RELATION BETWEEN COST, QUALITY, AND RISK IN PORTLAND CEMENT CONCRETE PAVEMENT CONSTRUCTION

By

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I would like to dedicate this dissertation to my supporting parents, Pavlos I. and Klere Vidalis and to my brother Joseph A. Vidalis.

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In highway cement concrete pavement construction, the contractor decides what levels of quality to target under statistical quality assurance specifications. The selection of appropriate target quality levels affects both the probability of being awarded a project and the subsequent profit margin. Contractors are currently using the deterministic approach in selecting combined target acceptance quality characteristics. This approach does not take risk and probabilities into consideration. A new procedure using the probabilistic approach has been addressed. This probabilistic approach has been developed into a computer program that calculates the risks and probabilities in selecting the overall target quality.

This proposed procedure and accompanying computer program can help a contractor select target quality levels that will maximize profit in a specific situation. It will also assist state highway agencies in validating their quality assurance specifications and pay adjustment provisions.

Based on the analysis conducted, it was found that the deterministic and probabilistic methods do not necessarily identify the same optimal target values. The difference in answers between the two methods can mean a significant difference in profit. The proposed procedure is an improvement because it relies on computer simulation to replace time-consuming trial and error.

CHAPTER 1
INTRODUCTION

1.1 Background

During 1956, the move toward Quality Assurance/Quality Control (QA/QC) acceptance plans in highway pavements began with the American Association of State Highway and Transportation Officials (AASHTO) Road Test. The test was an experiment designed principally to determine the effect of variations in traffic loadings on different pavement cross sections. Among the findings was that there was far greater variability in materials and construction than engineers at the time realized, which led to the conclusion that highway concrete specifications must be improved (Burati et al., 1995).

In a standard construction contract, the State Highway Agency (SHA) specifies the quality level of construction and material the contractor must deliver. Quality levels can be described for use within methods specifications or statistical QA specifications. The quality level under methods specifications is described in terms of specific materials, equipment, and procedures the contractor must employ. This approach to construction specification development is predicated on the assumptions that the SHA fully understands the relationships between the construction process and the quality of the product, and is the primary repository of the technical knowledge needed to link the two (Chamberlin, 1995). In this case, contractors will only need to deliver the minimum acceptable quality level specified. Thus, contractors typically have no incentive to deliver a greater quality level under these specifications.

On the other hand, the quality level under statistical QA specifications explicitly describes only the desired sample statistic and not the desired constructed product. Contractors are not provided a specific quality level to target during construction under these specifications either. Contractors are left to determine their own target quality. Although they can be innovative in determining these levels, they still need a guidance for economic evaluations in the cost of quality.

Choosing a target quality is important to both the SHA as well as the contractor. The probability of a contractor being awarded a project and his/her subsequent profit margin are affected by this process. It is important for SHAs to have a better understanding of how and why contractors select target quality levels. These levels will ultimately provide insight on the cost and performance of the constructed concrete pavement.

1.2 Problem Statement

A questionnaire was sent out to numerous SHAs and concrete contractors regarding the cost of highway concrete pavement acceptance quality characteristics (AQC) such as slab thickness, compressive strength, and surface smoothness. This questionnaire revealed that the majority of SHAs are not aware of the cost of AQCs and so they leave it up to the contractor to estimate them. This is because most SHAs' cost estimating procedures are independent of quality requirements. This means that the cost estimating procedure does not allow estimators to differentiate pavement construction costs with respect to the measure of quality.

The main objective of concrete contractors, as profit seeking firms, is to make a profit. That profit is to a large degree dependent on the target quality level, which in turn is very much influenced by the specifications. SHAs need to monitor the process of how

contractors react to the QA specifications and associated pay adjustment provisions. In addition, SHAs need to know if the specifications encourage the contractors to maintain a proper balance between high quality/high performance and low cost. All of the above mentioned important issues are analyzed in the next section.

1.3 Objectives

The objectives of this research are as follows:

- Compare the differences and similarities of the current (deterministic method) and a new (probabilistic) method used to predict estimated quality.
- Develop guidelines from the new method for concrete contractors in selecting target quality levels that will achieve maximum profit.
- Incorporate probabilities and risk percentiles in targeting the composite AQCs that maximize profit.
- Assess whether SHAs acceptance plans and pay adjustment systems encourage construction that offers an optimal balance between quality and cost such as to result in lowest life-cycle cost.
- Develop a computer program that will help concrete contractors and SHAs evaluate the economic consequences of AASHTO-recommended QA specifications for strength, thickness, and smoothness. Specifically, this program will aid concrete contractors in targeting AQC levels to achieve maximum profit. This will provide the SHA a means to check whether the contractor's optimum target values (target values that maximize profit) are reasonably close to what may be considered optimum from the SHA's point of view (target values that minimize life cycle cost).

1.4 Scope

The main goal of this research is to determine the effects of different target AQC combinations so as to maximize the contractor’s end profit. In addition, it will also provide types of contractor risk percentiles involved in the design phase of Portland Cement Concrete (PCC) pavement construction. Risk factors can vary depending on how confident a contractor is in achieving the specified construction and quality of the material achieved.

This study was limited to concrete pavement construction with only three types of AQCs: slab thickness, compressive strength, and surface smoothness. The questionnaire was developed in order to understand the following:

- The change in cost, as a percentage, of each incremental change in the numerical value of an AQC.
- The contractor's and SHA's understanding of economic evaluations in the change of cost of the numerical value of an AQC.
- The methods that concrete contractors and SHAs use to price AQC.

The questionnaire provided input to the development of a computer software to aid contractors and SHAs in PCC pavement construction work. This software program probes various quality levels that could be employed. It identifies the contractor's optimum target quality based on the risk the contractor is willing to take. Ultimately, this assists contractors with bidding and operating strategies. Moreover, this assists SHAs with developing and validating specifications and the contained pay adjustment systems.

1.5 Research Approach

The research approach that was followed in order to fulfill the research objectives mentioned in Subheading 1.3 is described in the following task:

1.5.1 Task 1: Literature Review

This task consisted of a literature search on the following:

- Concrete pavement AQCs
- Types of QA/QC concrete pavement construction specifications (e.g., AASHTO, state specifications, etc.)
- Current methods used to perform economic evaluations
- Pay adjustment procedures for AQCs
- Previous research reports

1.5.2 Task 2: Data Collection

This task was conducted to understand the cost associated with each AQC. The following steps were used to accomplish this task:

- Send a questionnaire to SHAs and concrete contractors on each AQC's economic evaluations in the initial construction of concrete pavements.
- Collect results of related studies on AQC economic evaluations in the initial construction of concrete pavements.

1.5.3 Task 3: Data Analysis

This task includes an analysis of the following:

- The data collected from the questionnaire sent to SHAs and concrete contractors.
- The data collected from past-related studies.
- Current procedures and methods (e.g., deterministic approach and probabilistic approach) used to calculate pay adjustment costs for each AQC.

1.5.4 Task 4: Computer Program Development

A spreadsheet computer program that uses Macros/Visual Basic was developed based from the data obtained from the questionnaire, current pay adjustment procedures, and AASHTO specifications. This software was used as a tool to relate cost, quality, and risk in PCC pavement construction. The design value, lower specification limit, standard deviation, number of samples taken per lot, and incremental cost percentage for each AQC are among the inputs in the computer program. Monte Carlo simulation was used in the computer program to simulate sampling from the various AQC populations. It also combined statistical methods (e.g., mean, standard deviation, and probabilities) to calculate the pay factor at each trial AQC target value.

The result represents the contractor's expected pay and profit for each target AQC at a specific risk probability. The profits are then ranked in descending order and the

three most profitable AQC target value combinations are identified for each of the four risk probabilities. In this case, the contractor can choose the best combination suited for him/her that will maximize his/her profit and apply that to a bid.

1.5.5 Task 5: Interpretation of Computer Program Output

This task was conducted to understand the economic evaluations of the relationship between cost, quality, and risk. The following was interpreted:

- The difference of profit between AQC target values alone and AQC target values once the composite pay equation is taken into account.
- How risk plays a part in the overall profit.
- Recommendations for improvement of current QA/QC specifications.
- Recommendations and future research possibilities for additions to the computer program.

1.6 Practical Applications

The results from this study will assist concrete contractors with intelligently setting target quality levels, to maximize their profit. In addition, it will also assist SHAs in validating their quality assurance specifications and pay adjustment provisions. The new method, along with the computer program, can be used to assist in the development of new and improved QA/QC specifications that will have significant economic advantage for SHAs and concrete contractors. Ultimately, this will not only have a positive impact on the agencies and contractors but also on the general public.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The quality of highways has always been a major concern to highway engineers and contractors. During the past 50 years, the highway construction industry has been evolving toward a Quality Assurance (QA) model as seen in Figure 2-1. According to this model, the SHA describes the highway pavement desired through design drawings and specifications that include quality assurance characteristics, quality levels and tolerances, acceptance sampling and testing schemes, and acceptance criteria. The contractor creates the highway pavement by establishing a process for manufacturing/constructing the product and by exercising control over the quality of the output. The contractual agreement is then structured in a way that assures an equitable distribution of risk between the contractor's expectation of fair compensation and the SHA's expectation of reasonable quality (Chamberlin, 1995).

2.2. Highway Pavement Construction Specifications

Concrete highway construction utilizes a wide variety of materials. The control of the quality of these materials and the methods by which they are used is a major concern of the highway practitioner throughout the planning, design, and construction stages of a project. The specific requirements for governing both the quality and utilization of materials are set up in the form of specifications. A construction specification should be practical for implementation purposes and should be developed with the goal of

achieving a high-quality constructed pavement at a reasonable price that will result in the lowest life-cycle cost.

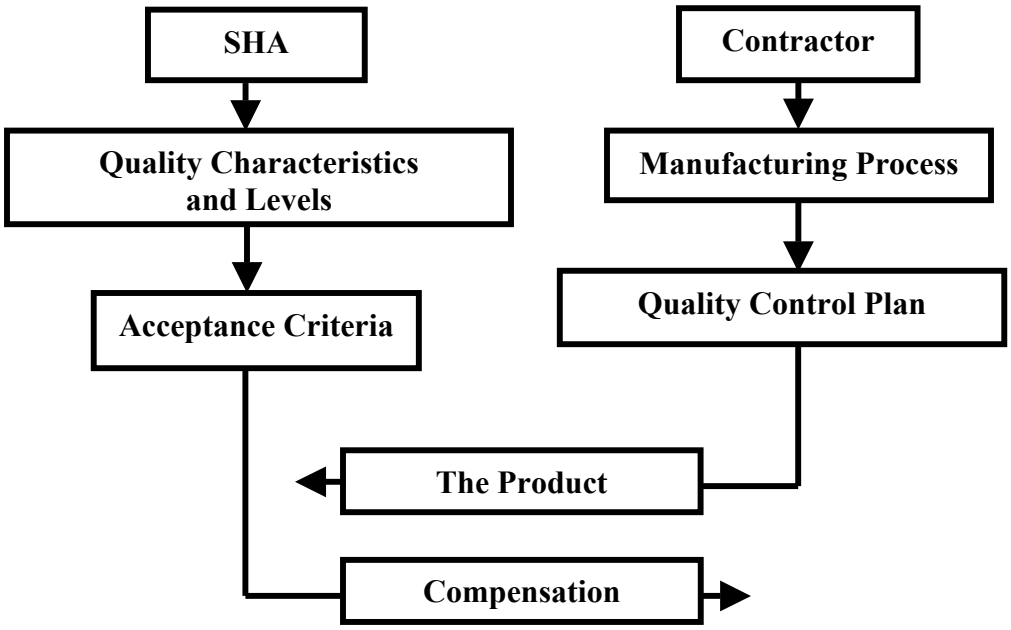


Figure 2-1. Elements of an Ideal Quality Assurance System

Specifications for highway construction materials and elements have taken different forms through the years as construction managers and highway agencies have adopted better methods of measuring compliance. These methods have typically been labeled as either prescriptive, QA, or performance (Chamberlin, 1995).

2.2.1 Prescriptive Specifications

The traditional specifications used are known as method specifications, also called prescriptive specifications. According to this specification, the contractor is provided with specific details on concrete pavement materials, design type, and method of construction. This specification does not provide the low-bid contractor any flexibility in making decisions about the design and process of the pavement construction. This does not give any incentives to use better methods or materials that will result in improving the quality of the specified methods and materials of the highway pavement. Contractors who

use this specification rely greatly on their engineering judgment, their intuition, and their past experience.

The contractor is responsible for the end-result of the project and its control parameters. Another major weakness associated with this specification is that it may not always produce the desired end-result even when it is properly followed. The reason is that it relies on past experiences achieved under conditions that may not be replicated in a new situation (Chamberlin, 1995; Solaimaniam et al., 1998).

2.2.2 Quality Assurance Specifications

Since the AASHTO Road Test in 1956, the discovery of the magnitude of variability in the quality of highway construction has raised concerns about the need for its improvement. The improvement has taken place as an evolution in quality assurance specifications. In QA specifications, the desired quality level, and the decisions to reach the desired quality are based on statistical principles. The SHA is responsible for describing the level of quality desired in the end product as well as the procedures that will be used to judge quality and acceptance. QA specifications can be easily enforced because there is a clear separation of responsibilities for control and acceptance. Moreover, this specification can be easily applied because pay adjustment for defective work is predetermined and thus, there is no need for negotiations.

The contractor working under quality assurance specifications typically has a positive/negative pay adjustment provision. This provides the contractor with incentives to achieve higher quality that can be more profitable. Under the earlier prescriptive specifications, a contractor's bid was often influenced by the reputation of the engineer who was in charge of acceptance of the end product. Unlike the historical data collected in conjunction with prescriptive specifications that have been notoriously unreliable,

quality assurance specifications produce useful data obtained with valid random sampling procedures. The obtained data can be further analyzed to develop better specifications for the future (Weed, 1996a).

2.2.3 Performance Related Specifications

Later in the 1980s, the Federal Highway Administration (FHWA), National Cooperative Highway Research Program (NCHRP), and State Highway Research Program (SHRP) integrated the development of relationships between construction quality measures and performance. This integration came to be known as Performance-Related Specifications (PRS) (Chamberlin, 1995). PRS improved quality assurance specifications by describing the desired levels of key materials and construction acceptance quality characteristics (AQCs). These characteristics, through PRS, have been found to correlate with fundamental engineering properties that predict performance (Hoerner et al., 2000).

Quality characteristics include material and construction variables that are under the control of the contractor and that are used for acceptance by the agency. These AQCs include means and standard deviations of slab thickness, concrete strength, entrained air content, and initial roughness (Darter et al., 1993). The primary component of a Performance-Related specification is the collection of prediction models that are used to determine the probable life-cycle cost (LCC) of the as-designed and as-constructed pavements.

An increasing number of SHAs are using QC/QA specifications compared to material and methods specifications. Although SHAs are increasingly using QC/QA specifications, the methods and procedures that constitute the QA programs of SHAs differ significantly. Figure 2-2 shows that the majority of SHAs use QA programs with

the contractor controlling quality and the agency-performing acceptance (16 out of 40 responses) (Hughes, 2005).

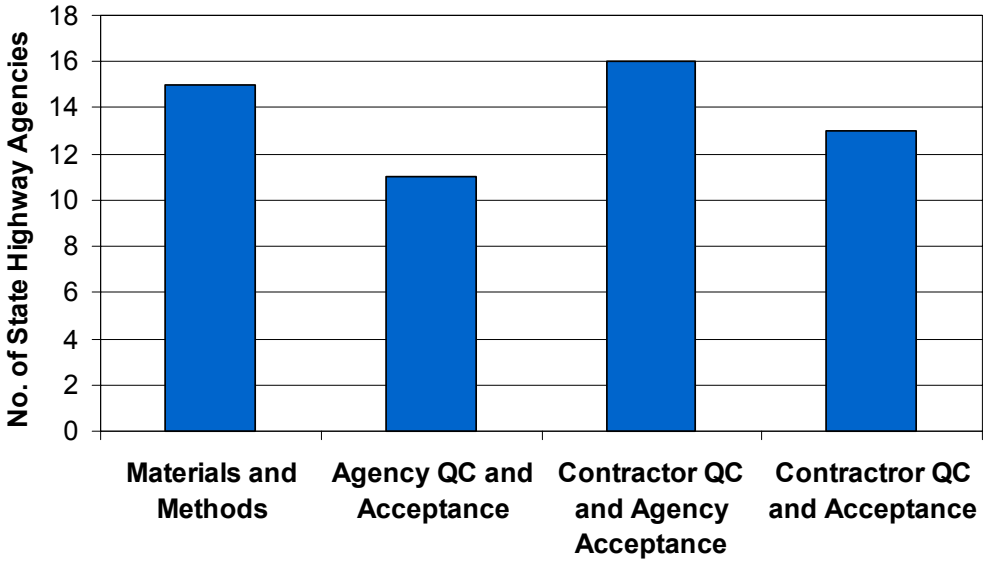


Figure 2-2. QA Programs for PCC Paving

2.3 Variability in Highway Pavement Construction

Since the Road Test findings were reported, both the FHWA and various State DOTs have conducted many studies on typical variability in highway construction. Variation exists in all material- and construction-related acceptance quality characteristics (AQC's) such as aggregate gradation, cylinder and beam strength, air content, slump, water/cement ratio, permeability, pavement thickness, and smoothness. The factors that influence this variability may be due to the period of time, distance, area, or quantity of material over which the variability is measured (Hughes, 1996). Due to the inconsistency in highway construction, different types of sampling and acceptance plans had to be implemented to develop QC procedures and requirements.

2.3.1 Random Sampling

Sampling is one of the most important features in QC/QA specifications. Quality Assurance Specifications use methods such as random sampling and lot-by-lot testing to

determine if the operations are producing an acceptable product (Burati et al., 2002). In sampling, one needs to know the point of sampling (where to sample), what technique to use, number of samples, and the time and production rate of sampling. If sampling is done inappropriately, a bias in test results may be introduced that cannot be detected or accounted for. The primary objectives in statistical sampling are to obtain a random sample which has the same probability of being taken as any other sample of material and a sufficient number of samples to adequately characterize the material. (Newcomb and Epps, 2001). This random sampling method can be used for quality assurance testing that allows every member of the population (lot) to have an equal opportunity of being selected as a sample. There are two types of random sampling: pure and stratified, as seen in Figure 2-3.

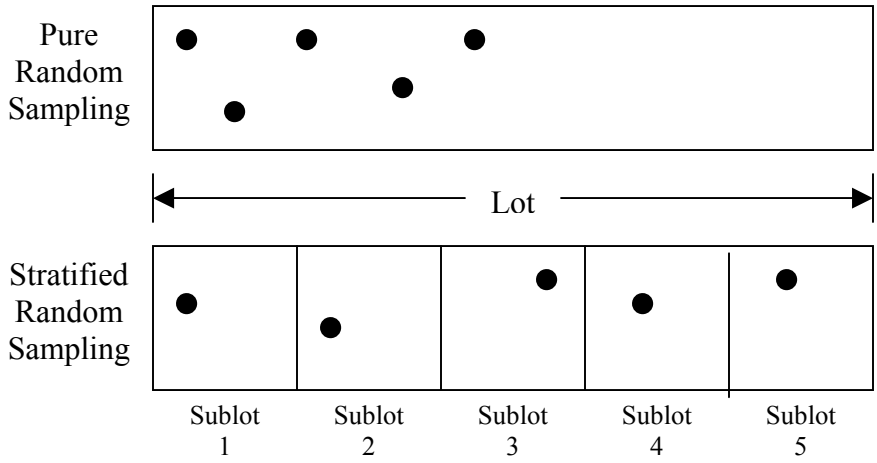


Figure 2-3. Examples of Pure and Stratified Random Sampling

2.3.1.1 Pure Random Sampling

The more fundamental method of random sampling is also known as pure random sampling. This allows the samples to be selected in an unbiased manner, based entirely on chance. A drawback of pure random sampling is that the samples occasionally tend to be clustered in the same location. Although this method of sampling is valid from a

statistical point of view, the samples may be spaced such that they do not adequately represent a lot (Pathomvanich, 2002).

2.3.1.2 Stratified Sampling

The stratified sampling method is designed to eliminate the clustering problem and spreads the sampling locations more uniformly throughout the work (Weed, 1989). This method ensures that the specimens for the sample are obtained throughout the lot, and are not concentrated in one portion or section of the lot. Therefore, most SHAs use stratified random sampling for their acceptance plan.

A lot is also known as the population. It is a specific quantity of similar material, construction, or units of product, subjected to either an acceptance or process control decision (TRC, 2005). The determination of lot size is primarily an economic decision. It is recommended that the lot length be set equal to one day's production. A lot can be stratified into a number of sublots equal to the sample size to be selected from the lot. Typically, sublots have approximately equal surface area. One core is randomly selected from within each sublot. This ensures that each portion of the lot has the same chance of being selected while, at the same time, ensuring that the sample is spread out over the entire lot (Hoerner et al., 1999; Burati et al.,1995). In order to test the sampling method for acceptance, different types of acceptance plans are specified.

2.4 Acceptance Schedule

An acceptance plan plays an important role in QA specifications. The plan specifies how many measurements are needed and how the accept versus reject (including pay adjustment) decision is made based on measured data (Chang and Hsie, 1995). There are two types of statistical acceptance plans in quality assurance specifications: attributes and variables.

2.4.1 Attributes Acceptance Plan

An attributes acceptance plan is a procedure where the acceptability of a lot of material or construction is evaluated by noting the presence or absence of some quality characteristic in each of the units or samples in the group under consideration and counting how many units do or do not possess this quality characteristic. The inspection does not provide information regarding the average quality level and the variability of a quality characteristic. Therefore, there generally are no clues in regard to the type of corrective action that should be taken (TRC, 2005; Chang and Hsie, 1995).

2.4.2 Variables Acceptance Plan

A variables acceptance plan is a procedure where the quality is evaluated by measuring the numerical magnitude of a quality characteristic for each of the units or samples in the group under consideration and computing statistics such as the average and the standard deviation of the group. This type of sampling procedure is more suitable for developing adjusted pay schedules to deal with the intermediate levels of quality. Attribute sampling is much less efficient than variable sampling because to obtain a certain buyer's risk or seller's risk, the number of samples needed for attribute sampling may be 30% greater than the number needed for variable sampling (Weed, 1989).

There are two cases in variable sampling: one where the standard deviation is known and the other where it is not known. The standard deviation-known acceptance plan is appropriate when the process has been running for some time and when a state of statistical control exists with respect to process variability. However, in most highway construction situations, the true standard deviation, σ, is not known.

With the standard deviation unknown (and the mean unknown), the beta distribution is used to estimate the percent within limits (PWL) of the AQC (TRC, 2005).

The beta distribution is a statistical method used for modeling random probabilities and proportions. The PWL is the amount of material or workmanship determined statistically to be within a boundary or boundaries, upper and/or lower limit, commonly used to determine acceptability (AASHTO, 1996b). These methods are discussed more in detail in Chapter 4.

2.5 Pay Adjustment

A pay adjustment plan is used to determine the overall pay for a submitted lot of material or construction. In order to do this, it requires that the SHA establishes a acceptable quality level (AQL) and a rejectable quality level (RQL). Work that meets the level of quality defined as acceptable is eligible for 100% payment. Work that fails to meet the desired quality level but that is not sufficiently deficient to warrant removal and replacement typically receives some degree of pay reduction (Weed, 1996a).

A pay factor in the specifications is used to adjust the contractor's pay according to the level of quality actually achieved. This is either added or subtracted from the contractor's payment for a unit of work. To receive full payment or more, the contractor is required to perform all work to a standard above the AQL. In terms of statistical quality assurance methods, this is typically specified as 90% within limits. By contrast, all work at a level below the RQL is totally unacceptable and must be removed and replaced. In terms of statistical quality assurance, this is typically specified as 50% within limits (Schexnayder and Ohrn, 1997).

Contractor pay incentives serve at least two objectives: (1) they encourage the contractor to construct pavements with significantly improved performance while at the same time maintaining costs at reasonable levels; and (2) they provide a rational alternative for dealing with marginally inadequate/adequate construction (Deacon et al.,

2001). Under the incentive pay concept, a contractor receives a bonus as a reward for providing superior quality and has a bidding advantage over contractors with poor quality control.

Although the pay adjustment approach to highway quality assurance is now widely used, there is not yet a consistency of practice regarding the magnitude of pay adjustment judged appropriate for varying levels of AQCs as seen in Figure 2-4. Figure 2-4 indicates that there are more incentive and disincentive pay adjustments for smoothness than thickness and strength.

2.6 Acceptance Quality Characteristics

Acceptance quality characteristics (AQCs) are measured for acceptance purposes. The AQCs that are considered in this study are concrete slab thickness, compressive strength, and surface smoothness. These AQCs are used in this research because they are used in the American Association of State Highway Transportation Officials (AASHTO) guide specifications and are easily associated with cost. They are also single sided, which means that they consist of a maximum or a minimum value and not both. Several other quality characteristics (e.g., air content, aggregate gradation, slump, dowel placement, tie bar placement) are important but are not considered in this study. This is because there is no incentive/disincentive percent pay given in the AASHTO guide specifications. In addition, some quality characteristics such as slump and aggregate gradation are typically controlled on a conventional acceptance or rejection criteria (Diwan et al., 2003).

The SHA is responsible for determining the acceptability of the material produced. Acceptance of the material is based on the inspection of the construction, monitoring of the contractor's QC Program, acceptance test results, and comparison of the acceptance test results to the quality control test results (AASHTO, 1996).

The following are the three AQCs used in this research, which include an explanation of how they are measured in the construction field pertaining to AASHTO's guidelines.

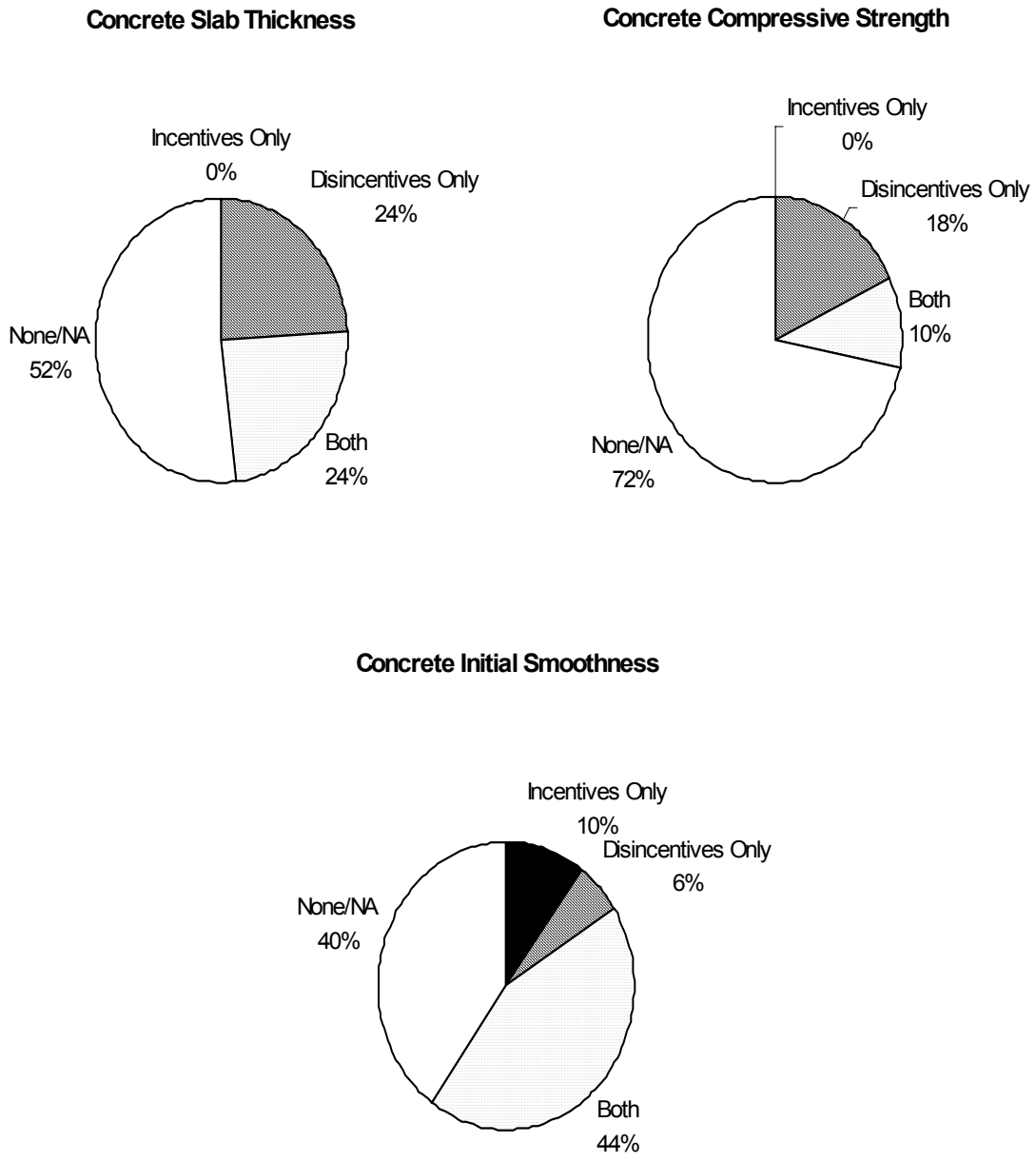


Figure 2-4. State DOT Concrete Pavement Incentive and Disincentive Pay Adjustment Practices (ACPA, 1999)

2.6.1 Slab Thickness

AASHTO's Quality Assurance Guide Specification provides an acceptable quality level for thickness. The pavement thickness is determined from an analysis of measurements made on cores. The cores should have a diameter at least three times the maximum size of the coarse aggregate in the concrete and a length as close to twice the diameter as possible (Kosmatka and Panarese, 1988). The slab thickness at a cored location is recorded to the nearest 0.1 inch (in), as the average of three caliper measurements along the core length. The total length of the paving lane in linear feet (ft) in the highway proper will be divided into sublots of 500 feet (0.1 mile (mi)), each. A sublot of pavement represented by a core deficient by more than one inch is not accepted. Cores from the balance of the pavement sublots are analyzed to determine the average and standard deviation of the pavement thickness. When evaluated in accordance with the Quality Level Analysis, the percent within limits (PWL) shall be at least 90%. A thickness measurement for each sublot is determined by taking a number of core borings at random locations in the sublot. Thus, the thickness sample size is the sum of the number of core borings at random locations per sublot (AASHTO, 1996b; Gharaibeh et al., 2001).

2.6.2 Strength

Strength is not always the most important characteristic of concrete quality, but it is the one that is most often measured. It is assumed to be indicative of the water-cement ratio and, accordingly, an indicator of durability (Darter et al., 1998). There are three types of testing used to measure strength: compressive, flexural, and tensile. The computer program only focuses on compressive and flexural testing.

Compressive strength testing is the most common quality attribute measured on paving projects today (ACPA, 2004a). The compressive strength of concrete pavement is determined by testing cores that are taken in the same manner as the analysis of pavement thickness but in this test a load is applied on top, see Figure 2-5. Two replicates are considered as one sample in a pavement sublot. The strength for each sublot sample is determined by the ASTM C-39 or AASHTO T-22 standard test method for compressive strength of cylindrical concrete specimens (Kosmatka and Panarese, 1988). The compressive strength average and standard deviation of a number of cylinder casts from a sample of concrete pavement from the sublot is calculated. It should be at least 28 days old but less than 90 days old when the cores are obtained. The concrete pavement is considered acceptable if the PWL is 90% or greater (AASHTO, 1996b).

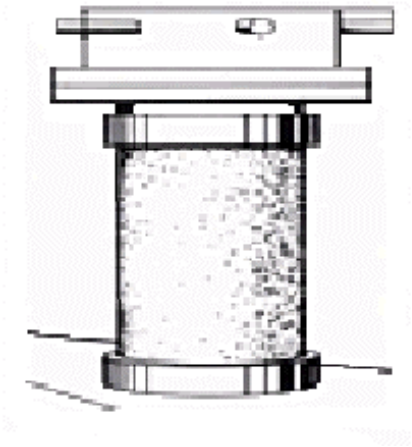


Figure 2-5. Concrete Compressive Strength Test

The flexural strength for each sublot sample can be determined by two tests: the third-point loading or the center-point loading. The flexural strength is measured by loading 6 x 6-inch (150 x 15-mm) concrete beams with a span length (L) at least three times the depth (d). The third-point loading flexural strength test is determined by the ASTM C-78 or AASHTO T-97 standard test method. In this method half of the load is

applied at each third of the span length, see Figure 2-6. The maximum stress is present over the center one-third portion of the beam.

