons.*

Various components, such as social, political, technical, and economic factors, can be involved in the decision-making process. The first step in using the AHP involving complex decisions is to break down the goal into its component parts, progressing from the general to the specific. This hierarchical structure involves not only goals but also criteria and alternatives. Each set of alternatives can be divided into as many further levels as necessary. The next step is to make a series of one-on-one comparisons of all criteria. The results are then synthesized to determine the priorities of the alternatives with respect to each criterion and the weight of each criterion with respect to the goal. For each pairing, the score is decided on a relative basis, not an absolute basis, comparing one criterion to another. For the final step, the mathematical model computes the relative scores for each pairing, generating a relative weight for each criterion. The sum of the weights is normalized to 1, or 100%.

Applications of the AHP can be found in transportation engineering and construction. Smith and Tighe (2006) used the AHP as a tool for infrastructure management. The uses of the AHP by Smith and Tighe range from comparing repair products of fast-tract concrete based on priorities set by an agency to comparing 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.

2.4 Percent within Limits

There are several quality measures that can be used in an acceptance plan. In early QA specifications in the late 1960s and 1970s, the mean or the average deviation from a target value was often used as the quality measure. However, the use of the average alone provides no measure of variability, and it is now recognized that variability is often an important predictor of performance (Burati, et al. 2004).

Several quality measures, including percent defective (PD) and PWL, have been preferred in recent years because they simultaneously measure the average level and the variability in a statistically efficient way. PD and PWL are, in reality, the same quality measure since they are directly related by the simple relationship PWL = 100 – PD (Burati, et al. 2004).

The PWL concept is applied to calculate pay factors in Section 334: Superpave Asphalt Concrete in the FDOT specification, *2007 Standard Specifications for Road and Bridge Construction.* Under Section 334 in the specifications, the quality characteristics to measure and their upper or lower specification limits are presented to determine the quality of the constructed material. Based upon the quality of the material, a pay adjustment to the bid price of the material is applied.

2.5 Acceptance Quality Characteristics

Federal Highway Administration (FHWA 1999) has defined the acceptance quality characteristics (AQC) as an inherent measurable pavement characteristic that significantly affects pavement performance, is under the direct control of the contractor, and is measurable at or near the time of construction. The AQC for this research will be identically selected to those in the FDOT specification, *2007 Standard Specifications for Road and Bridge Construction*, which is currently used by FDOT for acceptance of pavement materials at the mine, plant, or roadway. The selected AQC will be considered as factors of the CQI model. The AQC are listed in Appendix A.

For developing and validating the ICQI model, most of the AQCs selected as factors of the CQI model will be also considered as factors of the ICQI model as long as the MEPDG program can accept them as input variables. In this research, #8 sieve aggregate passing rate and asphalt sample density will be excluded from the ICQI model factors. The MEPDG program utilizes #4 sieve aggregate passing rate for an input variable instead of #8 aggregate sieve passing rate. Because the ranges of the AQC are not required for developing the ICQI model, the AQC of the ICQI are not listed in Appendix.

2.6 Mechanistic-Empirical Pavement Design Guide (MEPDG)

Methodology for pavement design and evaluation of paving materials is improved by the proposed MEPDG procedure. The new procedure depends on the characterization of the fundamental engineering properties of paving materials. In order to use the MEPDG to design flexible pavements, many states put forth an extensive effort to characterize asphalt mixes used in their states.

The Virginia Department of Transportation sponsored a project whose objective was to perform a full HMA characterization in accordance with the procedure established by the proposed MEPDG to support its implementation in Virginia (Flintsch et al. 2007). To achieve this objective, samples of surface, intermediate, and base mixes were tested. The dynamic modulus, the main HMA material property required by the MEPDG, and creep compliance and tensile strength were studied.

The Virginia Department of Transportation research revealed that the dynamic modulus test is quite effective for determining the mechanical behavior of HMA at different temperatures and loading frequencies. The test results demonstrated that the dynamic modulus can be sensitively changed as the mix constituents (aggregate type, asphalt content, percentage of recycled asphalt pavement, etc.) change. Even mixes of the same type used had different measured dynamic modulus values when the mixes did not have the same constituents.

The Montana Department of Transportation (MDT) conducted a similar research project as the Virginia investigation above. The research of the MDT was to develop performance characteristics of flexible pavements in Montana and to use them in the implementation of distress prediction models (VonQuintus and Moulthrop 2007). Utilizing reliable distress prediction models, the MDT intended to use Mechanistic-Empirical (ME) based principles for flexible pavement design and manage the Montana highway network. This study focused on developing local calibration factors for Montana climate, structures, and materials for flexible pavements by using the MEPDG software.

Chehab and Daniel (2006) studied the sensitivity of the predicted performance of recycled asphalt pavement (RAP) mixtures to the assumed binder grade using MEPDG software. In the research, MEPDG software was used to predict the performance of a specific flexible pavement structure with a RAP-modified hot-mix asphalt surface layer. To minimize variations of the other conditions, all the pavement properties and conditions were held constant except for the properties of the surface layer while different design runs were conducted.

Comparison of the predicted performance of the various runs was presented by Chehab and Daniel (2006). The importance of determining the effective binder grade of RAP mixtures was emphasized from the results of the study.

2.7 Conclusions

Through the literature review relating to the existing construction quality evaluation study, the researcher could consider several unanswered questions that might be answered by adopting the CQI/ICQI.

- 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?
- Are there any interactions among the construction quality characteristics in determining construction project performance?
- 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?
- What is the role of mechanistic-empirical procedures in assessing construction quality?
- Can the mechanistic-empirical procedures be combined with a mechanistic, statistical, or empirical model?

CHAPTER 3
METHODOLOGY

3.1 Data Collection

In this research, two models for pavement construction quality measurement will be developed. The CQI model will be developed using the PWL concept, not considering interactions between factors. The ICQI model will be developed with consideration of interactions and mechanistic-empirical analysis. These models then will be compared to FDOT ratings, assuming their evaluation is correct.

In order to develop and validate the CQI/ICQI model, actual test results of the acceptance quality characteristics from various pavement construction projects were required. Therefore, the project list for data collection was asked to be provided to FDOT personnel in order to retrieve actual test results of the acceptance quality characteristics from LIMS.

In the process of development and validation of the CQI model, the retrieved data was used only for validation purposes. The CQI model was formulated using the percent within limit concept from Florida specifications and the analytic hierarchy process for weighting factors of the CQI model. In order to acquire the weighting factors of the CQI model, an expert panel survey was held. Once the CQI model was developed, the retrieved actual test data was used to obtain CQI scores of the projects; then, the CQI scores were compared with FDOT ratings.

Unlike the process of CQI model development, the actual test data from LIMS was used to formulate the ICQI model. The ICQI model required output from the MEPDG program to use for regression analysis. When a set of actual test data is entered into the MEPDG program, the program produces its output in the form of several predicted distresses, such as roughness, top-down cracking, bottom-up cracking, thermal cracking, and rutting; therefore, conversion of the predicted distresses to the expected performance of pavement construction projects should be executed. In order to convert the output from the MEPDG program, information about the relationship between the predicted distresses and the performance of pavement construction projects was essential. To obtain their relationship, the expert panel survey and SuperDecisions program based on analytic hierarchy process were used.

3.1.1 Project List for Data Collection

When developing a CQI model, one of the considerations is making an objective model using objective data. As shown in Table 2-1, every state having a contractor rating system uses subjective forms. Development of a CQI that is as objective as possible may lower or eliminate the concern for construction owners. In an effort to maintain objectivity, two CQI models that rely completely on material and workmanship test results were developed. In addition, the data for the CQI must be the actual test results of the AQC and easily accessible from the database of the FDOT without significantly changing the current test properties or methods. Therefore, LIMS was used to retrieve data.

In order to retrieve data from LIMS, FDOT Construction and Materials officials were asked to provide project numbers to the study. The projects were to be recent enough to be relevant (having used current methods, such as Superpave) and use LIMS as the data management system (data in previous data management system may not be retrievable) but old enough so 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 in order to use for later evaluation purposes.

As a result of the request for project numbers to study, FDOT supplied a total of 105 project numbers from all districts including the turnpike district with FDOT’s level of satisfaction. The number of projects provided varied from 1 project in District 6 to 28 projects in

District 2. Even though there were a total of 105 projects, not all of them could be used after close investigation because some seemed as if large portions of important data had not been entered into the database or they did not have any data in LIMS at all. Project details are summarized in Appendix B, including project number, location, managing district, type of construction (resurfacing or reconstruction), FDOT rating, maximum number of possible layers according to the type of construction, number of layers containing data, and number of samples for each layer. Each pavement system consists of several layers with different functions and materials. Possible flexible pavement layers include embankment, subgrade, base, Superpave, and friction courses. The reason that maximum number of possible layers, number of layers containing data, and number of samples are included in Appendix B is to eliminate unsuitable projects from analysis. For example, when a project should have five layers according to its project type (i.e., new construction), if the project has data from only two layers, it may not be acceptable to claim that the data from the two layers represent the quality of the project. The number of samples for each layer was also investigated. When the number of samples for a layer was too small to represent the layer, the layer or the project was excluded from analysis.

In the early stage of this research, there were significant problems in the procuring of the data. The first problem encountered was gaining access to LIMS, which took months. Once the data was available, it became apparent that large portions of important data had not been saved in the LIMS when new construction projects included adding lanes that did not have an embankment, subgrade, or base data. In contrast, when resurfacing construction projects had foundation (embankment, subgrade, or base) data, inquiries for more detailed project descriptions to FDOT project managers were required in order to reveal whether the foundation data was actually related to the road construction.

For Superpave and friction course layers, having several mixes with different target values for the certain AQCs is not uncommon. In such cases, the tonnage report should be run through LIMS to obtain revised weighting factors for the mixes; however, for some reason, the tonnage report worked for only some project numbers. Target values for different design mixes are required to calculate CQI even though the target values are not saved in LIMS. The target values can be retrieved from FDOT's intranet. Some target values for design mixes were missing, and CQI for the design mix are excluded from analysis.

As seen in Appendix A, all AQC except material mixing depth are used as factors affecting the CQI. Mixing depth is not stored in the LIMS.

3.1.2 Expert Panel Surveys

3.1.2.1 Expert panel surveys for CQI

The weighting factors for both CQI and ICQI models were obtained using the analytic hierarchy process (AHP) concept. In the CQI model, weighting factors for parameter level as well as layer level weighting factors were required. The layer level weighting factors define the relationship among layers of pavement systems such as friction course, Superpave, base, subgrade, and embankment. The parameter level weighting factors define the relationship between the expected performance of pavement construction projects and the parameters, which are acceptance quality characteristics such as ¾" sieve passing rate, #4 sieve passing rate, #8 sieve passing rate, #200 sieve passing rate, asphalt content of mixes, air void ratio, density, lime bearing ratio (LBR), and ride number. To obtain experts' opinions concerning the factors affecting pavement construction performance, expert panel meetings were held.

Approximately 30 expert panel members from FDOT, the construction industry, academia, and consultants were selected and requested to attend the expert panel meeting, which was held three times in Gainesville, Orlando, and Tallahassee between June 2006 and August 2006. The three meetings were identical, so the panel members were requested to attend the one most convenient for them. As a result of the meetings, the research team was able to obtain opinions from 18 people: 7 members from contractors or contractor advocacy groups, 8 members from FDOT personnel, 2 members from academia, and 1 member who did not sign in.

Initially, there was strong confrontation from mostly the contractors' side concerning the purpose of the research and anticipated consequences after completing the research. The contractors' concern focused on why quality rating of construction projects is needed when the projects already at least meet, and in some cases exceed, the requirements of specifications to be accepted by the owners. They were also concerned about how the owners would use the research results. The contractors argued that if the owners want to get higher quality construction products than current projects, which already have passed the requirements according to specifications, then the owners can simply raise the specification requirements. The contractors seemed to be disturbed because there was a possibility that new regulations would be applied without increasing their fees.

The research team explained that the purpose of the CQI research was to develop practical and objective models and evaluate the quality of pavement construction. Not only meeting the requirements of the specifications by the use of the average values of the construction quality characteristics but also keeping PWL in certain ranges has been preferred in recent years because they simultaneously measure the average level and the variability in a statistically efficient way. Therefore, the research team's perspective of the construction quality with CQI was that variability might be an important predictor of performance. However, the research team could not answer the contractors' concern about the usage of the CQI because it belonged to the owner's authority.

The panel members were requested to fill out forms prepared by the rules of AHP. The forms used for flexible pavements are shown in Appendix C. The instructions for panel members answering questions in the form include: 1) Each response only represents your opinion concerning the relative importance of the pair of items on a single line, 2) Fill out all portions of the form for which you feel qualified to have an opinion, and 3) Fill out the forms without discussion with your neighbor.

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 results of the survey are rearranged in Appendix D for CQI flexible pavements. The average values were entered into SuperDecisions software to determine the weighting factors for the CQI formulation. These flexible pavement weighting factors for the CQI are presented in Table 3-1. At any given pavement layer, the sum of the weighting factors is always 1.

The first part of the forms shown in Appendix C concerning flexible pavement system components asks which layers have the greater influence on quality. In other words, this question was used to determine weighting factors for each layer of the flexible pavement system. These weighting factors for each layer will be identically applied to the ICQI model. However, weighting factors for the parameter level in the ICQI model will be determined through MEPDG results and statistical analysis. For this purpose, the expert panel surveys for ICQI were conducted and described in the next chapter.

3.1.2.2 Expert panel surveys for ICQI

When FDOT evaluates a pavement, they consider cracking, roughness, rutting, raveling, patching, and friction (FDOT 2003).

There are five distresses in the MEPDG model applicable for HMA: rutting, fatigue cracking (bottom-up), fatigue cracking (top-down), thermal cracking, and roughness. The MEPDG does not directly address friction, patching, and raveling. The researcher dismissed thermal cracking as negligible for Florida conditions. Therefore, roughness, rutting, and the fatigue cracking (both top-down and bottom-up) were used to predict pavement construction performance. Once the MEPDG program is run, all the results of the expected distresses are produced. Then, a way to rationally combine the results into a metric that can be used to compare to the ICQI needs to be developed. In order to correlate the results of the expected distresses and expected construction performance, the expert panel surveys for ICQI were conducted.

At this time, approximately 15 FDOT personnel specializing in asphalt material, most from State Material Office in Gainesville, were asked to fill out the survey forms in Appendix C. Just as the previous CQI survey forms were prepared by the rules of AHP, the ICQI survey forms followed the rules of AHP. From the experience of the previous CQI expert panel meeting, the researcher decided to do the surveys individually. The rules of AHP require attendants to fill out the forms without discussion with others because strong opinion leaders can change other panel members' opinions. The survey forms with instructions were sent and then returned by e-mail. The instructions for panel members answering questions on the ICQI form were same as the CQI survey forms.

The results of the survey are presented in Appendix D for ICQI flexible pavements. The average values were entered into SuperDecisions software to determine the relationship between the expected distresses and pavement performance. Once the relationship was found, the distresses were calculated to get the expected reliability of a sample. This reliability value served as the independent variable in the regression analysis.

3.2 Model Formulation

All FDOT projects are accepted in accordance with one or more construction specifications. The final product must pass certain criteria to show that it meets the expectations of the designer to protect public safety and provide the expected level of service. These criteria are enforced through testing of materials and workmanship, and the results of these tests are what the CQI/ICQI model uses to calculate a CQI/ICQI for each project.

In this research, two models are developed. In the CQI model, the CQI values for layers and AQC are obtained applying the percent within limits (PWL) concept, which is embedded in FDOT specifications. In the ICQI model, coefficients of the model are computed by statistical analysis (regression analysis) using the mechanistic-empirical pavement design guide (MEPDG). When the statistical analysis is executed, interactions between factors are also considered and analyzed. In addition, weighting factors for each layer for both CQI and ICQI models are computed using AHP. Details will be explained in later chapters.

3.2.1 Construction Quality Index (CQI) Model

3.2.1.1 Model concepts

The CQI formulation is based on the modular approach, allowing it to be scaled to all pavement construction projects. Figure 3-1 shows a conceptual pavement system consisting of a series of *n* layers. All existing layers in the pavement system do not have to 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 CQI model considers only the two layers, and according to the change, weighting factors for Layer 1 and Layer 2 are revised, with no other layers being considered in the calculations.

Figure 3-1. Schematic of a pavement structure with *n* layers

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

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

where W_{layer} = weighting factor for layer i

CQI_{layer} = construction quality index for layer i

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

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

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

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

where $(PWL)_{AQC}$ is the percent within limits. $(PWL)_{AQC}$ is calculated based on 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). This procedure requires the use of a PWL table, shown in Appendix E. The PWL concept is also applied to FDOT specifications.

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*):

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

A Q value is a quality index for its specification limit. For one-sided limits, the appropriate Q value is calculated and cross-referenced in FDOT's PWL table to find the PWL of that sample. Should the Q value be negative, the absolute value can be located in the tables, and the resulting PWL is subtracted from 100 to find the actual PWL. 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 difference between the sum of those two values and 100:

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

For all PWL values that fall between rows in the PWL table, linear interpolation is used.

3.2.1.2 Model weighting factors

The weighting factors are obtained using the analytic hierarchy process (AHP) concept that is a multi-criteria assessment tool for decision structuring and analysis (Isik et al. 2007). As mentioned earlier, the AHP is a special case of the ANP. The difference of the AHP from the ANP is that interconnections between decision factors at the same level cannot be considered with the AHP because the decision-making framework in an AHP model assumes a one-way hierarchical relationship among decision levels. AHP may not be an effective or correct decision-making tool to apply for some cases where there are interactions between decision variables.

However, for the purpose of this research, AHP is a powerful and flexible decision-making technique that helps decision makers to set priorities and choose the best alternative because interactions between AQCs are not considered in *2007 Standard Specifications for Road and Bridge Construction*, which is the FDOT specification from which the AQCs are selected. Therefore, the AHP is selected to obtain weighting factors for CQI model.

Expert panel members from FDOT, the construction industry, academia, and consultants were requested to fill out forms prepared by the rules of AHP. As mentioned earlier, the results of the survey were obtained in Appendix D, and the average values for each pair-wise comparison were entered into SuperDecisions software to determine the weighting factors for the CQI formulation. These flexible pavement weighting factors for the CQI are presented in Table 3-1. At any given pavement layer, the sum of the weighting factors is always 1.