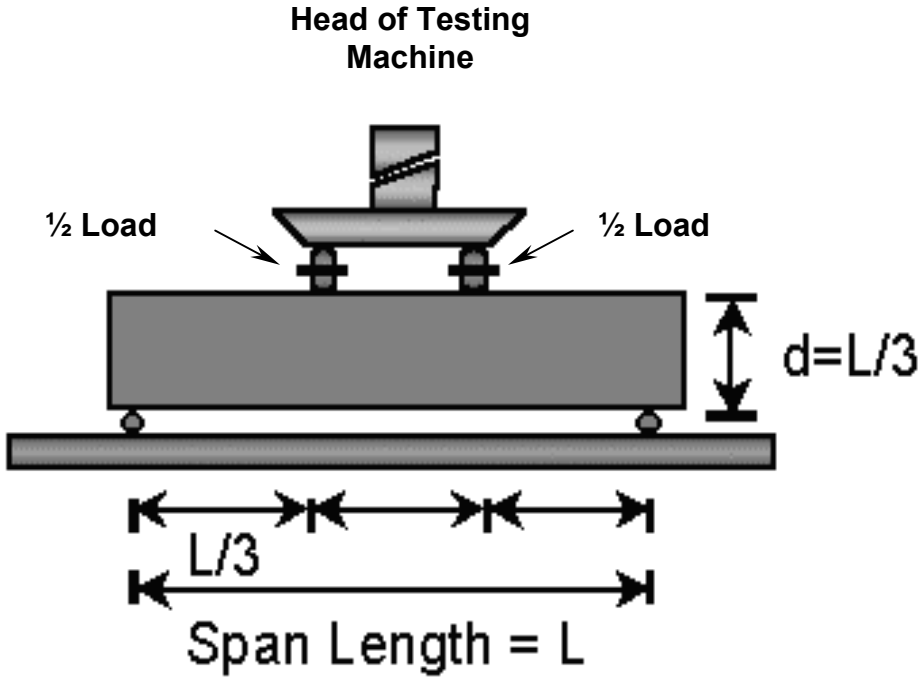


Figure 2-6. Third-Point Flexural Strength Test

The ASTM C-293 or AASHTO T-177 standard test method determines the center-point loading. In this method the entire load is applied at the center span, see Figure 2-7. The maximum stress will be present only at the center of the beam therefore; the modulus of rupture will be greater than the third-point loading (AASHTO, 1996a). The flexural strength or normal-weight concrete is often approximated as 7.5 to 10 times the square root of the compressive strength (Kosmatka and Panarese, 1988). The flexural strength conversion that was used in this dissertation uses the average of nine times the square root of the compressive strength.

2.6.3 Surface Smoothness

Initial pavement smoothness is a key factor in the long-term performance. The smoother a pavement is built the smoother it stays over time, resulting in lower

maintenances costs, decrease in traveling costs, and more comfort and safety for the traveling public. State highway agencies recognized the importance of initial pavement smoothness in the 1960s, and began developing and implementing smoothness specifications (Smith et al, 1997). There are many devices that measure pavement smoothness such as the Mays Meter, Rainhart Profilograph, Non-Contact Profilograph, California Profilograph, and Straight Edge. Past national surveys indicated that the majority of state highway agencies use the California Profilograph (76%), as seen in Figure 2-8 (ACPA, 1999; Ksaibati et al., 1996).

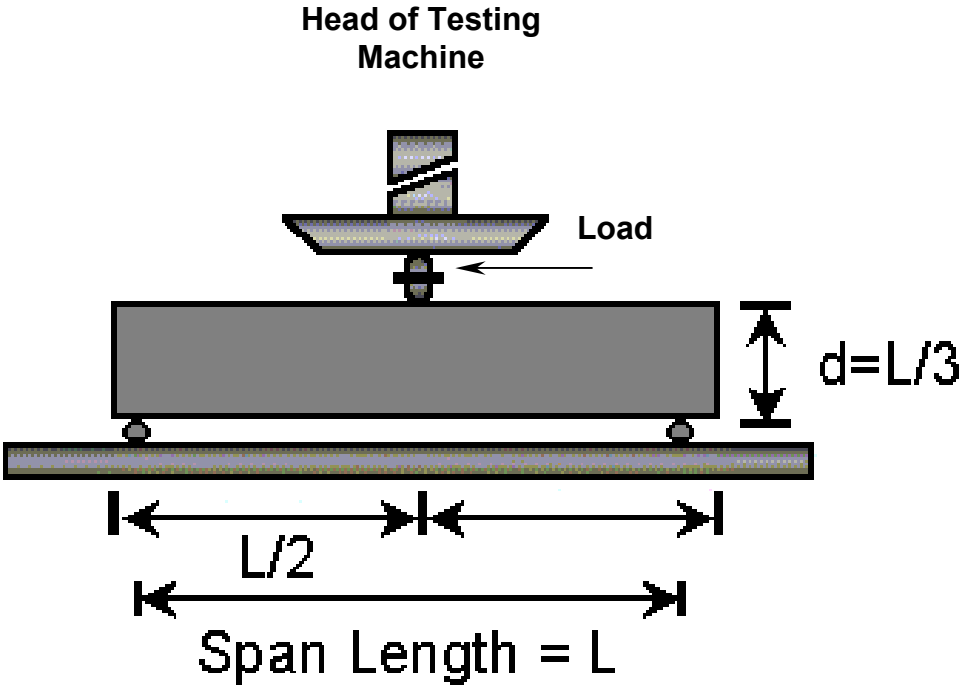


Figure 2-7. Center Point Flexural Strength Test

The California Profilograph is a 25-foot-long rolling straightedge with a recording wheel at the center of the frame, as seen in Figure 2-9. The sensing wheel moves freely in the vertical direction and records its motion on graph paper. The recorded profile is termed a profilograph trace and is developed on a scale of one-inch equals 25 feet

longitudinally and one-inch equals one inch vertically. Its measurement is a series of numbers representing elevation (AASHTO, 1996b, ACPA, 1990).

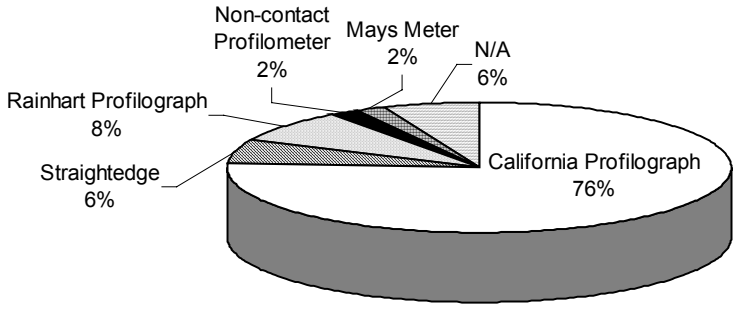


Figure 2-8. Percent of Different Measuring Devices Used in the United States

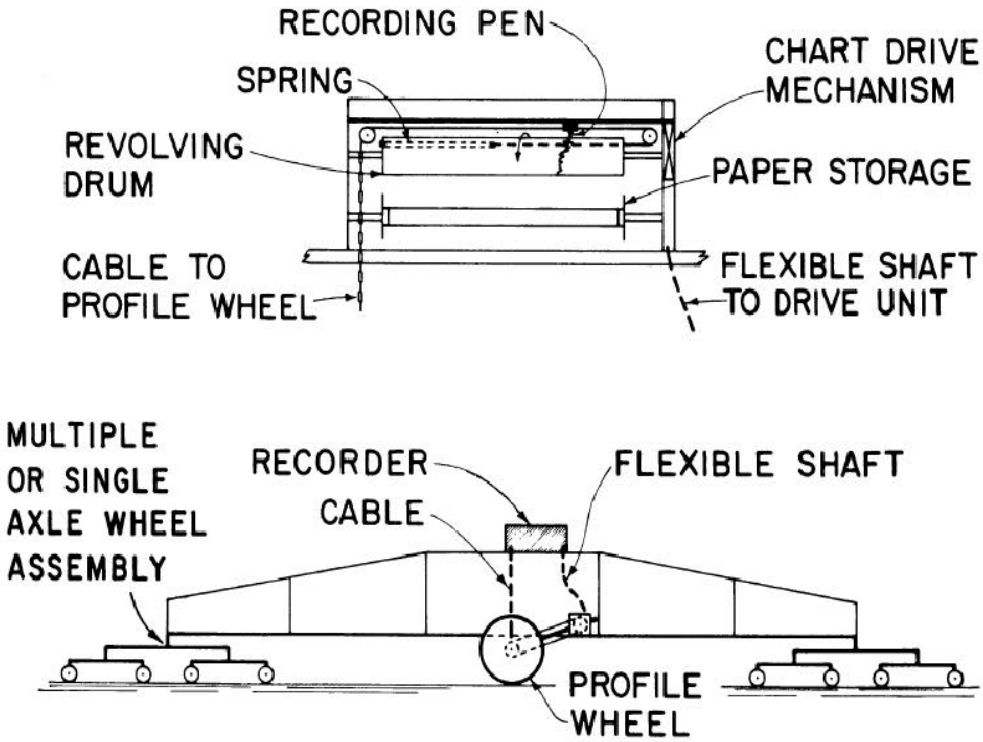


Figure 2-9. The California Profilograph (CalTrans, 2000)

Every device measures the smoothness differently. For example, the California and Rainhart Profilographs calculate smoothness using the profile index (PI), but still the test results between them are not identical. Studies show that the California model indicates larger deviations than the Rainhart (ACPA, 1990). The Non-contact calculates

smoothness with another method called the International Roughness Index (IRI) (Smith et al., 2002; ACPA, 2002).

2.6.3.1 Profile index

A PI is a summary number calculated from the many numbers that make up a profile. A large majority of States (39 out of 50 total) used the profile index with a blanking band (BB) of 0.2 inch ($PI_{0.2}$) (5 mm, PI_5) to calculate the smoothness (ACPA, 2004b). One advantage is that any valid profiler can measure a PI. A blanking band is a plastic scale 1.7 inches wide and 21.12 inches long representing a length of 0.1 miles on the profilograph trace (one inch equals 25 feet horizontal scale). Figure 2-10 shows an example of a California Profilograph reading with a $PI_{0.2\text{-}inch}$ of 8 in/mile (Waalkes, 2001; ACPA, 1990).

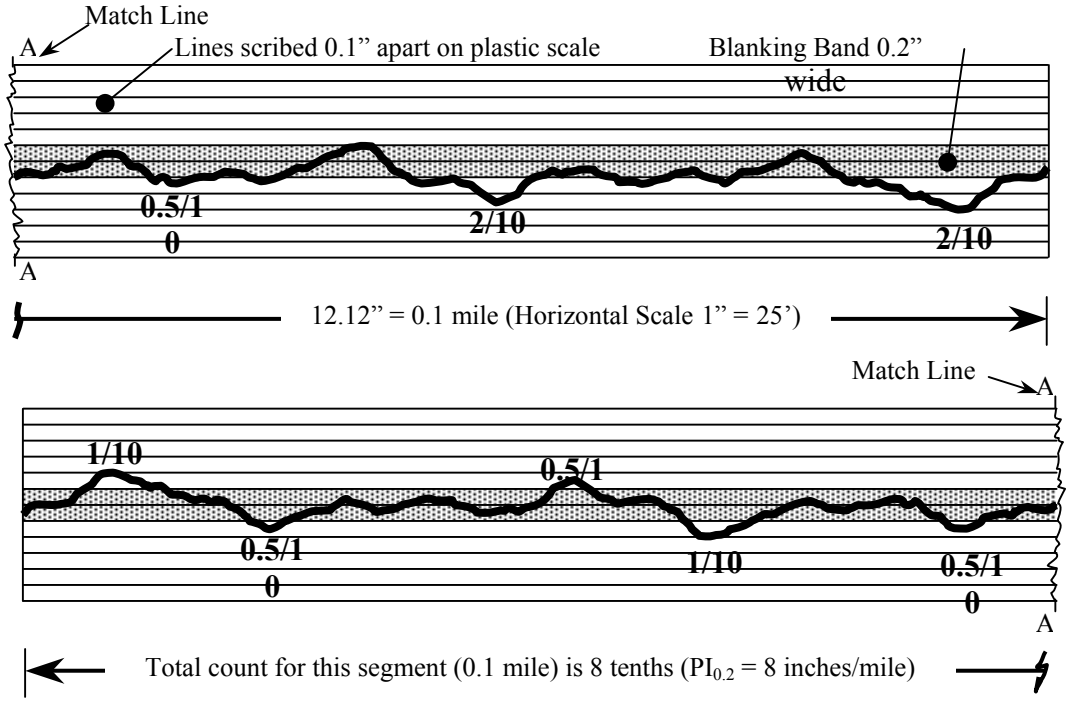


Figure 2-10. California Profilograph 0.2-inch Blanking Band Trace (ACPA, 1990)

On each side of this band are parallel scribed lines 0.1 inches apart that serve as a scale to measure the size of deviations of the profile line outside an opaque band that is

located at the midpoint of the running length of the BB. These deviations are known as scallops shown in Figure 2-11 A. An advantage of the BB is that it helped engineers and contractors calculate the profile index quickly and accurately. A two-tenths inch BB was initially used to ignore the bumps within 0.2-inch of the average. Some SHAs have moved away from the 0.2-inch BB because it can hide bumps that cause surface chatter, which can be annoying to the driving public. In this case, they have moved toward the 0.0-inch BB (the middle line in the opaque strip) or the 0.1-inch BB (Waalkes, 2001; ACPA, 1990).

Short portions of the profile line that are visible outside the BB are not included in the count unless it is 0.03 inch or more on the profilograph trace as seen in Figure 2-11 B. There are also some special conditions where the profile line is not included in the count. If the profilograph encounters rock or dirt on the pavement, the profile line creates a spike that is not included in the count. In addition, double-peaked scallops that do not go back into the blanking band are only counted once at the highest peak. These special conditions are shown in Figure 2-11 C and D (ACPA, 1990).

2.6.3.2 International Roughness Index

An International Roughness Index (IRI) is a number computed from a profilograph trace that is measured by a laser instead of a wheel riding on the surface. Almost every automated road profiling system includes software to calculate this statistic. IRI was developed and tested by the World Bank in the 1970s through the 1980s. Some devices that use the IRI are known as non-contact profilometers (e.g. Lightweight and High-Speed Profilers). They consist of an integrated set of vertical displacement sensors, vertical accelerometers, and analog computer equipment mounted in a vehicle equipped with distance-measuring instrument that can be operated at certain speeds, see Figures 2-

12 through 2-13. The Lightweight and High-Speed Profilers are able to measure the smoothness traveling at higher speeds than the California Profilograph. (AASHTO, 2004). The High-Speed Profiler uses the inertial reference system, which measures and computes longitudinal profile by using accelerometers placed on the body of the measuring vehicle to measure the vehicle body motion. The relative displacement between the accelerometer and the pavement profile is measured with either a "contact" or a "non-contact" sensor system (Sayers and Karamihas, 1998).

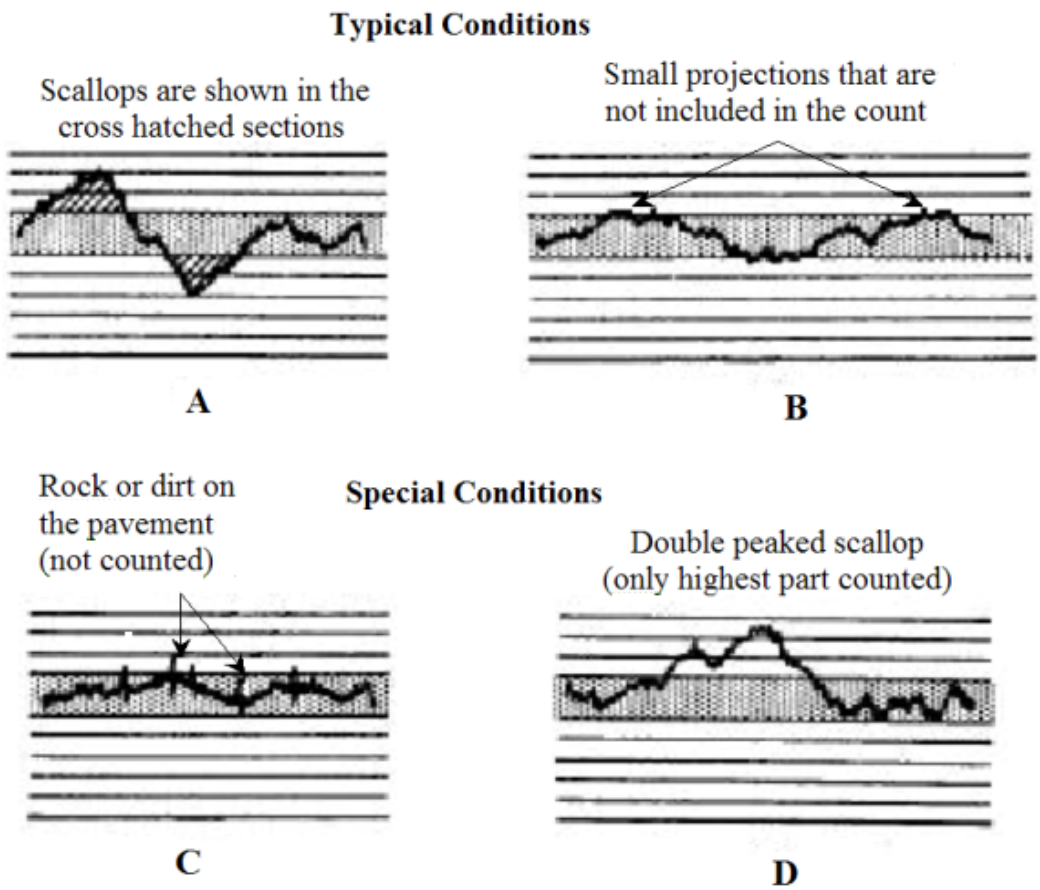


Figure 2-11. Types of Profiles from Profilograms (AASHTO, 2004)

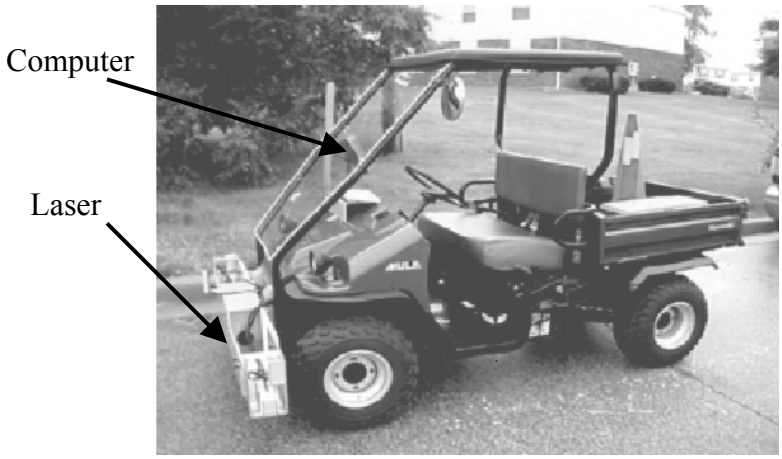


Figure 2-12. Lightweight Profilometer (Sayers and Karamihas, 1998)

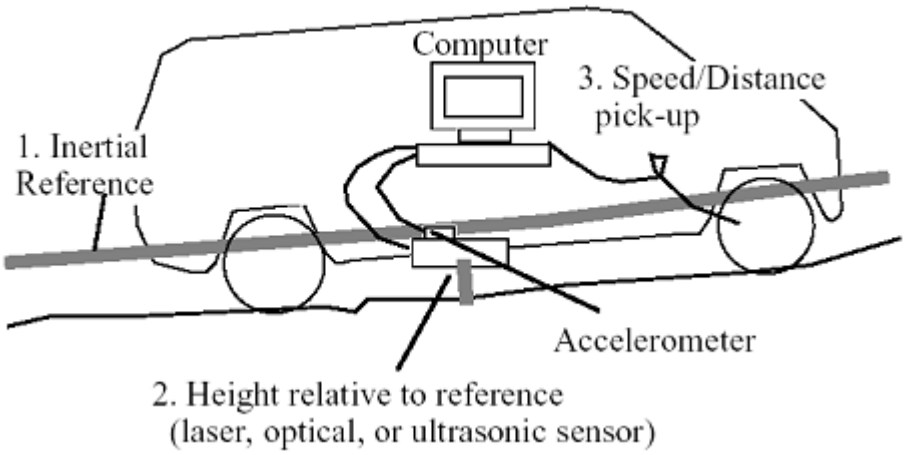


Figure 2-13. High-Speed Profilometer (Sayers and Karamihas, 1998)

IRI may also be expressed in inches per mile. There is only a small percentage of SHAs that are using Non-Contact Profilometers. Even though they are the state of the art, there have been studies that indicate most profilometers do not do a very good job of measuring smoothness on coarse concrete textures. The problem is that the profilers pick up the texturing which a car cannot feel, thus giving a higher number that is not

accurately reflective of the pavement's smoothness. There is continuing research on new profilers that can do multiple traces and compute both IRI and PI values (AASHTO, 2004).

2.6.3.3 Comparison of Profile Index with International Roughness Index

The use of inertial profilers has remained limited in initial construction acceptance testing due to their higher cost and constraints on timeliness of testing. Thus, in many agencies, initial pavement smoothness has been measured one way (PI) and smoothness over time has been measured another way (IRI). The research reported in this dissertation included both PI and IRI. The PI was included because of the majority of SHAs still use the California Profilograph device, and because it is specified in AASHTO's specifications. IRI calculations were included because it is evident that IRI will become the statistic of choice in future smoothness specifications (Smith et al., 2002). Although both indexes relate well to highway user response to roughness, their correlation to each other is not as strong because different roughness components (e.g., bumps and dips) are amplified or attenuated in computing each index. Studies show that the most significant differences between the two relate to the reference profiles from which the two indexes are computed, the type of sensors used, and the degree and type of wavelength filtering (moving average or third-order Butterworth) performed to produce the index values. Various studies have also found that the correlation of PI and IRI becomes progressively higher with the application of smaller and smaller BB widths (Hoerner et al., 2000).

The Long-Term Pavement Performance (LTPP) program established the relationship between IRI and three different variations of the PI statistic: $PI_{0.2\text{-inch}}$ ($PI_{5\text{-mm}}$), $PI_{0.1\text{-inch}}$ ($PI_{2.5\text{-mm}}$), and $PI_{0.0}$. As mentioned above, the research reported in this dissertation applies to the AASHTO guide specifications, which only specify Pay Factors

(PF) for $PI_{0.2\text{-inch}}$. Based on a standard filtering routine (2.5-ft [0.76-m] moving average smoothing filter) and the application of the three different variations of the PI statistic, the PI-to-IRI conversion equations were developed as seen in Table 2-1 (FHWA, 1993; Hoerner et al., 2000).

Table 2-1. Summary of IRI-PI Relationships with a 2.5-ft (0.76-m) Moving Average Smoothing Filter

Linear Regression Equation	
In/mile	**m/km**
$IRI = (2.625 \times PI_{0.2-inch}) + 75.541$	$IRI = (2.625 \times PI_{5-mm}) + 1.192$
$IRI = (2.240 \times PI_{0.1-inch}) + 58.163$	$IRI = (2.240 \times PI_{2.5-mm}) + 0.917$
$IRI = (2.233 \times PI_{0.0}) + 25.557$	$IRI = (2.233 \times PI_{0.0}) + 0.403$

2.7 Diamond Grinding

Diamond grinding is a concrete pavement restoration technique that corrects irregularities such as faulting and roughness on concrete pavements. It is a cost-effective treatment. On the average, it costs between $1.70 and $6.70 per square yard ($2.00 and $8.00 per square meter). An increase in the cost can depend on many factors including aggregate, PCC mix properties, average depth of removal, and smoothness requirements. As the increased competition in diamond grinding grows and as diamond blade performance improvements are made, the lower the cost (Correa and Bing, 2001). Because of the minimal cost associated with spot-grinding new pavements, (in comparison to overall construction costs), this research does not take into account the cost of spot-grinding any identified rough locations that the contractor needs to correct as required by the AASHTO guide specifications.

2.8 Related Research

To control the quality of construction, highway agencies have developed quality assurance methods or programs based on statistical sampling and procedures to ensure

that the work is in accordance with the acceptance plans and specifications. The current method used today by many SHAs is embodied in AASHTO's guide QA acceptance plans. As mentioned throughout this chapter, those plans only evaluate concrete pavement thickness, strength, and surface smoothness.

A computer simulation software program, COMPSIM, was developed on Quality Management to provide guidance on the use of practical and effective quality assurance procedures for highway construction projects. This program does the following:

- Analyze both pass/fail and pay adjustment acceptance procedures
- Construct operating characteristic curves
- Plot control charts
- Experiment with computer simulation
- Perform statistical comparisons of data sets
- Demonstrate the unreliability of decisions based on a single test result
- Explore the effectiveness of stratified random sampling (Weed, 1996b).

The program employs PWL as a quality measure but it does not allow the user to work with more than one AQC at the same time. In other words, it only calculates one PF at a time. A pay adjustment factor assigns a pay in percentage for the estimated quality level of a given quality characteristic (TRC, 2005).

A method was developed for analyzing risks and expected profit associated with PRS. The method was applied to a concrete paving project on I-295 in Jacksonville, Florida under Level A (simplified level) PRS. The method was based on Monte Carlo Simulation and probabilities. The specifications did not use PWL as a quality measure, and the method did not go so far as to consider the effect of the composite pay equation. In addition, it did not simulate enough samples for each AQC to get a close enough

output every time it was simulated (Gharaibeh et al., 2002). This research became an excellent starting point from which to make modifications and improvements necessary to meet the needs of contractor and SHAs working under the AASHTO-type QA specifications.

The Innovative Pavement Research Foundation (IPRF) developed a methodology for comparing the impact of various PCC pavement design features on cost and performance. In addition, a computer software tool was developed for comparing and evaluating trade-offs in assessing the relative performance benefits and costs of various PCC design features. Questionnaires were sent out to concrete contractors and SHAs to collect cost and performance data for the computer software tool that was developed (Hoerner et al., 2004). The IPRF strength cost data was used in this research because the smoothness costs that were gathered from the questionnaires from this research were not deemed to be as accurate. These three developed methods (Weed's, Gharaibeh's, and IPRF's) taken separately each serve different purposes. Together however, they became an excellent starting point from which to make modifications and improvements necessary to meet the objectives identified in this dissertation.

CHAPTER 3
DATA COLLECTION AND ANALYSIS

3.1 Introduction

Due to the many variables in concrete pavements, it is difficult to establish the exact cost associated with individual AQCs. The cost of thickness and strength depends on the cost of the material used (e.g., cement, aggregate, sand, admixtures, water, ground granulated blast-furnace slag, and fly ash). The cost of smoothness depends primarily on the time and effort taken to make the pavement smoother. Since cost depends on many variables (such as the equipment, materials, and procedures the contractor uses) it can be difficult to achieve the same cost in different projects. On any given project, however, if one disregards the effect of inspection, the following can be said: an increase in the contractor's target quality level increases the initial construction cost, and a decrease in the contractor's target quality level decreases the initial construction cost.

A data collection effort was required to obtain information necessary to assess the cost associated with individual AQC quality. This chapter describes each of the primary data collection activities and how the collected data were used to develop the software program.

3.2 Questionnaire Development

Once concrete pavement AQCs were identified, questionnaire surveys were developed. A request for participation along with the questionnaire was electronically mailed, snail mailed, or faxed to 50 SHAs and 40 PCC Contractors. The purpose of the questionnaire was to better understand:

- The degree to which contractor's consider construction quality in their bid strategy
- The SHA's cost estimating procedures
- How SHAs and concrete contractors price quality

There were two similar questionnaires, one for contractor respondents and one for SHA respondents. Each questionnaire was divided into two parts. The first part contained questions about bidding decisions and cost estimating procedures. The second part was designed to discreetly obtain AQC cost information with respect to Jointed Plain Concrete Pavement (JPCC). There are different types of concrete pavements such as Jointed Reinforced Concrete Pavement (JRCP) and Continuously Reinforced Concrete Pavement (CRCP) but the majority of the SHAs build JPCPs (68%), Figure 3-1 (ACPA, 1999).

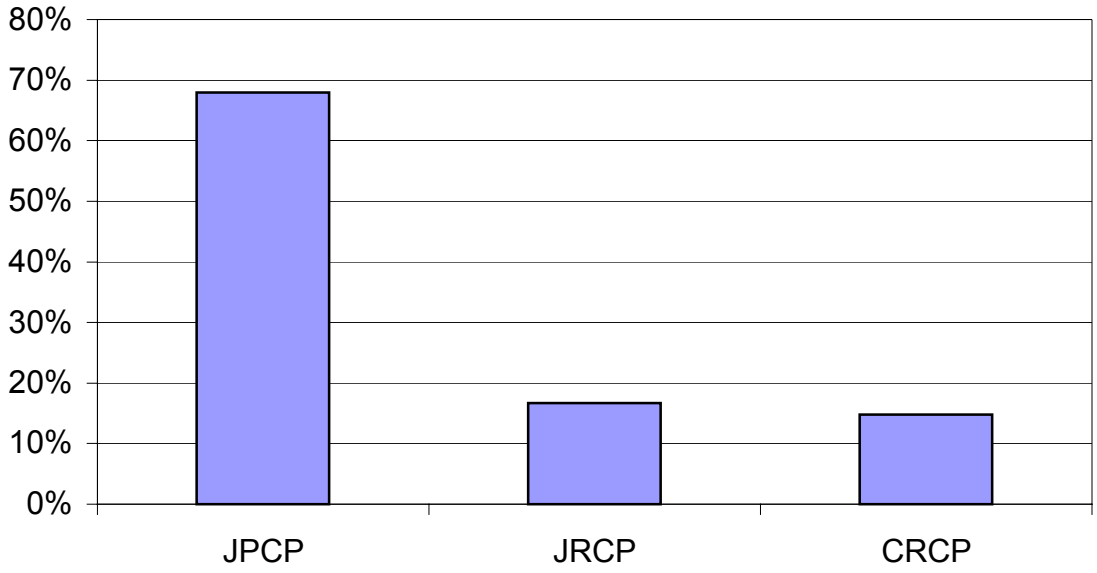


Figure 3-1. Concrete Cement Pavement Types Built

A JPCP is shown in Figure 3-2. The joints are usually spaced at intervals of 13-23 feet (4-7 meters (m)), although some specifications require a maximum spacing of 15 feet (4.6 m), such as this case (Atkins, 2003).

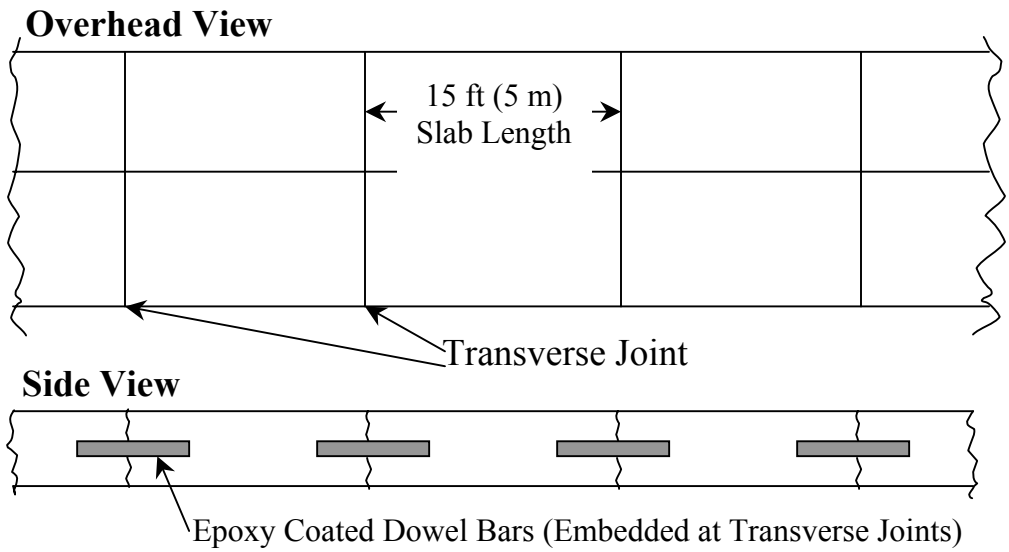


Figure 3-2. Jointed Plain Concrete Pavement Overhead and Side Views (ACPA, 2005)

The questions in the second part of the questionnaires related to the following JPCP construction situation:

- Four lane highway divided
- Five mile length, few horizontal and vertical curves
- New construction, no traffic control
- Rural area
- Epoxy coated dowels
- 15 feet transverse joint spacing
- Standard thickness used in the state
- Standard strength requirement used in the state
- Standard smoothness requirement used in the state
- Routine bidding situation for contractor (e.g., typical number of competing contractors, contractor is neither desperate for work nor overloaded with work, etc.)

The concrete contractors and SHAs were asked to answer cost questions based on the assumption that the above pavement construction situation was applicable. Moreover,

they were asked additional information on the tests and/or machines used for each AQC. The survey participants were then asked to assess the change in costs for improvements in strength, thickness, and smoothness quality levels so the relationship between quality and cost could be determined. Both questionnaires were structured so that only one design AQC was changed at a time. For example, one of the scenarios was to increase the concrete pavement strength by an additional 1,000 pounds per square inch (psi) (7 megapascal (Mpa)) from the specified strength that was the state standard for JPCP construction. The subgrade and type of materials (e.g., soil, aggregate, etc.) used were not considered in this research. This research dealt only with the quality characteristics of the concrete pavement slab.

If the respondents had no experience or if a question did not apply to them, they were asked to answer "Don't know" or "Not applicable." This was also useful information because it shed light on which party knows more about the cost associated with AQCs. It also showed which AQCs were relatively easier to relate to cost. Although the questionnaires were separate surveys, the questions that pertained to concrete pavement quality and cost were identical. A copy of the questionnaires along with detailed answers from both the concrete contractors and SHAs can be found in Appendices B and C.

3.2.1 Concrete Contractor Respondents

A total of ten responses, 25%, were received from the participating PCC paving contractors. Despite an effort to increase the response rate, this is a low, but not unexpected, number of concrete contractor respondents. All the responses (SHAs and concrete contractors) will be taken as a whole. Out of the respondents, 70% participated

and 30% did not want to participate or do not have enough data to complete the questionnaire.

PCC paving contractors providing responses to the questionnaire surveys included contractors from the following states: Colorado, Indiana, Iowa, Kansas, Louisiana, Ohio, and Oklahoma.

3.2.2 State Highway Agency Respondents

Out of the 50 SHAs, only 52% responded, and out of the respondents 77% participated and 23% said that they did not have enough data to complete the questionnaire or they do not construct any PCC pavements. The SHAs that provided data for to the questionnaire survey included: California, Delaware, Florida, Idaho, Illinois, Indiana, Iowa, Kansas, Louisiana, Maryland, Missouri, Nebraska, Nevada, Oklahoma, South Carolina, South Dakota, Virginia, Washington, West Virginia, and Wisconsin.

3.2.3 Desired Number of Acceptance Quality Characteristics Cost Responses

A statistical evaluation was performed to determine the desired number of questionnaire responses required to have a reasonable estimate of the change in cost for each AQC increase. In determining the desired sample size, it is assumed that the total population has a normal distribution. The purpose of the questionnaires is to estimate the average of the population, or more specifically, the average incremental change in cost of an AQC given incremental changes in the AQC quality level. The following equation is often used to determine sample size (i.e., number of respondents needed in a questionnaire survey) (Kopac, 1991).

$$n = \left[\frac{\sigma \times z_{\alpha/2}}{T} \right]^2 \tag{3-1}$$

Where

σ = population standard deviation

$z_{\alpha/2}$ = number of standard error units (based on the desired confidence level and obtained from a normal probability table)
T = required precision or tolerance

In this evaluation, the standard deviation is estimated from the original data. Furthermore, three desired confidence levels and four desired precision levels are selected. By running a range of values with an initially assumed, reasonable average, the effect these inputs have on the resulting number of samples can be determined. For the purposes of estimating the number of samples, the analyses for the cost taken from the questionnaires are broken out separately.

The change in incremental cost considered the three basic questions:

1. What would be the estimated cost ($/yd2) for the paving if the average thickness requirement is 1 in (25.4 mm) more than was initially assumed?
2. What would be the estimated cost ($/yd2) for the paving if the average strength requirement is 1,000 psi compressive strength (or 237 psi flexural strength) more than was initially assumed?
3. What would be the estimated cost ($/yd2) for the paving if the average smoothness requirement is 2 in/mile (PI0.2-in) (IRI = 80.8 in/mile, PI = 31.75 mm/km. IRI = 84.5 mm/km) better than was initially assumed?

Table 3-1 shows that for greater precision, and/or higher confidence levels, more cost responses (n) are needed. As indicated above, each standard deviation was estimated from the raw data to make a determination of whether the number of respondents resulted in sufficient precision and confidence levels. The desired number of respondents believed to be sufficient is indicated in bold text.

This research uses a 95% confidence level and a precision level of $0.5/yd^2 ($0.6/m^2) for thickness. A lower precision was used for thickness because it is a more costly AQC due to more materials (e.g., cement, aggregate, sand, fly ash, etc.) used to achieve a higher thickness. Therefore, assuming these, a minimum of 14 respondents is

desirable for the thickness cost portion, Table 3-1. This was met, having 20 responding to the change in thickness cost.

A 95% confidence level and a precision level of \$0.3/yd^2 (\$0.36/m^2) were used for strength. A higher precision than thickness was used for strength. This is because increasing strength is less costly than increasing thickness. Less material is used to increase strength than to increase thickness. For example, one way to increase compressive strength by 500 psi (201 psi flexural strength) is by adding 47 pounds of cement at \$0.04 per pound, which would only cost \$1.88 per cubic yard (Smith, 2005). Therefore, assuming 95% confidence level and a precision level of \$0.3/yd^2 (\$0.6/m^2), a minimum of 13 respondents is desirable for the strength cost portion, Table 3-1. There were only 10 respondents that gave a change in increase compressive strength cost. This was short by three respondents. The costs associated to each increase in AQC were compared with another report. Even though a sufficient number of responses was obtained at the 90%ile confidence level for the strength portion, there was not good agreement with the IPRF study (Hoerner et al., 2004).

For smoothness, a 95% confidence level and a precision level of \$0.2/yd^2 (\$0.24/m^2) was used for surface smoothness. A higher precision was used for smoothness because it is the least costly of the three AQCs as there is no need to add material to make a pavement smoother. Therefore, assuming these, a minimum of 11 surveys is desirable for the smoothness cost portion, Table 3-1. This was met, having 12 responding to the change in thickness cost. This simply means that the standard deviation of the means of 12 data points are lower than certain specified levels.

3.3 Contractor's Bidding Decision Making

This survey concentrated only on concrete contracting firms that produced from as low as $5 to $20 million per year to as high as $100 to $500 million per year of PCC work. Contractors' bidding behaviors are affected by numerous factors related to specific features of the project and dynamically changed situations. These can make decision problems highly unstructured. There are also many risks involved in bidding decisions. Most of the findings of this survey on bidding decisions are not unexpected, but some of them are important and need to be emphasized.

In order to obtain more information on contractor's bidding decisions, the questionnaire focused on questions pertaining to risk and competition. Many contractors use certain methods or techniques to assist them in winning the bid. Through the questionnaire, it was found that 43% of the contractors use a formal method to assist them in submitting a winning bid. One of the methods mentioned that was used was Oman Systems. Oman Systems is an estimating software that also includes Bid Tabs Professional and Pro Estimate. These software programs provide accurate and detailed project information, analyze projects to make better decisions and limit the risk of miscalculating or leaving an item out (Oman Systems, 2005). The majority of the contractors (57%) stated that they do not have a formal method to assist them in winning a bid, Figure 3-3.

All of the contractors that responded use a unit price contract for PCC pavement work. In this contract, the price is charged per unit for the major elements of the project. This consists of a breakdown of the work and estimated quantities for each of the items (Gould, 2002). To consider how concrete contractors consider uncertainty or risk in pricing concrete pavement elements, the following two questions were asked:

- How would you handle the uncertainty of pricing quality for JPC pavements while working on the bid?
- How do you consider job related contingency?

The questionnaire revealed that 42% considered uncertainty by adjusting a markup and 29% considered uncertainty by applying a correction factor on a certain quality factor, Figure 3-4. The remaining 29% stated that the money would be figured into the bid for quality and escrowed for the duration of the warranty or that they will not bid if uncertain about anything.

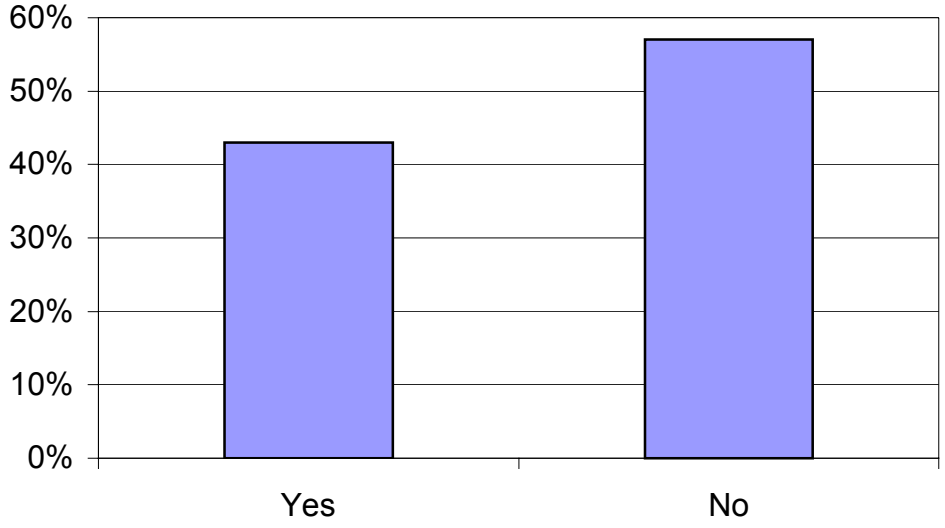


Figure 3-3. Percent of Contractors that Use a Formal Technique to Win a Bid

Table 3-1. Summary of the Required Number of Samples for Relative Incremental Cost for Each AQC

	Calculated σ change in cost ($/yd^2)	Number of Required Samples											
		90% Confidence (z = 1.645)				95% Confidence (z = 1.96)				99% Confidence (z = 2.58)			
		Precision of Average Cost Estimate (T) ($/yd^2)				Precision of Average Cost Estimate (T) ($/yd^2)				Precision of Average Cost Estimate (T) ($/yd^2)			
		within 0.5	within 0.4	within 0.3	within 0.2	within 0.5	within 0.4	within 0.3	within 0.2	within 0.5	within 0.4	within 0.3	within 0.2
Slab Thickness	0.95	9.80	15.31	27.22	61.24	**13.91**	21.74	38.64	86.94	24.10	37.66	66.96	150.65
Compressive Strength	0.53	3.07	4.80	8.53	19.19	4.36	6.81	**12.11**	27.24	7.55	11.80	20.98	47.21
Surface Smoothness	0.34	1.22	1.90	3.38	7.60	1.73	2.70	4.79	**10.79**	2.99	4.67	8.31	18.69

In addition, the majority of the contractors (57%) stated that they would charge contingency an additional cost item, Figure 3-5. All these are methods that take uncertainty and risk into consideration. Since risk is a major factor in pricing quality, it was added into the computer program as a percentile since there are different levels of risks (e.g., high risk taker, neutral, low risk taker).

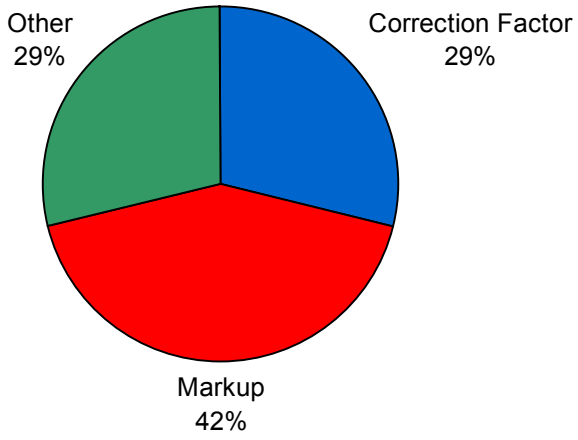


Figure 3-4. Method used to Handle Uncertainty in Pricing Quality in JPC Pavement

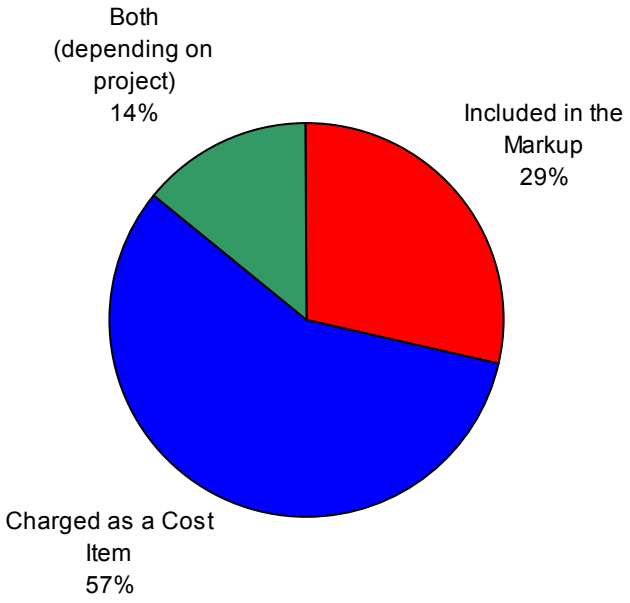


Figure 3-5. Method used for Job Related Contingency

3.4 State Highway Agency's Cost Estimating Procedures

SHAs use different methods to calculate cost estimates for a project. It was found through the questionnaire that the majority of the SHAs (61%) use a statewide database to calculate the estimated cost for a concrete pavement project. Figure 3-6 shows the methods used by SHAs to calculate costs for JPC pavement projects. Only 13% stated that they use a district wide database. The remainders 26% use the following methods:

- Complete Analysis Method: This method calculates production rates, labor costs, and material costs. It may be used individually or in combination with the Statewide and Districtwide database method.
- Worksheet: A normal worksheet that calculates local labor costs, local material costs, and etc.
- Historical Prices
- Phone surveys: Estimates based on actual costs from phone surveys with suppliers.

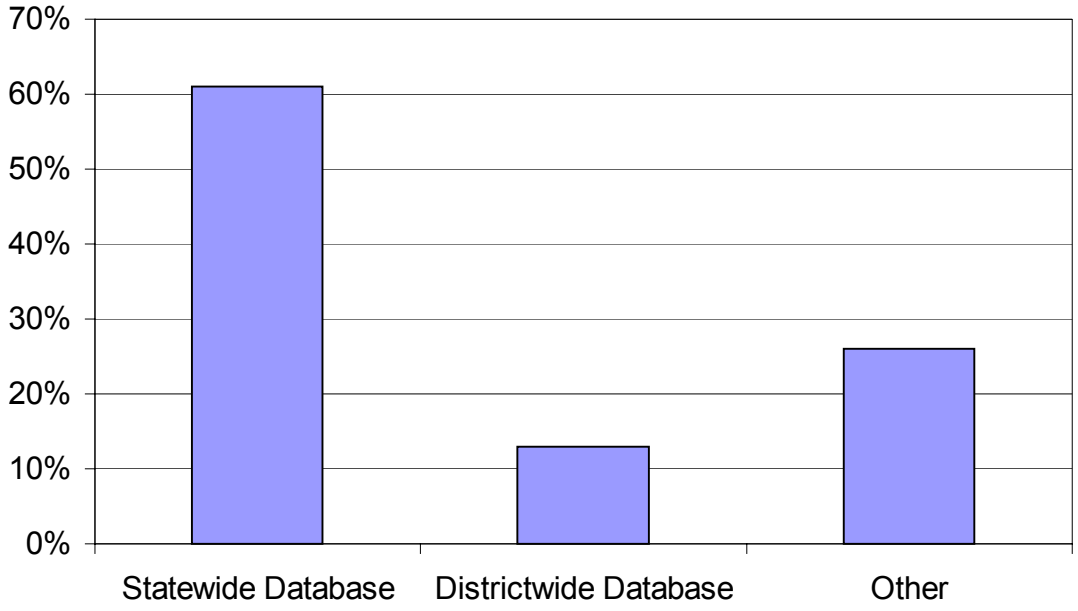


Figure 3-6. Method Used to Calculate Cost for Jointed Plain Concrete Cement Projects

It was found, through the questionnaire, that the majority of SHA's (95%) cost estimation procedures are independent of the quality requirements. Figure 3-7 shows the

percent of the cost estimating procedures used by SHAs that are independent or dependent of quality. Only 5% of the SHAs responded that the cost estimating procedure allows the estimator to differentiate costs with respect to quality. This indicates that SHAs are not sufficiently aware of the cost of quality. Higher cost does not necessarily mean higher quality.

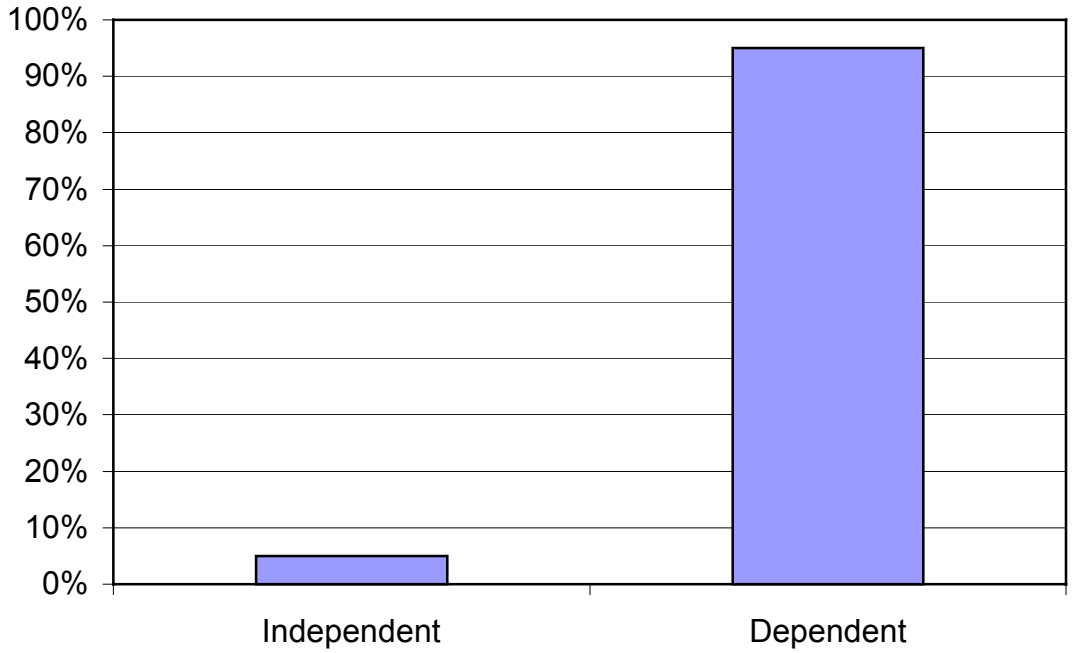


Figure 3-7. Cost Estimation Procedures that is Independent/Dependent of Quality

3.5 Concrete Pavement Acceptance Quality Characteristics Change in Cost

This research used both concrete contractor and SHA questionnaire responses to calculate the average cost associated with AQCs in PCC pavement. The questionnaire responses showed that concrete contractors have a better understanding of the cost of quality than do SHAs, see Figure 3-8. They also showed that SHAs have a better understanding of pricing thickness and smoothness than strength.

An initial review of the data indicated that an inch (0.0254 m) increase in thickness could increase the cost of paving by 5%. The questionnaire shows that an increase of

1,000-psi compressive strength (284 psi flexural strength or 7 MPa) can increase the cost of paving by 3%.

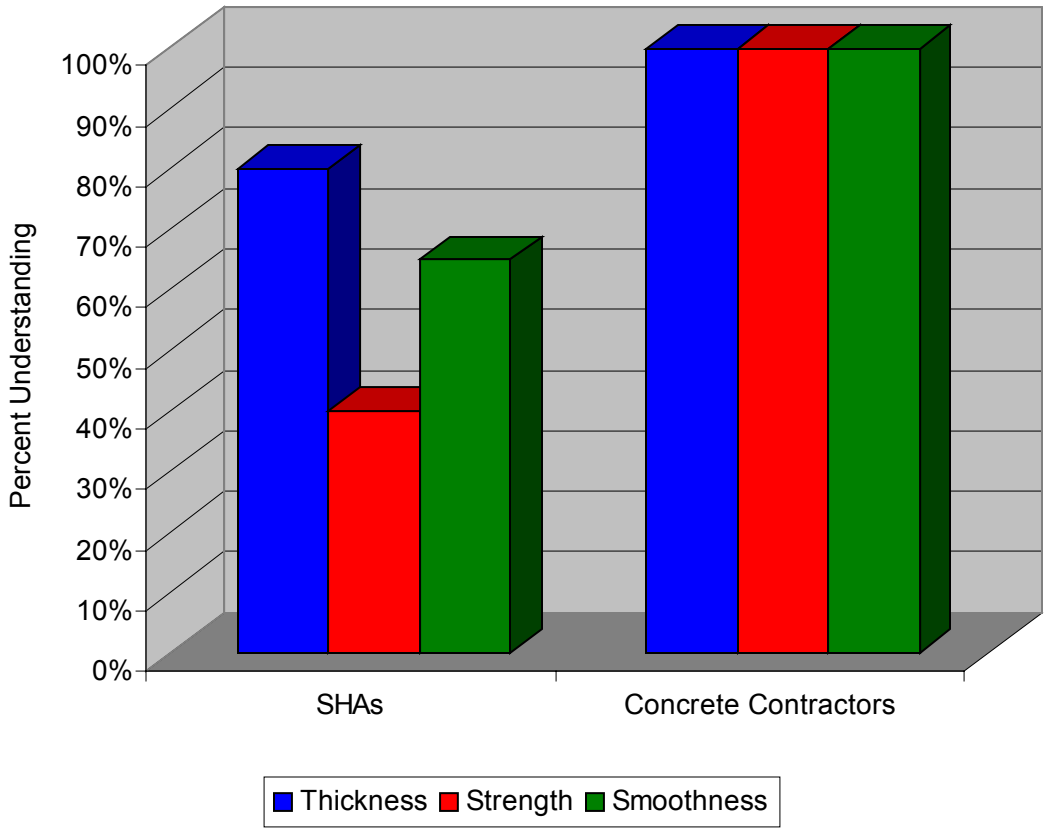


Figure 3-8. Understanding of Cost Associated with Incremental Change of AQC

An improvement in smoothness (i.e., a decrease in PI or IRI) does not require a major increase in total paving costs. The questionnaire responses showed that a one in/mi (16 millimeter/kilometer (mm/km)) improvement in smoothness can increase total paving costs by 1%. Table 3-2 shows the average incremental AQCs that were analyzed from the questionnaire with the original incremental change in cost for each AQC. The AQCs that are located in the center of the first, third, and fifth columns (eg., 10.9 in, 3,825 psi, and 5.71 in/mi) are considered the average design values from the questionnaire responses. Each design value equals a change in cost of zero percent. As the design value increases or decreases, the percent change of cost also increases or decreases. For example, a

thickness of 9.90 inches (a difference of one inch less from the design value) yields a percent change in cost of – 6.16%.

As mentioned before, the number of respondents to estimate strength cost data was not as high as desired. Since the change in cost for compressive strength was questionable (due to obvious misinterpretation of the strength questions by several respondents), cost data from the IPRF study (Hoerner et al., 2004) were used. Table 3-3 shows the final average incremental AQC values and costs that were used in this dissertation. The summarized cost data served as the "default" database for use in evaluating the relative cost of each concrete pavement design AQC. They can be considered as typical within the United States. A summary of the raw relative cost data collection from SHAs and Concrete Contractors is provided in Appendix D of this dissertation.

Table 3-2. Average AQCs and Incremental Change in Cost from Respondents

Thickness (in)	**Δ Cost (%)**	**Compressive Strength (psi)**	**Δ Cost (%)**	**Surface Smoothness (in/mi)**	**Δ Cost (%)**
8.90	-12.34	2,825	-7.27	3.79	2.51
9.90	-6.16	3,325	-3.55	4.71	0.81
10.90	0	3,825	0	5.71	0.00
11.90	6.16	4,325	3.55	6.71	-0.81
12.90	12.34	4,825	7.27	7.71	-2.51

Table 3-3. Average AQCs and Revised Incremental Change in Cost

Thickness (in)	**Δ Cost (%)**	**Compressive Strength (psi)**	**Δ Cost (%)**	**Surface Smoothness (in/mi)**	**Δ Cost (%)**
8.90	-12	2,825	-2	3.79	2
9.90	-6	3,325	-1	4.71	1
10.90	0	3,825	0	5.71	0
11.90	6	4,325	1	6.71	-1
12.90	12	4,825	2	7.71	-2

CHAPTER 4
STATISTICAL AND MATHEMATICAL METHODS UNDERLYING TARGET QUALITY IN HIGHWAY CONCRETE CONSTRUCTION

4.1 Introduction

At the start of the AASHTO Road Test, concrete thickness, strength, surface smoothness, and many other construction measures were found to vary widely about their target values. Construction data was illustrated in the form of the bell-shaped normal distribution curve. The Road Test was the Impetus for highway engineers to learn to understand the statistical principles associated with construction process. Today, construction specifications developed are based on statistical concepts. The purpose of this chapter is to present an overview of the mathematical and statistical concepts related to acceptance plans for quality assurance specifications.

4.2 Variability Measures in PCC Pavements

All materials and construction are not exactly the same because they are subjected to a different variability. The variations could be natural and occur randomly, which most specifications allow. However, variations resulting from poor process control (e.g., equipment, materials, or construction errors) are undesirable and will penalize the contractor by deducting a percentage of his/her payment depending on the amount of variation. In order to use variability data properly in specifications, it is important to understand the ways variability is measured (Hughes, 1996).

Extensive research has concluded that numerous measurements that occur in highway construction distribute themselves about some average value with the majority

of the measurements grouped near the mean and with progressively fewer results recorded as one proceeds away from the mean. This describes the normal distribution (bell-shaped curve), which is the most important probability distribution for highway construction and materials. The normal distribution is useful in the analysis of acquired data and in providing inferences about the population from sample data. It is defined by two parameters, the mean value and the standard deviation. Samples are intended to represent the population Samples can also range from very large to very small. The closer the sample size gets to the population size, the more likely the sample statistics will be representative of the population statistics (Chiang, 2003; Ott, 1993).

The population mean (μ) is the average value that determines the x-axis location of the normal distribution. The population mean can be obtained by summing all the values ($x_1 + x_2 + \ldots x_i$) in a data set and dividing it by the number of values (*N*) as follows (Ott, 1988):

$$\mu = \frac{\sum_{i=1}^{N} x_i}{N} \tag{4-1}$$

The population mean is usually unknown and can be estimated by the sample mean ($\bar{x}$). It is calculated from the following equation, where *n* is the number of values in the sample.

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{4-2}$$

The other useful parameter is the population variance (σ^2). It measures the variability or the spread of a data set. For example, a small variance indicates a tight data

set with little variability, and vice versa. The population variance is calculated using the following equation (Walpole and Myers, 1985):

$$\sigma^2 = \frac{\sum_{i=1}^{N}(x_i - \mu)^2}{N-1} \tag{4-3}$$

When the variance is computed in a sample, it is calculated using Equation 4-4.

$$s^2 = \frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{n-1} \tag{4-4}$$

Typically, it is the square root of the variance that is calculated. The square root of the population variance is the population standard deviation (σ). The standard deviation determines the height and width of the normal distribution. It measures the variability of data in a population. It is usually and unknown constant and is calculated as follows:

$$s = \sqrt{s^2} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \tag{4-5}$$

The sample standard deviation (s) measures the variability of data in a sample and is calculated using Equation 4-5 (Chiang, 2003).

$$\sigma = \sqrt{\sigma^2} = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \mu)^2}{N-1}} \tag{4-6}$$

4.3 Quality Measures

There are several quality measures that can be used. In past acceptance plans, 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. Several quality measures that have been preferred in recent years because they simultaneously measures both the

average level and the variability of AQCs are refereed as percent within limits (PWL), also called percent conforming, and percent defective (PD) (Burati et al., 1995).

4.3.1 Percent Within Limits

The PWL is the percentage of the lot falling above the lower specified limit (LSL), below the upper specified limit (USL), or between the specified limits, as seen in Figure 4-1. PWL may refer to either the population value or the sample estimate of the population value. The PWL quality measure uses the mean and standard deviation in a normally distributed curve to estimate the percentage of population in each lot that is within the specified limit (TRB, 2005).

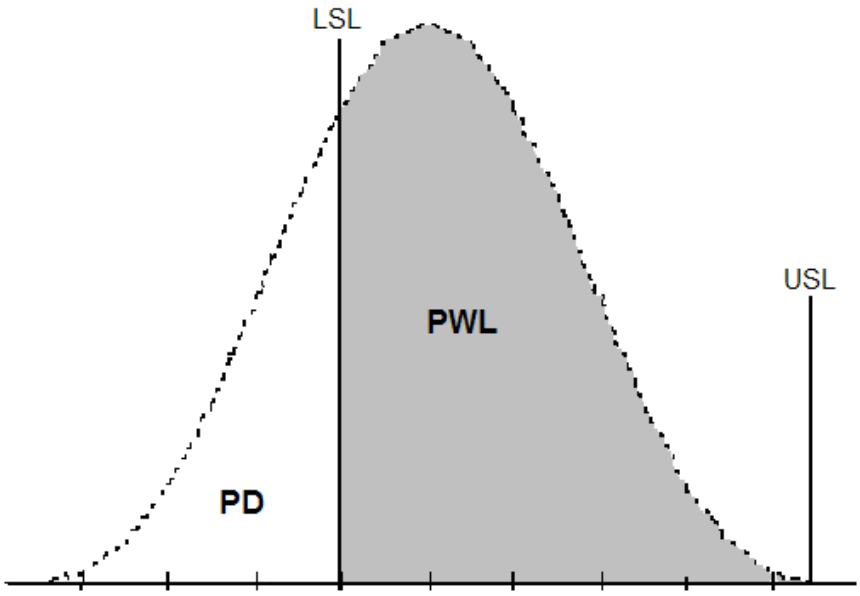


Figure 4-1. Percent Within Limits. LSL = Lower Specified Limit, USL = Upper Specified Limit, PD = Percent Defected, PWL = Percent Within Limits

In practice, it has been found that statistical estimates of quality are reasonably accurate provided the sampled population is at least approximately normal (i.e., bell

shaped and not bimodal or highly skewed). The PWL is calculated using the following equation:

$$PWL_i = 100 - PD = \left[1 - B(\alpha,\beta)\left(0.5 - Q_{Li}\sqrt{\frac{N}{(2(N-1))}}\right)\right] \times 100 \tag{4-7}$$

Where
PD = percent defected
$B(\alpha,\beta)$ = beta distribution with parameters α and β
(α,β) = shape parameters of the distribution
Q_{Li} = lower quality index for an AQC
N = number of samples per lot

Unlike the normal distribution, which is a single distribution that uses the z-statistic parameter to calculate areas below the distribution, the beta distribution is a family of distributions with four parameters alpha (α) and beta (β). The PWL calculation uses the symmetrical beta distribution. For symmetric distributions, the alpha and beta are the same. Figure 4-2 shows three examples of a symmetric beta distribution. As α and β values increase the distributions become more peaked. The uniform distribution has alpha and beta both equal to one. This does not have a well-defined mode because every point has the same probability. Distributions with alpha and beta less than one are bathtub shaped curves and generally not useful for statistical modeling (Ramanathan, 1993).

4.3.2 Quality Index

The *Q*-statistic, also referred to as the quality index (QI) performs identically the same function as the z-statistic of the normal distribution except that the reference point is the mean of an individual sample instead of the population mean. In addition, the points of interest with regard to areas under the curve are the specification limits: *LSL* and the *USL* (Burati et al., 1995).