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

Table 3-1. Continued

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
FC5	**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
FC9.5	**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
FC12.5	**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

As mentioned earlier, typically for rehabilitation projects, one or more layers of the system will not be a part of the construction project. For example, in a typical rehabilitation job that includes milling and overlaying, only the structural Superpave and friction course layers may be constructed in the project while all other layers remain undisturbed from previous construction projects. In such cases, revised layer weighting factors are recalculated by weighting their respective contributions to the project as shown in Table 3-2.

Table 3-2. Sample 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

3.2.1.3 Adaptation of the model for more than one asphalt mix

For construction projects using Superpave and friction course layers, it is not uncommon for several mixes with different target values for the certain AQCs to be involved in a project. For example, the CQI for the Superpave layer is adapted as follows:

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

where t_i is a tonnage weighting factor given by

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

For example, suppose a construction project used three Superpave mixes, designated by SP1, SP2, and SP3. A total of 20,000 tons was placed on the example project: 4,000 tons of SP1, 10,000 tons of SP2, and 6,000 tons of SP3. Table 3-3 explains how the Superpave layer CQI is calculated for this example. If that friction course has multiple mixes, the same process can be applied to adapt the CQI to the friction course layer.

Table 3-3 Sample 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

3.2.1.4 Additional data required other than test results

In order to calculate CQI, some additional data other than AQC test results are required. These data included target values of each AQC and asphalt tonnage constructed for each asphalt mix. Target values are used to get the PWL of the quality characteristics and eventually acquire the CQI of the same equality characteristics. Target value reports were posted in the FDOT intranet. With permission from FDOT, the researcher could gain access to the reports. A sample of the target value report is presented in Appendix F.

From the target value reports in Appendix F, general information and specific target values for the mixes can be obtained. General information concerning asphalt mixes includes the asphalt production contractor, asphalt mix number, and type of the mix identifying whether the mix is for Superpave or friction course and whether density of the mix is fine or coarse. For target values of the mixes, the aggregate passing percentages of various sieves can be found in the front page of the report. In the second page, optimum asphalt content and target air void ratio can be located. The target air void ratio for the asphalt mixes in the project list that the research team has was always 4%.

In order to determine constructed asphalt weight in a project where there are multiple asphalt mixes to determine revised weighting factors for each mix, the tonnage report should be run through LIMS. For some reason, the tonnage report worked for some project numbers but not for others. For example, some projects have asphalt mix numbers and test data for AQCs, but there is no asphalt amount tested according to the tonnage report. Even though the reliability level of the tonnage report was not as good as was expected, it was the only report that contained the asphalt tonnage according to FDOT asphalt materials personnel. Therefore, the research team used the tonnage report for the purpose of weighting factors revision. However, when some tonnage values for design mixes were missing or too big to be realistic, results of the tonnage reports for the design mix were excluded from analysis. In such cases, the number of constructed lots for each design mix was used to determine the amount of constructed asphalt under the assumption that weight variation of the constructed asphalt for different design mixes is insignificant.

3.2.1.5 Model implementation

The CQI model uses the Microsoft Windows® operating system and is 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.

3.2.2 Integrated Construction Quality Index (ICQI) Model

3.2.2.1 Mechanistic-empirical pavement design guide (MEPDG)

The American Association of State Highway and Transportation Officials (AASHTO) *Guide for Design of Pavement Structures* is currently the primary document for designing highway pavements. The AASHTO Guide is empirically based on performance equations developed using 1950's American Association of State Highway Officials (AASHO) Road Test data. Since the AASHO Road Test, the development of revisions of the AASHTO Guide has been made. Recently, the limitations of the AASHTO Guide have been apparent, and the need for developing an improved Design Guide has been recognized. AASHTO decided to develop a design guide based as fully as possible on mechanistic principles. This MEPDG is the result of the decision.

MEPDG is also known as NCHRP 1-37A Guide, 2002 Design Guide, New Design Guide, or Guide for M-E Design. It was developed to overcome limitations of design procedures based on the AASHO Road Test, which include considering only one climate condition, limited axle loads (2 million) in traffic, use of outdated vehicles and materials, and designing only new construction. The benefits of MEPDG are its wide range of pavement structure (new and rehabilitation) and direct consideration of major factors such as traffic, climate, materials, and support. The most notable advantage of this approach over the 1993 AASHTO Guide is that it is based upon a rigorous analytical and mechanistic approach using the best available technology. MEPDG is designed to calculate the pavement response and predict the pavement life by entering more than 35 kinds of input for flexible pavement. Even though it has not been calibrated for local conditions, the MEPDG is approved and under review for implementation by FHWA.

The MEPDG software is based on ME design concepts. This means that the design procedure considers pavement responses such as stresses, strains, and deflections, as well as the incremental damage over time. Damage over time is related to pavement distresses according to ME design concepts.

3.2.2.2 Model concepts

In the ICQI development, a combination of empirical methods and mechanistic methods are executed. Weighting factors for layers (W_{layer}) obtained from AHP are used in the model, while the ICQI for layers ($ICQI_{layer}$) are obtained using MEPDG and regression analysis.

The general form of the ICQI model for a layered pavement system is the same as CQI as shown in Equation 8.

$$ICQI = \sum_{layers} W_{layer} \times ICQI_{layer} \qquad \text{(Equation 8)}$$

where W_{layer} = weighting factor for layer i (obtained from AHP)

$ICQI_{layer}$ = integrated construction quality index for layer i (obtained from MEPDG and regression analysis)

For each layer, the ICQI will be acquired utilizing a regression model. Regression analyses will be performed to determine the statistical relationship between a response and the variables.

The following steps explain the ICQI development procedures and how to get ICQI scores from the model.

STEP 1: Collect data for acceptance quality characteristics from LIMS.

In order to retrieve data from LIMS, FDOT Construction and Materials officials from all districts including "Turnpike" district were asked to provide project numbers to the study with their ratings. Even though the researcher asked them to rate the projects in three levels, the rating categories from each district were different. As shown in Table 3-4, some classified their projects in two categories as "higher quality" and "lower quality," and some divided their projects ratings into "good to excellent," "average," and "poor," while the others classified them as "good," "fair," and "poor" or "excellent," "good," "fair," and "average."

In Table 3-4, the numbers in parentheses are the number of projects FDOT personnel provided regardless of whether the projects contained enough data for analysis. From District 2, 30 projects with ratings were supplied separately. The first 13 projects were provided for validation purposes for the CQI research project from FDOT, and the second 17 projects were requested and provided later for ICQI model development and validation.

Table 3-4. Project classification by FDOT

District	Project Ratings
1 & 7	Good to Excellent (12), Average (8), Poor (5)
2 (First Supply)	Higher Quality (6), Lower Quality (7)
2 (Second Supply)	Good (4), Average(12), Poor (1)
3	Good (9), Fair (5), Poor (3)
4 & 6	Excellent (1), Good (9), Fair (4), Average (1)
5	Good to Excellent (5), Average (3), Poor 2()
Turnpike	Excellent (3), Good (2) , Poor (2), Very Poor (1)

The researcher re-classified project ratings by FDOT personnel into three categories: good, average, and poor. Original FDOT project ratings of “good to excellent,” “excellent,” and “higher quality” are assigned to the “good” category. The “average” category contains “fair” and “average.” “Poor,” “very poor,” and “lower quality” comprise the “poor” category. This is shown in Table 3-5.

Table 3-5 Project re-classification by the researcher

District	Good	Average	Poor
1 & 7	Good to Excellent	Average	Poor
2	Higher Quality, Good	Average	Lower Quality
3	Good	Fair	Poor
4 & 6	Excellent, Good	Fair, Average	
5	Good to Excellent	Average	Poor
Turnpike	Excellent, Good		Poor, Very Poor

The projects should be recent enough to use Superpave since the model is based on current FDOT specifications which embedded Superpave. The projects should be also recent enough to use LIMS as the data management system since retrieving data from previous data management system is quite impractical. The most important requirement was for the projects to have their relevant data stored in the LIMS database.

Once the project numbers were given, data retrieving from LIMS was executed. The retrieved data using Crystal Report from LIMS was saved to Excel spread sheets as shown in Figure 3-2 below, which has a sample Superpave report. Among many test characteristics, five AQC are highlighted. However, the #8 sieve aggregate passing rate and asphalt sample density were not required for ICQI model factors among the highlighted AQCs. The MEPDG program uses the #4 sieve aggregate passing rate for an input variable instead of the #8 aggregate sieve passing rate for Superpave. For developing and validating the ICQI model, the required quality characteristics of the CQI model are ¾ in. aggregate passing rate, $^{3}/_{8}$ in. aggregate passing rate, #4 sieve aggregate passing rate, #200 sieve aggregate passing rate, asphalt content, and air void percentage because the MEPDG program can accept them as input variables.

While each column represents a sample, all of the samples sometimes could not be used for the ICQI model without data correction. Note that the second and third samples do not have test values for density (G_{mm}). Even though the density (G_{mm}) is not entered into MEPDG software for analysis, the missing value can occur in other quality characteristics, for example asphalt content or air void percentage.

Sometimes, asphalt reports retrieved inaccurate data as shown in Figure 3-2. The second, third, and fifth samples retrieved wrong values from LIMS. For example, the #8 sieve aggregate passing rate is 940%, where it must be between 0% and 100%, so the researcher had to search LIMS individually, and the correct value of the test was 49.14%. In many cases, the extra effort to retrieve data individually was required.

STEP 2: Run MEPDG to get output for each sample.

In the CQI, target values for AQC are required to obtain the CQI for the mix because the model was applied using the PWL concept. However, when the MEPDG calculates pavement performance, it only requires test results of a mix regardless of the target range of the mix to predict pavement performance.

In the ICQI model, layer-level ICQI equations for each layer will be developed using regression analysis. To develop the regression model (layer-level ICQI), sample data for a dependant variable is required. The MEPDG output using test results of the construction quality characteristics in asphalt reports from LIMS will be used as sample data for dependant variables.

Project No.: 41551315201
Pay Item: 2 334 1 13
Design Mix: SP 05-4423B
Mix Type: SP125C
Contractor: RANGER

Date Sample Taken:	1/31/2007	2/1/2007		2/2/2007	2/5/2007
Sample L / S : LIMS ID : TIN :	2C004V 1 / 4 0700016451 E61001381-000	2C005Q 2 / 1 0700013846 E61001381-000	2C005V 2 / 1 0700021086 E61001381-000	2C006Q 2 / 2 0700014546 E61001381-000	2C007Q 2 / 3 0700016752 E61001381-000
%Passing 3/4in	100.00	98.91	100.00	100	98.83
%Passing 1/2in	97.74	93.46	95.86	95.52	96.2
%Passing 3/8in	92.39	86.05	89.7	88.81	88.94
%Passing No.4	70.38	649.8	69.2	66.1	64.69
%Passing No.8	52.91	940	52.87	940.7	714.2
% Passing No.16	43.27	40.5	43.52	40.4	849.1
% Passing No.30	36.96	34.82	37.36	34.66	948.2
% Passing No.50	28.37	26.54	28.49	26.87	27.43
% Passing No.100	11.96	1658.1	11.28	1655.6	1280.9
% Passing No.200	4.69	4	4.51	4.01	4.36
%AC	5.7	5.26	5.52	5.51	5.49
Gmm	2.448	2.458	2.454	2.455	2.463
Gmb	2.353	2.347	2.344	2.353	2.352
Hgt @ Ni	123.7	123.3	123.5	123.7	122.9
Hgt @ Nd	117.4	117.3	117.4	117.3	117
%Air Voids	3.88	4.52	4.48	4.15	4.51
%VMA	15.20	15.07	15.40	15.07	15.1
%VFA	74.54	70.01	70.93	72.46	70.13
Dust/AC	0.94	0.86	0.94	0.84	0.94
Gse	2.670	2.663	2.670	2.67	2.68
Core 1 Gmb	2.304				2.341
Core 2 Gmb	2.312				2.326
Core 3 Gmb	2.254			2.324	2.317
Core 4 Gmb	2.326			2.304	
Core 5 Gmb	2.296			2.285	
Average Core %Gmm	93.89			93.85	94.52

Figure 3-2. Sample asphalt (Superpave) report from LIMS

To minimize variance of the model, two things are taken into consideration. First, when data is entered into the MEPDG program, all input except asphalt quality characteristics for the structure category need to be invariable. Even though the MEPDG has a wide range of input requirements (traffic, climate, etc.), the ICQI only needs pavement performance as an output of the MEPDG using as many AQCs in CQI as possible. Of course, AQC values are entered according to the test results. Then, samples that don't have inaccurate test results for AQC will be used. For example, in Figure 3-2, the second, third, or fifth sample will not be used unless the incorrect data is corrected.

To run the MEPDG software, input was needed. The input for the software included general project information, traffic, climate, and structure layering as shown in Figure 3-3. As mentioned earlier, traffic and climate input remained the same, using default values. Only the test results were put into the structure category to run the MEPDG program.

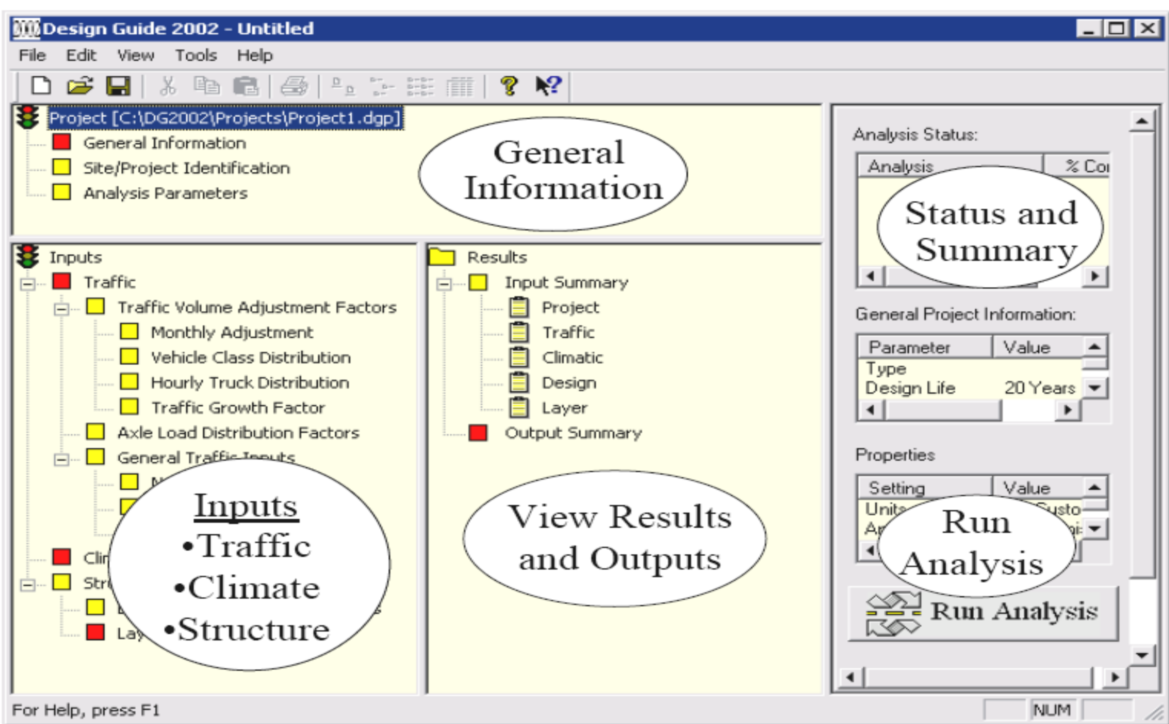


Figure 3-3. Layout of the MEPDG program for input and output (VonQuintus and Moulthrop 2007)

For the default value of the climate input, Gainesville climate data was used for all projects analyzed to eliminate variation except for construction quality characteristics even though the projects are widely separated across Florida. Figure 3-4 shows that Gainesville data was entered into the climate input.

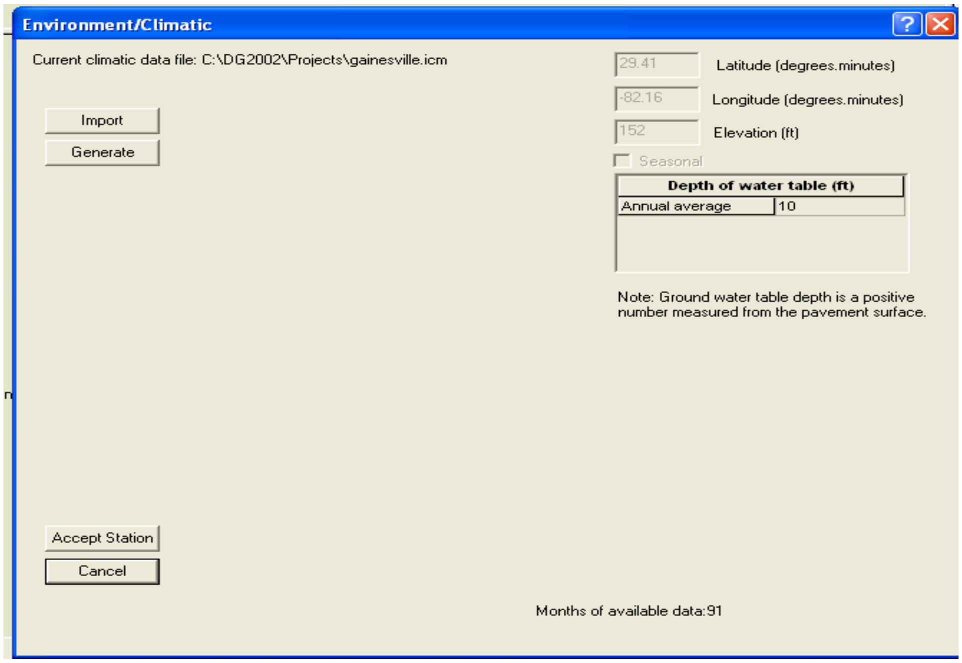


Figure 3-4. Climate input – Gainesville, FL

Status of all input for the program can be distinguished by colors as shown in Figure 3-5. Red means that data entry is required for the design process. The yellow input screens means that default values that are not yet verified and accepted will be used for the design. Input that has been verified and accepted by the user is coded in green. To run the program, all input screens must be either yellow or green.