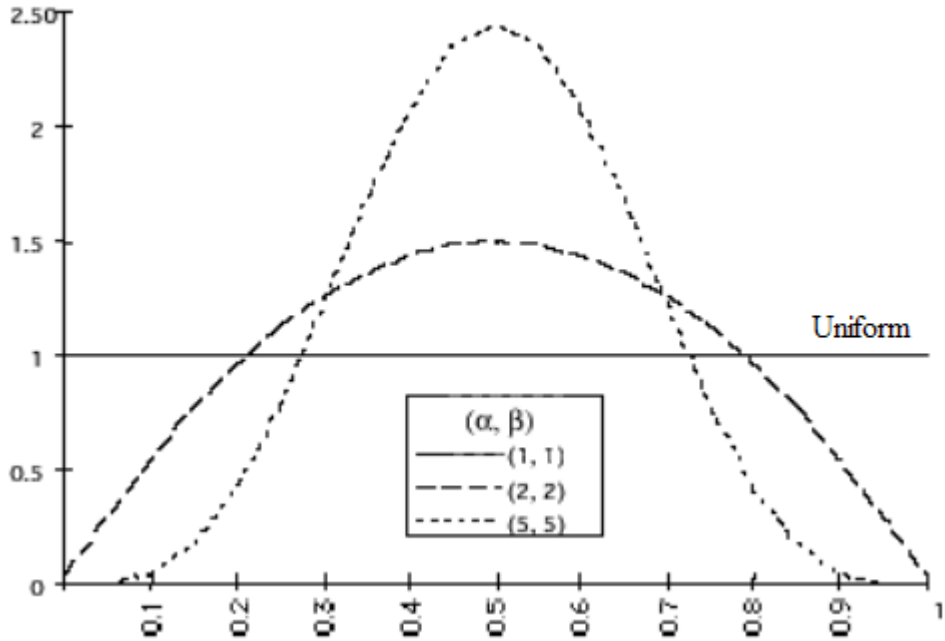


Figure 4-2. Three Examples of Symmetric Beta Distributions

The *USL* and *LSL* are the limiting value or values placed on an AQC for evaluating material or construction within the specification requirements. In this research only one limiting value was needed. The reason is that the AQCs used in this research are single sided and not double sided. Single-sided AQCs consist of a maximum or a minimum value and not both. The only specification limit specifically identified in the AASHTO QA guide specifications is the *LSL* for the slab thickness. It suggests the following equation (AASHTO, 1996b):

$$LSL_{Design\ Thickness} = DV - 0.2 \text{ inches} \tag{4-8}$$

The AASHTO QA guide specifications do not suggest a *LSL* equation for concrete strength. It is up to the contractor and SHA to choose the lower specified level for strength. For surface smoothness the guide specifications do not use the PWL to calculate the pay-adjusted factor. Instead, the individual smoothness measurement (an average

between two wheel paths) is used to determine pay adjusted factor values that are specified by AASHTO (AASHTO, 1993).

For double-sided AQCs (such as asphalt content or air voids), the quality index consists of an upper (Q_U) and lower (Q_L) quality limit.

$$Q_U = \frac{(USL - \bar{x})}{s} \tag{4-9}$$

$$Q_L = \frac{(\bar{x} - LSL)}{s} \tag{4-10}$$

As discussed above, this research addresses only one-sided AQCs but it can be extended without too much difficulty to the two-sided AQCs that are more prevalent in asphalt concrete pavement. A table relating quality index values with the appropriate PWL estimate is shown in a table for various sample sizes from N = 3 to N = 30, see Appendix A (AASHTO, 1996b).

4.4 Pay Adjustments

In highway pavement construction, an AQC may fall just short of the specified quality level. It may not be acceptable but neither does it deserve 100% payment. This provides the DOT with a decision point at which to exercise its option to require removal and replacement, corrective action, or the assignment of a minimum pay factor for the lot. Therefore, a pay adjustment factor (PF) in the specifications is used to adjust the contractor's pay according to the level of quality achieved. A pay adjustment factor is the percentage of the bid price that the contractor is paid for the construction of a concrete pavement lot. A PF is calculated for each AQC (Darter et al., 2003; Hughes, 1996).

4.4.1 Pay Factor

A PF is a multiplication factor expressed as a percentage used to determine the contractor's payment for a unit of work. It is based on the estimated quality of work and

applies to only one quality characteristic (TRC, 2005). Slab thickness and strength have the same quality measure (i.e., the PWL). These two AQCs also use the same equations below (Equation 4-11 and 4-12) to calculate their PF. If the PWL is over 60%, which is most often the case, then Equation 4-12 must be used. A PWL of 60%, however, may be the cause for rejection. In this case, AASHTO specifies that the agency's engineers make a special evaluation of the material to determine whether it is to be rejected or whether to accept it at considerably reduced pay (AASHTO, 1996b). In this research, Equation 4-12 was used for an AQC with a PWL less of 60%. The assumption was made that concrete pavement is rejected 25% of the time when the PWL is less than 60%, and the other 75% of the time it is accepted at a reduced PF in accordance with Equation 4-11. The following pay adjustment equations were used in this research:

$$\text{If } PWL > 60 \quad \text{Then} \quad PF = 55 + (0.5 \times PWL) \tag{4-11}$$

$$\text{If } PWL \leq 60 \quad \text{Then} \quad PF = 0.75\left[55 + \left(0.5 \times PWL\right)\right] \tag{4-12}$$

As seen from Equation 4-11, if the percent of test results within the specification limits is equal to 90% for a lot, then the contractor's PF is 100%. Therefore the contractor receives 100% payment for that concrete AQC for that lot. If the percent of test results within the specification limits is greater than 90%, then the contractor's PF is greater than 100% and the contractor receives greater than 100% payment for that concrete AQC for that lot. The contractor receives a bonus when the PWL is greater than 90%.

The maximum PF that can be achieved for 100% of test results within the specification limits is 105% (i.e. a 5% bonus in payment). Mathematically, the pay factor equation would generate a pay factor of 55% if there were zero percent of test results within the specification limits. However, the state highway agency's specifications have clauses that deal with low pay factor material. If the PWL is between 60% and 90%, then

the contractor receives a penalty. It is up to the agency to reject or further reduce pay when the PWL is lower than 60% (AASHTO, 1996b).

For smoothness, on the other hand, the PF results are based on a California profilograph (0.2 inch BB) traversing at a speed no greater than three miles per hour. The price adjustment for smoothness is shown in Table 4-1.

Table 4-1. AASHTO Price Adjustment Factors for Smoothness

Index Profile ($PI_{0.2\text{-inch}}$)	**Price Adjustment**
Inches per Mile per 0.1-Mile Section	Percent of Pavement Unit Bid Price (%)
3 or less	105
Over 3 to 4	104
Over 4 to 5	102
Over 5 to 7	100
Over 7 to 8	98
Over 8 to 9	96
Over 9 to 10	94
Over 10 to 11	92
Over 11 to 12	90
Over 12	Corrective work required

AASHTO states that when the $PI_{0.2\text{-inch}}$ is greater than 5 inches per mile but does not exceed 7 inches per mile per 0.1-mile section, payment will be made at the contract unit price for the completed pavement. When the $PI_{0.2\text{-inch}}$ is greater than 7 inches per mile but does not exceed 12 inches per mile per 0.1-mile section, the Contractor may accept a contract unit adjusted price in lieu of correcting the surface to reduce the $PI_{0.2\text{-inch}}$. When the $PI_{0.2\text{-inch}}$ is less than or equal to 5 inches per mile, the contractor is entitled to an increase in payment or profit (AASHTO, 1993).

4.4.2 Composite Pay Factor

The ultimate performance of most construction items is dependant upon several characteristics. Statistical construction specifications based on multiple AQCs use payment equations that include a separate term for each of the AQCs so that the resultant payment adjustment is a function of the combined effect of all quality measures. A composite factor (CPF) considers two or more quality characteristics and is used to determine the contractor's final payment for a unit of work (TRB, 2005; Burati et al., 1995). There are four different methods to calculate the composite pay factor pay factor: Weighted Average (CPF_{WAve}), Averaging Method (CPF_{Ave}), Summation Method (CPF_{Sum}), and the Product Method (CPF_{Prod}):

$$CPF_{WAve} = \frac{\sum_{i=1}^{n}(PF_i \times Wt_i)}{\sum_{i=1}^{n}(Wt_i)} \times 100 \tag{4-13}$$

$$CPF_{Ave} = \frac{\sum_{i=1}^{n} PF_i}{n} \times 100 \tag{4-14}$$

$$CPF_{Sum} = \left[\left(\sum_{i-1}^{n}(PF_i - 1)\right) + 1\right] \times 100 \tag{4-15}$$

$$CPF_{Prod} = \left(PF_1 \times PF_2 \times \ldots PF_n\right) \times 100 \tag{4-16}$$

The CPF_{WAve} method is different than the rest of the CPF equations because it considers a respective weight (Wt_n) for each PF. The value of each weight is determined through empirical observation or other engineering considerations. None of these methods is considered more correct than the other. There are many perspectives with regard to the actual value added for various quality attributes and their interrelationships are not completely understood (AASHTO, 1996a).

A cap is placed in order to put a limit on the highest CPF percentage a contractor can achieve. A CPF equation often includes a cap to define the minimum and/or maximum CPF allowed. The default cap that was used in this research was a cap of 108%. Therefore, when the calculated CPF exceeds the cap, the contractor receives only 108% payment.

4.5 Methods for Selecting Target Quality

Contractors are responsible for concrete pavement projects. Therefore, it is up to the contractors to establish a target quality level, target value, for each design (*D*) AQC value specified. According to Transportation Research Circular E-C074 (TRC, 2005):

"A target value is a number established as a goal for operating a given process. Once it is established, adjustments should be made in the process as necessary to maintain a central tendency about the target value. The target value for a quality characteristic is established by the contractor based on economic considerations. It may not be the same as the agency-established design value (obtained from structural or mixture design, or both) or the specified AQC value."

It is necessary for contractors to maintain a central tendency about the target value. There are two types of approaches in selecting target values: deterministic and probabilistic.

4.5.1 Deterministic Method

The most common method employed by contractors to establish target quality levels under QA specifications will be referred to as the deterministic method. The deterministic method is more of a mathematical thought process than a formal recognized method. Deterministic methods have predictable and repeatable input-output relationships. They contain no random variables. Contractors who use the deterministic

method often rely greatly on engineering judgment, intuition, and their past experience with the specifications to set target quality levels for specific projects. The deterministic method is based on an assumption that the sample statistics are equal to the population (e.g., lot) parameters. For example, if a contractor submits a lot having a compressive strength of PWL of 90, the assumption is that the acceptance sample taken from that lot will result in a compressive strength lot PWL estimate of 90%.

Figure 4-3 shows a decision tree of the deterministic structure that is used in this research. The deterministic method can be used by the contractor to assist in establishing a bid. The questionnaire survey, however, indicated most contractors use it prior to construction, as that is when they set target values. At any rate, before the bidding takes place, the contractor already knows the three design AQCs (e.g., thickness, strength, and smoothness) that are specified. Depending on the increment used, each design AQC has potential target AQC that is associated with different pay percentages. Each AQC pay is then combined to form one composite pay that calculates a certain profit. The contractor evaluates them and chooses the best AQC target value combination that will maximize profit before the bid phase (or, if so inclined, prior to construction).

To better understand the deterministic approach, the AQC values that were used for this example can be seen in Table 4-2. In addition, it will be assumed that the contractor's process capabilities reflect the standard deviations, which include sampling and testing error. Table 4-3 shows 15 different potential target quality levels with five target means (μ_T) for each of the three AQCs mentioned in Table 4-2.

The default change in cost was used. The deterministic approach uses the standard normal curve. The z- value is calculated by using the following equation:

$$z - value = \frac{(\bar{x}_T - LSL)}{\sigma} \tag{4-17}$$

Table 4-2. AQC Values and their Measures for Deterministic Example Problem

	Thickness	**Compressive Strength**	**Surface Smoothness**
Measure	core	28-day core	$PI_{0.2\text{-inch}}$
D	11 in	4,000 psi	7 in/mile
$\boldsymbol{\sigma}$	0.3 in	600 psi	1 inch/mile
LSL	10.8 in	3,200 psi	NA
n	4/lot	4/lot	one per 0.1 mile section
PF	Equations (4-11) and (4-12)		Use Table 4-1
CPF	$CPF_{Prod} \leq 108\%$		

The PWL is the area under the normal curve and is determined by looking up the z-value in the standard normal curve table, see Appendix A. The PF is calculated using the PWL. The percent pay increase/decrease and profit is calculated using the following two equations:

$$Percent\ pay\ increase/decrease = PF - 100 \tag{4-18}$$
$$Profit = percent\ pay\ increase/decrease - Cost \tag{4-19}$$

As seen in Table 4-3, if the contractor were to target (and achieve) a compressive strength of 4,500 psi with a standard deviation of 600 psi, the submitted lot will have an actual PWL of 98.46%, and the acceptance sample taken from the lot will yield a lot PWL estimate of 98.46%. That PWL estimate corresponds to a PF of 104.23%, or a pay increase of 4.23%. Since the relative cost to produce a compressive strength mean of 4,500 psi and a standard deviation of 600 psi is 1%, the contractor's extra profit is 3.23% for that individual AQC.

According to Table 4-3, the most profitable target quality levels for the contractor is a thickness of 11.5 in, a compressive strength of 4,500 psi, and a smoothness profile index of 3 in/mi. In this case, the profit calculations are made independently for each

AQC and do not consider the effect of the CPF equation on profit. If the CPF equation is taken into effect, the most profitable target values may actually be other than those identified in Table 4-3.

For example, considering the effect of the CPF equation, the contractor will have to do a trial and error approach with the AQCs to find the combination that is most profitable. Considering the CPF_{Prod} equation with a cap of 108% for the target values identified as most profitable in Table 4-3, the calculated composite pay is 114.37%. This composite pay goes over the cap of 108%. Therefore, the contractor can only receive 108%, a profit of 2% as the cost to achieve that particular target value combination is 6%. This is an indication that the overall target quality might be higher than necessary. In this case, the contractor needs to explore different scenarios with one or more lower-quality, lower-cost AQC target values that will result in a calculated composite pay closer to 108%.

Decreasing the target thickness from 11.5 inches to 11 inches and keeping the strength and smoothness the same may not yield the maximum profit. Such a decrease in thickness will yield a calculated composite pay of 100.98% and a profit of −2.02%. However, increasing the target thickness from 11 inches to 11.25 inches, after interpolation, (having the same strength and smoothness) will equal a composite pay of 108%, which will yield a profit of 3.5%.

Another possibility is to change the compressive strength from 4,500 psi to 4,000 psi and keeping a thickness of 11.5 inches with a smoothness of 3 in/mi. This will yield a profit of 3%. Further, keeping the change in mix design to 4,000-psi concrete strength with a simultaneous increase in smoothness $PI_{0.2\text{-inch}}$ from 3 in/mi to 4 in/mi, and a

thickness of 11.25 inches the calculated CPF will equal 108 with a profit of 3.16%. Similarly, an increase in strength from 4,000 psi to 4,500 psi with a thickness of 11.25 inches and a smoothness of 4 in/mi, will yield a profit of 4%. Similarly, a thickness of 11.5 in, strength of 4,500 psi, and a smoothness of 7 in/mile will also equal a profit of 4%.

Each combination of target values changes the contractor's profit. Using the deterministic approach, the two target AQC combinations that achieved the highest profit of 4% is the following:

- A thickness of 11.25 in, strength of 4,500 psi, and a smoothness of 4 in/mi
- A thickness of 11.5 in, strength of 4,500 psi, and a smoothness of 7 in/mi

Clearly, the maximum payment cap on the composite pay factor, along with the incremental cost of higher quality levels, have the effect of discouraging contractors from targeting especially high levels of quality. In addition, in some cases like this, the inclusion of a cap makes it more profitable for a contractor to target a decreased quality level for one or more individual quality characteristics and still be assured of obtaining a higher profit.

4.5.2 Probabilistic Method

The probabilistic approach, unlike the deterministic, evaluates different construction scenarios by eliminating the assumption regarding sample statistics. Probabilistic models account for system uncertainties and can be considered only as estimates of the true characteristics of a model. In determining price adjustments, the probabilistic approach takes the risks associated in concrete cement pavement construction variability into consideration. Moreover, the statistic could either be favorable or unfavorable to the contractor.

Figure 4-4 shows a decision tree of the probabilistic structure that is used in this research. It starts off in a similar manner as the deterministic method, but the probabilistic has four different types or risks associates with each AQC, which also calculate to four different costs for each risk. Each AQC pay, for each risk, is then combined to form one composite pay that calculates to a certain profit. The contractor evaluates them and chooses the best AQC combination that will maximize profit. Figure 4-4 only shows two targets for each AQC. The more target quality, more increments, and more AQCs, the more difficult it may become. In this case, the trial by error can get complex and take too long. Figure 4-4 only shows a few AQC combinations. The combinations that make up each CPF are the numbers that are shown in subscript.

The statistical calculations and the trial and error aspects of the problem, lend themselves to a computer-based approach. This led the development of a spreadsheet program that uses Macros and Visual Basic called Probabilistic Optimization for Profit (Prob.O.Prof).

A simulation technique, known as Monte Carlo simulation, draws values from the probability distributions for each target AQC input variable, and uses these values to compute single economic output values (e.g., single pay, profit, and composite pay). This sampling process is repeated thousands of times to generate a probability distribution for four types of risk probabilities. A more detailed description of this process is provided in Chapter 5.

4.6 Evaluating Probabilities of Risks in Concrete Pavement Construction

Prob.O.Prof draws on Monte Carlo computer simulation to arrive at four quality level percentiles from any desired thickness, strength, or smoothness population: upper 25th percentile (25% risk taker), 50th percentile (50% risk taker), lower 25th percentile

(75% risk taker), and lower 5th percentile (95% risk taker). In this dissertation, the word "risk" simply means "the probability of an outcome". A contractor trying to achieve a certain target acceptance quality characteristic cannot be sure what the test values will turn out to be, due to the variability of the test data. The test data may come out with low or high values, resulting in penalties or bonuses for the contractor. For example, a very optimistic contractor is said to be a 25% risk taker. This means that the AQC PF will be expected to come out at the upper 25th percentile of the population. The 50% risk taker is said to be neutral in respect to risks and therefore expected to come out at the median of the population. The pessimistic contractor is not sure if he/she will achieve the target AQC. A contractor that is uncertain in this situation is said to be a 75% risk taker or a 95% risk taker, depending on the percent of uncertainty. The 75% risk taker (moderately averse in taking a risk) means that the AQC PF will be expected to come out at the lower 25th percentile of the population. The 95% risk (highly risk averse) taker means that the AQC PF will be expected to come out at the lower 5th percentile of the population.

There may be some reasons why a user would want to make a decision based strictly on one specific risk probability, particularly when a project consists of only one or two lots. One such scenario is the case of a contractor who has obtained information just prior to or during construction to indicate that acceptance test results will be favorable. It may be due to a change in testing personnel or testing equipment, anticipation of ideal weather conditions or other conditions conducive to high-quality construction, etc. This contractor might then select the 25th percentile knowing that it allows him/her to decrease the target quality level, thereby decreasing his/her costs and leading to a greater profit (if indeed the test results are favorable as is assumed by this

risk taking contractor). However, it is recommended for the majority of applications that the user first examine Prob.O.Prof's output target value recommendations before committing to a specific risk probability. The user can in this manner gain information that could be helpful in the decision process.

In examining the totality of the profit information obtained from Prob.O.Prof's output, one must be careful to interpret correctly. For any target value, the 25th percentile profit can be expected to be exceeded 25% of the time; the 50th percentile profit can be expected to be exceeded 50% of the time; the 75th percentile profit can be expected to be exceeded 75% of the time; and the 95th percentile profit can be expected to be exceeded 95% of the time. A helpful way to view the risk probabilities is to look at the 25th and 75th percentile profits associated with a given target value as the higher and lower limits of a confidence interval centered at the 50th percentile profit. Thus for any given target quality level, the user can expect 50% of the time (75% minus 25%) to receive a profit between the profits indicated at the 25th and 75th percentiles, 70% of the time (95% minus 25%) to receive a profit between the profits indicated at the 25th and 95th percentiles, etc.

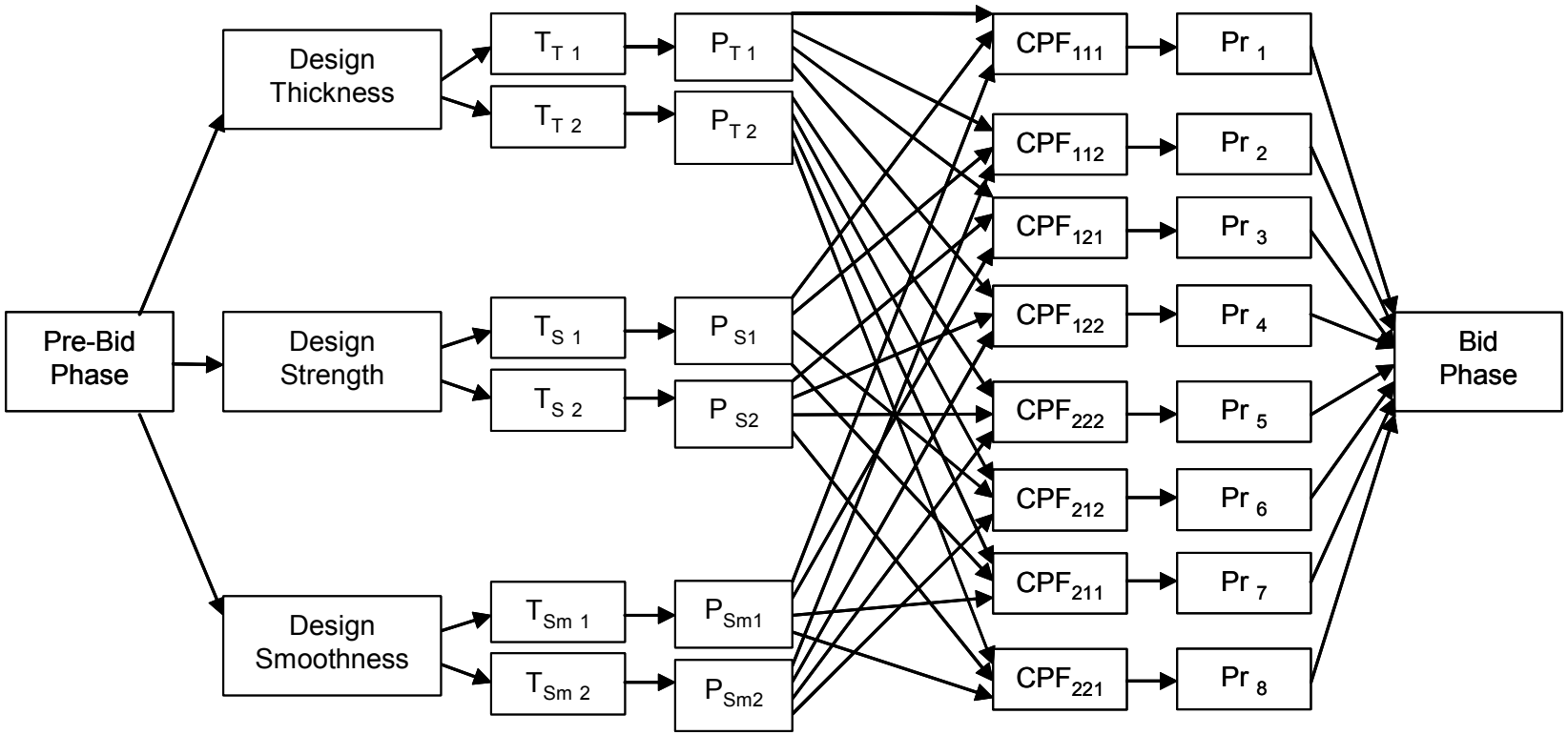


Figure 4-3. Deterministic Model. T_T = Target Thickness, T_S = Target Strength, T_{Sm} = Target Smoothness, P_T = Thickness Pay (%), P_S = Strength Pay (%), P_{Sm} = Smoothness Pay (%), CPF = Composite Pay Factor, Pr = Profit (%)

Table 4-3. Deterministic Method for Selecting Target Quality Levels

AQC	Potential Target $\mu_T = \bar{x}_T$	z-value	PWL	PF (%)	Pay +/-(%)	Cost (%)	Profit (%)	Max-Profit AQC Target
Thickness (in)	10.0	-2.67	0.39	41.40	-58.6	-6	-52.6	
	10.5	-1.00	15.87	47.20	-52.8	-3	-49.8	
	11.0	0.67	74.54	92.27	-7.73	0	-7.73	
	11.5	2.33	99.01	104.51	4.51	3	**1.51**	◄
	12.0	4.00	100.00	105.00	5.00	6	-1.00	
Compressive Strength (psi)	3,000	-0.33	37.07	55.15	-44.85	-2	-42.85	
	3,500	0.50	68.79	89.40	-10.6	-1	-9.60	
	4,000	1.33	90.82	100.41	0.41	0	0.41	
	4,500	2.17	98.46	104.23	4.23	1	**3.23**	◄
	5,000	3.00	99.87	104.93	4.93	2	2.93	
Surface Smoothness (in/mi)	3.0	NA	NA	105	5	2	**3**	◄
	5.0	NA	NA	102	2	1	1	
	7.0	NA	NA	100	0	0	0	
	9.0	NA	NA	96	-4	-1	-3	
	11	NA	NA	92	-8	-2	-6	

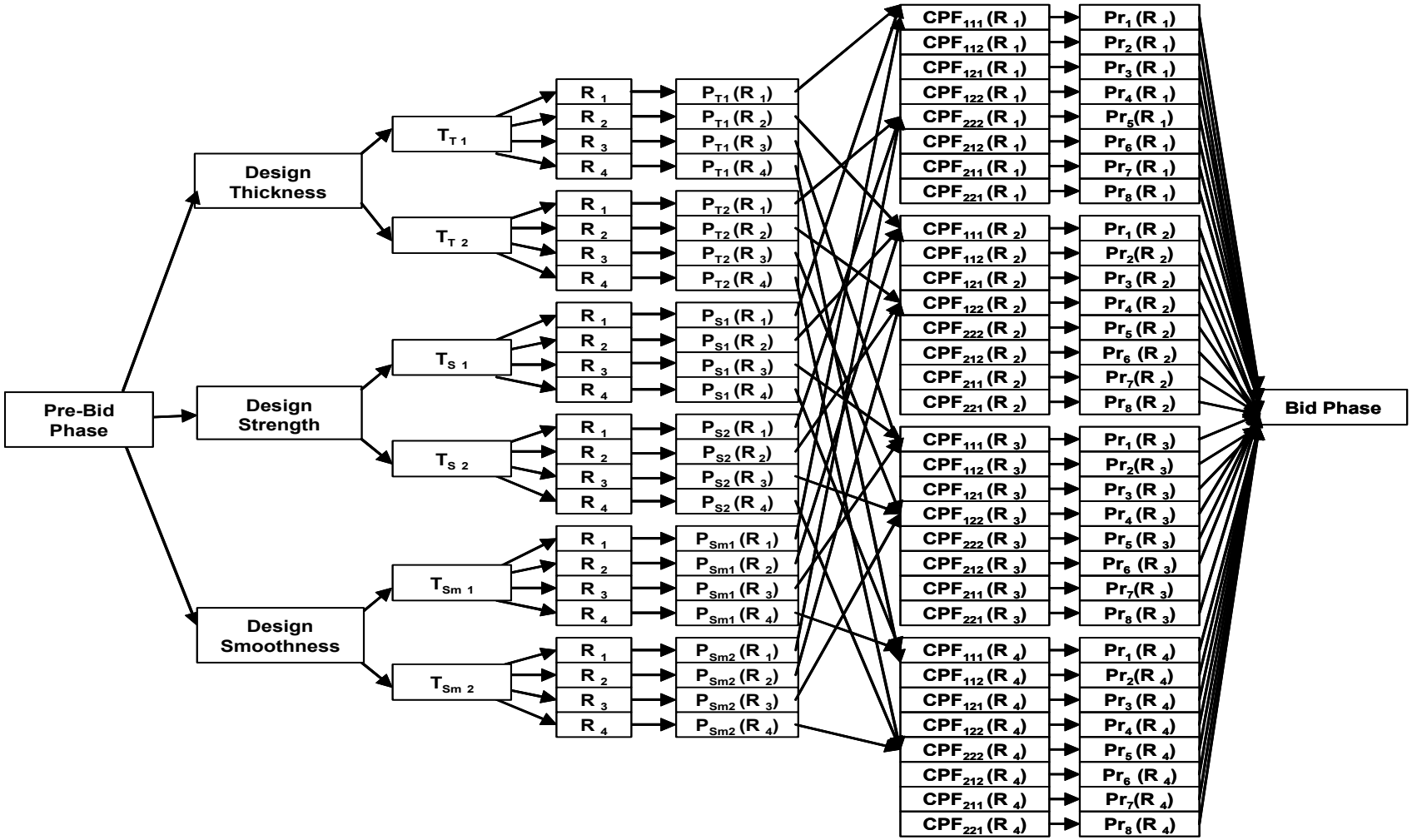


Figure 4-4. Probabilistic Model. T_T = Target Thickness, T_S = Target Strength, T_{Sm} = Target Smoothness, R = Risk Probability (%), P_T = Thickness Pay (%), P_S = Strength Pay (%), P_{Sm} = Smoothness Pay (%), CPF = Composite Pay Factor, Pr = Profit (%)

CHAPTER 5
COMPUTER PROGRAMMING AND ANALYIS

5.1 Introduction

Under statistical quality assurance specifications, contractors are responsible for the quality of concrete pavements. Their acceptance of the quality is based on the end result that is achieved. In the past, acceptance was written on a pass-fail basis with little consideration given to variability. Today, a development of adjustable payment plans set payment levels that accurately reflect diminished or enhanced value of the completed work (Chamberlin, 1995).

5.2 Purpose of Computer Program

The purpose of developing a computer program is to address the optimization of target quality levels for an associated risk probability. This will allow the contractor to target the levels of quality during the pre-construction phase or construction phase that will obtain high quality and maximize profit cost. In addition, it will help SHAs in validating their quality assurance specifications and pay adjustment provisions. In order to achieve this, a simulation technique known as Monte Carlo simulation was used.

5.2.1 Computer Program Development

The most common frequency distribution in nature is the normal distribution. The vast majority of highway construction measurements use normal random numbers. In order to evaluate the quality factors used in highway concrete pavement construction, it is necessary to have a method to generate random data that is essentially identical to the normally distributed data produced at a highway construction site. This is accomplished

by developing a computer subroutine to generate random numbers from a standard normal distribution (*NORM*) having a mean and standard deviation with any desired quality level in terms of PWL. The simulated construction variable (*X*) is as follows:

$$X = \overline{X} + \sigma \times NORM \tag{5-1}$$

There are a variety of algorithms available for generating normal random numbers. They all require several lines of coding and are computationally intensive that they tend to slow the execution of any program using thousands or replications.

Computer simulation is one of the most powerful analysis methods available for solving a wide variety of complex problems. Most simulations require only the following steps:

- Generate random data simulating the real process
- Apply the procedure that is to be tested
- Store the results in memory

This sequence of steps is then repeated many times to provide a large database to use to perform an analysis. In this manner, it is possible to accurately assess the performance of the procedure under evaluation. Computer simulation is particularly useful for problems for which direct, closed-form solutions do not exist or for which very complex mathematics would be required. They are able to provide users with practical feedback when designing real world systems. Highway acceptance procedures based on *PD* or PWL fall into this category and, in many cases, computer simulation is the only practical means of analysis (Weed, 1996b).

A different number of lots were simulated (e.g., 20, 100, 500, 1,000, 1,500, 2,000, and 2,500) for each individual AQC to determine the number of random values to generate. Each simulation was performed five times (five trials) for each risk probability

(e.g., upper 25th percentile, median, lower 25th percentile, and lower 5th percentile). In addition, an average of each simulated trial was then calculated for each risk probability. The variation of concrete pavement thickness pay adjustment, depending on the number of lots used, was simulated using a mean of 12 inches and a standard deviation of 0.5 inches. It simulated five thickness samples per lot and then calculated the average thickness and standard deviation per lot, then the quality index, PWL Figure 5-1 shows the convergence of pay decrease starts to take place at 1,500 simulated lots used.

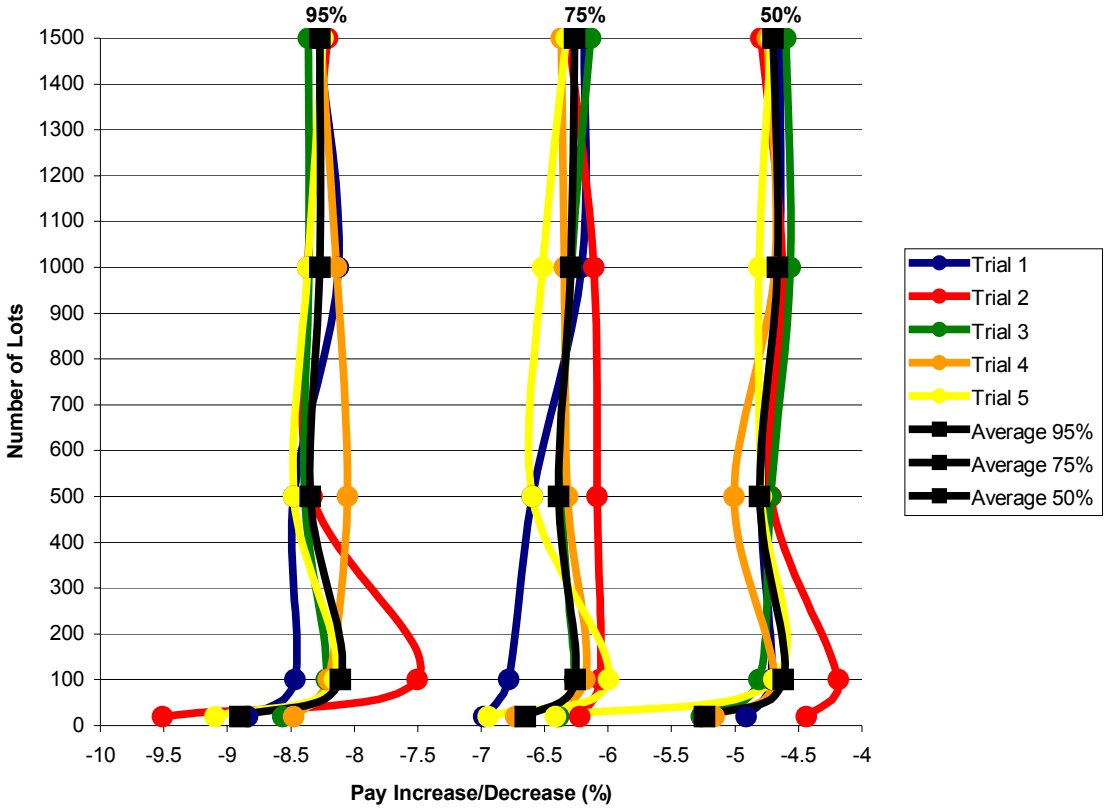


Figure 5-1. Variation of Average Thickness Depending on Number of Lots Used

The variation of average concrete pavement strength depending on the number of lots used was simulated using a mean of 3,200 psi, and a standard deviation of 500 psi. It simulated five strength samples per lot and then taken the average strength per lot. Figure 5-2 shows that convergence of pay decrease takes place at 2,000 simulated lots used.

The variation of average concrete pavement surface smoothness depending on the number of lots used was simulated using a mean of 3 in/mile, and a standard deviation of 1 in/mile. A simulation of the smoothness for each lot was calculated and then computed an average of inside and outside wheel paths for each lot. Figure 5-3 shows that convergence of pay increase takes place at 2,000 simulated lots used. Each AQC figure is also separated into three risk probabilities (e.g., ., upper 25th percentile, median, lower 25th percentile, and lower 5th percentile).

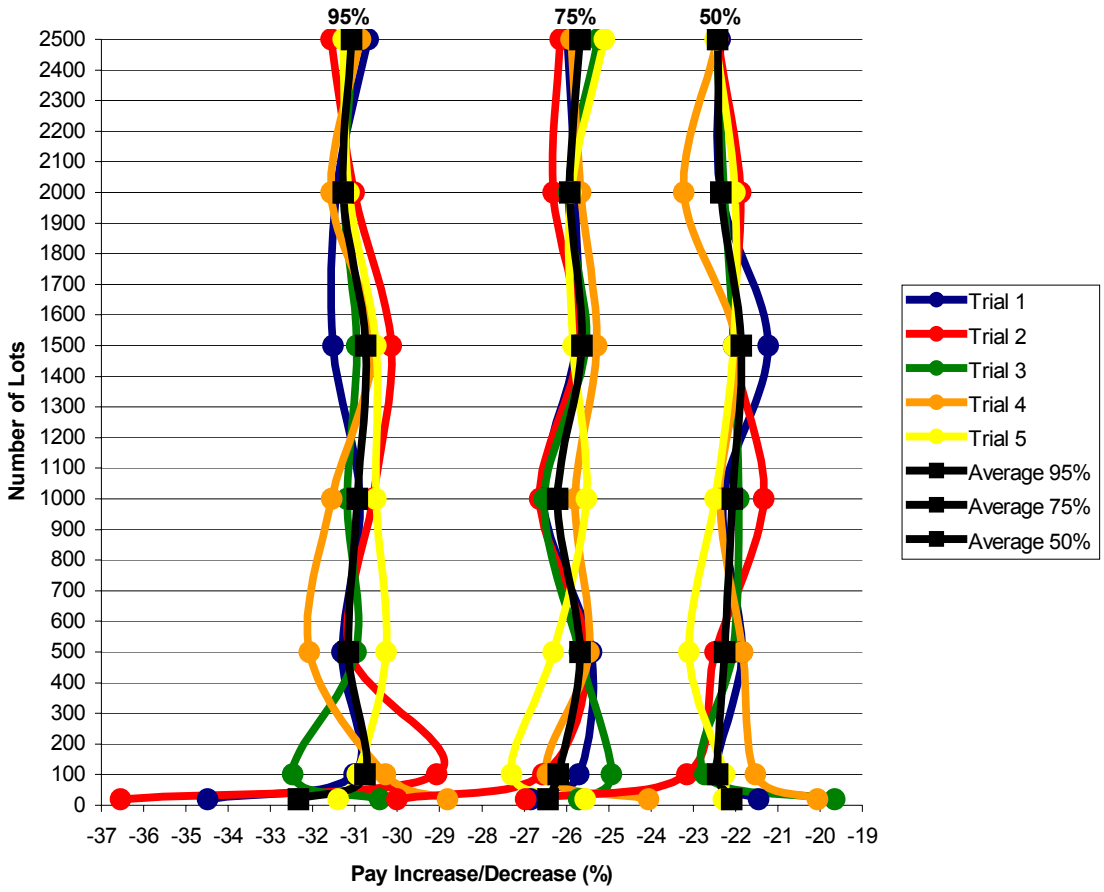


Figure 5-2. Variation of Strength Pay Adjustment Depending on Number of Lots

It was found through this analysis that as the number of lots increased, the spread of the data (e.g., variations of thickness, strength, and smoothness) converged. It was concluded to use a simulation of 2,000 lot-repetitions for the computer program to obtain the pay and profit for each incremental change of cost for each AQC.

It was pointed out to the author that the Figure 5-3 sinusoidal pattern with all trial points behaving together is likely more than simply coincidental. The author agrees and adds that the same patterns are also recognizable in Figures 5-1 and 5-2 (although to a lesser degree because of the different x-axis scales). The problem certainly needs to be investigated further, and the author is doing so. With respect to its effect on current Prob.O.Prof output, the pay increase/decrease values in Figures 5-1 through 5-3 are seen to converge by increasing the number of runs as should be expected, although perhaps not as quickly as could be expected. This and other performed checks on the Prob.O.Prof outputs used to draw conclusions in this thesis indicate that the risk probability profits are nonetheless reasonable and fairly accurate.

5.2.2 Monte Carlo Method

The Monte Carlo Method encompasses the technique of statistical sampling to approximate solutions to quantitative problems. This method can solve probability-dependent problems where physical experiments are impracticale and the creation of an exact formula is impossible. It involves determining the probability distribution of the variables under consideration and then sampling from this distribution by means of random numbers to obtain data. In effect, a generation of a large number (e.g., 100 – 1,000) of synthetic data sets generates a set of values that have the same distributional characteristics as the real population. (Manno, 1999; Thierauf, 1978).

The Monte Carlo Simulation method was used in the computer program to simulate the AQC samples per lot as if their samples were taken from the field. This method draws values from the probability distributions for each design AQC input variable, and uses these values to compute single economic output values (e.g., single pay, profit, and composite pay). This sampling process is repeated thousands of times to generate a

probability distribution for four types of risk probabilities, which were described in Chapter 4.

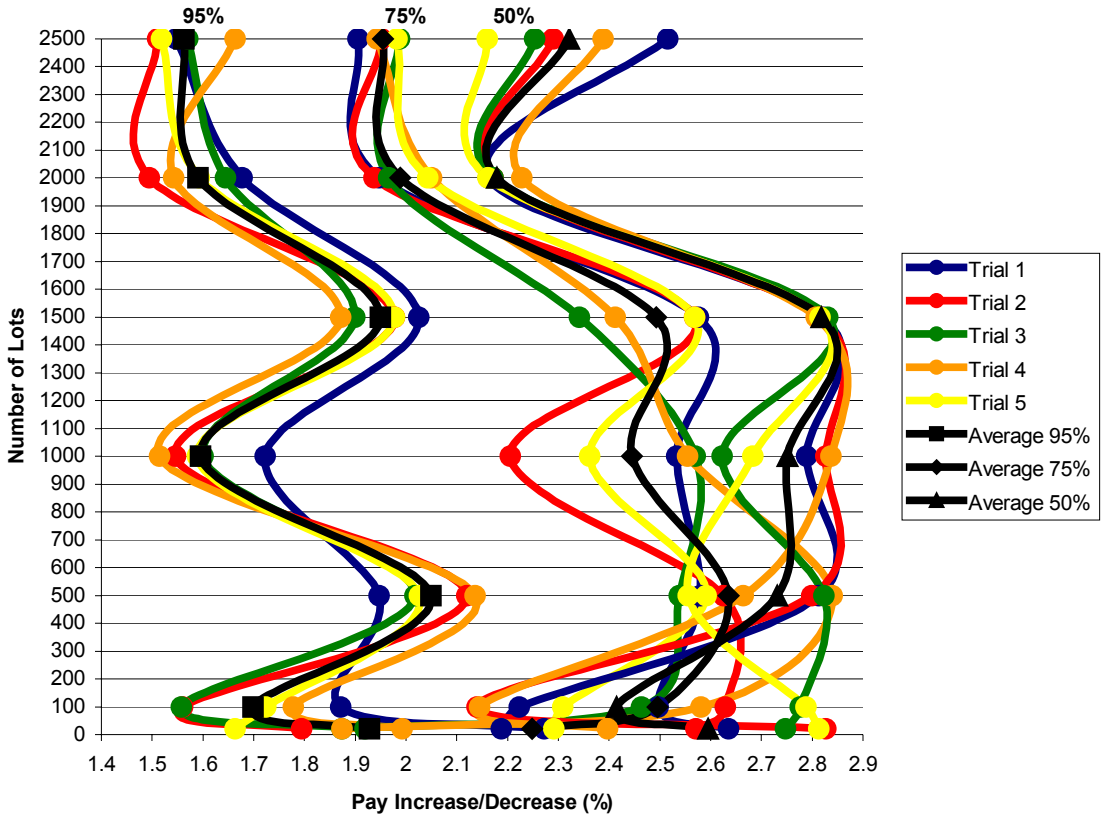


Figure 5-3. Variation of Smoothness Pay Adjustment Depending on Number of Lots

5.3 Program Structure

As mentioned before, this program uses Macros/Visual Basic. It is designed to generate pay factors for each AQC that will result in a combined target AQC that will maximize profit. As mentioned in Chapter 4, the default cost of change in quality used in the computer program was attained by a questionnaire and by IPRF (Hoerner and Bruinsma, 2004). The default cost for each incremental change of AQC can be changed so that the user can input other cost values. This program is limited for use of three to nine samples per lot for thickness and strength. In addition, the program is limited for use of 0.1 to seven miles of total sub lots for smoothness. However, the program can easily be modified to enable more PWLs of more than nine samples per lot for thickness and

strength. This program only uses the English unit system. This can also be easily modified to include the Metric system in later use.

The flowchart of the program is shown in Figure 5-4. The first step is to input the number of concrete pavement AQCs (thickness, strength, and smoothness) that will be analyzed. The user should input “one” for one AQC, “two” for two AQCs, or “three” for all three AQCs. If the thickness is chosen to be analyzed, the following should be inputted:

- The thickness design value that is specified in the construction specifications.
- The LSL for thickness.
- The standard deviation for thickness.
- The thickness target value increment to be analyzed.
- The number of samples per lot.
- The percent cost values of the bid price. A default cost will automatically be used if there are no input values.

If the strength is chosen to be analyzed, the following should be inputted:

- The type of concrete strength test used (e.g., compressive strength or flexural strength).
- The strength design value that is specified in the construction specifications.
- The LSL for strength.
- The standard deviation for strength.
- The number of samples per lot.
- The strength target value increment to be analyzed.
- The percent cost values of the bid price. A default cost will automatically be used if there are no input values.

If the smoothness is chosen to be analyzed, the following should be inputted:

- The type of index used for smoothness (e.g., $PI_{0.2\text{-inch}}$, or IRI).
- The smoothness design value that is specified in the construction specifications.
- The standard deviation for smoothness, for simulation purposes.
- The smoothness target value increment to be analyzed.
- The percent cost values of the bid price. A default cost will automatically be used if there are no input values.

Once all the AQC parameters are inputted, the program runs the Monte Carlo simulation. Random numbers are picked for each QI from a normal distribution. The QI is then calculated for each average thickness and strength for each lot. Each AQC is then placed in descending order to identify the QI for the upper 25th percentile, median, lower 25th percentile, and lower 5th percentile. Depending on the number of samples taken per lot, the QI is looked up in a matrix table to find the PWL for the associated thickness and strength. The PF is then calculated using the PWL.

However, the Monte Carlo simulation for smoothness is different. Smoothness does not use the PWL to measure the quality. The randomly generated test results for smoothness are directly entered into the AASHTO pay factor table to look up the PF for each smoothness result. The PF values are then placed in descending order to identify the corresponding PF for each risk probability. Knowing the pay and the cost, the profit is then calculated for each AQC at each risk probability.

The user should input a percent cap before selecting the composite pay method to calculate the CPF for each AQC combination. The default cap that the program uses is 108%. There are four composite pay methods to choose from: weighted average, average, summation, and product. There is no composite pay method considered more correct than the other because there are many perspectives with regard to the actual value added for

various quality attributed. In addition, the quality interrelationships are not completely understood (AASHTO, 1996a).

Once the user selects the composite pay method to use, a list of 27 combinations of AQCs for each risk probability is ranked from one to 27 (rank number one being the one with the highest profit). The best three ranked combinations that give the highest profit are highlighted so the user can easily see and choose the combined target quality. The user can choose another CPF method. This will automatically change the combined target AQCs and profit. It is also easy for the user to go back and make any changes and rerun the program.

5.4 Computer Program Output Variability

The variability between the number of runs performed and the composite pay method used was analyzed. The input values that were used for this analysis are shown in Table 5-1. Cost plays a major role in selecting the target quality. Depending on the incremental cost used for an AQC, the analysis can change dramatically. For the example used to find variance, the default incremental change in AQC cost was used and the AQC target combinations with the three highest profits were analyzed.

Table 5-1. AQC Properties Used

AQC	Weight (%)	μ	LSL	σ	n	Increment
Thickness	3	11 in	10.8 in	0.3 in	4	0.5 inch
Strength	3	4,000 psi	3,200 psi	600 psi	4	500 psi
Smoothness	5	7 in/mile	-	1 in/mile	10	2 in/mile

The average, standard deviation, and variance were calculated for the overall 10 trials that were executed from the program. These trials have been analyzed and the AQC variability output is shown in Table 5-2.

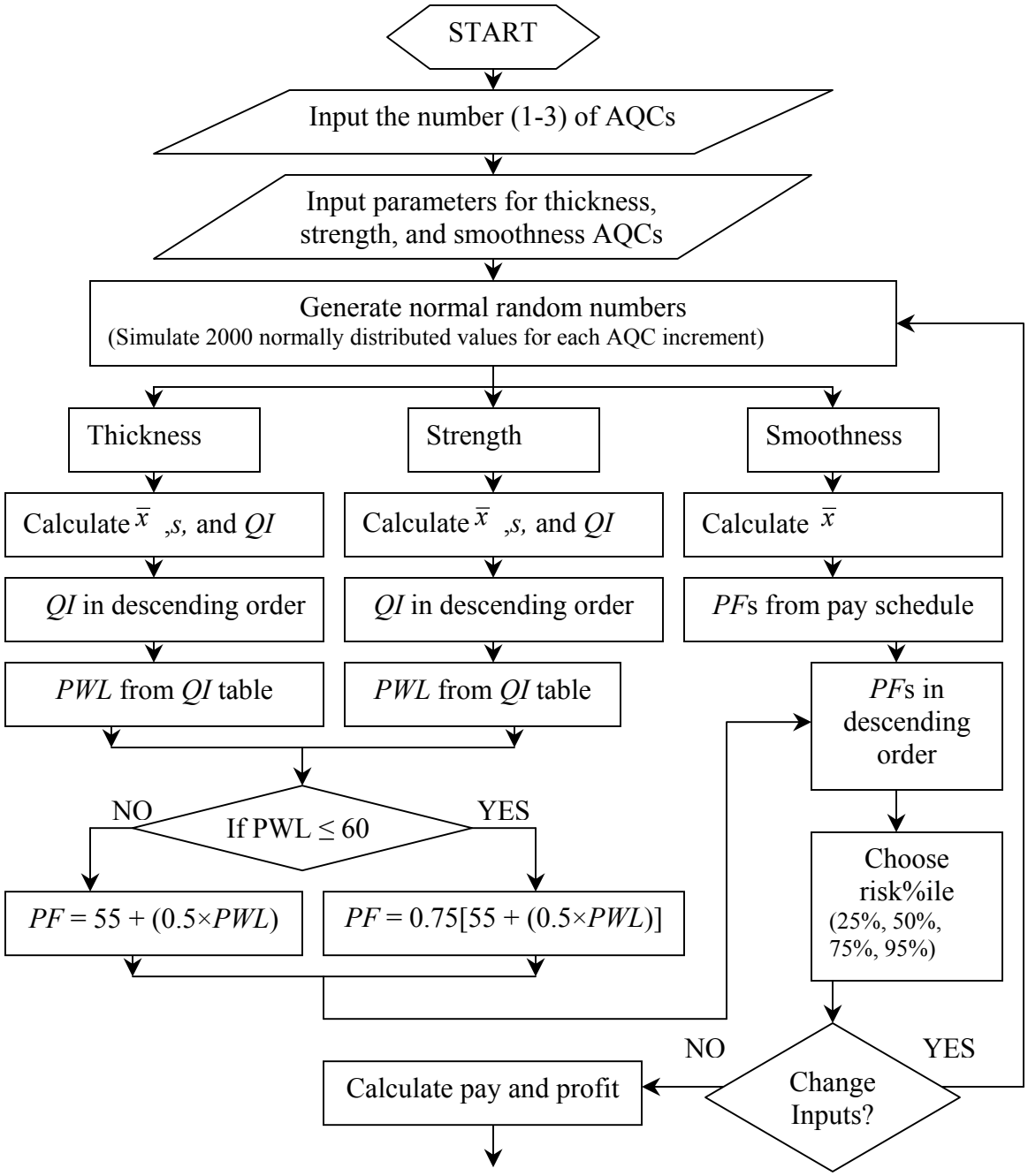


Figure 5-4. Computer Program Flow Chart. The user should be cautioned that Prob.O.Prof had not fully been beta tested.

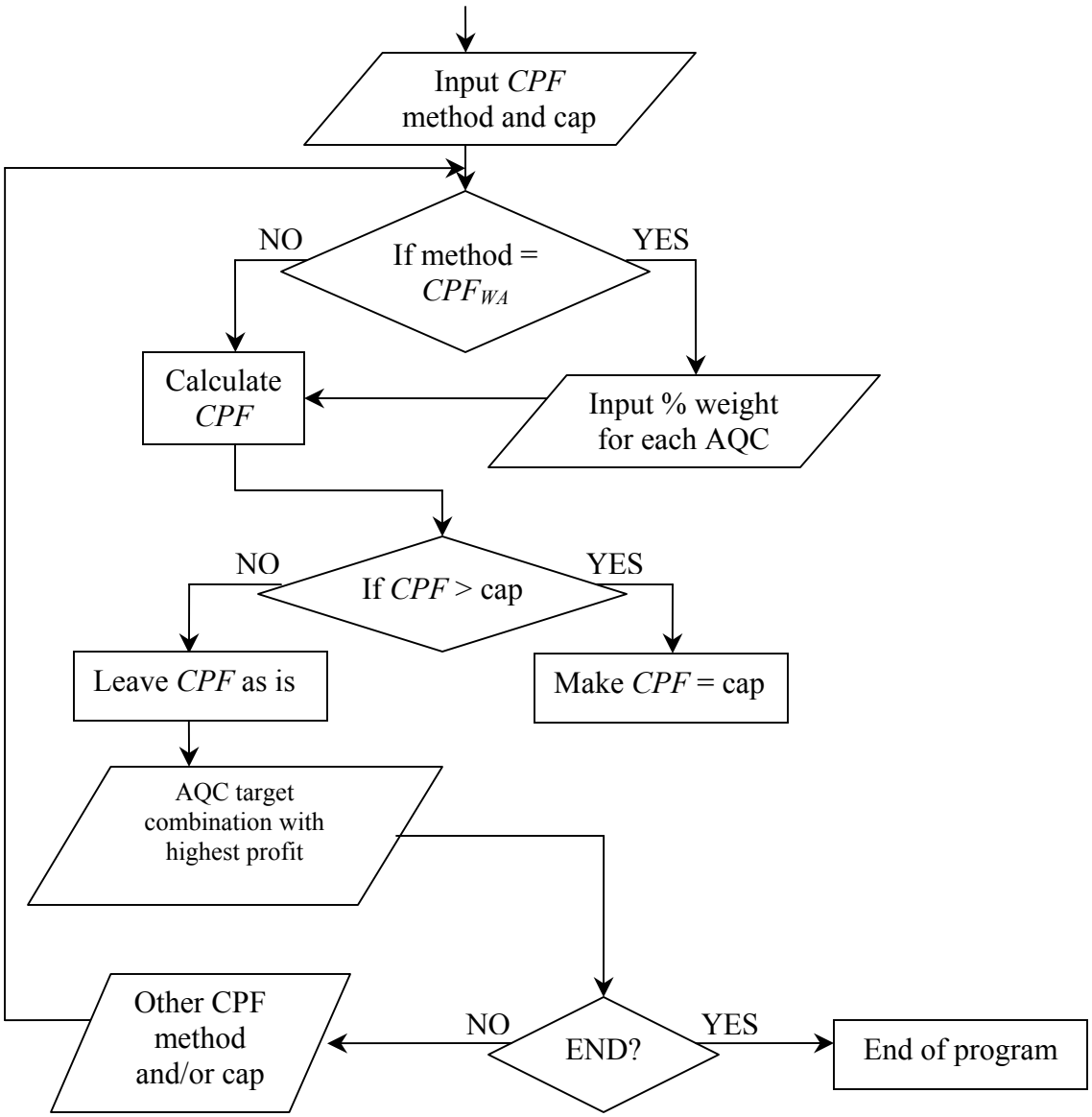


Figure 5-4. Computer Program Flow Chart (Continued). The user should be cautioned that Prob.O.Prof had not fully been beta tested.

The table is arranged to show where there was variability (marked in an “x”) for every composite method and three top combined AQC ranks used. For example, using the summation method and the number one ranked combination, variability occurred only at the 95th percent risk probability for profit. This means that the profit at the 95th percent risk probability may vary while the rest stay consistent on every run. The overall table shows that the majority of the variability takes place in the 95th percent risk probability. The contractor who is highly averse in taking a risk under the circumstances will have to account that the 95th risk probability in AQCs and profit may vary.

Table 5-2. Variability in AQC Combinations

Composite Pay Method	Rank	Variability in Target AQC															
		Thickness				Strength				Smoothness				Profit			
		95%	75%	50%	25%	95%	75%	50%	25%	95%	75%	50%	25%	95%	75%	50%	25%
Weighted Average	1	X								X				X			
	2	X				X				X				X		X	X
	3	X				X				X				X	X		X
Average	1													X	X		X
	2									X	X			X	X	X	X
	3									X	X	X	X	X	X	X	X
Summation	1													X			
	2	X				X		X						X			
	3	X				X				X				X	X	X	X
Product	1									X				X			
	2	X				X				X				X			
	3	X				X				X				X	X		X

It was also found that the type of composite method used can play a role in the outcome of the profit achieved. Figures 5-5 through 5-7 shows the profit versus the percent risk probability for each composite pay method for only the three top-ranked combined target AQCs. As seen in Figures 5-5, the Summation and Product methods compute the same profit outputs for the number one rank. The other ranks (e.g., number 2 and 3) can vary less than a percent difference but still compute very close to the same profit. In this example, the Summation and Product methods will always compute the

highest profit because of the use of multiplication. The Weighted Average and Average methods obtain lower profits but the Weighted Average computes the lowest compared to the rest of the composite pay methods. This is because it depends on the percent weight used for each AQC.

All of these composite pay methods give an increase in profit as the risk probability increases (e.g., upper 25th percentile). However, it should be noted that the profits shown in Figure 5-5 and in Table 5-3 cannot be compared for different risk probabilities of a given AQC in order to arrive at the best target value. The 25th risk probability will always contain the highest relative profit no matter what composite method is used. This is because the 25th risk probability uses the computer program in anticipation of getting favorable sample statistics. As the anticipation is to receive higher pay, the risk taker's expected profit is always greater than those at the 50th, 75th, or 95th percentiles. There is a risk/return trade-off. That is, the greater risk accepted, the greater must be the potential return as reward for an uncertain outcome. Generally, this may only happen if the contractor obtains extremely good test results.

5.5 Probabilistic Optimization for Profit

Prob.O.Prob allows the user to input the AQC parameters and analyze the output results. In order for the user to understand how Prob.O.Prof can be beneficial, an illustrative exercise will be worked through. The executed results for the exercise can be seen in Table 5-3. This table was developed using Prob.O.Prof. The table establishes the contractor's profit for the same 15 quality levels that were evaluated using the deterministic method in Chapter 4. The same AQC parameters from the deterministic approach example were used for this example. In addition, the default incremental change in cost for each AQC is used and a cap of 108%.

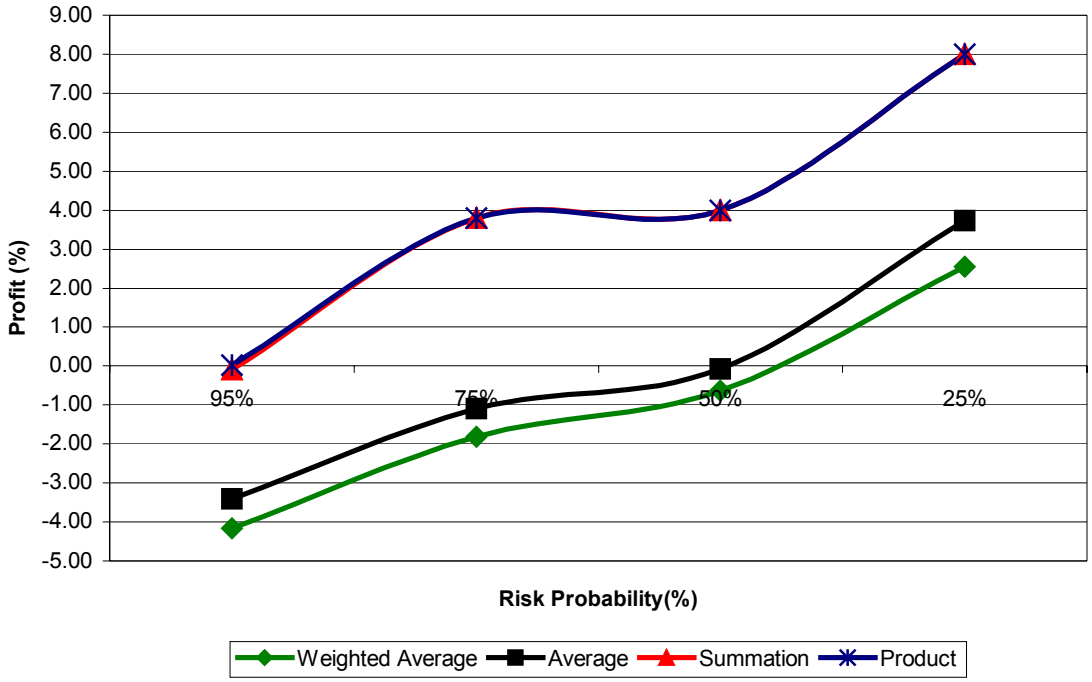


Figure 5-5. Profit versus Risk Probability for Number One Rank

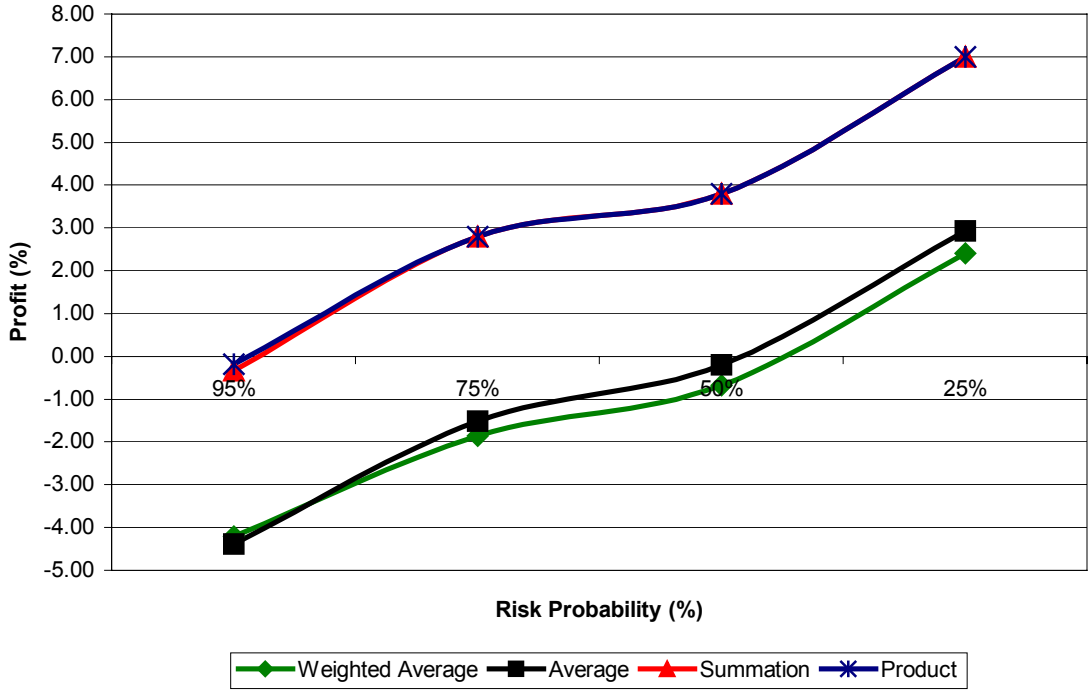


Figure 5-6. Profit versus Risk Probability for Number Two Rank

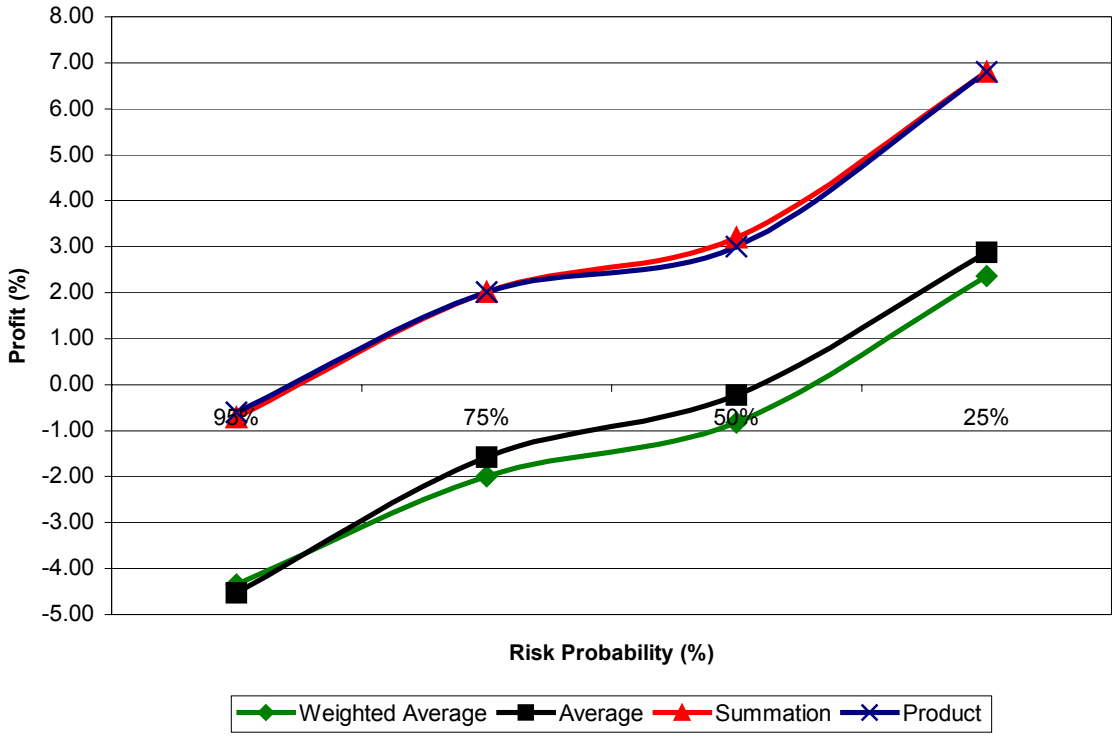


Figure 5-7. Profit versus Risk Probability for Number Three Rank

Table 5-3 is thus analogous to Table 4-3, for the deterministic approach. A major difference in Table 5-3 is that four AQC maximum-profit target values are identified for each of the four percent risk probabilities. Once the parameters of each AQC are inputed, the program can be executed. The highest individual AQC profit achieved for each risk probability is indicated in bold.