After verifying traffic and climate input, the data for the structure input was entered. In this research, six quality characteristics were filled with actual test results from LIMS. As shown in Figure 3-6, the required asphalt gradation for the MEPDG program includes cumulative % retained ¾ inch sieve, cumulative % retained $^3/_8$ inch sieve, cumulative % retained #4 sieve, and

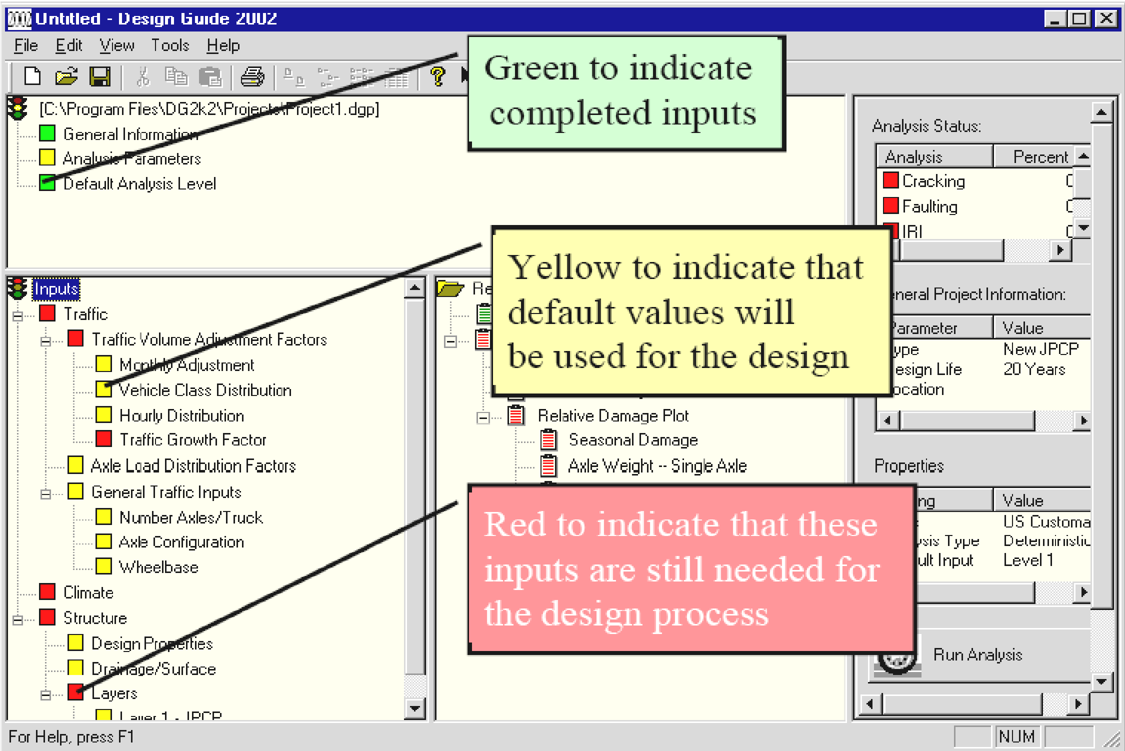


Figure 3-5. Color-coded inputs (VonQuintus and Moulthrop 2007)

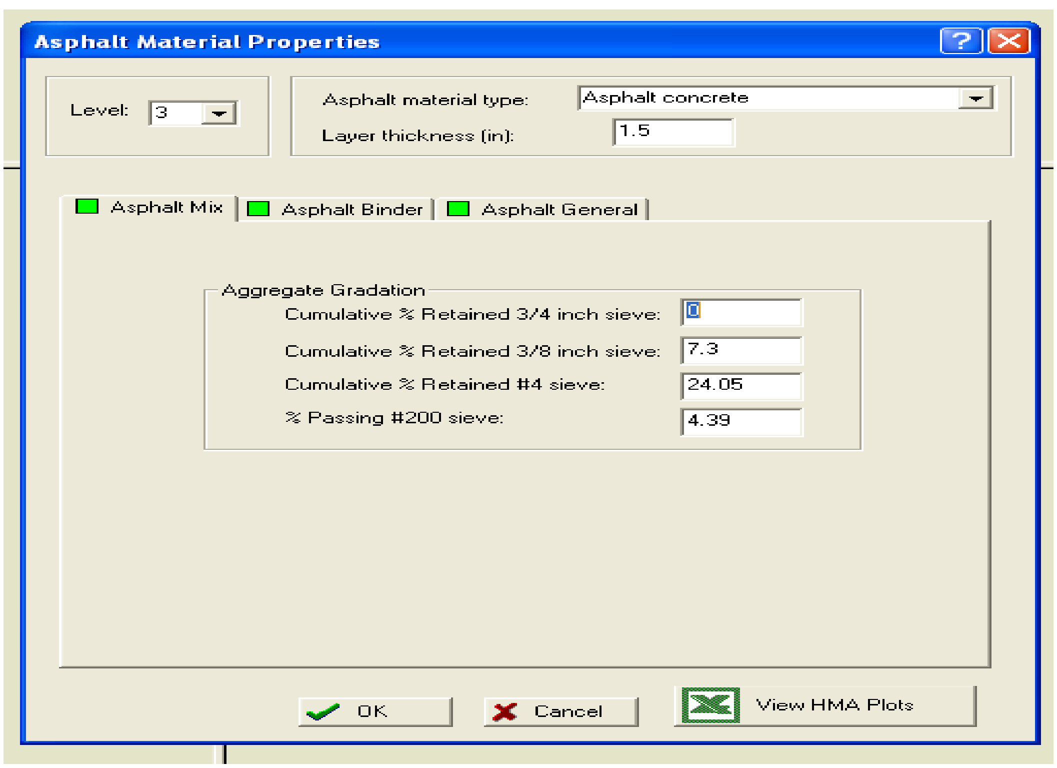


Figure 3-6. Asphalt material properties – asphalt mix

% passing #200 sieve. Except for the #200 sieve passing rate, the retained percentage instead of passing rate was required for the other properties. Therefore, the passing rate for the properties in the asphalt report as shown in Figure 3-2 must be converted to the retained rate for the sieves before entering the data into the MEPDG program.

Effective binder content and air voids are the other two quality characteristics to be entered into the MEPDG program. They can be found under the “Asphalt General” tab in asphalt material properties as shown in Figure 3-7. Except for the two quality characteristics, effective binder content and air voids, all the other categories will be filled with default values.

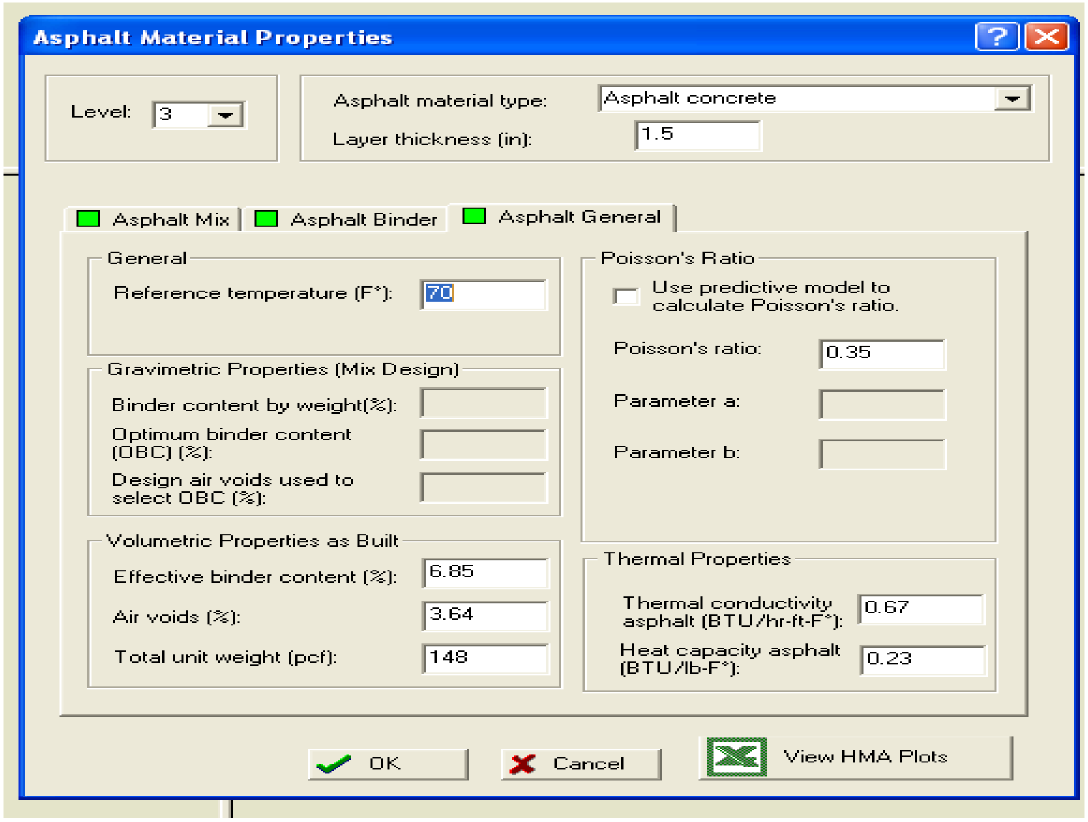


Figure 3-7. Asphalt material properties – asphalt general

As seen on asphalt material properties in Figure 3-6 and Figure 3-7, analysis by this program is for one design or one sample. Once all input is entered into the program, the analysis of the sample is ready to begin. When the run is completed, the program creates a summary of all input and output of the design. The summary of output is the distress and performance prediction in both tabular and graphical formats. The output report is created in Microsoft Excel files.

STEP 3: Determine how to translate expected distresses to pavement performance in MEPDG.

Once the MEPDG program run is complete, it generates a Microsoft Excel file with the expected pavement distresses and the International Roughness Index (IRI) as an output report. Table 3-6 is an example of an expected distress in tabular format. The table shows that design life of the project is 15 years.

Table 3-6. Sample of an expected distress in tabular format

Fatigue Cracking: Project 19384825201-fc4376B-01

Pavement age			Top Down at Surface			Top Down at 0.5"			Bottom Up at h_{ac}			Reliability	
mo	yr	Month	Maximum Damage (%)	Maximum Cracking (ft/mi)	Location (in)	Maximum Damage (%)	Maximum Cracking (ft/mi)	Location (in)	Maximum Damage (%)	Maximum Cracking (%)	Location (in)	Top Down Cracking (ft/mi)	Bottom Up Cracking (%)
1	0.08	June	0.212	0.91	0	0.00205	0	0	0.00305	0	0	474.63	1.45
2	0.17	July	0.857	7.61	0	0.0035	0	0	0.00916	0	0	937.33	1.45
3	0.25	August	1.46	17	0	0.00476	0	0	0.0153	0.01	0	1240.89	1.45
4	0.33	September	1.61	19.8	0	0.00678	0	0	0.0178	0.01	0	1304.38	1.46
5	0.42	October	1.65	20.5	0	0.00892	0.01	0	0.0188	0.01	0	1320.59	1.46
6	0.5	November	1.66	20.8	0	0.0111	0.01	0	0.0189	0.01	0	1324.72	1.46
7	0.58	December	1.67	21	0	0.0125	0.01	0	0.0189	0.01	0	1328.74	1.46
8	0.67	January	1.68	21.1	0	0.0139	0.01	0	0.0189	0.01	0	1332.64	1.46
9	0.75	February	1.69	21.4	0	0.0158	0.02	0	0.019	0.01	0	1336.72	1.46
10	0.83	March	1.71	21.7	0	0.0179	0.02	0	0.0193	0.01	0	1344.54	1.46
11	0.92	April	1.74	22.3	0	0.0198	0.02	0	0.0203	0.01	0	1356.3	1.46
12	1	May	1.96	26.7	0	0.0212	0.03	0	0.0243	0.01	0	1438.33	1.46
13	1.08	June	2.49	38.3	0	0.0224	0.03	0	0.0312	0.01	0	1611.28	1.46
169	14.1	June	44.5	2390	0	0.231	1.04	0	0.843	0.52	0	5369.74	1.97
170	14.2	July	45.5	2450	0	0.233	1.05	0	0.861	0.53	0	5434.03	1.98
171	14.3	August	46.7	2520	0	0.234	1.06	0	0.881	0.54	0	5508.95	2
172	14.3	September	47	2540	0	0.235	1.07	0	0.891	0.55	0	5530.15	2
173	14.4	October	47	2550	0	0.237	1.08	0	0.893	0.55	0	5540.15	2
174	14.5	November	47	2550	0	0.24	1.1	0	0.894	0.55	0	5540.15	2
175	14.6	December	47.1	2550	0	0.241	1.11	0	0.894	0.55	0	5540.55	2.01
176	14.7	January	47.1	2550	0	0.243	1.12	0	0.894	0.55	0	5540.55	2.01
177	14.8	February	47.1	2550	0	0.245	1.13	0	0.895	0.55	0	5540.55	2.01
178	14.8	March	47.1	2550	0	0.247	1.15	0	0.896	0.55	0	5540.55	2.01
179	14.9	April	47.3	2560	0	0.248	1.16	0	0.903	0.56	0	5551.33	2.01
180	15	May	47.7	2590	0	0.25	1.17	0	0.913	0.56	0	5582.89	2.02

Figure 3-8 is an example of an expected distress in graphical format. In this graph, expected surface cracking at the end of 180 months (blue line) is much larger than design limits (red line). If this sample is for the real design of a pavement system, the expected cracking must not exceed the design limits, so a redesign might be required in this case. However, the fact that expected cracking is above design limits is not important because all of the other design criteria, such as traffic, climate, and structure properties, in the other layers of the pavement system are not properly designed for ICQI model development. For the ICQI model development, only the relative ratio to target values of the mix will be required.

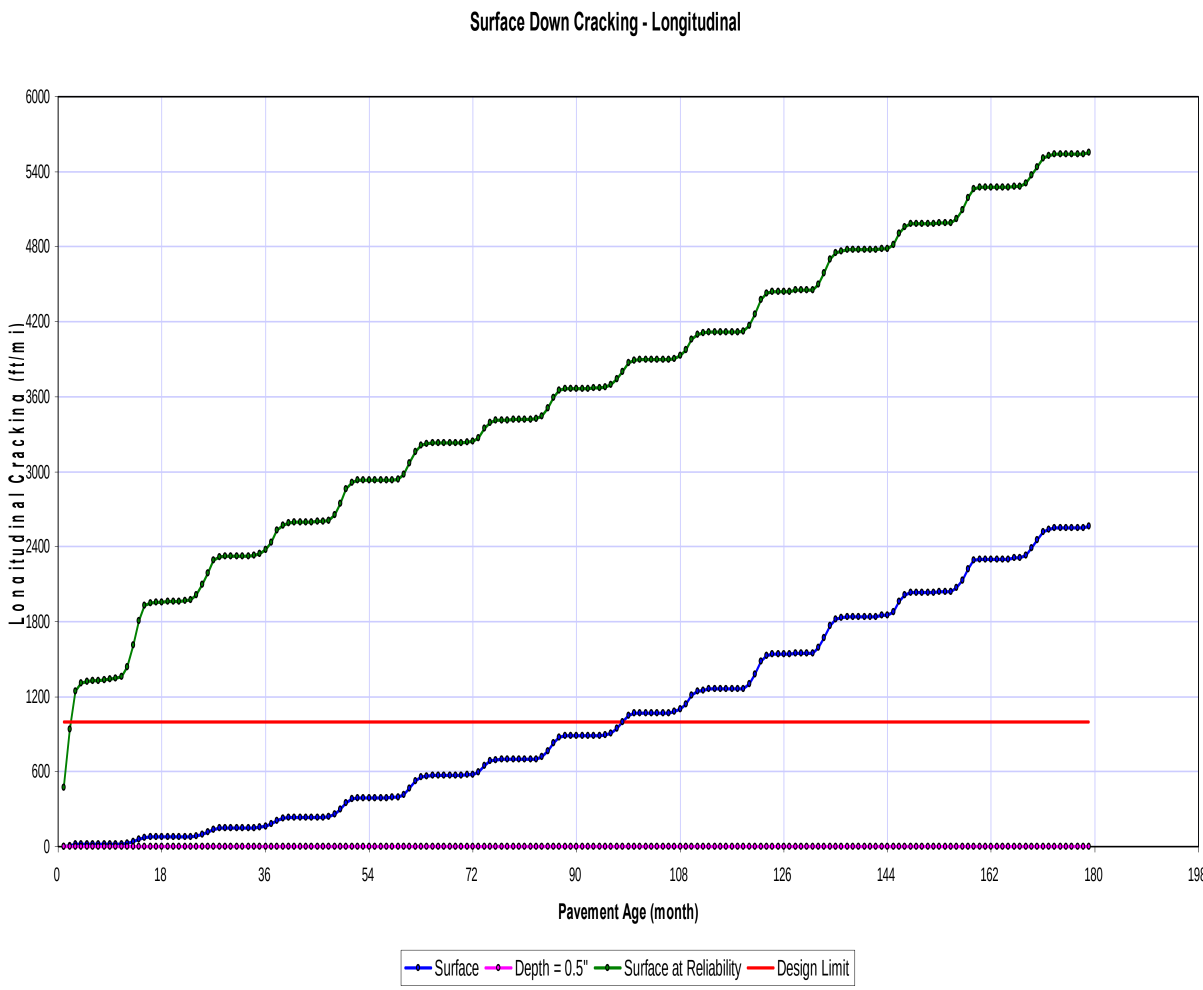


Figure 3-8. Sample of an expected distress in graphical format

As shown in Table 3-7, the MEPDG program generates a reliability summary for the expected pavement distresses and the IRI. The expected pavement distresses include surface down cracking, known as top-down cracking, bottom-up cracking, thermal cracking, and permanent cracking, known as rutting.