The individual target values identified as most profitable are as follows:

- Lower 5th percentile (95%): 12 in, 5,000 psi, and 3 in/mile (PWL = 108%, profit = -2%)
- Lower 25th percentile (75%): 11.5 in, 4,500 psi, and 3 in/mile (PWL = 108%, profit = 2%)
- Median (50%): 11.5 in, 4,500 psi, and 3 in/mile (PWL = 108%, profit = 2%)
- Upper 25th percentile (25%): 11.5 in, 4,000 psi, and 3 in/mile (PWL = 108%, profit = 3%)

These profit calculations are made independently for each AQC. They do not consider the effect of the composite pay equation on profit. As mentioned before, upon considering each composite pay, the target AQCs mentioned above may not be profitable.

The optimum target value combinations for the each risk probability, using the Weighted Average method are shown in Table 5-3. The contractor does not have to target an overall quality level that yields the maximum 108% pay. In this example, there are no profitable target value combinations. In this case, if the SHA chooses to use the Weighted Average method, an increase in profit margin to compensate the losses should be applied. As mentioned before, the Weighted Average method depends on the percent weight given for each AQC. In other words, a higher weight may be given to a higher quality AQC and a lower weight may be given to a lower quality AQC. If this is the case, then the CPF will be larger.

The optimum target value combinations for the each risk probability, using the Average method are shown in Table 5-5. Similar with the Weighted Average method, the contractor does not have to target an overall quality level that yields the maximum 108% pay. In this example, like the Weighted Average method, there are no profitable target value combinations. The same concept that was used in the Weighted Average method should be used in the Average method compensate for the loss in profit. In Table 5-5, the second rank profit target values at the 95th risk probability are a two-way tie between 11.5 in thickness, 5,000 psi compressive strength, 3 in/mi smoothness PI and 11.5 in thickness, 5,000 psi compressive strength, 5 in/mi smoothness PI. This can happen when the change in cost values are whole numbers or closely related to each other symmetrically. The

optimum target value combinations for the each risk probability, using the Summation method are shown in Table 5-6.

In this method, the contractor targets an overall quality level that exceeds the maximum cap of 108% pay, which the contractor can only receive 108% pay. This method gives the contractor more profitable target value combinations than the Weighted Average and Average methods. Table 5-6 shows more two-way ties between some combined target AQCs in the 75th, 50th, and 25th risk probability. In addition, it shows a three-way tie in the number three rank of the 75th risk probability. Although these target values are considered as the optimum target values, the contractor might want to further use Prob.O.Prof to zero-in on more precise optimal target values that lie in between the AQC level intervals analyzed (similar to what was done in the deterministic exercise to arrive at 11.25 in, 4,500 psi, and 4 in/mi).

The optimum target value combinations for the each risk probability, using the Product method are shown in Table 5-7. Similarly, like the Summation method, the contractor targets an overall quality level that exceeds the maximum cap of 108% pay, which the contractor can only receive 108% pay. In addition, there are two-way ties between some combined target AQCs in the 75th, 50th, and 25th risk probabilities. Unlike the above-mentioned methods, the Product method was the only method that had a two-way tie between two-combined target AQCs in the number one rank (median). As seen from the other composite pay methods, since the change in incremental cost for the strength and smoothness were similar, a tie between combined target AQCs can easily happen.

5.5 Deterministic vs. Probabilistic Approach

As seen from the previous chapter, the most profitable combinations in the deterministic approach were a thickness of 11.25 in, strength of 4,500 psi, a surface smoothness of 4 in/mile and a thickness of 11.5 in, strength of 4,500 psi, and strength of 7 in/mi. These two AQC combinations gave a profit of 4%. Using the Product method and the 50th percent risk probability, Prob.O.Prof also calculated two target AQC combinations that gave a profit of 4%, as seen in Table 5-7. The deterministic method and Prob.O.Prof both agree on one of the two-combined target AQCs (thickness of 11.5 in, 4,500 psi, and 7 in/mi). This is because the two approaches both happen to exceed the cap on that target AQC combination. The contractor, in this case, might want zero-in on more precise optimal target values that lie in between quality level intervals analyzed using Prob.O.Prof. The contractor can do this by inputting a smaller change of increment for the individual AQC.

It is clear that the two approaches will yield different profits. It happened for this example that one of the two approaches equaled the same profit. This may be in some cases. Both approaches have different single quality characteristics. The deterministic approach is based on an assumption that the sample statistics are equal to the population parameters and Prob.O.Prof (probabilistic approach) evaluates different construction scenarios and eliminates the assumption regarding sample statistics. In addition, the deterministic approach uses the average value of the statistic, while Prob.O.Prof uses the median value of the statistic.

There is a great difference among the top-ranked profit percentages between different risk probabilities using the probabilistic approach. For example, looking at the 50th and 75th percent risk probability (Product Method), achieving a four percent profit in

the number one rank is 33% more than the 3% profit that is achieved in the number two rank. That is a significant difference to the contractor. The same magnitude of differences can be seen at the other percentiles. As the risk probability decreases, the difference between percent profit between the ranks decreases.

For example, at the 25th risk probability achieving an 8% profit in the number one rank yields 14% more than the seven percent profit that is achieved in the number two rank. The only problem with using the 25th risk probability is that the risk taker assumes favorable statistics in anticipation of getting by with somewhat lower actual quality levels. That is why lower risk probabilities such as the 5th percentile have not been included in Prob.O.Prof.

In contrast, the 95th risk probability will give the most percent difference in profit between the ranks. This is because at the lower 5th percentile yields very low profits and big differences in profit between the ranks. The highly risk-averse user assumes the least favorable sample test results, and thus must choose higher target quality levels in order to meet the specifications with unfavorable statistics. The cost of the higher quality reduces the highly risk-averse contractor's profit. Tables 5-4 through 5-7 show that the lower 5th percentile results indicate that the contractor's profit can be small when the target AQC is high such as a mix design strength is as high as 5,000 psi or a thickness of 12 in. The profit can be zero or even negative in some cases with higher quality AQC. This illustrates the importance to the contractor of selecting truly optimum target values.

In comparison with the deterministic method and Prob.O.Prof the PF is not symmetrical for any AQC. They are all skewed. For skewed distributions, the mean and median are not the same, as seen in the Table 5-8. The mean will be pulled in the

direction of the skewness. That is, if the right tail is heavier than the left tail, the average will be greater than the median, as seen in the smoothness. Likewise, if the left tail is heavier than the right tail, the average will be less than the median, as seen in the thickness and strength.

The thickness and strength PFs are skewed to the right as the AQC increases. This is true for both methods and for both the calculated average and median. In addition, the smoothness PFs are skewed to the left as the quality of smoothness decreases for both methods (calculated average and median). The average PF from the deterministic approach is close but not exact to the average calculated from the average PF of Prob.O.Prof (probabilistic approach). The two approaches may not always be exact because Prob.O.Prof uses simulation and the quality index tables to calculate the PWL to calculate the PF.

Table 5-3. Prob.O.Prof Output for Individual AQC Acceptance Plans

AQC	Target Mean	Δ Cost (%)	Pay (%) for 4 Risk Probabilities				Profit (%) for 4 Risk Probabilities			
			95%	**75%**	**50%**	**25%**	**95%**	**75%**	**50%**	**25%**
Thickness (in)	10.00	-6	-58.75	-58.75	-58.75	-58.75	-52.75	-52.75	-52.75	-52.75
	10.50	-3	-58.75	-58.75	-53.75	-48.50	-55.75	-55.75	-50.75	-45.25
	11.00	0	-41.50	-14.33	-8.16	0.84	-41.50	-14.33	-8.16	0.84
	11.50	3	1.34	5.00	5.00	5.00	-1.66	**2.00**	**2.00**	**2.00**
	12.00	6	5.00	5.00	5.00	5.00	**-1.00**	-1.00	-1.00	-1.00
Compressive Strength (psi)	3,000	-2	-58.75	-49.63	-44.50	-40.12	-56.75	-47.63	-42.50	-38.12
	3,500	-1	-45.19	-37.69	-10.66	-3.25	-44.19	-36.69	-9.66	-2.25
	4,000	0	-12.16	-4.08	3.84	5.00	-12.16	-4.08	3.84	**5.00**
	4,500	1	-1.00	5.00	5.00	5.00	-2.00	**4.00**	**4.00**	4.00
	5,000	2	5.00	5.00	5.00	5.00	**3.00**	3.00	3.00	3.00
Surface Smoothness (in/mi)	3.00	2	3.60	4.00	4.30	4.50	**1.60**	**2.00**	**2.30**	**2.50**
	5.00	1	0.60	1.00	1.40	1.80	-0.40	0.10	0.40	0.80
	7.00	0	-2.00	-1.40	-1.20	-0.80	-2.00	-1.40	-1.20	-0.80
	9.00	-1	-5.9	-5.20	-4.80	-4.40	-4.90	-4.20	-3.80	-3.40
	11.00	-2	-9.50	-9.00	-8.60	-8.20	-7.50	-7.00	-6.60	-6.20

Table 5-4. Prob.O.Prof Ranking of Highest-Profit Target AQC Value Combinations for Weighted Average Method

Risk Probability	Rank	AQC Target Values			Composite Pay (%)	Profit (%)
		Thickness (in)	Compressive Strength (psi)	Surface Smoothness (in/mi)		
95%	1	11.5	5,000	3	103.37	-3.63
	2	11.5	5,000	5	102.00	-4.00
	3	11.5	5,000	7	100.82	-4.18
75%	1	11.5	4,500	3	10455	-1.45
	2	11.5	4,500	5	103.18	-1.82
	3	11.5	4,500	7	102.09	-1.91
50%	1	11.5	4,000	3	104.37	-0.63
	2	11.5	4,000	5	103.05	-0.95
	3	11.5	4,500	7	101.87	-1.13
25%	1	11.0	4,000	3	103.64	1.64
	2	11.0	4,000	5	102.41	1.41
	3	11.0	4,000	7	101.23	1.23

Table 5-5. Prob.O.Prof Ranking of Highest-Profit Target AQC Value Combinations for Average Method

Risk Probability	Rank	AQC Target Values			Composite Pay (%)	Profit (%)
		Thickness (in)	Compressive Strength (psi)	Surface Smoothness (in/mi)		
95%	1	11.5	5,000	7	101.45	-3.55
	2	11.5	5,000	3	103.31	-3.69
	2	11.5	5,000	5	102.31	-3.69
	3	11.5	5,000	9	100.15	-3.85
75%	1	11.5	4,500	7	102.87	-1.13
	2	11.5	4,500	3	104.67	-1.33
	2	11.5	4,500	5	103.67	-1.33
	3	11.5	4,500	9	101.60	-1.40
50%	1	11.5	4,000	7	102.55	-0.45
	2	11.5	4,000	5	103.41	-0.59
	3	11.5	4,000	3	104.38	-0.62
25%	1	11.0	4,000	7	101.68	1.68
	2	11.0	4,000	5	102.55	1.55
	3	11.0	4,000	9	100.48	1.48

Table 5-6. Prob.O.Prof Ranking of Highest-Profit Target AQC Value Combinations for Summation Method

Risk Probability	Rank	AQC Target Values			Composite Pay (%)	Profit (%)
		Thickness (in)	Compressive Strength (psi)	Surface Smoothness (in/mi)		
95%	1	11.5	5,000	3	108.00	1.00
	2	11.5	5,000	5	106.94	0.94
	3	12.0	5,000	7	108.00	0
75%	1	11.5	4,500	7	108.00	4.00
	2	11.5	4,500	5	108.00	3.00
	2	11.5	5,000	7	108.00	3.00
	3	11.5	4,500	3	108.00	2.00
	3	11.5	5,000	5	108.00	2.00
50%	1	11.5	4,000	7	107.64	4.64
	2	11.5	4,000	5	108.00	4.00
	2	11.5	4,500	7	108.00	4.00
	3	11.5	4,000	3	108.00	3.00
	3	11.5	5,000	5	108.00	3.00
25%	1	11.0	4,000	5	107.64	6.64
	2	11.0	4,000	3	108.00	6.00
	3	11.0	4,500	5	107.64	5.64

Table 5-7. Prob.O.Prof Ranking of Highest-Profit Target AQC Value Combinations for Product Method

Risk Probability	Rank	AQC Target Values			Composite Pay (%)	Profit (%)
		Thickness (in)	Compressive Strength (psi)	Surface Smoothness (in/mi)		
95%	1	11.5	5,000	5	107.05	1.05
	2	11.5	5,000	3	108.00	1.00
	3	12.0	5,000	7	108.00	0
75%	1	11.5	4,500	7	108.00	4.00
	2	11.5	4,500	5	108.00	3.00
	2	11.5	5,000	7	108.00	3.00
	3	11.5	4,500	3	108.00	2.00
	3	11.5	5,000	5	108.00	2.00
50%	1	11.5	4,000	7	107.72	4.72
	2	11.5	4,000	5	108.00	4.00
	2	11.5	4,500	7	108.00	4.00
	2	11.5	4,000	3	108.00	3.00
	3	11.5	4,500	5	108.00	3.00
25%	1	11.0	4,000	5	107.79	6.79
	2	11.0	4,000	3	108.00	6.00
	3	11.0	4,000	7	105.03	5.03

Table 5-8. Deterministic and Prob.O.Prob Average Output

Acceptance Quality Characteristic	Target mean	Pay Factor		
		Deterministic	Probabilistic	
		Average (%)	Average (%)	Median (%)
Thickness (in)	10	41.4	41.37	41.25
	10.5	47.2	47.49	46.62
	11	92.27	87.7	92.17
	11.5	104.51	104.51	105
	12	105	105	105
Strength (psi)	3,000	55.15	57.42	55.38
	3,500	89.4	82.48	88.84
	4,000	100.41	100.07	105
	4,500	104.23	104.27	105
	5,000	104.93	104.93	105
Smoothness (in/mi)	3	105	104.23	104.3
	5	102	101.44	101.4
	7	100	98.83	98.8
	9	96	95.19	95.2
	11	92	91.38	91.4

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary and Findings

Up until now, concrete contractors and state highway agencies had no procedure to address the optimization of target quality levels using the probabilistic approach. Contractors have been using the deterministic method to establish target quality levels under QA specifications. The deterministic approach is based on an assumption that the sample statistics are equal to the population parameters. This means that the PWL sample statistic will have a value that is the same as the PWL lot parameter being estimated. The probability for this situation to happen is unlikely.

The deterministic and probabilistic approaches do not necessarily identify the same optimal target values. The only time that both approaches can identify the same optimal target values is when those target values exceed the maximum cap percent pay. This situation is likely to happen if the change in cost percentages used are symmetrical, closely related, or whole numbers. The default cost values used in the examples throughout this dissertation have similar change in percent cost values for strength and smoothness. This allowed for more than one combination of target AQCs to equal the same profit.

The deterministic method actually uses the average value of the statistic while the probabilistic method uses the median value of the statistic (at the 50th percent risk probability). The median value is more meaningful in this case because it is primarily used for skewed distributions, which it represents more accurately than the arithmetic

mean. For a statistic such as the PWL, which does not follow a normal distribution at high quality levels (around 90% PWL and higher), the difference in answers between the two methods can mean a significant difference in profit. The median value separates the higher half of a population sample or a probability from the lower half. In this case, half of the population will have values less than or equal to the median value and the other half of the population will have values equal to or greater than the median.

The deterministic method, if used properly under the right circumstances, can provide good approximate answers without considering risk or probabilities. This is especially true if the user makes trial and error adjustments to find the most profitable combined target AQCs in view of the composite pay equation and the pay cap.

6.2 Conclusions

Each questionnaire survey was structured in a similar manner so that the relative performance and cost data could be matched up for each design feature. The results from the questionnaire surveys serve as one "data set" for use in the evaluation tool. This tool was then used in a computer program to calculate pay and profits for each AQC. The combined pay of target AQC depended on these cost values to target the combined AQC with maximum profit.

The proposed procedure is an improvement primarily because it considers risk and probability. It also relies on a Monte Carlo simulation technique that is simulated using a computer program (Prob.O.Prof) in order to replace the time-consuming trial and error approach. The difference between the deterministic and the probabilistic approach presented in this dissertation shows concrete-paving contractors can use Prob.O.Prof to maximize their profits under AASHTO-type acceptance plans. Agencies, on the other hand, can use the program to guarantee that contractors are making reasonable profits

while carrying out high quality levels. Delivering high quality on certain concrete pavement material and characteristics can result in low life-cycle costs, such as better smoothness.

6.3 Recommendations for Future Research

Improvements in this research are significantly important towards the ultimate solution to accurate concrete construction pay adjustments. Possible directions of future research are to consider other AQCs. The computer program only analyzes three AQCs: concrete slab thickness, initial strength, and surface smoothness. It is recommended that Prob.O.Prof be expanded to allow analysis of other AQCs such as air content, spacing factory, and water cement ratio. These AQCs are also important for cost and life cycle cost purposes. In addition, it is recommended that Prob.O.Prof be expanded to allow other types of construction such as hot-mix paving.

The Monte Carlo Simulation method in the computer program only simulates 2,000 random values for each AQC depending on the number of lots. As discussed in Chapter 5, variability still occurs between the target AQCs, especially in rank numbers two and three. Moreover, the majority of the variability is seen in the lower 5th percentile (95th percent risk percentile). For example, using the same AQC parameters for each computer run, the user may get a different AQC combination from the first run compared to the second run. This may be due the number of random numbers simulated. For more precise accuracy, a simulation of 10,000 random AQC values may reduce this variability. In addition, the program only allows the user to choose up to nine samples per lot. It is recommended to add more samples per lot. An addition of metric units is also necessary since some state highway agencies rely more on metric units than English units.

Some state highway agencies do not use AASHTO's guide specifications. They use their own pay adjustment schedules. A choice of allowing the user to input their pay adjustment method can also be recommended for future use. Implementing all these will allow QA efforts and procedures such as the one proposed here, proceed to the point where the optimization of construction quality and minimizing project life-cycle cost can become a reality.

APPENDIX A
STATISTICAL TABLES

The numbers in the body of the percent within limits estimation tables, for each sample size, are estimates of percent within limits corresponding to specific quality index (Q) values. For a quality index of less than zero, subtract the table value from 100 (AASHTO, 1996b). For example, looking at Table A-1 with a sample size of 3, a quality index of 0.77 will give a PWL of 73.24%. If the quality index was –0.77 then the PWL will equal 26.76% (100% minus 73.24%).

Table A-1. Percent Within Limits For a Sample Size of 3

PERCENT WITHIN LIMITS ESTIMATION TABLE

VARIABILITY-UNKNOWN PROCEDURE — SAMPLE SIZE 3 — STANDARD DEVIATION METHOD

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.28	50.55	50.83	51.10	51.38	51.65	51.93	52.21	52.48
0.1	52.76	53.04	53.31	53.59	53.87	54.15	54.42	54.70	54.98	55.26
0.2	55.54	55.82	56.10	56.38	56.66	56.95	57.23	57.51	57.80	58.08
0.3	58.37	58.65	58.94	59.23	59.51	59.80	60.09	60.38	60.67	60.97
0.4	61.26	61.55	61.85	62.15	62.44	62.74	63.04	63.34	63.65	63.95
0.5	64.25	64.56	64.87	65.18	65.49	65.80	66.12	66.43	66.75	67.07
0.6	67.39	67.72	68.04	68.37	68.70	69.03	69.37	69.70	70.04	70.39
0.7	70.73	71.08	71.43	71.78	72.14	72.50	72.87	73.24	73.61	73.98
0.8	74.36	74.75	75.14	75.53	75.93	76.33	76.74	77.16	77.58	78.01
0.9	78.45	78.89	79.34	79.81	80.27	80.75	81.25	81.75	82.26	82.79
1.0	83.33	83.89	84.47	85.07	85.69	86.34	87.02	87.73	88.49	89.29
1.1	90.16	91.11	92.18	93.40	94.92	97.13	100.00	100.00	100.00	100.00

Table A-2. Percent Within Limits for a Sample Size of 4

PERCENT WITHIN LIMITS ESTIMATION TABLE

VARIABILITY-UNKNOWN PROCEDURE — SAMPLE SIZE 4 — STANDARD DEVIATION METHOD

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.33	50.67	51.00	51.33	51.67	52.00	52.33	52.67	53.00
0.1	53.33	53.67	54.00	54.33	54.67	55.00	55.33	55.67	56.00	56.33
0.2	56.67	57.00	57.33	57.67	58.00	58.33	58.67	59.00	59.33	59.67
0.3	60.00	60.33	60.67	61.00	61.33	61.67	62.00	62.33	62.67	63.00
0.4	63.33	63.67	64.00	64.33	64.67	65.00	65.33	65.67	66.00	66.33
0.5	66.67	67.00	67.33	67.67	68.00	68.33	68.67	69.00	69.33	69.67
0.6	70.00	70.33	70.67	71.00	71.33	71.67	72.00	72.33	72.67	73.00
0.7	73.33	73.67	74.00	74.33	74.67	75.00	75.33	75.67	76.00	76.33
0.8	76.67	77.00	77.33	77.67	78.00	78.33	78.67	79.00	79.33	79.67
0.9	80.00	80.33	80.67	81.00	81.33	81.67	82.00	82.33	82.67	83.00
1.0	83.33	83.67	84.00	84.33	84.67	85.00	85.33	85.67	86.00	86.33
1.1	86.67	87.00	87.33	87.67	88.00	88.33	88.67	89.00	89.33	89.67
1.2	90.00	90.33	90.67	91.00	91.33	91.67	92.00	92.33	92.67	93.00
1.3	93.33	93.67	94.00	94.33	94.67	95.00	95.33	95.67	96.00	96.33
1.4	96.67	97.00	97.33	97.67	98.00	98.33	98.67	99.00	99.33	99.67
1.5	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table A-3. Percent Within Limits for a Sample Size of 5

PERCENT WITHIN LIMITS ESTIMATION TABLE

VARIABILITY-UNKNOWN PROCEDURE — SAMPLE SIZE 5 — STANDARD DEVIATION METHOD

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.36	50.71	51.07	51.42	51.78	52.13	52.49	52.85	53.20
0.1	53.56	53.91	54.27	54.62	54.98	55.33	55.69	56.04	56.39	56.75
0.2	57.10	57.46	57.81	58.16	58.52	58.87	59.22	59.57	59.92	60.28
0.3	60.63	60.98	61.33	61.68	62.03	62.38	62.72	63.07	63.42	63.77
0.4	64.12	64.46	64.81	65.15	65.50	65.84	66.19	66.53	66.87	67.22
0.5	67.56	67.90	68.24	68.58	68.92	69.26	69.60	69.94	70.27	70.61
0.6	70.95	71.28	71.61	71.95	72.28	72.61	72.94	73.27	73.60	73.93
0.7	74.26	74.59	74.91	75.24	75.56	75.89	76.21	76.53	76.85	77.17
0.8	77.49	77.81	78.13	78.44	78.76	79.07	79.38	79.69	80.00	80.31
0.9	80.62	80.93	81.23	81.54	81.84	82.14	82.45	82.74	83.04	83.34
1.0	83.64	83.93	84.22	84.52	84.81	85.09	85.38	85.67	85.95	86.24
1.1	86.52	86.80	87.07	87.35	87.63	87.90	88.17	88.44	88.71	88.98
1.2	89.24	89.50	89.77	90.03	90.28	90.54	90.79	91.04	91.29	91.54
1.3	91.79	92.03	92.27	92.51	92.75	92.98	93.21	93.44	93.67	93.90
1.4	94.12	94.34	94.56	94.77	94.98	95.19	95.40	95.61	95.81	96.01
1.5	96.20	96.39	96.58	96.77	96.95	97.13	97.31	97.48	97.65	97.81
1.6	97.97	98.13	98.28	98.43	98.58	98.72	98.85	98.98	99.11	99.23
1.7	99.34	99.45	99.55	99.64	99.73	99.81	99.88	99.94	99.98	100.00

Table A-4. Percent Within Limits for a Sample Size of 6

PERCENT WITHIN LIMITS ESTIMATION TABLE

VARIABILITY-UNKNOWN PROCEDURE — SAMPLE SIZE 6 — STANDARD DEVIATION METHOD

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.37	50.73	51.10	51.47	51.84	52.20	52.57	52.94	53.30
0.1	53.67	54.04	54.40	54.77	55.14	55.50	55.87	56.23	56.60	56.96
0.2	57.32	57.69	58.05	58.41	58.78	59.14	59.50	59.86	60.22	60.58
0.3	60.94	61.30	61.66	62.02	62.38	62.73	63.09	63.45	63.80	64.16
0.4	64.51	64.86	65.21	65.57	65.92	66.27	66.62	66.96	67.31	67.66
0.5	68.00	68.35	68.69	69.04	69.38	69.72	70.06	70.40	70.74	71.07
0.6	71.41	71.75	72.08	72.41	72.74	73.08	73.40	73.73	74.06	74.39
0.7	74.71	75.04	75.36	75.68	76.00	76.32	76.63	76.95	77.26	77.58
0.8	77.89	78.20	78.51	78.82	79.12	79.43	79.73	80.03	80.33	80.63
0.9	80.93	81.22	81.51	81.81	82.10	82.39	82.67	82.96	83.24	83.52
1.0	83.80	84.08	84.36	84.63	84.91	85.18	85.45	85.71	85.98	86.24
1.1	86.50	86.76	87.02	87.28	87.53	87.78	88.03	88.28	88.53	88.77
1.2	89.01	89.25	89.49	89.72	89.96	90.19	90.42	90.64	90.87	91.09
1.3	91.31	91.52	91.74	91.95	92.16	92.37	92.58	92.78	92.98	93.18
1.4	93.37	93.57	93.76	93.95	94.13	94.32	94.50	94.67	94.85	95.02
1.5	95.19	95.36	95.53	95.69	95.85	96.00	96.16	96.31	96.46	96.60
1.6	96.75	96.89	97.03	97.16	97.29	97.42	97.55	97.67	97.79	97.91
1.7	98.02	98.13	98.24	98.34	98.45	98.55	98.64	98.73	98.82	98.91
1.8	98.99	99.07	99.15	99.22	99.29	99.36	99.43	99.49	99.54	99.60
1.9	99.65	99.70	99.74	99.78	99.82	99.85	99.88	99.91	99.93	99.95
2.0	99.97	99.98	99.99	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table A-5. Percent Within Limits for a Sample Size of 7

PERCENT WITHIN LIMITS ESTIMATION TABLE

VARIABILITY-UNKNOWN PROCEDURE — SAMPLE SIZE 7 — STANDARD DEVIATION METHOD

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.37	50.75	51.12	51.50	51.87	52.24	52.62	52.99	53.37
0.1	53.74	54.11	54.49	54.86	55.23	55.60	55.97	56.35	56.72	57.09
0.2	57.46	57.83	58.20	58.56	58.93	59.30	59.67	60.03	60.40	60.77
0.3	61.13	61.50	61.86	62.22	62.58	62.94	63.31	63.67	64.02	64.38
0.4	64.74	65.10	65.45	65.81	66.16	66.51	66.87	67.22	67.57	67.92
0.5	68.26	68.61	68.96	69.30	69.64	69.99	70.33	70.67	71.01	71.34
0.6	71.68	72.02	72.35	72.68	73.01	73.34	73.67	74.00	74.32	74.65
0.7	74.97	75.29	75.61	75.93	76.25	76.56	76.88	77.19	77.50	77.81
0.8	78.12	78.42	78.73	79.03	79.33	79.63	79.93	80.22	80.52	80.81
0.9	81.10	81.39	81.67	81.96	82.24	82.52	82.80	83.08	83.35	83.63
1.0	83.90	84.17	84.44	84.70	84.97	85.23	85.49	85.74	86.00	86.25
1.1	86.51	86.75	87.00	87.25	87.49	87.73	87.97	88.21	88.44	88.67
1.2	88.90	89.13	89.35	89.58	89.80	90.02	90.23	90.45	90.66	90.87
1.3	91.07	91.28	91.48	91.68	91.88	92.08	92.27	92.46	92.65	92.83
1.4	93.02	93.20	93.38	93.55	93.73	93.90	94.07	94.23	94.40	94.56
1.5	94.72	94.87	95.03	95.18	95.33	95.48	95.62	95.76	95.90	96.04
1.6	96.17	96.31	96.43	96.56	96.69	96.81	96.93	97.05	97.16	97.27
1.7	97.38	97.49	97.59	97.70	97.80	97.89	97.99	98.08	98.17	98.26
1.8	98.35	98.43	98.51	98.59	98.66	98.74	98.81	98.88	98.94	99.01
1.9	99.07	99.13	99.19	99.24	99.30	99.35	99.40	99.44	99.49	99.53
2.0	99.57	99.61	99.64	99.68	99.71	99.74	99.77	99.79	99.82	99.84
2.1	99.86	99.88	99.90	99.92	99.93	99.94	99.95	99.96	99.97	99.98
2.2	99.99	99.99	99.99	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table A-6. Percent Within Limits for a Sample Size of 8

PERCENT WITHIN LIMITS ESTIMATION TABLE

VARIABILITY-UNKNOWN PROCEDURE — SAMPLE SIZE 8 — STANDARD DEVIATION METHOD

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.38	50.76	51.14	51.51	51.89	52.27	52.65	53.03	53.41
0.1	53.78	54.16	54.54	54.92	55.29	55.67	56.04	56.42	56.79	57.17
0.2	57.54	57.92	58.29	58.66	59.03	59.41	59.78	60.15	60.52	60.89
0.3	61.25	61.62	61.99	62.35	62.72	63.08	63.45	63.81	64.17	64.53
0.4	64.89	65.25	65.61	65.96	66.32	66.67	67.03	67.38	67.73	68.08
0.5	68.43	68.78	69.13	69.47	69.82	70.16	70.50	70.84	71.18	71.52
0.6	71.85	72.19	72.52	72.85	73.18	73.51	73.84	74.17	74.49	74.81
0.7	75.14	75.46	75.77	76.09	76.41	76.72	77.03	77.34	77.65	77.96
0.8	78.26	78.56	78.86	79.16	79.46	79.76	80.05	80.34	80.63	80.92
0.9	81.21	81.49	81.77	82.05	82.33	82.61	82.88	83.15	83.43	83.69
1.0	83.96	84.22	84.49	84.75	85.00	85.26	85.51	85.76	86.01	86.26
1.1	86.51	86.75	86.99	87.23	87.46	87.70	87.93	88.16	88.39	88.61
1.2	88.83	89.06	89.27	89.49	89.70	89.91	90.12	90.33	90.53	90.74
1.3	90.94	91.13	91.33	91.52	91.71	91.90	92.09	92.27	92.45	92.63
1.4	92.81	92.98	93.15	93.32	93.49	93.65	93.81	93.97	94.13	94.29
1.5	94.44	94.59	94.74	94.88	95.03	95.17	95.31	95.44	95.58	95.71
1.6	95.84	95.97	96.09	96.21	96.33	96.45	96.57	96.68	96.79	96.90
1.7	97.01	97.11	97.21	97.31	97.41	97.51	97.60	97.69	97.78	97.87
1.8	97.96	98.04	98.12	98.20	98.28	98.35	98.42	98.49	98.56	98.63
1.9	98.69	98.76	98.82	98.88	98.93	98.99	99.04	99.09	99.14	99.19
2.0	99.24	99.28	99.33	99.37	99.41	99.45	99.48	99.52	99.55	99.58
2.1	99.61	99.64	99.67	99.70	99.72	99.74	99.77	99.79	99.81	99.83
2.2	99.84	99.86	99.87	99.89	99.90	99.91	99.92	99.93	99.94	99.95
2.3	99.96	99.96	99.97	99.98	99.98	99.98	99.99	99.99	99.99	100.00

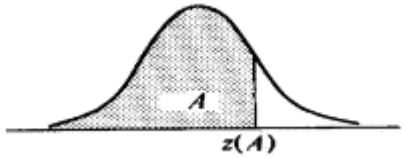
Table A-7. Percent Within Limits for a Sample Size of 9

PERCENT WITHIN LIMITS ESTIMATION TABLE

VARIABILITY-UNKNOWN PROCEDURE SAMPLE SIZE 9 STANDARD DEVIATION METHOD

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.38	50.76	51.15	51.53	51.91	52.29	52.67	53.05	53.43
0.1	53.82	54.20	54.58	54.96	55.34	55.71	56.09	56.47	56.85	57.23
0.2	57.60	57.98	58.36	58.73	59.11	59.48	59.85	60.23	60.60	60.97
0.3	61.34	61.71	62.08	62.45	62.81	63.18	63.54	63.91	64.27	64.63
0.4	65.00	65.36	65.71	66.07	66.43	66.79	67.14	67.49	67.85	68.20
0.5	68.55	68.90	69.24	69.59	69.93	70.28	70.62	70.96	71.30	71.64
0.6	71.97	72.31	72.64	72.97	73.30	73.63	73.96	74.28	74.61	74.93
0.7	75.25	75.57	75.89	76.20	76.51	76.83	77.14	77.44	77.75	78.06
0.8	78.36	78.66	78.96	79.25	79.55	79.84	80.13	80.42	80.71	81.00
0.9	81.28	81.56	81.84	82.12	82.39	82.67	82.94	83.21	83.47	83.74
1.0	84.00	84.26	84.52	84.77	85.03	85.28	85.53	85.78	86.02	86.27
1.1	86.51	86.74	86.98	87.21	87.45	87.68	87.90	88.13	88.35	88.57
1.2	88.79	89.00	89.22	89.43	89.64	89.85	90.05	90.25	90.45	90.65
1.3	90.84	91.04	91.23	91.41	91.60	91.78	91.96	92.14	92.32	92.49
1.4	92.67	92.83	93.00	93.17	93.33	93.49	93.65	93.80	93.96	94.11
1.5	94.26	94.40	94.55	94.69	94.83	94.97	95.10	95.23	95.36	95.49
1.6	95.62	95.74	95.86	95.98	96.10	96.22	96.33	96.44	96.55	96.66
1.7	96.76	96.86	96.97	97.06	97.16	97.25	97.35	97.44	97.53	97.61
1.8	97.70	97.78	97.86	97.94	98.02	98.09	98.16	98.24	98.30	98.37
1.9	98.44	98.50	98.56	98.63	98.68	98.74	98.80	98.85	98.90	98.95
2.0	99.00	99.05	99.10	99.14	99.18	99.23	99.27	99.30	99.34	99.38
2.1	99.41	99.45	99.48	99.51	99.54	99.57	99.59	99.62	99.64	99.67
2.2	99.69	99.71	99.73	99.75	99.77	99.79	99.80	99.82	99.83	99.85
2.3	99.86	99.87	99.89	99.90	99.91	99.92	99.92	99.93	99.94	99.95
2.4	99.95	99.96	99.96	99.97	99.97	99.98	99.98	99.98	99.99	99.99
2.5	99.99	99.99	99.99	100.00	100.00	100.00	100.00	100.00	100.00	100.00

A-8. Area (A) Under the Standard Normal Curve From -∞ to z (A)



z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.1	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
3.2	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.3	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997
3.4	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9998

APPENDIX B
CONCRETE CONTRACTOR QUESTIONNAIRE

June 26, 2002

Dear Sir or Madam,

I am seeking your cooperation in completing the attached two-page questionnaire. The purpose of the questionnaire is to develop a guidance to enable contractors to determine economic evaluations for various strength, thickness, and smoothness scenarios in concrete pavement construction to maximize profit.