Table 3-7. Sample of a reliability summary 1

Performance Criteria	Distress Target	Reliability Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	118.2	94.99	Pass
AC Surface Down Cracking (Long. Cracking) (ft/mile):	1000	90	2590	24.8	Fail
AC Bottom Up Cracking (Alligator Cracking) (%):	100	90	0.6	99.999	Pass
AC Thermal Fracture (Transverse Cracking) (ft/mi):	100	90	1	93.61	Pass
Permanent Deformation (AC Only) (in):	0.25	90	0.83	0.25	Fail
Permanent Deformation (Total Pavement) (in):	0.75	90	0.88	26.52	Fail

Table 3-7 shows the output obtained from the MEPDG program after running a sample from a friction course mix in a District 1 project. From the same mix in the same project, another sample was chosen for running the program and comparing the results. Table 3-8 is the result of the run. Comparing these two tables for a reliability summary, “Distress Predicted” and “Reliability Predicted” have different values from each other; which means that the expected pavement performance will be different, so the way in which the predicted distress is related to pavement performance needs to be revealed.

When permanent deformation for total pavement from the above two tables are compared, values for distress predicted are the same at 0.88 each; however, values for reliability predicted are different at 26.52 and 27.05, respectively. The reason is that the values for distress predicted are rounded, and values for reliability predicted are more sensitive. In addition, values for reliability predicted range from 0 to 100, which means a scale adjustment between distress categories is not required.

Table 3-8. Sample of a reliability summary 2

Performance Criteria	Distress Target	Reliability Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	117.8	95.18	Pass
AC Surface Down Cracking (Long. Cracking) (ft/mile):	1000	90	229	66.27	Fail
AC Bottom Up Cracking (Alligator Cracking) (%):	100	90	0.1	99.999	Pass
AC Thermal Fracture (Transverse Cracking) (ft/mi):	100	90	1	93.61	Pass
Permanent Deformation (AC Only) (in):	0.25	90	0.83	0.26	Fail
Permanent Deformation (Total Pavement) (in):	0.75	90	0.88	27.05	Fail

For these reasons, predicted reliability was used to find the relationship between distresses and pavement performance. The definition of target design reliability is the probability that the pavement will not exceed performance criterion limits over the design period.

The relationship between distresses and pavement performance were sought using the expert panel survey prepared by the rules of AHP. As mentioned in chapter 3.1.2.2, the results of the survey were presented in Appendix D for ICQI flexible pavements. The average values were entered into SuperDecisions software to determine the relationship between the expected distresses and the pavement performance. SuperDecisions hierarchical model for weighting distresses to convert the summary of distresses to pavement performance is shown in Figure 3-9.

Once the hierarchical model was set up, Figure 3-10 shows pair-wise comparisons with respect to the goal when mean values in Appendix D for ICQI flexible pavement are entered. Numbers in the matrix are the dominance judgment that is derived from the expert panel survey. The blue number in the matrix indicates the element listed at the left is more important than the

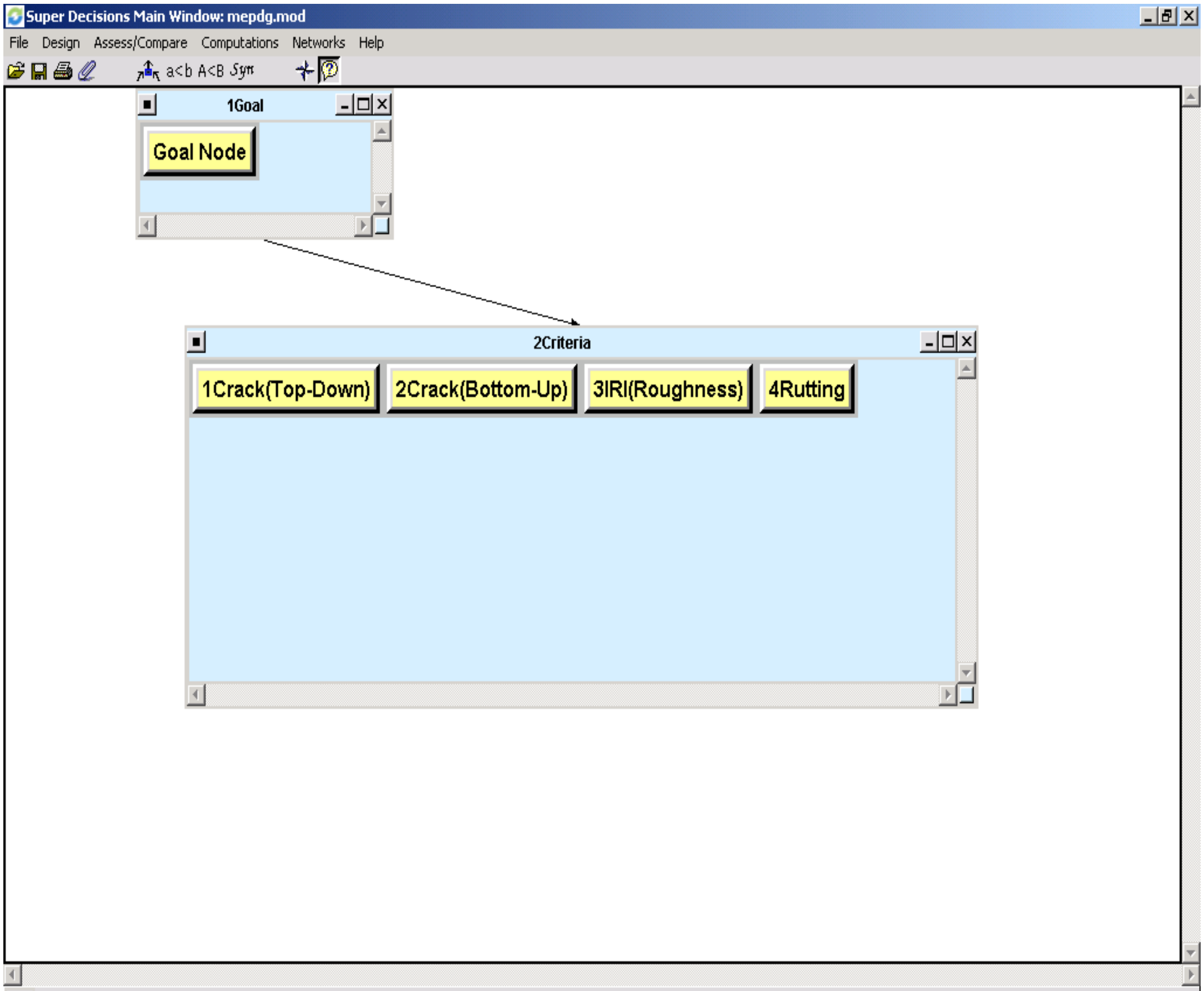


Figure 3-9. SuperDecisions hierarchical model for weighting distresses

element listed at the top. The red number means that the element listed at the top is dominant. A judgment of 1.0 means that they are equally important, and a judgment of 5.0 means strongly or five times as much if the categories are measurable. The maximum number of judgment is 9. Judgments greater than 9 may be entered, but it is suggested that they be avoided. In those cases, the hierarchical structure should be re-organized so that such a comparison is not required.

After entering average values from the survey results of ICQI flexible pavement, the results of the pair-wise comparisons are shown in Figure 3-11; the inconsistency is shown in the top part of the properties screen. At 0.07, it is less than 0.10, so no correction of judgment is needed.

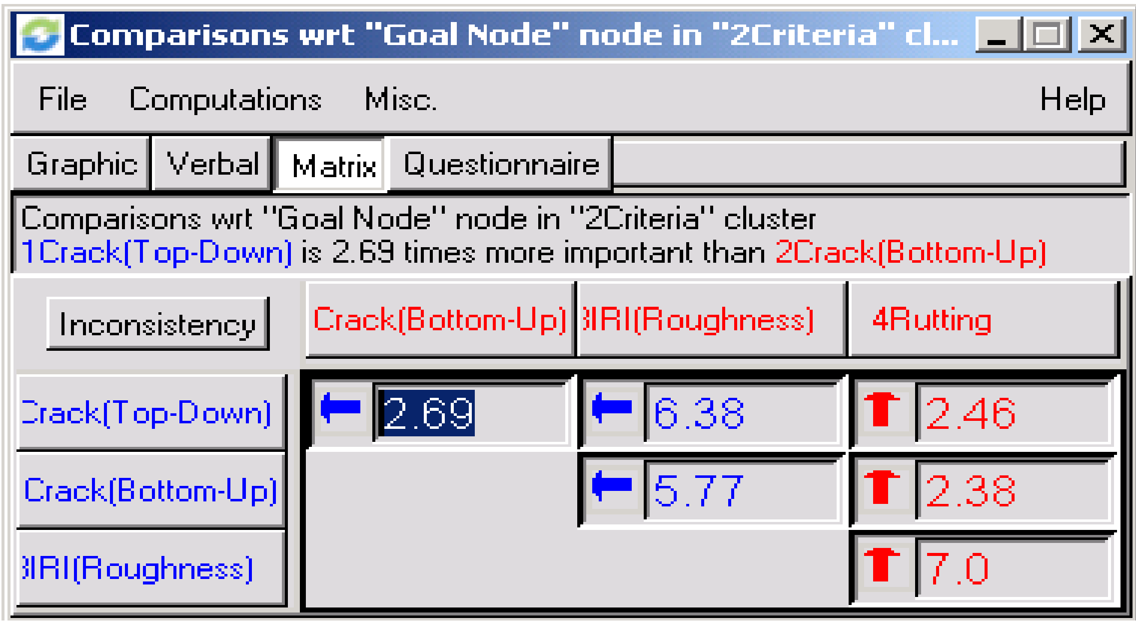


Figure 3-10. Matrix pair-wise comparison screen

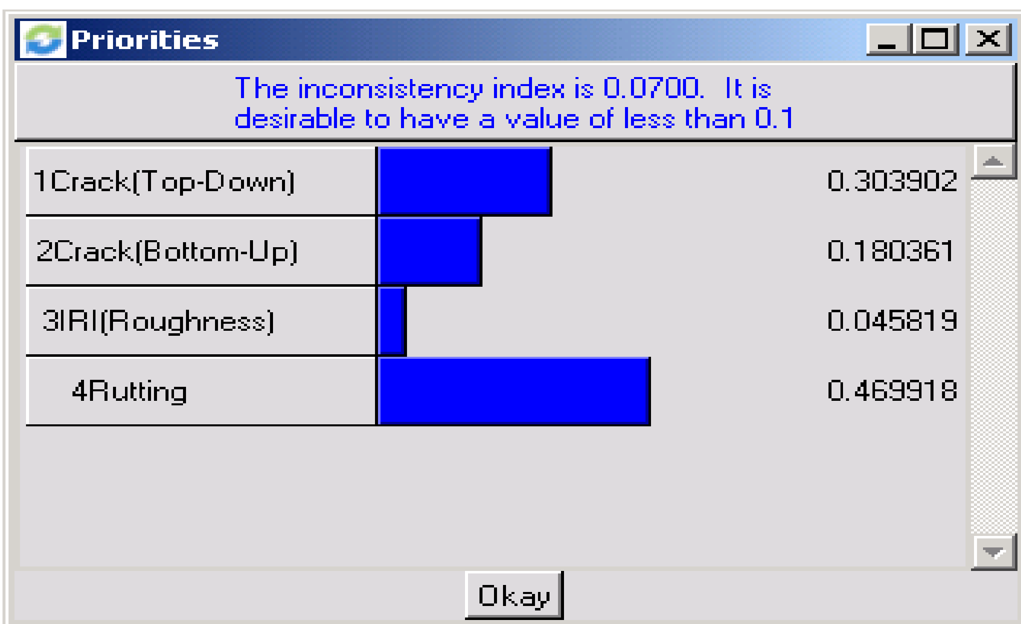


Figure 3-11. Results of the pair-wise comparisons

Once the relationship is found, the distresses are calculated to get the expected reliability of a sample. For example, Table 3-7 and Table 3-8 show reliability summaries after running the

MEPDG program. Each table represents expected distresses of one sample. Table 3-9 shows how to convert predicted distresses to overall performance reliability of the samples. When the overall reliability is obtained from a sample (here, 42.39 and 55.25 are the overall reliability of each sample), it is ready to go to the next step, which is developing a regression model for each layer.

Table 3-9. Conversion of predicted distresses to overall reliability

	Weight	Sample in Table 3-8		Sample in Table 3-9	
		Reliability Predicted	Revised Reliability	Reliability Predicted	Revised Reliability
Top-Down Cracking	0.3039	24.80	7.54	66.27	20.14
Bottom-Up Cracking	0.1804	99.999	18.04	99.999	18.04
IRI (Roughness)	0.0458	94.99	4.35	95.18	4.36
Rutting	0.4699	26.52	12.46	27.05	12.71
SUM			42.39		55.25

STEP 4: Develop regression model for each layer.

The MEPDG program has no target values for input, which means that the MEPDG produces its output according to the input value without consideration of specification limits or target values. Therefore, to compare sample qualities when each sample has different target values (or specification limits), the response should be the ratio between MEPDG output using test (sample) data and MEPDG output using target value.

For example, overall reliabilities of 42.39 and 55.25 in Table 3-10 do not have any meaning in themselves. The overall reliability should be compared to target values of the same mixes. Table 3-10 explains why the overall reliability should be compared to target values of the same asphalt mixes to be used in developing a regression model.

In Table 3-10, samples in Table 3-7 and Table 3-8 are taken as examples. The overall reliability of sample A is 42.39, whereas the overall reliability of sample B is 55.25. This does not necessarily mean that asphalt pavement was laid better in sample A than in sample B. Even though overall reliability of sample B is larger than that of sample A, the ratio between the sample and target value for sample A is larger than the ratio for sample B. This means that in the "good" sample, construction was executed close to the design target, or even exceeds the design target quality. Overall reliability of sample A, 42.39, can be regarded as in the "good" category when overall reliability of the target value is 41.05. As seen in Table 3-10, unlike the CQI model, sample quality can be better than target quality; accordingly, the ratio can exceed 1, or 100%.

Table 3-10. Conversion example of the overall reliability to ratio to target value

	Sample A	Sample B
Overall Reliability of a Sample (1)	42.39	55.25
Overall Reliability of Target Value (2)	41.05	56.20
Ratio (1)/(2)	1.033	0.983

In addition, the variables are construction quality characteristics such as asphalt content and air void ratio. By using the ratio between test (sample) MEPDG output and target MEPDG output, pavement performance from MEPDG can be properly estimated under the assumption that pavement performance from MEPDG is 100% when target values for the mix are entered.

In the Equation 9 below, y is the same value as the ratio in Table 3-10.

Several assumptions are required for the regression model, which is expressed by

$$ICQI_{layer} = y = \left(\frac{y_{(sample)}}{y_{(target)}}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_p x_1 x_2 + \ldots + \varepsilon, \qquad \text{(Equation 9)}$$

where $y_{(sample)}$ is the pavement performance from MEPDG when test results from samples are entered, and $y_{(target)}$ is the pavement performance from MEPDG when target values for the samples are entered. The assumptions of the model are (Rawlings et al. 1998):

- y is regarded as the response that corresponds to the levels of the explanatory variables $x_1, x_2, \ldots, x_p$.
- $\beta_0, \beta_1, \ldots, \beta_p$ are assumed to be the coefficients in the linear relationship. If there is a single factor (p = 1) for the equation, β_0 will be the intercept, and β_1 will be the slope of the straight line defined.
- $\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_n$ are assumed to be errors that make a scatter pattern around the linear relationship at each of the n observations. These errors are mutually independent, are normally distributed, and have a zero mean and variance, σ^2, under the assumption of the regression model.

STEP 5: Generate sample-level ICQI for each sample.

The developed regression model in step 4 is an ICQI model which was used to calculate layer-level ICQI. By entering the construction quality characteristics values to the model, sample-level ICQI can be calculated for the layer. For example, if there are 30 samples in a specific layer, 30 ICQI are obtained for the layer.

STEP 6: Compute $ICQI_{layer}$ from sample-level ICQI.

In the CQI model development, the PWL concept was used. The basic assumption of the concept is that variability of quality can affect performance. However, in the ICQI model, mechanistic-empirical and mathematical (regression) approaches are used, so the $ICQI_{layer}$ can be computed to the average value of the calculated sample-level ICQI for the layer from step 5.

When there are several mixes in a layer, the same concept used in chapter 3.2.1.3. is applied.

STEP 7: Multiply weighting factors for each layer and $ICQI_{layer}$ to get the project-level ICQI.

As shown in Equation 8 earlier, the general form of the ICQI model for a layered pavement system is as follows:

$$ICQI = \sum_{layers} W_{layer} \times ICQI_{layer} \qquad \text{(Equation 8)}$$

where W_{layer} = weighting factor for layer i

$ICQI_{layer}$ = integrated construction quality index for layer i (Step 5)

CHAPTER 4
DATA ANALYSIS

4.1 Overview

In order to validate the model, the research team asked FDOT to provide projects to study. The most important requirement was that the projects have their relevant data stored in the LIMS database. It was also requested that FDOT provide a "level of satisfaction," or rating of "good" or "poor," for each project provided.

FDOT supplied 105 flexible paving projects from all districts for review. The projects consisted of 12 new or reconstruction projects that require earth work and 93 resurfacing projects that require only asphalt work. Details of these projects, such as constructed district, project number, construction type, and FDOT rating, can be seen in Table 4-1.