The questionnaire is a part of a larger study that is expected to result in improved specifications and a development of a computer software. Your response is important to us and will be kept highly confidential.

I would like to thank you in advance for your support. Please fill out the questionnaire completely and return your response by fax or by using a stamped envelope provided to:

Dr. Fazil T. Najafi, Professor
Attn: Sofia M. Vidalis, Graduate Student
345 Weil Hall
PO Box 116580
Gainesville, FL 32611-2450

A copy of the complete study will be available upon request.

Sincerely,

Sofia M. Vidalis
E-mail: vidalis@ufl.edu
Phone: (352) 392-1033
Fax: (352) 392-3394

QUESTIONNAIRE: QUESTIONS ABOUT YOUR FIRM AND YOUR BIDDING DECISION MAKING PROCESS

All responses will remain fully confidential.

NOTE: All these questions apply only to Portland Concrete Cement (PCC) work

Please respond by placing an "x" next to the appropriate number in questions 1- 14.

Title or position of the respondent_____

State_____

1) Annual sales (millions of dollars) of Portland Concrete Cement (PCC) work

(a) Under 5 (b) 5-20 (c) 20-100 (d) 100-500 (e) Over 500 (f) Don't know

2) Average job size in PCC paving (million of dollars)

(a) Under 1 (b) 1-5 (c) 5-10 (d) 10-25 (e) 25-50 (f) Over 50

3) Dollar value of construction equipment owned (million of dollars) for PCC work.

(a) Under 1 (b) 1-10 (c) 10-25 (d) 25-100 (e) Over 100 (f) Don't know

4) What percentage of your PCC work is obtained through competitive bidding?

(a) Under 25% (b) 25% to 50% (c) 50% to 75% (d) 75% to 100% (e) Don't know

5) What type of contract do you generally use for PCC work? (Can mark more than one) (a) Unit bid (b) Lump sum (c) Other (please specify)

6) If you are uncertain about pricing quality for Jointed Plain Concrete Pavements (JPCP) while working on your bid, how would you handle it?

(a) Considered by applying a correction factor

(b) Considered by adjusting markup

(c) Not considered

(d) Another way to consider the uncertainty (please specify)

7) Percentage of work for which performance bond is provided

(a) Under 25% (b) 25% to 50% (c) 50% to 75% (d) 75% to 100%

8) Job related contingency is

(a) Included in the markup

(b) Charged as a cost item

(c) Either of the above depending on the job

(d) Other (please specify)

9) On an average, how well does the actual cost reflect the bid price that you have submitted in paving the concrete?

(a) actual cost is within 1% of bid price (minus profit)

(b) actual cost is within 2% of bid price (minus profit)

(c) actual cost is within 3% of bid price (minus profit)

(d) actual cost is more than 3% of bid price (minus profit)

(e) Don't know

(f) Other (please specify)

10) How do you come up with the cost estimates needed to submit a bid? (Check all that apply)

(a) past experience

(b) your company's cost accounting database

(c) non-company specific cost estimation guidance

(d) "seat-of-the-pants" approach

(e) Other (please specify)

11) How do you decide when to adjust your bid (either higher or lower)?

12) Do you use any formal method (i.e., statistical/mathematical bidding strategy techniques) to assist you submit a winning bid?

(a) Yes, if yes please name (optional) Can you provide a sample?

(b) No

(c) Other informal techniques (please specify)

13) What factors make you feel that "There is a good chance of winning this project?" (Please check all that are appropriate)

(a) State highway agency

(b) Competitors

(c) Your strength in the industry

(d) Your experience

(e) Overall economy

(f) Others (please specify)

14) What factors make you think, "I must get this work?" (Please check all that are appropriate.)

(a) Need for work

(b) Your strength in the industry

(c) Size of job

(d) Location of project

(e) General (office) overhead requirement

(f) Others (please specify)

15) Lets say you are making a government cost estimate on the following planned Jointed Plain Concrete Pavement (JPCP) project in your state:

- 4 lane highway divided
- 5 mile length, few horizontal and vertical curves
- New construction, no traffic control
- Rural area
- Epoxy coated Dowels
- 15' transverse joint spacing (tells you how many epoxy coated dowels are needed and joint sawing is done, part of concrete cost)
- Typical thickness for your state dot

- Standard smoothness requirements for you state dot
- Standard strength requirements for your state dot
- Circumstances under which you are bidding are not unusual (e.g., you are not desperate to get to work, but your crews could do the work)

Note: The following questions ask for English units however, you can use metric units if you prefer.

a. What is your estimated cost ($/yd^2) for that paving?

b. Does it include overhead? If so how much (percent)?

c. What thickness (inches) did you use to arrive at this cost?

d. What smoothness (inches/mile) did you use to arrive at this cost?

e. How was the smoothness measured (e.g., California Profilograph using 0.2 blanking band)?

f. What average concrete strength and standard deviation (or flexural and tensile strength) did you use to arrive at this cost?

g. What test method did you use for strength? (e.g., cylinder compressive strength at 7 days, cone compressive strength at 14 days, flexural beam at 28 days)

h. How far was the concrete plant from the project?

i. (1) For the same pavement design, let's say the average strength requirement is 1000 psi (237 psi flexural strength) more than was assumed in question f. What would be the estimated cost ($/yd^2) for that paving?

(2) For the same pavement, let's say the average strength requirement is 2000 psi (335psi flexural strength) more than was assumed in question f. What would be the estimated cost ($/yd^2) for the paving?

j. (1) For the same pavement, let's say the standard deviation for strength is 100psi compressive strength (flexural strength of 75psi) more than was assumed in question f. What would be the estimated cost ($/yd^2) for that paving?

(2) For the same pavement, let's say the standard deviation for strength is 200 psi compressive strength (flexural strength of 106 psi) more than was assumed in question f. What would be the estimated cost ($/yd^2) for the paving?

k. (1) For the same pavement design, let's say the smoothness <u>decreases</u> (better smoothness) by 1 in/mile less (i.e., smoother) than was assumed in question d. What would be the estimated cost ($/yd^2) for that paving?

(2) What would be the estimated cost ($/yd^2) for the paving if the required smoothness was:

i. <u>Decreases</u> 2 in/mile less than was assumed in question d?

ii. <u>Decreases</u> 4 in/mile less than was assumed in question d?

iii. <u>Decreases</u> 10 in/mile less than was assumed in question d?

iv. <u>Decreases</u> 20 in/mile less than was assumed in question d?

l. (1) For the same pavement design, lets say the required thickness is 1 in. more than was assumed in question c. What would be the estimated cost ($/yd^2) for that paving?

(2) What would the estimated cost ($/yd^2) be for the paving if the required thickness is 2 in/mile more than was assumed in question c?

The abbreviated words shown in Table B-1 through Table B-5 are explained in a key box after the tables. The subscript letters with numbers after them are extra comments made by concrete contractors. These comments are also shown after the tables.

Table B-1. Concrete Contractor's Responses (Questions 1 – 11)

#	State	Title	1						2						3						4					5			6				7				8				9						10					11
			a	b	c	d	e	f	a	b	c	d	e	f	a	b	c	d	e	f	a	b	c	d	e	a	b	c	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d	e	f	a	b	c	d	e	
1	**CO**	M		x						x						x								x		x				x					x			x				x						x				a1
2	**IN**	CQCD			x							x						x						x		x					x[b1]				x			x			x									x[b2]	b2,3
3	**IA**	SVP			x					x							x							x		x				x					x	x						x				x	x	x			c1
4	**KS**	P				x						x						x							x	x			x						x	x					x					x	x				d1
5	**LA**				x					x						x								x		x				x					x		x						x			x	x				e1
6	**OH**	GM		x						x						x								x		x					x[f1]				x		x				x					x	x				f2
7	**OK**	CE			x							x					x							x		x			x						x		x					x						x				g1

Table B-2. Concrete Contractor's Responses (Questions 12 – 15d)

#	State	Title	12			13						14						15			
			a	b	c	a	b	c	d	e	f	a	b	c	d	e	f	a	b	c	d
1	**CO**	M	x			x	x	x	x			x			x			$20/yd^2	10%	10 in	8 in/mi
2	**IN**	CQCD		x			x	x	x	x		x			x	x		$32.13/m^2 ($26.86/yd^2)	3%-6%	350 mm (13.78 in)	3 in/mi[b4]
3	**IA**	SVP		x		x	x	x	x			x						$26.5/yd^2	Yes[c2]	10 in	4 – 7 in/mi[c3]
4	**KS**	P		x		x	x	x	x			x		x	x			$31/m^2 ($25.92/yd^2)	12%	300 mm (11.81 in)	15 mm/km (1 in/mi)
5	**LA**		x[e2]			x	x	x				x		x	x	x		$45/yd^2	7.50%	9 in	10 in/mi
6	**OH**	GM		x		x	x		x			x			x	x		$28/yd^2	6%	9 in	7 in/mi
7	**OK**	CE			x[g2]		x	x	x	x		x					x[g3]	$24/yd^2	27%	10 in	< 3 in/mi

Table B-3. Concrete Contractor's Responses (Questions 15e – 15h)

#	State	Title	15	15		
			e	f	g	h
1	**CO**	M	CP, 0.1 bb	650 psi FS (4000 psi CS)	FB, 28 days	O
2	**IN**	CQCD	CP, 0.2 bb	630 psi FS (3800 psi CS)[b5]	7 day, 3 pt FB	O
3	**IA**	SVP	CP, 0.2 bb[c4]	550 psi (3250 psi CS)[c5]	Maturity	O
4	**KS**	P	CP, 0.0 bb	31Mpa (4500 psi), steddev ±3.0 (435 psi)	cylinder at 7 + 28 days beams	O
5	**LA**		CP	4000 psi CS, 150 psi steddev	CC	w/in 5 mi
6	**OH**	GM	CP, 0.2 bb	CS, 4000 psi	CC	3 mi
7	**OK**	CE	CP, 0.2 bb	4200 psi, 500 psi stddev	CC, 28 days	3 mi

Table B-4. Concrete Contractor's Responses (Questions 15i – 15j)

			15			
			i		j	
			1	2	1	2
1	**CO**	M	add $2/yd^2	add $5/yd^2	add $1/yd^2	add $3/yd^2
2	**IN**	CQCD	$33.5/m^2 ($28.01/yd^2)	$34.5/m^2 ($28.85/yd^2)	$32.4/m^2 ($27.09/yd^2)	$33.5/m^2 ($28.01/yd^2)
3	**IA**	SVP	$30.5/yd^2	$35/yd^2	[C6]	[C6]
4	**KS**	P	add $1-2/yd^2	add $4-5/yd^2 [d2]	±$1/yd^2	±$3/yd^2
5	**LA**		$46/yd^2	$47/yd^2	$47/yd^2	$47/yd^2
6	**OH**	GM	+ 2% ($0.56/yd^2)	+ 5% ($1.40/yd^2)	+ 2% ($0.56/yd^2)	+5% ($1.40/yd^2)
7	**OK**	CE	$25.50/yd^2	$29/yd^2	$24/yd^2	$24/yd^2 [g4]

Table B-5. Concrete Contractor's Responses (Questions 15k – 15l)

#	State	Title	15						
			k					l	
			1	2a	2b	2c	2d	1	2
1	**CO**	M	add. $0.25/yd^2	add $0.5/yd^2	$1/yd^2			add $2/yd^2	add $4/yd^2
2	**IN**	CQCD	no change	no change	no change	$32.25/m^2 ($26.97/yd^2)	$32.5/m^2 ($26.97/yd^2)	$33.15/m^2 ($27.72/yd^2)	$34.15/m^2 ($28.55/yd^2)
3	**IA**	SVP	$27.25/yd^2	$29.5/yd^2	$32/yd^2	?	?	add $2.25/yd^2	add $4.00/yd^2
4	**KS**	P	no change	no change	add $0.50/yd^2	add $1/yd^2	add $1/yd^2	add$2.50/yd^2	add $5.00/yd^2
5	**LA**		$45/yd^2	$44.75/yd^2	$44.5/yd^2	$44/yd^2	$42/yd^2	add $3.25/yd^2	add $6.50/yd^2
6	**OH**	GM	no change	no change	add 5% ($1.40/yd^2)	f3	f3	add 4% ($1.12/yd^2)	add 9% ($2.52/yd^2)
7	**OK**	CE	$24/yd^2 g5	$24/yd^2	NA	NA	NA	$26/yd^2	$28/yd^2

KEY

ACP =California Type Ames Profilograph (25')
BB = Blanking Band
CP =California Profilograph
CS = Compressive Strength
FB = Flexural Beam
FS = Flexural Strength
IRI = Internatinal Roughness Index
LWP = Light Weight Profilometer
NA = not available
NS =not sure
O = on site
OH = overhead
Pr = profit
PS = Project Specific
RP = Rainhart Profilograph
SDTRP = South Dakota Type Road Profiler
SE = Straight Edge Profilograph
Stddev = standard deviation
w/ = with

Concrete Contractor's Responses and Comments to Questionnaire

The following letters are comments made by the respondents. These individual letters are shown where the comment was made in the tables shown above.

a

a1) Based on need for work and market price

b

b1) Money would be figured into the bid for quality and escrowed for the duration of the warranty

b2) All bids are developed specifically for individual project based on the past production performance and on similar project, company workload, and accounting.

b3) Each project is unique

b4) 10 in/mi maximum, averaging 3 in/mi

b5) 630 psi Flexural (3pt) at 7 days, 45 psi standard deviation – 570 minimum required

c

c1) Totally dependent on the estimated RISK

c2) Not a percent but as function of time

c3) 100% pay

c4) 0.50 in must grinds

c5) Third point in mix design – field tests for gradation, etc.

c6) No way for me to even take a stab at risk since there is no data from experience

d

d1) Analyze risk – degree of difficulty of work

d2) Cement and aggregate

e

e1) Appetite and competition

e2) Oman Systems

f

f1) We will not bid if uncertain about any aspect of bid

f2) 1) Competition, 2) Backlog, 3) Relationship and history with owner, 4) Complexity of job

f3) Not applicable to profilograph

g

g1) Combination of resource capacity and market conditions

g2) Bid tab analysis

g3) Market development

g4) Cannot reduce costs/over design because the minimum cement content must be met

g5) The profilograph is not precise enough to distinguish between 1 in/mi – 3 in/mi, therefore cost should not be adjusted

APPENDIX C
STATE HIGHWAY AGENCY QUESTIONNAIRE

June 26, 2002

Dear Sir or Madam,

I am seeking your cooperation in completing the attached two-page questionnaire. The purpose of the questionnaire is to develop a guidance to enable state highway agencies to determine the optimal quality levels and economic evaluations for various strength, thickness, and smoothness scenarios in concrete pavement construction.

The questionnaire is a part of a larger study that is expected to result in improved specifications and a development of a computer software. Your response is important to us and will be kept highly confidential.

I would like to thank you in advance for your support. Please fill out the questionnaire completely and return your response by fax or by using a stamped envelope provided to:

Dr. Fazil T. Najafi, Professor
Attn: Sofia M. Vidalis, Graduate Student
345 Weil Hall
PO Box 116580
Gainesville, FL 32611-2450

A copy of the complete study will be available upon request.

Sincerely,

Sofia M. Vidalis
E-mail: vidalis@ufl.edu
Phone: (352) 392-1033
Fax: (352) 392-3394

QUESTIONNAIRE: BIDDING DECISION MAKING PROCESS AND QUALITY CONTROL

All responses will remain fully confidential.
NOTE: All these questions apply only to Portland Concrete Cement (PCC) work
Please respond by typing an "x" next to the appropriate number in questions 1-3.

Title or position of the respondent_____

1) How do you come up with the cost estimates needed to produce the government cost estimate?

   (a) Statewide database

   (b) District wide database

   (c) Other (please specify)

2) Typically, how far off from the government's cost estimate is the winning contractor's unit bid in $/yd^2 using the standard thickness, strength, and smoothness you use in JPCP projects?

   (a) Winning contractor's unit bid is within 1% of government cost estimate

   (b) Winning contractor's unit bid is within 2% of government cost estimate

   (c) Winning contractor's unit bid is within 3% of government cost estimate

   (d) Winning contractor's unit bid is more than 3% of government cost estimate

   (e) Don't know

   (f) Comments

3) Which is true for you state's cost estimating procedure?

4) (a) The cost estimating procedure allows estimator to differentiate costs with respect to quality requirements.

   (b) The cost estimation procedure is independent of quality requirements.

5) Lets say you are making a government cost estimate on the following planned Jointed Plain Concrete Pavement (JPCP) project in your state:

   - 4 lane highway divided

   - 5 mile length, few horizontal and vertical curves

- New construction, no traffic control
- Rural area
- Epoxy coated Dowels
- 15' transverse joint spacing (tells you how many epoxy coated dowels are needed and joint sawing is done, part of concrete cost)
- Typical thickness for your state dot
- Standard smoothness requirements for you state dot
- Standard strength requirements for your state dot
- Circumstances under which you are bidding are not unusual (e.g., you are not desperate to get to work, but your crews could do the work)

Note: The following questions ask for English units however, you can use metric units if you prefer.

a) What is your estimated cost ($/yd^2) for that paving?

b) Does it include overhead? If so how much (percent)?

c) What thickness (inches) did you use to arrive at this cost?

d) What smoothness (inches/mile) did you use to arrive at this cost?

e) How was the smoothness measured (e.g., California Profilograph using 0.2 blanking band)?

f) What average concrete strength and standard deviation (or flexural and tensile strength) did you use to arrive at this cost?

g) What test method did you use for strength? (e.g., cylinder compressive strength at 7 days, cone compressive strength at 14 days, flexural beam at 28 days)?

h) How far was the concrete plant from the project?

(1) For the same pavement design, let's say the average strength requirement is 1,000 psi (237 psi flexural strength) more than was assumed in question f. What would be the estimated cost ($/yd^2) for that paving?

(2) For the same pavement, let's say the average strength requirement is 2,000 psi (335psi flexural strength) more than was assumed in question f. What would be the estimated cost ($/yd^2) for the paving?

j)

(1) For the same pavement, let's say the standard deviation for strength is 100 psi compressive strength (flexural strength of 75psi) more than was assumed in question f. What would be the estimated cost ($/yd^2) for that paving?

(2) For the same pavement, let's say the standard deviation for strength is 200 psi compressive strength (flexural strength of 106 psi) more than was assumed in question f. What would be the estimated cost ($/yd^2) for the paving?

k)

(1) For the same pavement design, let's say the smoothness <u>decreases</u> (better smoothness) by 1 in/mile less (i.e., smoother) than was assumed in question d. What would be the estimated cost ($/yd^2) for that paving?

(2) What would be the estimated cost ($/yd^2) for the paving if the required smoothness was:

(2a) <u>Decreases</u> 2 in/mile less than was assumed in question d?

(2b) <u>Decreases</u> 4 in/mile less than was assumed in question d?

(2c) <u>Decreases</u> 10 in/mile less than was assumed in question d?

(2d) <u>Decreases</u> 20 in/mile less than was assumed in question d?

l)

(1) For the same pavement design, lets say the required thickness is 1 in. more than was assumed in question c. What would be the estimated cost ($/yd^2) for that paving?

(2) What would the estimated cost ($/yd^2) be for the paving if the required thickness is 2 in/mile more than was assumed in question c?

The abbreviated words shown in Table C-1 through Table C-6 are explained in a key box after the tables. The subscript letters with numbers after them are extra comments made by SHAs. These comments are also shown after the tables.

Table C-1. State Highway Agencies' Responses (Questions 1 –4c)

#	State	PCCP work	1			2						3		4		
			a	b	c	a	b	c	d	e	f	a	b	a	b	c
1	**AK**	No														
2	**CA**	Yes	x	x	x[a1]						x[a2]		x	~$100/m^3 (~$83.61/yd^2)	No	NA[a3]
3	**DE**	Yes	x								x[b1]		x	$23-$32/yd^2	Yes	12 in
4	**FL**	Yes												PS	PS	PS
5	**ID**	Yes	x							x			x	$25/yd^2	No	13 in
6	**IL**	Yes			x[e1]					x			x	$28-$38/yd^2	15%	9 in
7	**IN**	Yes			x[f1]					x			x	$29.5/yd^2	No	12 in
8	**IA**	Yes			x[g1]				x				x	$26/yd^2	Yes	10 in
9	**KS**	Yes	x								x[h1]	x		$30/yd^2	No	9 in
10	**LA**	Yes	x			x							x	$35/yd^2	No	10 in
11	**MD**	Yes	x					x					x	$35/yd^2	20%	12 in
12	**MO**	Yes			x[k1]					x			x	$42.56/yd^2 [k2,3]	5% OH + 10% Pr [k2,4]	12 in [k2]
13	**MT**	No														
14	**NE**	Yes	x					x			x[l1]		x	$22.5/yd^2	Yes	10 in
15	**NV**	Yes	x							x			x	$30/yd^2	No, 10% OH	12 in
16	**NH**	No														
17	**OK**	Yes	x						x				x	$30/yd^2	No	10 in
18	**OR**	No														
19	**SC**	Yes	x							x	x[m1]		x	$28/yd^2	No	10 in
20	**SD**	Yes	x								x[n1]		x	$29/yd^2	[n2]	9 in
21	**TN**	No														
22	**VT**	No														
23	**VA**	Yes		x	x				x				x	$26-$30/yd^2	No	12 in
24	**WA**	Yes	x								x[p1]		x[p2]	$40-$60/yd^2 [o3]	In place cost	10-12 in
25	**WV**	Yes	x					x					x	$45/m^2 ($37.63/yd^2)	No	275 mm (11 in)
26	**WI**	Yes	x	x						x	x[q1]		x	$18.58/yd^2	Yes	10 in

Table C-2. State Highway Agencies' Responses (Questions 4d –4f)

#	State	PCCP work	4		
			d	e	f
1	**AK**	No			
2	**CA**	Yes	[a4]	SE, CP, 0.2 bb [a5]	[a6]
3	**DE**	Yes	15 in/mi	CP, 0.0 bb	3500 psi min. CS
4	**FL**	Yes	PS	CP, 0.2 bb	3000 psi min. strength (28-day)
5	**ID**	Yes	5 in/mi	XII, 0.2 ββ	4500 psi CS
6	**IL**	Yes	Not considered	CP, 0.2 bb [e2]	3500 psi [e3]
7	**IN**	Yes	percent std specs	SE, percent std specs	[f2]
8	**IA**	Yes	3.1-7.0 in/mi	CP, 0.2 bb	650psi FS w/ 50 psi Stddev
9	**KS**	Yes	15.1-18 in/mi	CP, 0.0 bb	450 psi, FS (2500 psi CS)
10	**LA**	Yes	6 in/mile lot, lot=4000 yd^2	ACP	4000 psi, CS
11	**MD**	Yes	70 IRI	CP, 0.0 bb	4200 psi, CS w/ 630 psi Stddev
12	**MO**	Yes	12-15 in/mi [k2]	CP, 0.0 bb [k2]	didn't [k2]
13	**MT**	No			
14	**NE**	Yes	10 in/mi	CP, 0.0 bb	3500 psi CS
15	**NV**	Yes	5 in/mi	CP, 0.2 bb	4500 psi CS
16	**NH**	No			
17	**OK**	Yes	5-7 in/mi	CP or LWP, 0.2 bb	3700 psi
18	**OR**	No			
19	**SC**	Yes	10 in/mi	RP, 0.2 bb	600 psi FS, No Stddev
20	**SD**	Yes	26 in/mi	CP, 0.0 bb	4000 psi, minimum strength
21	**TN**	No			
22	**VT**	No			
23	**VA**	Yes	60 in/mi	SDTRP	650 psi, No Stddev
24	**WA**	Yes	[p4]	CP, 0.2 bb	650 psi, FS at 14 days
25	**WV**	Yes	100 mm/km (6.336 in/mi)	Mays Ride Meter	20.7 Mpa CS or 3.5 Mpa FS
26	**WI**	Yes	45 in/mi	CP	~4000 psi

Table C-3. State Highway Agencies' Responses (Questions 4g – 4h)

#	State	PCCP work	4	
			g	h
1	**AK**	No		
2	**CA**	Yes	FB at 7, 14, and 28 days	[a7]
3	**DE**	Yes	CS, 28 days	O
4	**FL**	Yes	cylinder CS, 7 days	NA
5	**ID**	Yes	cylinder CS at 28 days (AASHTO T22)	O
6	**IL**	Yes	cylinder CS or FS at 14 days	O
7	**IN**	Yes	[f2]	within 10 mi
8	**IA**	Yes	FB at 28 days	O
9	**KS**	Yes	450 psi, FB min. in 4 days	1/4 mile
10	**LA**	Yes	core CS	O
11	**MD**	Yes	Cylinder CS at 28 days	O
12	**MO**	Yes	core CS at 28 days [k2]	[k5]
13	**MT**	No		
14	**NE**	Yes	cores at 56 days of age	O
15	**NV**	Yes	cylinder CS at 28 days	< 2 miles
16	**NH**	No		
17	**OK**	Yes	cylinder CS at 28 days	O
18	**OR**	No		
19	**SC**	Yes	550 psi flex at 14-day	O
20	**SD**	Yes	cylinder CS at 28 days	varies
21	**TN**	No		
22	**VT**	No		
23	**VA**	Yes	FB	O
24	**WA**	Yes	[p5]	20-60 mile [p6]
25	**WV**	Yes	CS at 28 days	O
26	**WI**	Yes	cylinder CS at 28 days (AASHTO T-22)	unknown

Table C-4. State Highway Agencies' Responses (Questions 4i – 4j)

#	State	PCCP work	4			
			i		j	
			1	2	1	2
1	**AK**	No				
2	**CA**	Yes	[a8]	[a8]	[a8]	[a8]
3	**DE**	Yes	$23-$32/yd^2 [b2]	$28-$37/yd^2 [b3]	NA	NA
4	**FL**	Yes	-$0.80/yd^3 for each 10 psi [c1]	-$0.80/yd^3 for each 10 psi [c1]	-$0.80/yd^3 for each 10 psi [c1]	-$0.80/yd^3 for each 10 psi [c1]
5	**ID**	Yes	[d1]	[d1]	[d1]	[d1]
6	**IL**	Yes	[e4]	[e4]	[e5]	[e5]
7	**IN**	Yes	NA	NA	NA	NA
8	**IA**	Yes	maybe $30 [g2]	unknown	same	unknown
9	**KS**	Yes	add 5% ($1.5/yd^2)	Add 7.50%	unknown	unknown
10	**LA**	Yes	[i1]	[i1]	[i1]	[i1]
11	**MD**	Yes	$35/yd^2 [j1]	$35/yd^2 [j1]	$35/yd^2 [j1]	$35/yd^2 [j1]
12	**MO**	Yes	$43.41/yd^2 [k2,6]	$43.41/yd^2 [k2,7]	$43.41/yd^2 [k2,8]	$43.41/yd^2 [k2,9]
13	**MT**	No				
14	**NE**	Yes	$25/yd^2	$28/yd^2	[l2]	[l2]
15	**NV**	Yes	add $1/yd^2	add $2/yd^2	don't know	don't know
16	**NH**	No				
17	**OK**	Yes	no data	no data	no data	no data
18	**OR**	No				
19	**SC**	Yes	unknown	unknown [m2]	same [m3]	unknown [m4]
20	**SD**	Yes	[n3]	[n3]	[n4]	[n4]
21	**TN**	No				
22	**VT**	No				
23	**VA**	Yes	NS, 650 psi type design	NS, 650 psi type design	NS	NS
24	**WA**	Yes	NA	NA	NA	NA
25	**WV**	Yes	NA	NA	NA	NA
26	**WI**	Yes	unknown	unknown	unknown	unknown

Table C-5. State Highway Agencies' Responses (Question 4k)

#	State	PCCP work	4				
			k				
			1	2a	2b	2c	2d
1	**AK**	No					
2	**CA**	Yes	a9	a9	a9	a9	a9
3	**DE**	Yes					
4	**FL**	Yes	c2	c2	c2	c2	c2
5	**ID**	Yes	d1	d2	d2	d2	d2
6	**IL**	Yes	e6	e6	e6	e6	e6
7	**IN**	Yes	NA	NA	NA	NA	NA
8	**IA**	Yes	$27/yd^2	$28/yd^2	$30/yd^2	NA	NA
9	**KS**	Yes	h2	h2	h2	h2	h2
10	**LA**	Yes	i2	i2	i2	i2	i2
11	**MD**	Yes	$35/yd^2	$35/yd^2	$35/yd^2	$35/yd^2	$35.32/yd^2
12	**MO**	Yes	$42.56/yd^2 k2,10	$42.54/yd^2 k2,11	$45.54/yd^2 k2	$46.82/yd^2 k2,12	not possible k2,10
13	**MT**	No					
14	**NE**	Yes	l2,3	$23.50/yd^2	$26.00/yd^2	NA	NA
15	**NV**	Yes	add $0.25/yd^2				
16	**NH**	No					
17	**OK**	Yes	1% less (-$0.30/yd^2)	3% less (-$0.90/yd^2)	5% less (-$1.50/yd^2)	20% less (-$6.00/yd^2)	not acceptable
18	**OR**	No					
19	**SC**	Yes	unknown m4	unknown m4	unknown m4	unknown m4	unknown m4
20	**SD**	Yes	n5	n5	n5	n5	n5
21	**TN**	No					
22	**VT**	No					
23	**VA**	Yes	o1	o1	o1	o1	o1
24	**WA**	Yes	NA	NA	NA	NA	NA
25	**WV**	Yes	NA	NA	NA	NA	NA
26	**WI**	Yes	unknown	unknown	unknown	unknown	unknown

Table C-6. State Highway Agencies' Responses (Question 4l)