Table 4-1. All provided projects for validation from FDOT

District	Project Number	Construction Type	FDOT Rating
1	404201-1-52-01	Resurfacing	Average
1	193848-2-52-01	Resurfacing	Good
1	194437-2-52-01	Resurfacing	Average
1	201015-2-52-01	Resurfacing	Good
1	194100-2-52-01	Resurfacing	Good
1	194172-2-52-01	Resurfacing	Poor
1	195736-1-52-01	Add Lanes & Rehabilitation	Poor
1	197308-2-52-01	Resurfacing	Average
1	197291-2-52-01	Resurfacing	Good
1	197388-2-52-01	Resurfacing	Average
1	197309-2-52-01	Resurfacing	Average
1	197679-1-52-01	Add Lanes & Reconstruction	Poor

Table 4-1. Continued

District	Project Number	Construction Type	FDOT Rating
1	411862-1-52-01	Resurfacing	Average
1	196960-3-52-01	Resurfacing	Good
1	196960-2-52-01	Resurfacing	Good
1	197007-2-52-01	Resurfacing	Good
2	207545-2-52-01	Resurfacing	Average
2	208085-2-52-01	Resurfacing	Good
2	208363-1-52-01	Add Lanes & Reconstruction	Average
2	208366-2-52-01	Resurfacing	Good
2	209301-1-52-01	New Road Construction	Average
2	209543-2-52-01	Resurfacing	Average
2	209648-3-52-01	Miscellaneous Construction	Poor
2	209949-2-52-01	Resurfacing	Average
2	209970-2-52-01	Resurfacing	Average
2	210221-2-52-01	Resurfacing	Average
2	210273-2-52-01	Resurfacing	Average
2	210374-2-52-01	Resurfacing	Good
2	210384-2-52-01	Widening/Resurfacing	Average
2	210432-2-52-01	Resurfacing	Average
2	210889-3-52-01	Resurfacing	Average
2	210949-2-52-01	Resurfacing	Good
2	213520-2-52-01	Resurfacing	Average
2	207947-2-52-01	Resurfacing	Good
2	207956-2-52-01	Resurfacing	Poor

Table 4-1. Continued

District	Project Number	Construction Type	FDOT Rating
2	207956-3-52-01	No Data	
2	208200-2-52-01	Resurfacing	Poor
2	208226-4-52-01	Resurfacing	Good
2	209166-3-52-01	Resurfacing	Poor
2	209692-2-52-01	Resurfacing	Poor
2	209999-1-52-01	Add Lanes & Reconstruction	Poor
2	210004-1-52-01	No Data	
2	210253-1-52-01	Add Lanes & Reconstruction	Poor
2	213251-2-52-01	Resurfacing	Good
3	217947-1-52-01	Add Lanes & Reconstruction	Good
3	217948-1-52-01	Add Lanes & Reconstruction	Poor
3	409022-1-52-01	Resurfacing	Average
3	413426-1-52-01	Resurfacing	Good
3	411389-1-52-01	Resurfacing	Average
3	408878-1-52-01	Resurfacing	Good
3	409017-1-52-01	Resurfacing	Good
3	411391-1-52-01	Resurfacing	Good
3	411395-1-52-01	Resurfacing	Good
3	218539-1-52-01	Add Lanes & Reconstruction	Poor
3	409006-1-52-01	Resurfacing	Poor
3	403930-1-52-01	Resurfacing	Good
3	411697-1-52-01	Resurfacing	Good
3	406326-1-52-01	Resurfacing	Average

Table 4-1. Continued

District	Project Number	Construction Type	FDOT Rating
3	411396-1-52-01	Resurfacing	Good
3	411397-1-52-01	Resurfacing	Average
3	413442-1-52-01	Resurfacing	Average
4	411321-1-52-01	Resurfacing	Fair
4	411322-1-52-02	Resurfacing	Good
4	231726-1-52-01	Resurfacing	Average
4	231735-1-52-02	Resurfacing	Good
4	415397-1-52-01	Resurfacing	No rating
4	231737-1-52-01	Resurfacing	Good
4	411323-1-52-01	Resurfacing	Fair
4	227861-1-52-01	Resurfacing	Fair
4	228110-1-52-01	Resurfacing	Fair
4	228188-1-52-01	Resurfacing	Excellent
4	228615-1-52-01	Resurfacing	Good
4	413801-1-52-01	Resurfacing	No rating
4	411441-1-52-01	Resurfacing	Good
4	228135-1-52-01	Intersection	Good
4	403605-1-52-01	Resurfacing	Good
4	403619-1-52-01	Resurfacing	Good
5	415513-1-52-01	Resurfacing	Average
5	419993-1-52-01	No Data	
5	411603-1-52-01	Resurfacing	Good
5	413585-1-52-01	Resurfacing	Average

Table 4-1. Continued

District	Project Number	Construction Type	FDOT Rating
5	415514-1-52-01	Resurfacing	Average
5	415512-1-52-01	Resurfacing	Good
5	239725-1-52-01	Add Lanes & Reconstruction	Poor
5	417155-1-52-01	Resurfacing	Good
5	415526-1-52-01	Resurfacing	Good
5	413583-1-52-01	Resurfacing	Good
6	250548-2-52-01	Reconstruction	Good
7	411332-1-52-01	Resurfacing	Good
7	411266-1-52-01	Resurfacing	Good
7	406560-1-52-01	Resurfacing	Good
7	257076-1-52-01	Resurfacing	Poor
7	411277-1-52-01	Resurfacing	Average
7	408913-1-52-01	Resurfacing	Average
7	413413-1-52-01	Resurfacing	Good
TPK	232352-1-52-01	No Data	
TPK	406092-1-52-01	Add Lanes & Reconstruction	Good
TPK	411533-1-52-01	Resurfacing	Good
TPK	411532-1-52-01	Resurfacing	Excellent
TPK	413623-2-52-01	Resurfacing	Excellent
TPK	413623-1-52-01	Resurfacing	Excellent
TPK	413669-1-52-01	Resurfacing	Poor
TPK	406102-1-52c-01	Interchange	Poor

The researcher had significant problems in the procuring of data from LIMS. LIMS seemed to be an efficient tool that different levels of users could employ to enter various test results; however, it was a difficult system from which to retrieve data. When LIMS specialists were asked to show how to retrieve particular data, only a few of them were able to do so. Even after the data was procured, it became apparent that large portions of important data had not been entered into the database.

Another problem in getting correct data was that the LIMS report sometimes showed incorrect data without specific reasons. For example, the researcher needed to know the #8 sieve passing rate, which must be between 0 and 100. The LIMS report sometimes retrieved #8 sieve passing weight instead of passing rate, showing hundreds or thousands for passing percentage as a result. Therefore, once that type of incorrect data was procured, the researcher had to check and re-retrieve data individually.

4.2 Data Deduction

Each pavement system consists of several layers with different functions and materials. Embankment, subgrade, base, Superpave, and friction courses are among possible flexible pavement layers. As shown in Table 4-1, construction type of the flexible pavement can be divided into two categories: resurfacing construction or reconstruction.

Resurfacing construction generally requires milling of top layers of the flexible pavement system and does not require earth work such as embankment, subgrade, or base. Therefore, the maximum number of possible layers for resurfacing construction is two: Superpave and friction course. However, it was impossible to know whether the actual number of layers for a particular resurfacing construction project was one or two because the amount of information available through LIMS was limited.

Reconstruction and new construction require earth work that includes embankment, subgrade, or base according to design. Therefore, the maximum number of possible layers for reconstruction or new construction is five: embankment, subgrade, base, Superpave, and friction course. The actual number of layers for reconstruction or new construction also depended upon the design of a particular project.

For more reliable analysis, some projects were excluded from the project list provided by FDOT. The first factor to consider was the number of layers constructed. When the number of constructed layers is over 50 percent of the possible number of layers, then CQI analysis was done. As mentioned earlier, some projects, such as straight asphalt resurfacing projects, have only two layers; therefore, analysis was done to determine the CQI for any project for which data was available for either Superpave or friction course layers constructed. For new construction or reconstruction projects, at least three constructed layers containing data were required to determine the CQI because three layers was the minimum requirement for over 50 percent of the possible number of layers. However, if a project's three constructed layers were all earth work, such as embankment, subgrade, and base, then the project was excluded from the CQI analysis because the sum of earth work layers' CQIs could represent only slightly less than 30% of the project's CQI.

Another factor to consider was the number of samples that were tested and those test results entered into the LIMS database. Extremely low sample counts greatly reduce the reliability of any model result; therefore, any project that had less than 30 samples was excluded from the CQI analysis.

Table 4-2 below shows all the projects that were excluded from the CQI analysis and the reasons for the exclusions. As shown in Table 4-2, some projects were eliminated from the analysis because no data were found in the LIMS or no rating from FDOT was provided.

Table 4-2. Eliminated projects from CQI analysis

District	Project Number	Max. Possible Layers	No. Layers of Data	No. of Samples	Reason for Elimination
1	195736-1-52-01	5	2	11	Not enough number of layers
1	403890-1-52-01				No Data
1	196960-3-52-01	2	2	15	Not enough number of samples
1	196960-2-52-01	2	2	15	Not enough number of samples
1	197007-2-52-01	2	2	30	No target value
1	201015-2-52-01	2	1	23	Not enough number of samples
2	208363-1-52-01	5	2	232	Not enough number of layers
2	210374-2-52-01	2	2	13	Not enough number of samples
2	210949-2-52-01	2	2	25	Not enough number of samples
2	207956-3-52-01				No Data
2	208226-4-52-01	2	1	2	Not enough number of samples
2	209999-1-52-01	5	2	104	Not enough number of layers
2	210004-1-52-01				No Data
2	210253-1-52-01	5	1	34	Not enough number of layers
3	409022-1-52-01	2	2	22	Not enough number of samples
3	411391-1-52-01	2	2	16	Not enough number of samples

Table 4-2. Continued

District	Project Number	Max. Possible Layers	No. Layers of Data	No. of Samples	Reason for Elimination
3	411395-1-52-01	2	2	9	Not enough number of samples
3	218539-1-52-01	5	2	74	Not enough number of layers
3	413442-1-52-01	2	2	24	Not enough number of samples
4	415397-1-52-01				No rating from FDOT
4	413801-1-52-01				No rating from FDOT
4	411441-1-52-01	2	2	22	Not enough number of samples
4	228135-1-52-01				No Data
4	403605-1-52-01	2	2	18	Not enough number of samples
5	419993-1-52-01				No Data
5	415514-1-52-01	2	1	16	Not enough number of samples
5	239725-1-52-01	5	2	27	Not enough number of layers
5	417155-1-52-01	2	2	24	Not enough number of samples
5	413583-1-52-01	2	1	25	Not enough number of samples
7	408913-1-52-01	2	2	31	No tonnage for mixes
7	411266-1-52-01	2	2	61	No tonnage for mixes
TPK	232352-1-52-01				No Data

After 32 projects were eliminated from CQI analysis for various reasons, 73 projects from all 8 districts were selected for CQI analysis. Table 4-3 below shows the list of the projects, including district in which the projects were constructed, project number, construction type, and ratings from FDOT personnel.

Table 4-3. Selected projects for CQI analysis

District	Project Number	Construction Type	FDOT Rating
1	404201-1-52-01	Resurfacing	Average
1	193848-2-52-01	Resurfacing	Good
1	194437-2-52-01	Resurfacing	Average
1	194100-2-52-01	Resurfacing	Good
1	194172-2-52-01	Resurfacing	Poor
1	197308-2-52-01	Resurfacing	Average
1	197291-2-52-01	Resurfacing	Good
1	197388-2-52-01	Resurfacing	Average
1	197309-2-52-01	Resurfacing	Average
1	197679-1-52-01	Add Lanes & Reconstruction	Poor
1	197368-2-52-01	Resurfacing	Good
1	411862-1-52-01	Resurfacing	Average
2	207545-2-52-01	Resurfacing	Average
2	208085-2-52-01	Resurfacing	Good
2	208366-2-52-01	Resurfacing	Good
2	209301-1-52-01	New Road Construction	Average
2	209543-2-52-01	Resurfacing	Average
2	209648-3-52-01	Miscellaneous Construction	Poor
2	209949-2-52-01	Resurfacing	Average
2	209970-2-52-01	Resurfacing	Average
2	210221-2-52-01	Resurfacing	Average
2	210273-2-52-01	Resurfacing	Average
2	210384-2-52-01	Widening/Resurfacing	Average

Table 4-3. Continued

District	Project Number	Construction Type	FDOT Rating
2	210432-2-52-01	Resurfacing	Average
2	210889-3-52-01	Resurfacing	Average
2	213520-2-52-01	Resurfacing	Average
2	207947-2-52-01	Resurfacing	Good
2	207956-2-52-01	Resurfacing	Poor
2	208200-2-52-01	Resurfacing	Poor
2	209166-3-52-01	Resurfacing	Poor
2	209692-2-52-01	Resurfacing	Poor
2	213251-2-52-01	Resurfacing	Good
3	217947-1-52-01	Add Lanes & Reconstruction	Good
3	217948-1-52-01	Add Lanes & Reconstruction	Poor
3	413426-1-52-01	Resurfacing	Good
3	411389-1-52-01	Resurfacing	Average
3	408878-1-52-01	Resurfacing	Good
3	409017-1-52-01	Resurfacing	Good
3	409006-1-52-01	Resurfacing	Poor
3	403930-1-52-01	Resurfacing	Good
3	411697-1-52-01	Resurfacing	Good
3	406326-1-52-01	Resurfacing	Average
3	411396-1-52-01	Resurfacing	Good
3	411397-1-52-01	Resurfacing	Average
4	411321-1-52-01	Resurfacing	Fair
4	411322-1-52-02	Resurfacing	Good

Table 4-3. Continued

District	Project Number	Construction Type	FDOT Rating
4	231726-1-52-01	Resurfacing	Average
4	231735-1-52-02	Resurfacing	Good
4	231737-1-52-01	Resurfacing	Good
4	411323-1-52-01	Resurfacing	Fair
4	227861-1-52-01	Resurfacing	Fair
4	228110-1-52-01	Resurfacing	Fair
4	228188-1-52-01	Resurfacing	Excellent
4	228615-1-52-01	Resurfacing	Good
4	403619-1-52-01	Resurfacing	Good
5	415513-1-52-01	Resurfacing	Average
5	411603-1-52-01	Resurfacing	Good
5	413585-1-52-01	Resurfacing	Average
5	415512-1-52-01	Resurfacing	Good
5	415526-1-52-01	Resurfacing	Good
6	250548-2-52-01	Reconstruction	Good
7	411332-1-52-01	Resurfacing	Good
7	406560-1-52-01	Resurfacing	Good
7	257076-1-52-01	Resurfacing	Poor
7	411277-1-52-01	Resurfacing	Average
7	413413-1-52-01	Resurfacing	Good
TPK	406092-1-52-01	Add Lanes & Reconstruction	Good
TPK	411533-1-52-01	Resurfacing	Good
TPK	411532-1-52-01	Resurfacing	Excellent

Table 4-3. Continued

District	Project Number	Construction Type	FDOT Rating
TPK	413623-2-52-01	Resurfacing	Excellent
TPK	413623-1-52-01	Resurfacing	Excellent
TPK	413669-1-52-01	Resurfacing	Poor
TPK	406102-1-52c-01	Interchange	Poor

4.3 Model Validation

Once projects to be analyzed were identified, the available data for each project were entered into the CQI and ICQI models. Then, calculated CQI and ICQI was grouped by district or score to compare to FDOT ratings.

4.3.1 Construction Quality Index (CQI) Model

4.3.1.1 Validation process

As explained earlier, a project's CQI is the sum of each layer's CQI of the project. Unfortunately, for several projects, it is clear that some data were missing or irretrievable from LIMS. In addition, of course, not every project should have data for every possible layer. In resurfacing construction, usually only the top two layers of the pavement system- friction course, and Superpave- are constructed; therefore, when there are missing layers, a weight correction of the layers with data should be considered.

As explained in Table 3-2 in chapter 3.2.1.2, in order to make the sum of the remaining layers' weights 100 percent, or 1.00, the revised layer weighting factors are rearranged by weighting their respective contributions to the projects. A weight correction of parameters followed the same rule. For example, if a "density" and "ride number" are the only two parameters for a friction course layer out of six parameters, then the revised weighting factors of density and ride number should be recalculated to make the sum of the factors 1, or 100 percent. Then, the revised CQIs for density and ride number represent the CQI for the entire friction course. This arrangement was not ideal, so the researcher avoided analyzing these projects.

When the researcher asked for the project numbers to study, a total of 105 projects were initially provided. Among the 105 projects, 12 were categorized as reconstruction or new construction that had embankment, subgrade, or base in their pavement system. After data deduction, seven reconstruction or new construction projects were eliminated from analysis, so five reconstruction projects were included in the 73 projects to be analyzed. Because of the limited number of reconstruction projects, comparison between reconstruction and resurfacing construction could not be done.

4.3.1.2 The CQI model validation through all projects from every district

All projects were compared by FDOT rating categories. Figure 4-1, Figure 4-2, and Figure 4-3 show the CQI results of projects classified as good, average, and poor by FDOT, respectively.

In these figures, the CQI results are displayed by three columns representing overall CQI, friction course CQI, and Superpave CQI, respectively. Of course, some projects have layers of embankment, subgrade, or base in their pavement construction. However, most projects are resurfacing projects that only have layers of friction course and Superpave; in addition, the sum of the layer weighting factors of the friction course and Superpave is 0.705. This means the combined CQIs of the friction course and Superpave represent an overall CQI for resurfacing projects and 70% of the CQI for reconstruction projects.

As seen in Figure 4-1, Figure 4-2, and Figure 4-3, some projects' CQIs are affected severely by one layer's extremely low CQI. For most of these cases, that's because one particular parameter's CQI is very low. For example, when all other parameters' CQIs are marked normally, ranging from 0.7 to 1.0, one parameter's CQI was 0.05. When this low parameter CQI is included in a project, the CQI for the project usually marks much lower than expected and may not represent the project's performance.

In Figure 4-1, CQIs of 32 projects from every district are arranged in the order of CQI score. Projects with lower CQI among this group show a tendency to have an extremely low layer CQI of either friction course or Superpave rather than having layer CQIs of both friction course and Superpave in the normal range. The number of projects whose CQI is greater than 0.9 is 15 out of 33, while the number of projects whose CQI is less than 0.8 is four.

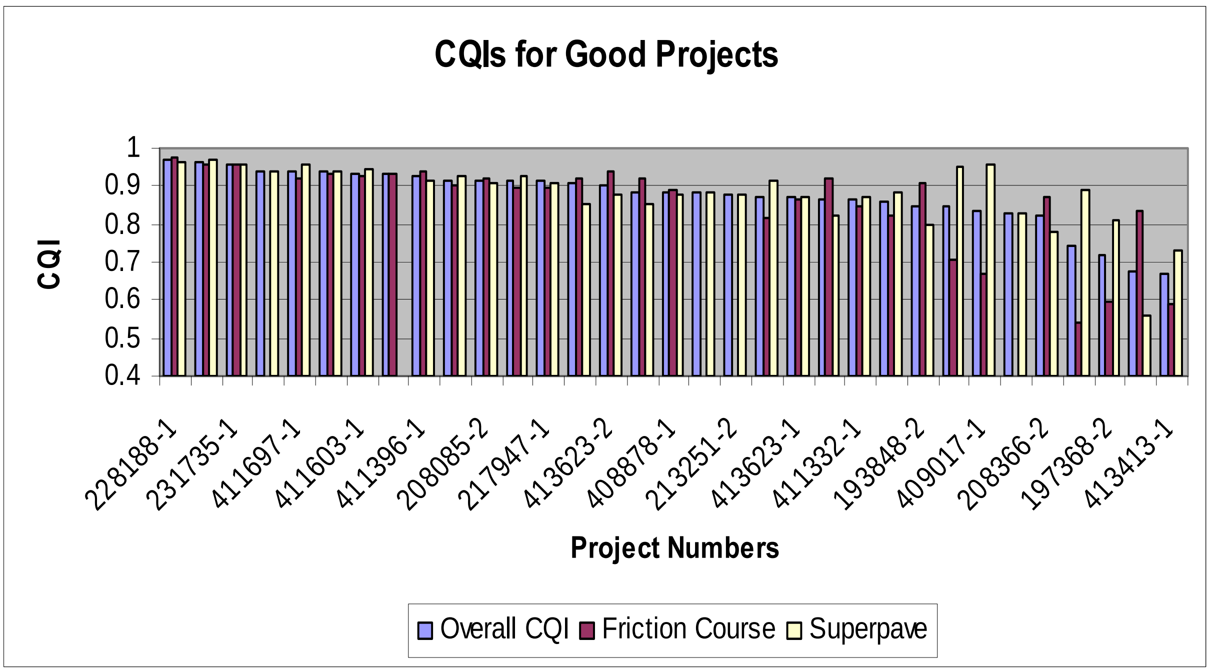


Figure 4-1. Distribution of CQIs for good projects

In Figure 4-2, 28 projects from every district are arranged in the order of CQI score. Projects with lower CQI among this group showed the same tendency as the group of good projects, having an extremely low layer CQI of either friction course or Superpave. Upon close investigation, it was revealed that four projects out of last six projects had extremely low ride number (roughness) CQIs. The number of projects whose CQI is greater than 0.9 is five out of 28, while the number of projects whose CQI is less than 0.8 is six.

Figure 4-3 shows CQIs of 12 projects arranged in the order of CQI score. Unlike the good

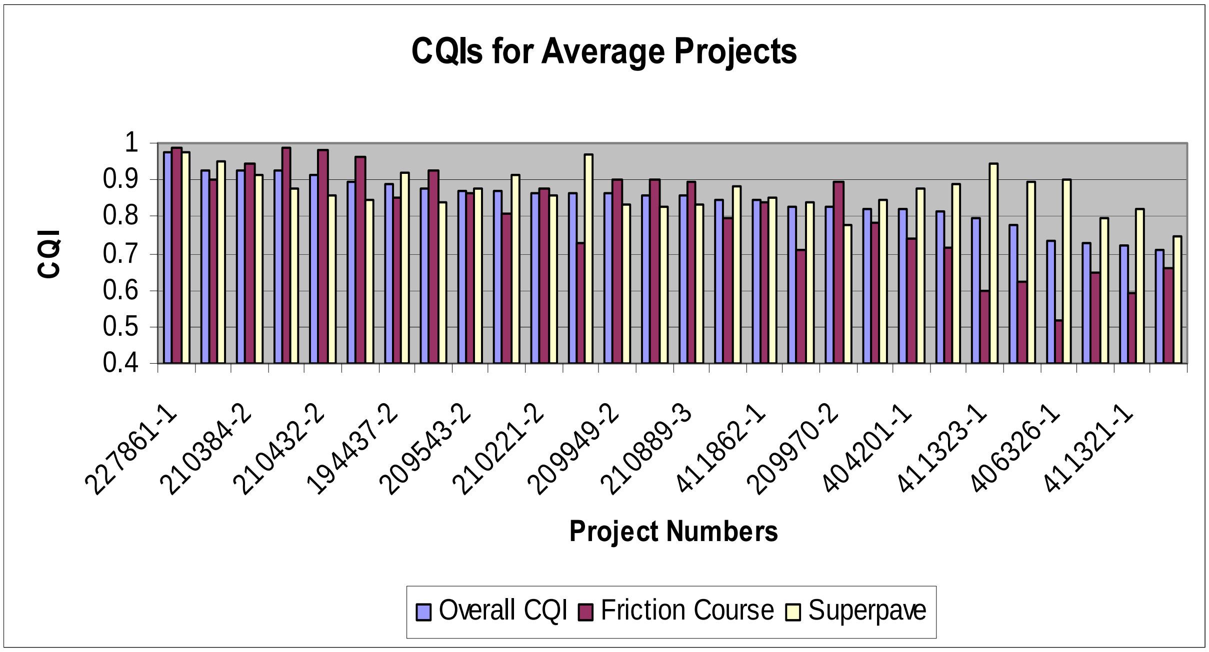


Figure 4-2. Distribution of CQIs for average projects

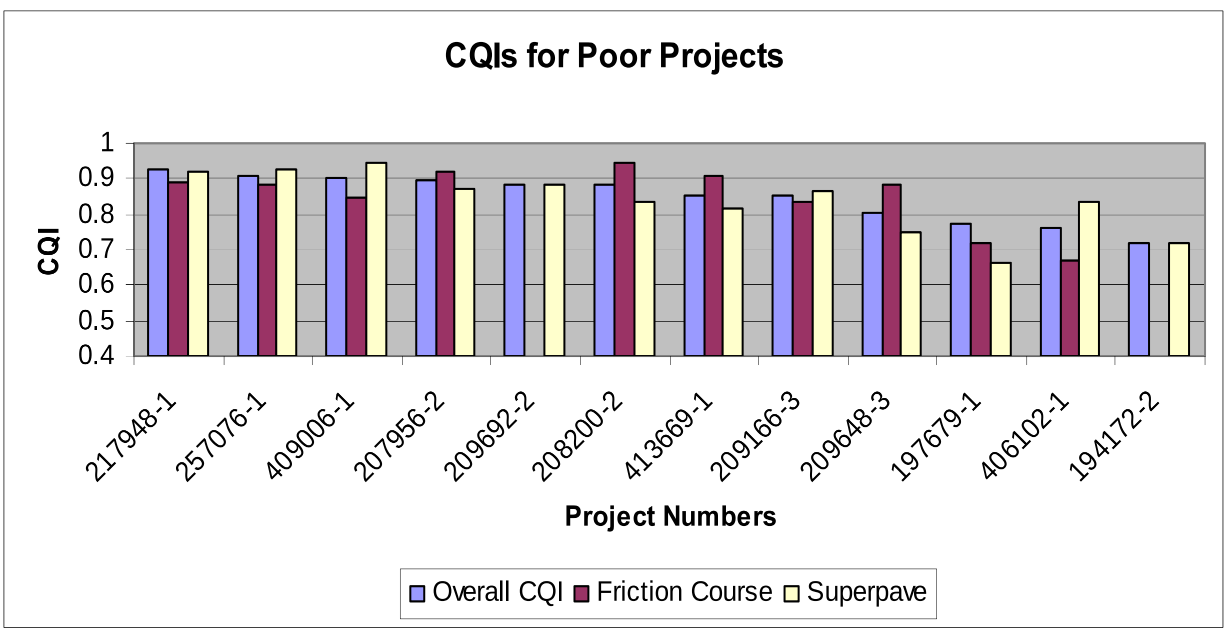


Figure 4-3. Distribution of CQIs for poor projects

and average groups, projects with lower CQI among this group have low layer CQIs of both friction course and Superpave. That means low CQIs of the projects are not caused by a particular parameter performance but, rather, by each parameter's unsatisfactory performance. The number of projects whose CQI is greater than 0.9 is three out of 12, while the number of projects whose CQI is less than 0.8 is three.

Table 4-4 shows mean value, number of projects whose CQI is greater than 0.9, and number of projects whose CQI is less than 0.8. Good-rated projects have a higher mean value and a higher number of projects whose CQI is greater than 0.9 than the other two groups; however, the average group and the poor group show almost the same results. The mean CQI has a difference of 0.003, and the proportion of number of projects whose CQI is greater than 0.9 or less than 0.8 is very close.

Table 4-4. Summary of the CQI projects by FDOT ratings

	FDOT Raring		
	Good	Average	Poor
Mean CQI	0.874	0.844	0.847
Number of total projects	33	28	12
Number of projects (CQI>0.9)	15	5	3
Number of projects (CQI<0.8)	4	6	3

One possible reason is, first, the FDOT rating from one personnel member cannot be the same as another member's rating. For example, Districts 4 and 6 personnel rated their levels of satisfaction as good, fair, and average, while most other districts classified projects as good, average, and poor. In this case, it is doubtful that the average in Districts 4 and 6 have the same meaning (or quality) as the other district's average; therefore, in order to remove the ambiguity, comparison of only the good and poor groups might be a reasonable approach.

Figure 4-4 shows CQIs of good projects and poor projects. Even though there are several projects with very low CQI in the good project group, generally CQIs of good projects are higher than the poor group.

Even though not all FDOT-rated “good” projects have a higher CQI than any FDOT-rated “poor” projects, as seen in Table 4-4 and Figure 4-4, good projects had a better mean CQI value than poor projects.

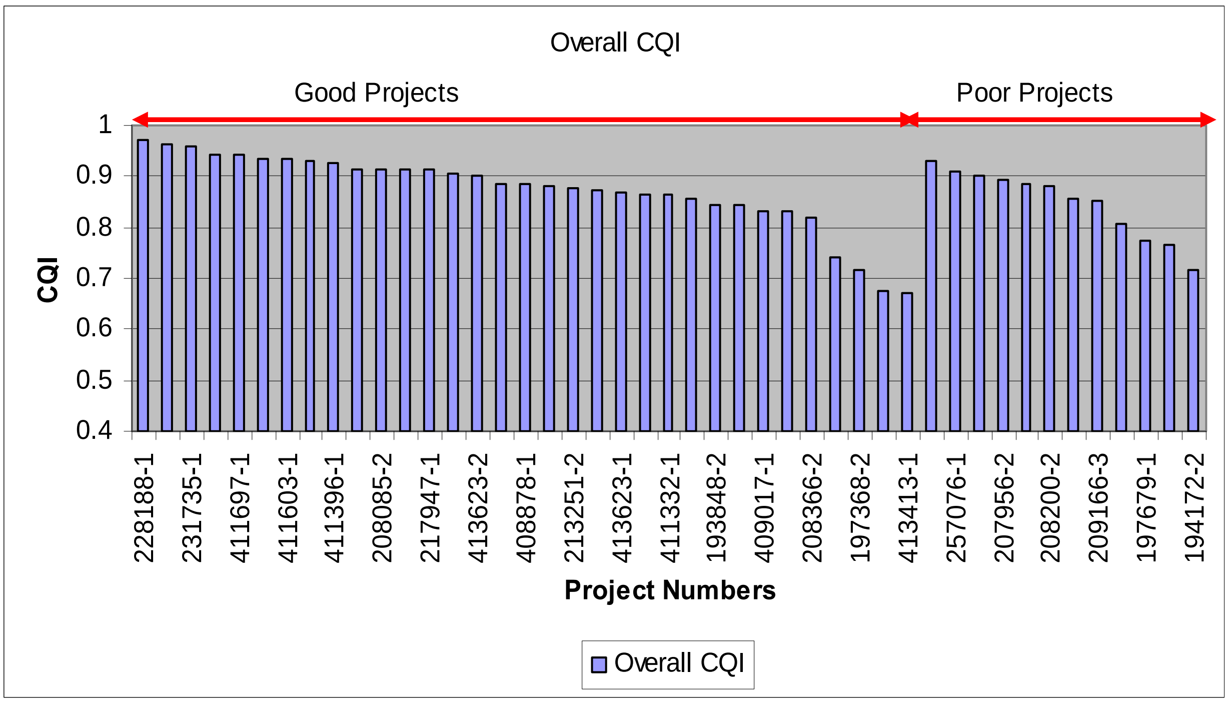


Figure 4-4. Overall CQIs of good and poor projects

4.3.1.3 The CQI model validation by district

As mentioned in the previous chapter, FDOT ratings were done by different persons in different districts; thus, they may not be consistent. In this chapter, then, CQI comparison by district is discussed. Table 4-5 shows the comparison of CQI means by district. Districts 4 and 6 and District 5 did not have poor projects to analyze; in fact, Districts 4 and 6 did not have a "poor" category at all. District 5 had one project classified as "poor" in the list they provided, but the poor project was excluded from the analysis because of a lack of data.

Except for Districts 1 and 7 and District 3, good project groups of other districts have higher mean values of CQI than poor project groups. In Districts 1 and 7 and District 3, the means of the poor projects are higher than those of the good projects. However, it should be noted that because the project rating groups are divided by six districts, the number of samples of each category are limited. In particular, the number of poor projects by districts is very small because total number of poor projects to be analyzed was originally only 12. Districts 1 and 7 had three poor projects. Even though two of them had low CQI, the average CQI was much higher because the other project had the second highest CQI in the district.

Table 4-5. Mean value of the CQI projects by districts

	District					
FDOT Rating	1 & 7	2	3	4 & 6	5	Turn Pike
Good	0.783	0.887	0.891	0.925	0.900	0.880
Average	0.815	0.854	0.825	0.856	0.894	
Poor	0.799	0.863	0.916			0.809

4.3.2 Integrated Construction Quality Index (ICQI) Model

ICQI models for only friction course and Superpave layers were developed in this research. The number of projects that had embankment, subgrade, and base layers were too small to develop a model. In the development of the CQI model, actual test data was not required because the CQI model obtained its weighting factors from AHP without test data. However, not having a high enough number of projects that include construction of embankment, subgrade, and base layers is a problem because actual test data is required in developing ICQI.

4.3.2.1 Validation process

A total of 1,334 data sets were used to develop a regression model for the ICQI. Among those data sets, 487 were used for friction course and 847 for Superpave. The data sets were derived from LIMS and the MEPDG output report after running the program. From the data sets, all six construction quality characteristics used in the MEPDG program and 15 combinations of two characteristics, a total of 21 factors, were chosen for the regression analysis at the first stage. Combinations of two characteristics whose format is multiplication of the two characteristics were selected to consider interactions between characteristics; however, a factor (3/4 inch sieve passing rate) was removed from the first regression equation because most of the values were either 100 or very close to 100.

The regression analysis disclosed quite interesting results comparing the CQI model. Air void ratio, which is the most important factor in the CQI model for friction course 9.5 and 12.5 as seen in Table 3-1, is also the most affecting factor in the ICQI model for both friction course and Superpave. Some construction quality characteristics such as ride number, #8 sieve passing rate, and density were not used as factors of the ICQI model. Among the unused construction quality characteristics as inputs of the MEPDG, the ride number, representing roughness, was rather used as one of the performance indicators of the ICQI model.

The #200 sieve passing rate, which is the least important factor in the CQI model for friction course 9.5 and 12.5 as seen in Table 3-1, is the second most affecting factor, next to air void ratio, in the ICQI model for both friction course and Superpave.

Friction course regression model: The results of the regression analysis revealed that at the 95% confidence level, ten of the 21 factors were statistically significant.

Tables 4-6 and 4-7 show the regression and the ANOVA statistics for the final equation. From Table 4-6, it is interesting to note that asphalt content, itself, is not a significant factor, while some combination factors including the asphalt content factor have a significant relationship with the ICQI. When the regression analysis was executed without consideration of correlations between the factors, asphalt content was the significant factor.

In Table 4-7, the P-value indicates that the regression as a whole is very significant for a significance level of less than 1%. The coefficient of determination, R^2, indicates that over 80% of the variation in the variables is explained by the regression model, shown in Equation 10.

Table 4-6. Regression on friction course ICQI

Variables	Coefficients	Standard Error Coefficients	t-ratio	P-value
Constant	1.12	0.12	9.41	0.000
3/8 in. passing rate	0.00828	0.0010	7.99	0.000
No. 4 passing rate	0.00882	0.0019	4.61	0.000
No. 200 passing rate	-0.0527	0.0175	-3.01	0.003
Air void ratio	-0.226	0.0270	-8.38	0.000
3/8 * No.4	-0.000049	0.000013	-3.81	0.000
3/8 * No.200	0.00151	0.00018	8.22	0.000
3/8 * Asphalt content	-0.00190	0.00014	-13.25	0.000
No. 4 * Air void	-0.00107	0.00041	-2.6	0.010
No. 200 * Air void	-0.0173	0.0028	-6.13	0.000
Asphalt content * Air void	0.0425	0.0030	14.03	0.000

Table 4-7. ANOVA statistics for regression on friction course ICQI

Source	Degree of Freedom	Sum of Squares	Mean Square	F	P
Regression	10	3.04338	0.30434	250.71	0.000
Residual Error	476	0.57783	0.00121		
Total	486	3.62121			
R^2	84.0 %				

$$ICQI_{FC} = 1.12 + 0.00828\ 3/8in + 0.00882\ No.4 - 0.0527\ No.200 - 0.226\ AV - 0.000049\ 3/8{*}No.4 + 0.00151\ 3/8{*}No.200 - 0.00190\ 3/8{*}AC - 0.00107\ No.4{*}AV - 0.0173\ No.200{*}AV + 0.0425\ AC{*}AV \qquad \text{(Equation 10)}$$

In the above equation 10, $ICQI_{FC}$ is ICQI at friction course layers.

Superpave regression model: The results for the regression analysis revealed that at the 95% confidence level, eight of the 21 factors were statistically significant in the Superpave layer regression analysis.

Tables 4-8 and 4-9 show the regression and the ANOVA statistics for the final equation. From Table 4-8, even though the 3/8 inch sieve passing rate itself is not the significant factor, some combination of factors, including the 3/8 inch sieve passing rate, have a significant relationship with the ICQI.

Table 4-8. Regression on Superpave ICQI

Variables	Coefficients	Standard Error Coefficients	t-ratio	P-value
Constant	2.09	0.12	18.07	0.000
No. 4 passing rate	0.0172	0.0046	3.78	0.000
No. 200 passing rate	-0.236	0.0625	-3.77	0.000
Asphalt content	-0.150	0.0146	-10.28	0.003
Air void ratio	-0.254	0.0281	-9.02	0.000
3/8 * No.4	-0.00020	0.000049	-4.05	0.000
3/8 * No.200	0.00345	0.00070	4.88	0.000
No. 200 * Air void	-0.0188	0.0036	-5.21	0.000
Asphalt content * Air void	0.0367	0.0038	9.57	0.000

In Table 4-9, the P-value indicates that the regression as a whole is very significant for a significance level of less than 1%. The coefficient of determination, R^2, indicates that over 70% of the variation in the variables is explained by the regression model, shown in Equation 11.

$$ICQI_{SP} = 2.09 + 0.0172\ No.4 - 0.236\ No.200 - 0.150\ AC - 0.254\ AV - 0.000200\ 3/8*No.\ 4 + 0.00345\ 3/8*No.200 - 0.0188\ No.200*AV + 0.0367\ AC*AV \qquad \text{(Equation 11)}$$

In the equation 11, $ICQI_{SP}$ is ICQI at Superpave layers.

Table 4-9. ANOVA statistics for regression on Superpave ICQI

Source	Degree of Freedom	Sum of Squares	Mean Square	F	P
Regression	8	9.9702	1.2463	275.29	0.000
Residual Error	838	3.7938	0.0045		
Total	846	13.7639			
R^2	72.4 %				

4.3.2.2 The ICQI model validation by district

When developing the ICQI regression model for the friction course and Superpave layer, the project list was divided into two parts. One part was composed of projects from Districts 1 and 7, District 2, and District 3 and was used to develop the ICQI regression model, and another part included Districts 4 and 6, District 5, and the Turnpike district and was used to analyze and validate the regression model.

Table 4-10 shows the results of the analysis of projects in Districts 4 and 6, District 5, and the Turnpike district. As mentioned earlier, it is unreasonable to expect that all FDOT construction and materials personnel from different districts would have the same rating standard. In other words, “fair” projects in one district might be “good” projects in another district. For example, Districts 4 and 6 personnel originally rated 17 projects as “excellent,” “good,” “fair,” and “average” when they were asked to provide the project list with three-level ratings. In this research, “excellent” and “good” are classified as “good.” “Fair” and “average” are categorized as “average.”

For this reason, comparison of ICQI model performance within the same group should be a rational method of analysis. In Table 4-10, projects rated by the same FDOT personnel are grouped together. ICQI does not have a wide range, so it is hard to tell whether the model performs correctly as expected. The highest ICQI was 1.041 from project number 41551215201 in District 5, and the lowest ICQI was 0.9835 from project number 41551315201 also in District 5. Therefore, the maximum ICQI difference possible from Table 4-10 is 0.0575. In order to compare these projects easily, Table 4-11 shows the mean values for each category.

Table 4-10. Performance of the ICQI model

District	Project Number	Overall ICQI	FDOT Rating
4	228188-1	1.0157	Good
4	228615-1	1.0307	Good
4	231735-1	1.0055	Good
4	231737-1	1.0305	Good
4	403619-1	1.0015	Good
4	411322-1	0.9839	Good
6	250548-2	1.0210	Good
4	228110-1	1.0221	Average
4	411321-1	1.0255	Average
4	411323-1	0.9894	Average
4	231726-1	0.9989	Average
5	411603-1	1.0020	Good
5	415512-1	1.0410	Good
5	415526-1	0.9993	Good
5	413585-1	1.0264	Average
5	415513-1	0.9835	Average
TPK	411532-1	1.0181	Good
TPK	413623-1	1.0064	Good
TPK	413623-2	1.0198	Good
TPK	406092-1	1.0144	Good
TPK	411533-1	1.0157	Good
TPK	413669-1	0.9847	Poor

Table 4-11 shows that the model has rendered ICQI values that are in line with the considered opinion of the owner regarding the quality of the project even though differences of

ICQI values between rating categories range only from 0.004 to 0.0302. However, considering the ICQI ranges are narrow, having the correct order by the FDOT ratings shows that there is a tendency for better rated projects by FDOT to produce higher ICQI. The most important result is that no mean value of ICQI for projects rated “good” by FDOT construction and materials personnel was lower than any other ICQI mean values for projects rated “average” or “poor.” The same relationship can be seen between “average” and “poor.”

Table 4-11. Mean value of the ICQI projects by districts

FDOT Rating	District 4 & 6	District 5	Turnpike
Good	1.0127	1.0141	1.0149
Average	1.0087	1.0050	
Poor			0.9847

In order to determine if there is a significant difference between “good” projects and “average” projects from District 4 and 6 and District 5, t-tests were executed. The t-test results showed that there is a significant difference at the 74% level of confidence between the ICQI mean of “good” projects and “average” projects from District 4 and 6. Also, there is a significant difference at the 72% level of confidence between the ICQI mean of “good” projects and “average” projects from District 5. Because the number of projects rated “poor” in the Turnpike district is only 1, t-test for the Turnpike district could not be executed.

When all the “good” projects from District 4 and 6, District 5, and the Turnpike district and “average” projects from District 4 and 6 and District 5 are combined for t-test, the results showed that there is a significant difference at the 44% level of confidence between the ICQI mean of the “good” projects and “average” projects. This 44% level of confidence for combined districts’ t-test results is much lower than 74% and 72% level of confidence for each district’s t-test results.

Because the FDOT rating is either not tangible or does not have concrete guidance, it might be a better idea to have just two rating categories. Even though the number of projects analyzed is insufficient, the Turnpike shows the largest difference of mean ICQI between the "good" and "poor" categories.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

A practical and effective pavement CQI/ICQI has been developed that only uses the most objective data and test results. The CQI formulation employed the PWL concept that is already used by FDOT and familiar to the pavement contractor. The ICQI formulation used the MEPDG program to develop the ICQI model based on regression analysis. Both the CQI and ICQI used data from the LIMS, which serves as the department's enterprise database system for all construction quality data.

The CQI/ICQI applies material and structural characteristics. The CQI uses pavement smoothness characteristics as input, whereas the ICQI recognizes pavement smoothness characteristics as a future performance indicator in terms of distress.

The CQI is applicable for both new and rehabilitation projects; however, the ICQI is only developed for rehabilitation because of the limited number of projects that have stored test data into LIMS.

Because a pavement system consists of a series of multiple layers, the CQI/ICQI formulation is based upon the modular approach, allowing a summation of the CQI/ICQI of each individual layer multiplied by a weighting factor. The CQI of each layer is similarly determined by adding the products of the PWL of each AQC multiplied by a matching weighting factor. However in the layer level, ICQI is determined by a regression model that uses construction quality characteristics in MEPDG as dependant variables.

Weighting factors were calculated from information gathered from expert panel surveys, which was prepared by rules of AHP. These were applied to both the CQI and ICQI models.

The CQI/ICQI model showed positive results with the limited data procured through the LIMS database. FDOT was asked to provide 105 projects to the research team along with an associated "rating" for each project. The projects submitted by FDOT were to be ones that had data entered into the LIMS database.

For the projects that met the criteria for inclusion, the CQI model showed positive results, rendering higher CQI for projects rated "good" by FDOT. The result was clearer when the projects were put into two categories; good and poor. Because the rating by FDOT is a criterion of the model, having a consistent and precise rating is essential for successful application of the CQI model.

There is a tendency for better-rated projects by FDOT to produce a higher ICQI. No mean value of ICQI for projects rated "good" by FDOT construction and materials personnel was lower than any other ICQI mean values for projects rated "average" or "poor." The same relationship can be seen between "average" and "poor."

5.2 Recommendations

The research team found that a great deal of data had either not been entered into LIMS or had been entered into 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 in which no asphalt data were found under some asphalt design mix numbers that had been listed for the project.

The ultimate goal is to have the data available to the model so that the model can obtain it directly and automatically calculate the CQI/ICQI. Obviously, the kinds of database problems experienced by the research team on this project will doom these plans to failure. It is the observation of the research team that problems of this sort are not limited to Florida. In fact, Florida is far ahead of many states in its ability to store accurate construction data electronically.

It is therefore recommended that all states upgrade their electronic construction testing results database if using something such as CQI is of interest.

In addition, further research should be conducted on this model. Because there was no actual performance data for the projects, the FDOT rating was the only applicable measure for project performance. This research used the most objective data (test data) excluding all other aspects of contractor performance (e.g., financial resources, ownership of equipment or ability to lease equipment, adherence to schedule, job safety, past performance). Even though the CQI/ICQI model was developed based on the objective data, the final decision regarding whether the model performs properly was determined by the FDOT rating, which is subjective. Therefore, it is recommended that the CQI/ICQI results be compared with performance data.

APPENDIX A:
FDOT PAVEMENT ACCEPTANCE QUALITY CHARACTERISTICS

Table A-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 A-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 A-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

APPENDIX B
PROJECT LIST

District	Project Number	Construction Type	FDOT Rating	Max. Possible Layers	No. Layers of Data	No. of Samples	Location
1	404201-1-52-01	Resurfacing	Average	2	2	61	SR 31 from Charlotte C/L to north of Se Apache Dr.
1	193848-2-52-01	Resurfacing	Good	2	2	133	SR 70 from east of SR 31 to Highlands C/L
1	194437-2-52-01	Resurfacing	Average	2	2	62	SR 70 from east of US 27 to Harney Pond Canal
1	201015-2-52-01	Resurfacing	Good	2	2	23	I-275 (SR 93) from east of Gillette Rd to Tera Ceia River
1	194100-2-52-01	Resurfacing	Good	2	1	36	US 17 (SR 35) from north od Desoto C/L to south of 3rd Ave.
1	194172-2-52-01	Resurfacing	Poor	2	1	48	SR 29 from Collier Co/L to south of Keri Rd.
1	195736-1-52-01	Add Lanes & Rehabilitation	Poor	5	2	11	US 41 from Collier Co/L to north of Bonita Beach Rd.
1	197308-2-52-01	Resurfacing	Average	2	2	31	SR 60 from Rattlesnake Rd to Stembridge Rd.
1	197291-2-52-01	Resurfacing	Good	2	2	37	SR 60 from west of CR 17B to west of Capps Rd.
1	197388-2-52-01	Resurfacing	Average	2	2	38	SR 60 from west of Stembridge Rd to west of Nalcrest Creek
1	197309-2-52-01	Resurfacing	Average	2	2	55	SR 60 from Nalcrest Creek to east of Tiger Lake
1	197679-1-52-01	Add Lanes & Reconstruction	Poor	5	5	244	US 27 from SR 544 to Blue Heron Bay Blvd.
1	403890-1-52-01	Add Lanes & Rehabilitation	Poor	5	No Data		US 27 from Blue Heron Bay Blvd. to 0.5 mile north of CR 547
1	197368-2-52-01	Resurfacing	Good	2	2	118	US 27 (SR 25) from north Alturis/Babson Pk to SR 60
1	411862-1-52-01	Resurfacing	Average	2	2	183	I-75 from Lee C/L to US 17
1	196960-3-52-01	Resurfacing	Good	2	2	15	US 98 from north of Illinois Ave to south of A-z Park Rd.
1	196960-2-52-01	Resurfacing	Good	2	2	15	US 98 from Banana Creek Bridge to south of SR 540
1	197007-2-52-01	Resurfacing	Good	2	2	30	US 17 from south of Br #160207/219 to Sand Mountain Rd.
7	411332-1-52-01	Resurfacing	Good	2	2	75	SR 597 from Fletcher Ave west to Van Dyke Rd.
7	411266-1-52-01	Resurfacing	Good	2	2	61	SR 60 from Hills Mem Garden Ctr to Bryan Rd.
7	406560-1-52-01	Resurfacing	Good	2	2	47	SR 6 from 50th St. to west of US 301
7	257076-1-52-01	Resurfacing	Poor	2	2	35	SR 693 from Park St to Tyrone Blvd.
7	411277-1-52-01	Resurfacing	Average	2	2	44	US 301 from Hollomans Branch to Hills/pasco Co/L.
7	408913-1-52-01	Resurfacing	Average	2	2	31	US 301 from Old Harney Rd to Hollomans Branch Brdg.
7	413413-1-52-01	Resurfacing	Good	2	2	55	I-275 from north of 4th St to Hwd Frankland Bridge

District	Project Number	Construction Type	FDOT Rating	Max. Possible Layers	No. Layers of Data	No. of Samples	Location
2	207545-2-52-01	Resurfacing	Average	2	2	36	SR 222 from East of I-75 to west of 43rd St.
2	208085-2-52-01	Resurfacing	Good	2	2	38	SR 15 from SR 16 to Governors Creek
2	208363-1-52-01	Add Lanes & Reconstruction	Average	5	2	232	SR 47 from I-75 to US 41
2	208366-2-52-01	Resurfacing	Good	2	2	40	SR 10 from LCCC entrance to Baker C/L
2	209301-1-52-01	New Road Construction	Average	5	5	150	SR 9A from Beach Blvd to north of Jtb Blvd.
2	209543-2-52-01	Resurfacing	Average	2	2	84	SR 212 from Parental Home Rd to St. Johns Bluff Rd.
2	209648-3-52-01	Miscellaneous Construction	Poor	2	2	38	SR 228 from Mcduff Ave to SR 211
2	209949-2-52-01	Resurfacing	Average	2	2	42	SR 15 from St. Johns River to SR 100
2	209970-2-52-01	Resurfacing	Average	2	2	165	SR 15 from CR 209 to Clay C/L
2	210221-2-52-01	Resurfacing	Average	2	2	69	SR 16 from CR 13 to CR 16A
2	210273-2-52-01	Resurfacing	Average	2	2	98	SR 5 from Flagler C/L to SR 206
2	210374-2-52-01	Resurfacing	Good	2	2	13	SR 500 from SR 24 to end of C & G
2	210384-2-52-01	Widening/Resurfacing	Average	2	2	114	SR 24 from CR 345 to US 19
2	210432-2-52-01	Resurfacing	Average	2	2	70	SR 45 from Marion C/L to US 27 in Williston
2	210889-3-52-01	Resurfacing	Average	2	2	204	SR 55 from 7.8 north of C/L to Fenholloway River
2	210949-2-52-01	Resurfacing	Good	2	2	25	SR 16 from SR 121 to Bradford C/L
2	213520-2-52-01	Resurfacing	Average	2	2	150	I-10 from US 129 to Columbia C/L
2	207947-2-52-01	Resurfacing	Good	2	2	55	SR 21 from Clay C/L to Clay C/L
2	207956-2-52-01	Resurfacing	Poor	2	2	78	SR 100
2	207956-3-52-01	No Data					
2	208200-2-52-01	Resurfacing	Poor	2	2	129	SR 16
2	208226-4-52-01	Resurfacing	Good	2	0		SR 21 from Putnam C/L to SR 100
2	209166-3-52-01	Resurfacing	Poor	2	2	42	SR 152
2	209692-2-52-01	Resurfacing	Poor	2	2	82	SR 134
2	209999-1-52-01	Add Lanes & Reconstruction	Poor	5	2	104	SR 20 from Rowland Ave to Francis/Radcliff Rd
2	210004-1-52-01	No Data					
2	210253-1-52-01	Add Lanes & Reconstruction	Poor	5	1	34	SR 207 from CR 305 to west of I-95
2	213251-2-52-01	Resurfacing	Good	2	1	98	I-295 from I-95 to Buckman Bridge

District	Project Number	Construction Type	FDOT Rating	Max. Possible Layers	No. Layers of Data	No. of Samples	Location
3	217947-1-52-01	Add Lanes & Reconstruction	Good	5	4	123	Sr 77 from north Bay to CR 2300
3	217948-1-52-01	Add Lanes & Reconstruction	Poor	5	5	184	Sr 77 from CR 2300 to Mill Creek Bridge
3	409022-1-52-01	Resurfacing	Average	2	2	22	SR 10 from Sinclair St to end 4L east of FDOT
3	413426-1-52-01	Resurfacing	Good	2	1	27	SR 2 from Ten Mile Creek Br to Jackson C/L
3	411389-1-52-01	Resurfacing	Average	2	2	50	SR 75 from south of SR 8 to south of SR 10
3	408878-1-52-01	Resurfacing	Good	2	2	194	I-10 from west of Yellow River to east of Shoal River
3	409017-1-52-01	Resurfacing	Good	2	2	45	SR 10 from west of Yellow River Br to east of Coleman St.
3	411391-1-52-01	Resurfacing	Good	2	2	16	SR 85 from end 3 Lane Crestview to CR 85A Bill Lundy Rd.
3	411395-1-52-01	Resurfacing	Good	2	2	9	SR 173 from CR 292A Gulf Beach Hwy to end 41 north of SR 292
3	218539-1-52-01	Add Lanes & Reconstruction	Poor	5	4	74	SR 291 from SR 742 burgesss Rd to SR 8
3	409006-1-52-01	Resurfacing	Poor	2	2	136	SR 87 from Clear Creek Bridge to north of SR 4
3	403930-1-52-01	Resurfacing	Good	2	2	163	SR 65 from SR 30 to Liberty C/L
3	411697-1-52-01	Resurfacing	Good	2	2	35	SR 10 from east end Ochlockonee Br to SR 263 Capital Circle
3	406326-1-52-01	Resurfacing	Average	2	2	75	SR 63 from gadsden C/L to SR 8
3	411396-1-52-01	Resurfacing	Good	2	2	52	SR 63 from north of SR 159 to Geirgia State Line
3	411397-1-52-01	Resurfacing	Average	2	2	36	SR 2 from east of SR 75 to west of Spring Creek Br.
3	413442-1-52-01	Resurfacing	Average	2	2	24	SR 10 from end 4L Grand Ridge to Begin 4 Lane at Sneads

District	Project Number	Construction Type	FDOT Rating	Max. Possible Layers	No. Layers of Data	No. of Samples	Location
4	411321-1-52-01	Resurfacing	Fair	2	2	220	I-75 from Dade/Brow C/L to north of Sheridan St.
4	411322-1-52-02	Resurfacing	Good	2	1	96	I-75 from north of Sheridan St. to Sawgrass Expwy
4	231726-1-52-01	Resurfacing	Average	2	2	73	I-595 from 136th Ave to west of Pine Island Rd.
4	231735-1-52-02	Resurfacing	Good	2	2	63	I-95 from north end Powerline Rd Bridge to south end Mcnab Rd Bridge
4	415397-1-52-01	Resurfacing	No rating				
4	231737-1-52-01	Resurfacing	Good	2	2	94	I-95 from Sample Rd to Palm Beach C/L
4	411323-1-52-01	Resurfacing	Fair	2	2	62	I-595 from west of Pine Island Rd to Davie Rd.
4	227861-1-52-01	Resurfacing	Fair	2	2	35	SR 842 from University Dr to east Acre Dr.
4	228110-1-52-01	Resurfacing	Fair	2	2	70	SR 845 from SR 814 to south of SR 834
4	228188-1-52-01	Resurfacing	Excellent	2	2	31	SR 7 from NW 3rd St to south of 29th St.
4	228615-1-52-01	Resurfacing	Good	2	1	55	SR 5 from north of CR 510 to Harrison St.
4	413801-1-52-01	Resurfacing	No rating				
4	411441-1-52-01	Resurfacing	Good	2	2	22	SR 68 from 32nd St to 13th St.
4	228135-1-52-01	Intersection	Good	2			SR 7 from Barry Rd to Royal Palm Blvd.
4	403605-1-52-01	Resurfacing	Good	2	2	18	SR 804 from west of Old Boynton Rd to west of SR 5
4	403619-1-52-01	Resurfacing	Good	2	2	57	SR 710 from Mp 11.8 to west of Northlake Blvd.
6	250548-2-52-01	Reconstruction	Good	2	2	40	SR A1A from Bertha St to SR 5

District	Project Number	Construction Type	FDOT Rating	Max. Possible Layers	No. Layers of Data	No. of Samples	Location
5	415513-1-52-01	Resurfacing	Average	2	2	66	SR 50 from 0.156 mile west of SR 520 ramp to 0.027 mile east of St.. Anne
5	419993-1-52-01	No Data					
5	411603-1-52-01	Resurfacing	Good	2	2	108	SR 25 from south of Citizens Blvd to SR 500
5	413585-1-52-01	Resurfacing	Average	2	2	117	SR 500 from 0.28 mile south of Sprint Blvd to 0.104 mile north of Dudley
5	415514-1-52-01	Resurfacing	Average	2	1	16	SR 434 from SR 436 to west of Markham Woods Rd.
5	415512-1-52-01	Resurfacing	Good	2	2	36	SR 434 from SR 50 to 0.208 mile north of Centauras
5	239725-1-52-01	Add Lanes & Reconstruction	Poor	5	2	27	SR 500 from 1500's Osceola Pkwy to Orange Co/L
5	417155-1-52-01	Resurfacing	Good	2	2	24	SR 15A from north of Beresford Ave to souht of Plymouth Ave.
5	415526-1-52-01	Resurfacing	Good	2	2	50	SR 40 from Lake Co/L to 0.099 mile east of US 17
5	413583-1-52-01	Resurfacing	Good	2	1	25	SR 200 from Pc east of I-75 to SR 25

District	Project Number	Construction Type	FDOT Rating	Max. Possible Layers	No. Layers of Data	No. of Samples	Location
TPK	232352-1-52-01	No Data					
TPK	406092-1-52-01	Add Lanes & Reconstruction	Good	5	5	500	Widen Tpk from 1 mile north of Atlantic Ave to Lantana Toll Plaza
TPK	411533-1-52-01	Resurfacing	Good	2	2	178	St. Lucie resurfacing mp 153.6 to 169.3 northbound & southbound
TPK	411532-1-52-01	Resurfacing	Excellent	2	2	203	Osceola resurfacing mp 190.5 to 227.0
TPK	413623-2-52-01	Resurfacing	Excellent	2	2	69	Lake County resurfacing mp 275.7 to 281.8 southbound only
TPK	413623-1-52-01	Resurfacing	Excellent	2	2	170	Lake County resurfacing mp 275.9 to 297.8 northbound only
TPK	413669-1-52-01	Resurfacing	Poor	2	2	131	Seminole Expwy resurfacing mp 0 to 6.9 northbound & southbound
TPK	406102-1-52-01	Interchange	Poor	2	2	104	SR 408/SR 91 Interchage modification. MP 265

APPENDIX C
EXPERT PANEL MEETING FORMS

Table C-1. Survey Form of CQI

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

Table C-1. Continued

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

Table C-2. Survey Form of ICQI

FDOT INTEGRATED CONSTRUCTION QUALITY INDEX
EXPERT PANEL RATING SHEET
FLEXIBLE PAVEMENT

Name: ______________________________

Date: ______________________________

*** Instructions for panel members answering questions in the form below ***
1) Each response only represents your opinion concerning the relative importance of the pair of items on a single line.
2) Fill out all portions of the form for which you feel qualified to have an opinion.
3) Fill out the forms without discussion with your neighbor.

Example: On the first line below, if you think IRI (Roughness) and Cracking (Top-Down) are equally important to the flexible pavement performance, then mark on "0". If you think Cracking (Top-Down) is a stronger indicator than IRI (Roughness), mark on between "1" and "8" on the right side of the line. Marking on right side "8" means that almost only Cracking (Top-Down) of the 2 factors affects to the pavement performance.

Which factor is the stronger indicator of flexible pavement performance?

Factor	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	Factor
IRI (Roughness)																		Cracking (Top-Down)
IRI (Roughness)																		Cracking (Bottom-Up)
IRI (Roughness)																		Rutting
Cracking (Top-Down)																		Cracking (Bottom-Up)
Cracking (Top-Down)																		Rutting
Cracking (Bottom-Up)																		Rutting

APPENDIX D
TABULATION OF RESULTS FROM EXPERT PANEL MEETINGS

Table D-1. Results of the CQI Survey

FDOT CONSTRUCTION QUALITY INDEDX

FLEXIBLE PAVEMENT

Comparison	Construction Industry								FDOT									Academia			Other	GRAND MEAN
- +	1	2	3	4	5	6	7	AVG	8	9	10	11	12	13	14	15	AVG	16	17	AVG	18	
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	1.00								(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)	(1.00)								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	0.00								2	2.00					1.00
Roadway Density vs. Thickness							0	0.00								1	1.00					0.50

Table D-1. Continued

Comparison - / +	1	2	3	4	5	6	7	Construction Industry AVG	8	9	10	11	12	13	14	15	FDOT AVG	16	17	Academia AVG	Other 18	GRAND MEAN
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	0.00								(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	0.00								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	0.00								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	0.00								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	0.00								(1)	(1.00)					(0.50)

Table D-2. Results of the ICQI Survey

FDOT INTEGRATED CONSTRUCTION QUALITY INDEDX FLEXIBLE PAVEMENT														
- +	Expert Panel Members													MEAN
	1	2	3	4	5	6	7	8	9	10	11	12	13	
Flexible Pavement System Distresses														
IRI (Roughness) vs. Cracking (Top-Down)	5	4	8	6	4	5	6	3	8	4	3	6	8	5.38
IRI (Roughness) vs. Cracking (Bottom-Up)	6	2	8	6	0	5	6	3	8	6	(3)	7	8	4.77
IRI (Roughness) vs. Rutting	7	6	8	8	(2)	6	6	5	8	4	7	7	8	6.00
Cracking (Top-Down) vs. Cracking (Bottom-Up)	(2)	(5)	(8)	(3)	(4)	0	(5)	0	0	4	(3)	4	0	(1.69)
Cracking (Top-Down) vs. Rutting	3	(1)	0	0	(4)	2	(6)	2	4	1	5	5	8	1.46
Cracking (Bottom-Up) vs. Rutting	(7)	1	0	6	2	2	(6)	2	4	0	6	0	8	1.38

APPENDIX E
PWL TABLES

Table E-1. PWL Table (n=3-11)

PWL	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

Table E-1. Continued

PWL	n = 3	n = 4	n = 5	n = 6	n = 7	n = 8	n = 9	n = 10 to 11
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

Table E-2. Pwl Table (n=12-∞)

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 F
TARGET VALUE REPORT SAMPLE

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Contractor: Pavex Corporation Address: 18300 N.W. 122nd Avenue, Miami, FL 33016

Phone No.: (305) 828-6659 Fax No.: (305) 828-9464 E-mail:

Submitted By: Ed McCarthy Type Mix: Fine SP-12.5 Recycle Intended Use of Mix: Structural

Design Traffic Level: C Gyrations @ N des: 75

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. Crushed R.A.P.	A0672	Pavex Corporation	Stockpile A0672-1	01 - 25 - 2000
2. S-1-A Stone	41	White Rock Quarries	87-339	01 - 25 - 2000
3. S-1-B Stone	51	White Rock Quarries	87-339	01 - 25 - 2000
4. Screenings	20	White Rock Quarries	87-339	01 - 25 - 2000
5.				
6.				

PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

	Blend	30%	10%	30%	30%			JOB MIX	CONTROL	RESTRICTED
	Number	1	2	3	4	5	6	FORMULA	POINTS	ZONE
	3/4" 19.0mm	100	100	100	100			100	100	
E	1/2" 12.5mm	98	84	100	100			98	90 - 100	
Z	3/8" 9.5mm	95	42	89	100			89	- 90	
I	No. 4 4.75mm	76	5	38	100			65		
S	No. 8 2.36mm	60	4	9	86			47	28 - 58	39.1 - 39.1
	No. 16 1.18mm	53	3	5	55			34		25.6 - 31.6
E	No. 30 600µm	47	3	4	33			26		19.1 - 23.1
V	No. 50 300µm	35	2	3	17			17		
E	No. 100 150µm	18	2	2	6			8		
I	No. 200 75µm	6.4	2.0	2.0	2.5			5.0	2 - 10	
S	G_{SB}	2.554	2.407	2.412	2.508			2.481		

The mix properties of the Job Mix Formula have been conditionally verified, pending successful final verification during production at the assigned plant, the mix design is approved subject to F.D.O.T. specifications.

No. 200 reflects aggregate changes expected during production.

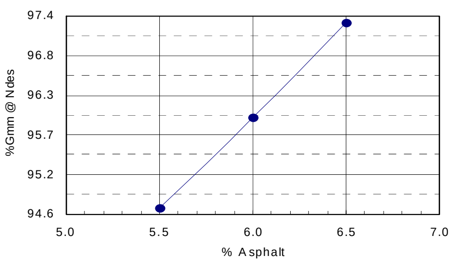
SP 03-2314B (TL-C)

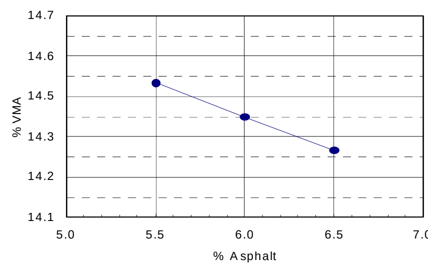
Revised to reflect change in JMF and Optimum Asphalt.

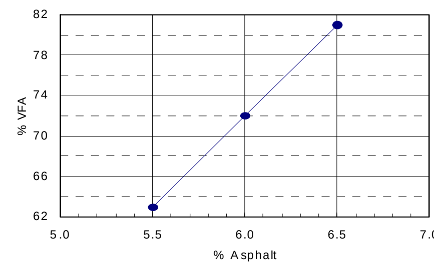
HOT MIX DESIGN DATA SHEET

SP 03-2314B (TL-C)

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
5.5	2.244	2.370	5.3	14.5	63	4.2	1.2	86.8	95.8
6.0	2.259	2.354	4.0	14.4	72	4.7	1.1	88.0	97.1
6.5	2.275	2.338	2.7	14.3	81	5.2	1.0	89.2	98.5







Optimum Asphalt 5.7 % FAA 45 % Mixing Temperature 300 °F 149 °C

Lab. Density 141.0 Lbs/Ft^3 2259 Kg/m^3 %G_{mm} @ N_{des} 96.0 Compaction Temperature 300 °F 149 °C

VMA 14.4 % NCAT Oven -0.10 % Additives Arr-Maz Ad-here LOF 65-00 (D140) Antistrip 0.5 %

Calibration Factor
(+To Be Added)/(-To Be Subtracted)

Optimum Asphalt = 5.7%

Asphalt using 30% Milled Material @ 5.3% = 1.6%

PG 64-22 to be added = 4.1%

LIST OF REFERENCES

Bekheet, W., Helali, K., Halim, A. E., and Springer, J. (2005). "A Comprehensive Approach for the Development of Performance Models for Network Level PMS using LTPP Data," Transportation Research Board 84th Annual Meeting.

Burati, J. L, Weed, R. M., Hughes, C. S. and. Hill, H. S. (2004). *Evaluation of Procedures for Quality Assurance Specifications*, FHWA-HRT-04-046, Federal Highway Administration, McLean, VA.

Buttlar, W. G. and Harrell, M. (1998). "Development of End-Result and Performance-Related Specifications for Asphalt Pavement Construction in Illinois" *Transportation Conference Proceedings*. pp. 195-202.

Chehab, G. R. and Daniel, J. S. (2006). "Evaluating Recycled Asphalt Pavement Mixtures with Mechanistic-Empirical Pavement Design Guide Level 3 Analysis," *Transportation Research Record 1962*, Paper No. 11, pp. 90-100.

FDOT State Material Office. (2003). Flexible Pavement Condition Survey Handbook http://www.dot.state.fl.us/statematerialsoffice/administration/resources/library/publications/researchreports/pavement/2003flexhandbook.pdf

FHWA. (1999). *Guide to Developing Performance Related Specifications for Concrete Pavements*, Volume 1: Practical Field Guide, Final Report, and Appendix A, Publication No. FHWA-RD-98-155, Federal Highway Administration, McLean, VA

Flintsch, G. W., Loulizi, A., Diedenderfer, A. D., Galal, K. A., and Diefenderfer, B. K. (2007). "Asphalt Materials Characterization in Support of Implementation of the Proposed Mechanistic-Empirical Pavement Design Guide," *Virginia Transportation Research Council*.

Hirsch, Jr. E. D., Kett, J. F., and Trefil, J. (2002). *The New Dictionary of Cultural Literacy*, Third Edition. Houghton Mifflin Company.

Hybert, P. (1996). "Five Ways to Improve the Contracting Process." *American Society of Quality*. Quality Progress, Vol. 29-2, pp. 65-70

Isik, Z., Dikmen, I. and Birgonul, M. T. (2007). "Using Analytic Network Process (ANP) for Performance Measurement in Construction," *The Construction and Building Research Conference of the Royal Institution of Chartered Surveyors*, Georgia Tech, Atlanta, USA, 6-7 September 2007.

Killingsworth, B. M. (2004). "Quality Characteristics and Test Methods for Use in Performance-Related Specifications of Hot Mix Asphalt Pavements" *NCHRP Project 9-15*.

MacAuley, P., Cosslett, P. D., and Randolph, Jr. J.N. (1993). “Construction – Industry Overview” *US Industrial Outlook*. US Department of Commerce's International Trade Administration.

McCaffrey, J. (2005). “Test Run: The Analytic Hierarchy Process,” *MSDN Magazine*.

Minchin, R.E. and Smith, G.R. (2001). “Quality-based Performance Rating of Contractors for Prequalification and Bidding Purposes,” *Final Report for NCHRP Project 10-54*, Published as NCHRP Web Document 38, Washington, DC.

Monismith, C. L., Popescu, L., and Harvey, J. (2004). “Performance-Based Pay Factors for Asphalt Concrete Construction; Comparison with a Curruntly Used Experienced-Based Approach” *Journal of Association of Asphalt Paving Technologists*. Volume 73. pp. 147-194.

Noureldin, A. S. (1997). “Quantifying the Effects of Pavement Performance Characteristics Using Partial Derivatives,” *Transportation Research Record 1575*. Paper No. 970142. pp. 75-84.

Rawlings, J. O., Pantula, S. G., and Dickey, D. A. (1998). *Applied Regression Analysis*, Second Edition, Springer Texts in Statistics.

Saaty, T. L. (1980). *The Analytic Hierarchy Process*, New York, NY, McGraw Hill.

Saaty, T. L. (1996). *Decision Making with Dependence and Feedback: The Analytic Network Process*, RWS Publications, 4922 Ellsworth Avenue, Pittsburgh, PA. 15213.

Saaty, T. L. (1999). “Fundamentals of the Analytic Network Process,” *International Symposium on the Analytic Hierarchy Process (ISAHP)*, Kobe, Japan, August 12-14, 1999.

Saaty, T. L. and Vargas, L. G. (2006). *Decision Making with the Analytic Network Process - Economic, Political, Social and Technological Applications with Benefits, Opportunities, Costs and Risks,* 1st Edition, ISBN: 978-0-387-33859-0, Springer.

Smith, R. L., R. J. Bush, and D.L. Schmoldt. (1995). “A Hierarchial Model and Analysis of Factors Affecting the Adoption of Timber as a Bridge Material,” *Wood and Fiber Science*, 27(3), pp. 225-238.

Smith, J. T. and S. L. Tighe (2006). “The Analytical Hierarchy Process as a Tool for Infrastructure Management,” presented at the 85th Annual Meeting*, Transportation Research Board*, Washington, DC.

VonQuintus, H. L. and Moulthrop, J. S. (2007). “Mechanistic-Empirical Pavement Design Guide Flexible Pavement Performance Prediction Models for Montana,” *Research Programs Montana Department of Transportation*.

Weed, R. M. (1998). “A Rational Method for Relating As-Built Quality to Pavement Performance and Value” *Transportation Research Board 77th Annual Meeting.*

Weed, R. M. (2000). “Method to Model Performance Relationships and Pay Schedules” *Transportation Research Board 79th Annual Meeting.*

Weed, R. M. and Tabrizi, K. (2005). “Conceptual Framework for Pavement Smoothness Specification” *Transportation Research Board 84th Annual Meeting.*

Whiteley, L., Tighe, S., and Zhang, Z. (2005). “Incorporating Variability into Pavement Performance, Life Cycle Cost Analysis and Specification Pay Factors” *Transportation Research Board 84th Annual Meeting.*

BIOGRAPHICAL SKETCH

Junyong Ahn, a native of Korea, earned his BS in the Civil Engineering Department at Yonsei University in Seoul, Korea in 1991. Then, he worked at Dongbu Corporation in Korea for eight and half years. The company engaged in construction and engineering, and he involved various projects such as Kwangyang roadway pavement and drainage construction project, Seoul Metropolitan water supply system project, Seoul Metropolitan subway construction (Line 6) project, and Hwoengsung dam construction project. He also worked at the head office of the company as duties included cost estimation and project budget control. He earned his MSCE at the University of Washington, where he studied construction engineering and management in Civil Engineering Department with Dr. Phillip Dunston. In August 2002, he started his Ph. D. studies at the University of Florida. He worked with Applied Research Associates during his Ph.D. track for his doctoral dissertation research. He received his Ph.D. degree under the guidance of Dr. Ralph D. Ellis in civil engineering at the University of Florida in 2008. His research interests include construction productivity, contracting methods, and construction quality ratings.