#	State	PCCP work	4	
			l	
			1	2
1	AK	No		
2	CA	Yes	~$100/m^2 [a10]	~$100/m^2 [a10]
3	DE	Yes		
4	FL	Yes	[c3]	[c3]
5	ID	Yes	$27/yd^2	$29/yd^2
6	IL	Yes	[e7]	[e7]
7	IN	Yes	NA	NA
8	IA	Yes	$29/yd^2	$31/yd^2
9	KS	Yes	maybe add $1.50/yd^2	add $3/yd^2
10	LA	Yes	$36-$37/yd^2	$37-$38/yd^2
11	MD	Yes	$35/yd^2	$37/yd^2
12	MO	Yes	$43.41/yd^2 [k2,13]	$43.41/yd^2 [k2]
13	MT	No		
14	NE	Yes	$23.00/yd^2	$23.50/yd^2
15	NV	Yes	add $1/yd^2	add $1.05/yd^2
16	NH	No		
17	OK	Yes	add$2/yd^2	add $4/yd^2
18	OR	No		
19	SC	Yes	$30/yd^2	$32/yd^2
20	SD	Yes	$30/yd^2	[n6]
21	TN	No		
22	VT	No		
23	VA	Yes	$28-$32/yd^2	$30-$34/yd^2
24	WA	Yes	NA	NA
25	WV	Yes	$4.00/m^2 ($3.34/yd^2)	$10.00/m^2 ($8.36/yd^2)
26	WI	Yes	$30.25/yd^2	$31.86/yd^2

KEY

ACP =California Type Ames Profilograph (25')
BB = Blanking Band
CP =California Profilograph
CS = Compressive Strength
FB = Flexural Beam
FS = Flexural Strength
IRI = Internatinal Roughness Index
LWP = Light Weight Profilometer
NA = not available
NS =not sure
O = on site
OH = overhead
Pr = profit
PS = Project Specific
RP = Rainhart Profilograph
SDTRP = South Dakota Type Road Profiler
SE = Straight Edge Profilograph
Std = standard
Stddev = standard deviation
w/ = with

Title of DOT Respondents

- Professional Engineer
- Pavement Design Engineer
- State Pavement Program Engineer
- State Pavement Engineer
- Bid Letting Engineer
- Concrete Engineer
- Specification Engineer
- Assistant Bureau Chief of Construction and Maintenance
- Research Coordination Engineer
- Portland Cement Concrete and Physical Tests Engineer
- Chief Pavement Engineer
- Chief Materials and Research Engineer
- Deputy State Highway Engineer Development
- Senior Systems Analyst
- Assistant Chief Materials Engineer
- Pavement Engineer and Contracts Office
- Senior Transportation Engineer Specialist
- Research and Development Engineer

Agencies' Responses and Comments to Questionnaire

The following letters are comments made by the respondents. These individual letters are shown in superscript where the comment was made in the tables shown above.

a

a1) Five pilot projects this year that are implementing these specs. Prior to this there was no PCC performance parameter link to estimating bid prices and even now there obviously isn't, but we'll have the potential to create them in the future. The new Complete Analysis Method where production rates, labor costs, and material costs are considered. This method may be used individually or in combination with the Statewide and Districtwide database method.

a2) Although Unit Costs are most commonly based upon Statewide and District wide cost databases, the specific unit cost of an item is secondary to the total project cost contingency of approximately 5%.

a3) Thickness is not applicable, although unit costs are sensitive to quantity and project location

a4) Smoothness requirements are included in the full contract price paid per cubic meter for concrete pavement. Deficiencies in pavement thickness are deducted from money due or money that may become due.

a5) Smoothness is measured by the use of a straight edge and the California Profilograph, or equivalent. Other methods are being investigated for quality and production rates, such as inertial profilographs. The blanking band is 5mm (i.e., 0.2 inch).

a6) Cost of the concrete is not based upon average concrete strength. Average concrete strength is applicable to acceptance standards. For "conventional" concrete (Class 3) used for pavement, the minimum modulus of rupture prior to placing traffic is 3.8 MPa within 10 days of concrete placement. For "Rapid Strength Concrete" (i.e. fast setting concrete), the specified modulus of rupture is 2.8 MPa prior to placement of traffic after concrete placement. Pay factors for Rapid Strength Concrete are applicable if the concrete achieves a modulus of rupture less than 4.2 MPa within seven days of placement.

a7) The Contractor is responsible for the availability of materials to be placed within a project and therefore, if commercially available concrete is not possible, then the contractor may choose to produce concrete from a portable plant located in the vicinity of the project. Concrete transported by truck mixer or agitator, discharge of the concrete must be started reached the specified strength requirements. If the specified concrete strength is not achieved but reaches 95% of the strength requirement, then the Contractor is responsible for making corrections and is charged \$14 for each m^3 in place, if the concrete is within 85%-95% of the

specified strength requirements, the contractor will make corrective changes and be charged $20/m^3$ in place.

a8) If the specified concrete strength is not achieved within the specifies time limits, then the Engineer will not open the facility to traffic until the concrete has reached the specified strength requirements. If the specified concrete strength is not achieved but reaches 95% of the strength requirement, then the contractor is responsible for making corrections and is charged 14% for each m^3 in place, if the concrete is within 85% – 95% for the specified strength requirements, the contractor will make corrective changes and be charged $20/m^3$ in place.

a9) No deductions are made if the smoothness measurements by profilograph are not within specifications. The Contractor shall bring the smoothness of the pavement within specifications. If, in the process of grinding or grooving of the pavement, the thickness as shown on the plans or specifications is deficient, then a deduction shall be made. A pavement thickness deficiency of not more than 15 mm results in a deficiency adjustment from $0.40/m^2$ - $4.70/m^2$. If the thickness deficiency is more than 15 mm, then the contractor may: 1) Be required to remove and replace those panels that do not meet thickness requirements, or 2) Be required to pay $32.5/m^2$ for the panels left in place.

a10) The cost would remain the same and the Contractor will not be compensated for any pavement constructed in excess of the thickness requirements of the plans and specifications.

b

b1) Varies, depending upon many factors such as workload, available labor/equipment

b2) The $23-$32 range would still cover the price because our mixes consistently break 500-1,000 psi higher than specified

b3) Add $5/yd^2$ for new mix design

c

c1) The Engineer will determine payment reductions for low strength concrete, accepted by the Department and represented by either cylinder or core strength test results below the specified minimum strength, in accordance with the following: Reduction in Pay = $0.80/yd^3$ ($1.05/m^3$) for each 10 psi (70 kP) of strength test value below the specified minimum strength. The Engineer will apply a reduction in pay to the entire lot of concrete represented by the low strength test results except as noted above for concrete paid on a per foot (meter) basis, where the amount might exceed one lot.

c2) pp. 372 – 373 of the FDOT Rigid Pavement Design Manual

c3) The Department will not pay for any pavement, which is more than 1/2 inch (13 mm) less than the specified thickness

d

d1) Don't know. It will probably increase.

d2) Don't know. It will probably decrease. It is difficult to provide a good answer to these questions. The project designer would not necessarily increase or decrease the unit price for this item based on these changes. The Engineer's estimate is based on statewide average unit costs and is normally conservative. If the Materials people felt these changes were necessary, they might ask the designer to bump the unit cost up by 10% or so to reflect the change. Idaho Transportation Department uses an incentive/disincentive for smoothness in order to encourage the contractor to build smoother pavements.

e

e1) Uses cubic yard cost of concrete, which would be higher if high early strength concrete Historical data is not used for estimating. A worksheet is used, which takes a number of variables into account, such as local labor costs, local material costs, etc.

e2) New special provision uses 0.0 blanking band

e3) Estimate is specified. Normally, 3,500 psi compressive (650 psi flexural) strength is standard. The standard deviation is not considered.

e4) Material cost would be estimated based on mix design requirements.

e5) No difference in cost estimate.

Table C-7. Price Adjustment Schedule from 0.0 Blanking Band Special Provision

Mainline Pavement PI in/mi (mm/km) per 0.1 mi (160 m) section	Other Pavement Sections PI in/mi (mm/km) per segment or 0.1 mi (160 m) section	Contract Price Adjustment per 0.1 mi (160 m) section
6.0 (95) or less		+$1200.00
6.1 (96) to 10 (160)	15 (235) or less	+$1000.00
10.1 (161) to 15 (235)		+$750.00
	15.1 (236) to 25 (400)	+$500.00
15.1 (236) to 18 (290)		+370.00
18.1 (291) to 30 (475)	25.1 (401) to 45 (720)	+0.00
30.1 (476) to 40 (640)	45.1 (721) to 65 (1040)	+0.00*
40.1 (641) or more	65.1 (1041) or more	-$750.00*

* Mainline pavement shall be corrected to 30.0 in/mi (475 mm/km). Other pavement sections shall be corrected to 45.0 in/mi (720 mm/km).

e6) The estimated cost does not change with changes in smoothness. It is not considered in the cost estimate. For contract payment information see the following

table above. The estimated cost increases for every inch increase in thickness based on the material cost of the concrete. As thickness increases, cost will increase based on material cost of the concrete. A "Percent Within Limits" method is used for contract payment. For more details, go to out website: www.dot.state.il.us, and select "Doing Business," then select "BDE Special Provisions," and find "Pavement Thickness Determination for Payment".

f

f1) Historical prices

f2) Standard specifications

g

g1) By area of state, project size

g2) Hard to estimate since we don't pay on strength. We pay incentive for better aggregate gradation which yields higher strengths

h

h1) Since we use historical price averages for estimating purposes, the bids are not too far off the estimate. Typically 3% – 5%. Sometimes the bid is higher than the estimate, but usually the bid is slightly lower than the estimate.

h2) In Kansas we pay an incentive for smooth pavement. On the average we have 80% of the pavement meet the 15.1 in/mi maximum. We have 50% meet the 10.1 to 15 in/mi maximum, 30% meet the 6 to 10 in/mi maximum and 10%-15% meet the 6in/mi maximum. Since we have the incentive, the contractor's bid based on receiving some incentive, so we have not seen an increase in the unit cost of the pavement due to smoothness requirements..

Table C-8. Profile Index Adjusted Pay for the State of Kansas

Average Profile Index (in/mi per 0.1 mi section per lane)	Contract Price Adjustment (additional cost per 0.1 mi section per lane)
6 or less	+$2,000.00
6 to 10	+$1000.00
10.1 to 15	+$750.00
15.1 to 18	+$370.00

i

i1) Cost may not change significantly with increase in strength. Increase in flexural strength would allow decrease in pavement thickness where the cost would probably offset one another.

i2) Have not let any jobs to contract where increased smoothness, better than our specification, was taken into account. Possible in future that this issue will be addressed.

j

j1) No incentive for greater strength

k

k1) Estimates are based on actual costs from phone surveys with suppliers. We do have a database with both Statewide and Districtwide unit bid prices, but our estimators only use average prices from this as a data quality check.

k2) I am using our draft performance-related specs, which have NOT gotten final approval. I am only going through this exercise to supply you with some info rather than leaving everything blank. As it stands we have performance-related specs will include 'percent within limits' (PWL) pay factors within the QC/QA framework. The two PWL pay factors are thickness and compressive strength. There is a separate non-PWL pay scale table for smoothness.

k3) Using 2001 Statewide bid price average does not reflect any one particular area.

k4) This is an average the estimators add to their actual cost prices and therefore would not have seen included in the price in question 4a.

k5) Hard to predict. We have the standard 90-minute plant-to-placement limit on fresh mix.

k6) In order to answer this question within the PWL system I needed a lower spec limit (LSL) strength (we will use 4650 psi, which is the average 28-day strength we've gotten in recent history), a standard deviation (I don't have the historical data, so I'll guess 200 psi), and number of sublot samples (we'll say 5). Under these circumstances the lower limit (there is no upper for strength and thickness) quality index (QI) is 5, which in turn produces a PWL = 100. The strength pay factor (PF) for PWL $\geq$ 70 = 0.5*(PWL) + 55 = 105%. Assuming the thickness PF is a straight 100% and the smoothness pay was also 100%, then the total PF = 0.5*(100) + 0.5*(105) = 102.5%. So the adjusted bid price would increase by 2.5% and become \$43.41/yd^3.

k7) Price will remain the same as in the previous part, since the strength PF has already maxed out at 105%.

k8) Assuming your mean with the 1,000 psi average strength increase

k9) Standard dev. would have to increase more than 400 psi under the assumed inputs stated above before our strength PF would fall below 105%.

k10) Our 100% pay band for smoothness in the proposed specs is 12.1 inches – 15 inches. We will assume the contractor was going to achieve 13.5" under normal circumstances.

k11) 7% bonus range

k12) 10% bonus range

k13) Assuming a standard deviation of 0.2 inch and that the average expected thickness is 12 inch and again assuming a sublot size of 5, then the lower limit Quality Index (QI) is 5, which with gives a PF = 105%. Holding the strength pay factor constant at 100% gives an identical result to the one in k6. Bonus is maxed out for thickness at this point on.

l

l1) Varies considerably from project to project

l2) Estimates are based on minimum compressive strength

l3) Most contractors achieve smoothness well below the 10 inches per mile. These cost estimates are only for the pay item 10 in. Doweled Concrete Pavement. It does not cover mobilization, grading, culverts, or any other item related to the project.

m

m1) This number has been variable due to variations in the classification of the roads being paved. Consequently, we have been very close on some occasions and far off in others.

m2) Unknown, but we would never design for that value because it is too far from the parameters studies at the AASHTO Road Test. Consequently, its behavior is uncertain.

m3) Flexural strength controlled by project average

m4) This would be dependent on many factors. Because we construct concrete pavements so infrequently, our cost estimation is not particularly precise. Many of the factors regarding strength, thickness, and smoothness have not been varied in our construction.

n

n1) Costs vary depending on the area of the State, the time of year, the number of large concrete projects being let that year, and various other factors. The low bid can often vary \$1-\$2/yd^2 from the Engineer's Estimate which makes the variance for that particular item 3% –7% different from the low bid.

n2) It is up to the Contractor to determine where the general overhead for the project is bid. Certain items have to be bid in a particular way, but general overhead can be found in various items on a project, depending on the bid item.

n3) South Dakota DOT does not vary the strength of the concrete and therefore have no data to accurately answer this question.

n4) No available accurate data

n5) The South Dakota DOT pays a smoothness bonus on percent of bid price for smoother PCCP.

Table C-9. Profile Index Adjusted Pay for the State of South Dakota

Profile Index (in/mi per 0.1 mi section per lane)	Bonus on percent Bid Price (%)
10 or less	104
10.1 to 15	103
15.1 to 20	102
20.1 to 25	101
25.1 to 35	100
35.1 to 40	98
40.1 and greater	Grind

n6) We do not typically pave to 11inch depth for jointed concrete. When we do, it involves small quantities, increasing the cost rather dramatically.

o

o1) Performance based specification is used, not sure what the cost effect is for reduced roughness. We have specified what we require for 100% payment. These answers are based on very limited recent projects. Most new construction and reconstruction is performed using asphalt concrete.

p

p1) Without conducting an analysis of our database, I would think that a more realistic value would be within 5% – 10%

p2) The contractor is required to meet standard specifications as they relate to strength, gradation, smoothness, aggregate properties, etc.. Cost estimates will only differ

depending on availability of aggregate, opening to traffic requirements, and presence of dowel bars.

p3) Rural vs. urban

p4) Specification: requires ride to be between 4 and 7, Contractor will receive a 1 compliance adjustment for 3-4, 2 compliance adjustment for 2-3, 3 compliance adjustment for 2-3, and 4 compliance adjustment for 1 or less. For ride over 7 results in a -2 compliance adjustment and requires correction to 7 inches per mile.

p5) During design we require flexural strength and submittal of 5 cylinders to coordinate flexural to compressive strength, then compressive strength or maturity curve is used during construction for acceptance.

p6) Ranges depending on location in state, but typically is within 20 to 60 miles

q

q1) Amount varies considerably with each project and the accuracy of the estimate and the unknowns associated with the project

APPENDIX D
COST OF ACCEPTANCE QUALITY CHARACTERISTICS

Table D-1. Thickness Costs per Square Yard

#	State	Respondent	Estimated Cost of Paving ($/yd^2)	Thickness (in)	1 inch increment increase ($/yd^2)	Inc/Dec ($/yd^2)	Inc/Dec (%)
1	CO	Concrete Contractor		8	-	-4.00	-20.00
				9	-	-2.00	-10.00
			20.00	**10**	-	0	0
				11	22.00	2.00	10.00
				12	24.00	4.00	20.00
2	ID	SHA		11	-	-4.00	-16.00
				12	-	-2.00	-8.00
			25.00	**13**	-	0	0
				14	27.00	2.00	8.00
				15	29.00	4.00	16.00
3	IN	Concrete Contractor		12	-	-1.69	-6.29
				13	-	-0.86	-3.20
			26.86	**14**	-	0	0
				15	27.72	0.86	3.20
				16	28.55	1.69	6.29
4	IA	Concrete Contractor		8	-	-4.00	-15.09
				9	-	-2.25	-8.49
			26.50	**10**	-	0	0
				11	28.75	2.25	8.49
				12	30.50	4.00	15.09
5	IA	SHA		8	-	-5.00	-19.23
				9	-	-3.00	-11.54
			26.00	**10**	-	0	0
				11	29.00	3.00	11.54
				12	31.00	5.00	19.23
6	KS	Concrete Contractor		10	-	-5.00	-19.29
				11	-	-2.50	-9.65
			25.92	**12**	-	0	0
				13	28.42	2.50	9.65
				14	30.92	5.00	19.29

Table D-1. Thickness Costs per Square Yard (Cont.)

#	State	Respondent	Estimated Cost of Paving ($/yd^2)	Thickness (in)	1 inch increment increase ($/yd^2)	Inc/Dec ($/yd^2)	Inc/Dec (%)
7	KS	SHA		7	-	-3.00	-10.00
				8	-	-1.50	-5.00
			30.00	9	-	0	0
				10	31.50	1.50	5.00
				11	33.00	3.00	10.00
8	LA	Concrete Contractor		7	-	-6.55	-14.56
				8	-	-3.25	-7.22
			45.00	**9**	-	0	0
				10	48.25	3.25	7.22
				11	51.55	6.55	14.56
9	LA	SHA		8	-	-2.50	-7.14
				9	-	-1.50	-4.29
			35.00	**10**	-	0	0
				11	36.50	1.50	4.29
				12	37.50	2.50	7.14
10	MD	SHA		10	-	-2	-5.71
				11	-	0	0
			35.00	**12**	-	0	0
				13	35.00	0	0
				14	37.00	2.00	5.71
11	MO	SHA		10	-	-0.85	-2.00
				11	-	-0.85	-2.00
			42.56	**12**	-	0	0
				13	43.41	0.85	2.00
				14	43.41	0.85	2.00
12	NE	SHA		10	-	-1.00	-4.44
				11	-	-0.50	-2.22
			22.50	**12**	-	0	0
				13	23.00	0.50	2.22
				14	23.50	1.00	4.44
13	NV	SHA		10	-	-1.50	-5.00
				11	-	-1.00	-3.33
			30.00	**12**	-	0	0
				13	31.00	1.00	3.33
				14	31.50	1.50	5.00
14	OH	Concrete Contractor		7	-	-2.52	-9.00
				8	-	-1.12	-4.00
			28.00	**9**	-	0	0
				10	29.12	1.12	4.00
				11	30.52	2.52	9.00

Table D-1. Thickness Costs per Square Yard (Cont.)

#	State	Respondent	Estimated Cost of Paving ($/yd^2)	Thickness (in)	1 inch increment increase ($/yd^2)	Inc/Dec ($/yd^2)	Inc/Dec (%)
15	OK	Concrete Contractor		8	-	-4.00	-16.67
				9	-	-2.00	-8.33
			24.00	**10**	-	0	0
				11	26.00	2.00	8.33
				12	28.00	4.00	16.67
16	OK	SHA		10	-	-4.00	-13.33
				11	-	-2.00	-6.67
			30.00	**12**	-	0	0
				13	32.00	2.00	6.67
				14	34.00	4.00	13.33
17	SC	SHA		8	-	-4.00	-14.29
				9	-	-2.00	-7.14
			28.00	**10**	-	0	0
				11	30.00	2.00	7.14
				12	32.00	4.00	14.29
18	SD	SHA		7	-	N/A	-
				8	-	-1.00	-3.45
			29.00	**9**	-	0	0
				10	30.00	1.00	3.45
				11	N/A	N/A	-
19	VA	SHA		10	-	-4.00	-14.29
				11	-	-2.00	-7.14
			28.00	**12**	-	0	0
				13	30.00	2.00	7.14
				14	32.00	4.00	14.29
20	WV	SHA		9	-	-8.36	-22.22
				10	-	-3.34	-8.88
			37.63	**11**	-	0	0
				12	40.97	3.34	8.88
				13	45.99	8.36	22.22
Total Average				8.90	-		-12.34
				9.90	-		-6.16
			29.75	10.90	-		0
				11.90	31.04		6.16
				12.90	32.66		12.34

Table D-2. Strength Costs per Square Yard

#	State	Respondent	Estimated Cost of Paving ($/yd^2)	Strength (psi)	1,000 psi increment increase ($/yd^2)	Inc/Dec ($/yd^2)	Inc/Dec (%)
1	CO	Concrete Contractor	20.00	3,000	-	-2.50	-12.50
				3,500	-	-1.00	-5.00
				4,000	-	0	0
				4,500	21.00	1.00	5.00
				5,000	22.50	2.50	12.50
2	IN	Concrete Contractor	26.86	2,800	-	-1.00	-3.72
				3,300	-	-0.58	-2.16
				3,800	-	0	0
				4,300	27.44	0.58	2.16
				4,800	27.86	1.00	3.72
3	IA	Concrete Contractor	26.50	2,250	-	-4.00	-15.09
				2,750	-	-2.00	-7.55
				3,250	-	0	0
				3,750	28.50	2.00	7.55
				4,250	30.50	4.00	15.09
4	KS	Concrete Contractor	25.92	3,500	-	-3.00	-11.57
				4,000	-	-1.50	-5.79
				4,500	-	0	0
				5,000	27.42	1.50	5.79
				5,500	28.92	3.00	11.57
5	KS	SHA	30.00	1,500	-	-1.13	-3.77
				2,000	-	-0.75	-2.50
				2,500	-	0	0
				3,000	30.75	0.75	2.50
				3,500	31.13	1.13	3.77
6	LA	Concrete Contractor	45.00	3,000	-	-1.00	-2.22
				3,500	-	-0.50	-1.11
				4,000	-	0	0
				4,500	45.50	0.50	1.11
				5,000	46.00	1.00	2.22
7	NE	SHA	22.50	2,500	-	-2.75	-12.22
				3,000	-	-1.25	-5.56
				3,500	-	0	0
				4,000	23.75	1.25	5.56
				4,500	25.25	2.75	12.22

Table D-2. Strength Costs per Square Yard (Cont.)

#	State	Respondent	Estimated Cost of Paving ($/yd^2)	Strength (psi)	1,000 psi increment increase ($/yd^2)	Inc/Dec ($/yd^2)	Inc/Dec (%)
8	NV	SHA		3,500	-	-1.00	-3.33
				4,000	-	-0.50	-1.67
			30.00	**4,500**	-	0	0
				5,000	30.50	0.50	1.67
				5,500	31.00	1.00	3.33
9	OH	Concrete Contractor		3,000	-	-0.56	-2.00
				3,500	-	-0.28	-1.00
			28.00	**4,000**	-	0	0
				4,500	28.28	0.28	1.00
				5,000	28.56	0.56	2.00
10	OK	Concrete Contractor		3,200	-	-1.50	-6.25
				3,700	-	-0.75	-3.13
			24.00	**4,200**	-	0	0
				4,700	24.75	0.75	3.13
				5,200	25.50	1.50	6.25
Total Average				2,825	-		-7.27
				3,325	-		-3.55
			27.88	3,825	-		0
				4,325	28.79		3.55
				4,825	29.72		7.27

Table D-3. Smoothness Costs per Square Yard

#	State	Respondent	Estimated Cost of Paving ($/yd^2)	Smoothness (psi)	1 in/mile increment increase ($/yd^2)	Inc/Dec ($/yd^2)	Inc/Dec (%)
1	CO	Concrete Contractor		6	-	0.50	2.50
				7	-	0.25	1.25
			20.00	**8**	-	0	0
				9	20.25	-0.25	-1.25
				10	20.50	-0.50	-2.50
2	IN	Concrete Contractor		1	-	0	0
				2	-	0	0
			26.86	**3**	-	0	0
				4	26.86	0	0
				5	26.86	0	0
3	IA	Concrete Contractor		3.5	-	3.00	11.32
				4.5	-	0.75	2.83
			26.50	**5.5**	-	0	0
				6.5	27.25	-0.75	-2.83
				7.5	29.50	-3.00	-11.32
4	IA	SHA		3	-	2.00	7.69
				4	-	1.00	3.85
			26.00	**5**	-	0	0
				6	27.00	-1.00	-3.85
				7	28.00	-2.00	-7.69
5	KS	Concrete Contractor		0	-	0	0
				0	-	0	0
			25.92	**1**	-	0	0
				2	25.92	0	0
				3	25.92	0	0
6	LA	Concrete Contractor		8	-	-0.25	-0.56
				9	-	0	0
			45.00	**10**	-	0	0
				11	45.00	0	0
				12	44.75	0.25	0.56

Table D-3. Smoothness Costs per Square Yard (Cont.)

#	State	Respondent	Estimated Cost of Paving ($/yd^2)	Smoothness (psi)	1 in/mile increment increase ($/yd^2)	Inc/Dec ($/yd^2)	Inc/Dec (%)
7	MD	SHA		4	-	0	0
				5	-	0	0
			35.00	**6**	-	0	0
				7	35.00	0	0
				8	35.00	0	0
8	NE	SHA		8	-	1	4.44
				9	-	0	0
			22.50	**10**	-	0	0
				11	22.50	0	0
				12	23.50	-1.00	-4.44
9	NV	SHA		3	-	0.50	1.67
				4	-	0.25	0.83
			30.00	**5**	-	0	0
				6	30.25	-0.25	-0.83
				7	30.50	-0.50	-1.67
10	OH	Concrete Contractor		5	-	0	0
				6	-	0	0
			28.00	**7**	-	0	0
				8	28.00	0	0
				9	28.00	0	0
11	OK	Concrete Contractor		0	-	0	0
				1	-	0	0
			24.00	**2**	-	0	0
				3	24.00	0	0
				4	24.00	0	0
12	OK	SHA		4	-	0.90	3.00
				5	-	0.30	1.00
			30.00	**6**	-	0	0
				7	30.30	-0.30	-1.00
				8	30.90	-0.90	-3.00
Total Average				3.79	-	0.90	2.51
				4.71	-	0.30	0.81
			28.50	5.71	-	0	0
				6.71	28.50	-0.30	-0.81
				7.71	29.00	-0.90	-2.51

APPENDIX E
COMPUTER PROGRAM (MICROS/VISUAL BASIC) SCRIPTING CODE

```
Sub Button1_Click()

If Range("G4") = "" Or Range("G4") > 3 Then
MsgBox "You must enter the number of AQCs (1, 2, or 3)"
Else:
'End If
'If Range("G4") > 3 Then
'MsgBox "You must enter the number of AQCs (1, 2, or 3)"
'End If

'If Range("G4") = 1 Then
   Worksheets("Output").Range("AZ6") = 1
   Range("O3:BB10018").Select
   Selection.ClearContents
   Range("BD3:BD10018").Select
   Selection.ClearContents
   Range("BG1:CV10018").Select
   Selection.ClearContents
   Range("CX3:IK10018").Select
   Selection.ClearContents
   Range("IN3:IN10018").Select
   Selection.ClearContents
   Range("IL3:IL10018").Select
   Selection.ClearContents
   Worksheets("Output").Range("E35:E39").ClearContents
   Worksheets("Output").Range("B5:O9").ClearContents
   Worksheets("Output").Range("B14:O18").ClearContents
   Worksheets("Output").Range("B23:O27").ClearContents
   Worksheets("Output").Range("E81:H107, K81:N107").ClearContents
   Worksheets("Output").Range("D30").ClearContents
   Worksheets("Output").Range("M31:M33").ClearContents
   Worksheets("Output").Range("C48:O74, C81:O107").ClearContents
   Worksheets("Output").Range("C48:O107,J48:J74,J81:J107").Interior.ColorIndex = 0
   Worksheets("Output").Range("EG3:ET21").ClearContents
   Worksheets("Output").Range("D48:H74,K48:N74").ClearContents
Worksheets("Output").Range("D48:H74,K48:O74,D81:H107,K81:O107").Interior.ColorIndex = 36
Worksheets("Output").Range("EF48:EF74,EM48:EM74,EF81:EF107,EM81:EM107").Interior.ColorIndex
= 36

'____________THICKNESS_____________________________________
'For the first Thickness mean
Dim Ran_num(1 To 10000) As Double
Dim group(0 To 30) As Double
Dim iRow As Double, jRow As Double, Count As Double, Amount As Double, n As Double
Dim Mean As Single, StdDev As Single
Dim U1 As Double, U2 As Double, V1 As Double, V2 As Double, S As Double
Mean = Range("G13").Value
```

```
StdDev = Range("D15").Value
Amount = 2000
n = Range("D17").Value
  If Amount Mod 2 = 0 Then
    Count = Amount / 2
  Else
    Count = (Amount + 1) / 2
  End If
  Randomize

  For iColumn = 16 To (16 + n) - 1

    For iRow = 1 To Count
      S = 2
    Do While S > 1
      U1 = Rnd
      U2 = Rnd
      V1 = 2 * U1 - 1
      V2 = 2 * U2 - 1
      S = V1 ^ 2 + V2 ^ 2
    Loop
      Ran_num(iRow * 2 - 1) = (Sqr(-2 * Log(S) / S) * V1) * StdDev + Mean
    If Amount Mod 2 = 0 Or iRow <> Count Then
      Ran_num(iRow * 2) = (Sqr(-2 * Log(S) / S) * V2) * StdDev + Mean
    End If
  Next iRow
Cells(1, 15).Value = "#"
For iRow = 1 To Amount
    Cells(iRow + 2, 15).Value = iRow
    Cells(iRow + 2, iColumn).Value = Format(Abs(Ran_num(iRow)), "0.000")

Next iRow
Next iColumn

'For the second Thickness mean
Dim Ran_num2(1 To 10000) As Double
Dim group2(0 To 30) As Double
Dim iRow2 As Double, jRow2 As Double, Count2 As Double, Amount2 As Double, n2 As Double
Dim Mean2 As Single, StdDev2 As Single
Dim U12 As Double, U22 As Double, V12 As Double, V22 As Double, S2 As Double

Mean2 = Range("G14").Value
StdDev2 = Range("D15").Value
Amount2 = 2000
n2 = Range("D17").Value
  If Amount2 Mod 2 = 0 Then
    Count2 = Amount2 / 2
  Else
    Count2 = (Amount2 + 1) / 2
  End If
  Randomize

  For iColumn2 = 16 To (16 + n2) - 1

    For iRow2 = 1 To Count2
      S2 = 2
```

```
    Do While S2 > 1
      U12 = Rnd
      U22 = Rnd
      V12 = 2 * U12 - 1
      V22 = 2 * U22 - 1
      S2 = V12 ^ 2 + V22 ^ 2
    Loop
      Ran_num2(iRow2 * 2 - 1) = (Sqr(-2 * Log(S2) / S2) * V12) * StdDev2 + Mean2
    If Amount2 Mod 2 = 0 Or iRow2 <> Count2 Then
      Ran_num2(iRow2 * 2) = (Sqr(-2 * Log(S2) / S2) * V22) * StdDev2 + Mean2
    End If
  Next iRow2
Cells(1, 15).Value = "#"
For iRow2 = 1 To Amount2
    Cells(iRow2 + 2006, 15).Value = iRow2
    Cells(iRow2 + 2006, iColumn2).Value = Format(Abs(Ran_num2(iRow2)), "0.000")

Next iRow2
Next iColumn2

'For the third Thickness mean
Dim Ran_num3(1 To 10000) As Double
Dim group3(0 To 30) As Double
Dim iRow3 As Double, jRow3 As Double, Count3 As Double, Amount3 As Double, n3 As Double
Dim Mean3 As Single, StdDev3 As Single
Dim U13 As Double, U23 As Double, V13 As Double, V23 As Double, S3 As Double

Mean3 = Range("G15").Value
StdDev3 = Range("D15").Value
Amount3 = 2000
n3 = Range("D17").Value
  If Amount3 Mod 2 = 0 Then
    Count3 = Amount3 / 2
  Else
    Count3 = (Amount3 + 1) / 2
  End If
  Randomize

  For iColumn3 = 16 To (16 + n3) - 1

    For iRow3 = 1 To Count3
      S3 = 2
    Do While S3 > 1
      U13 = Rnd
      U23 = Rnd
      V13 = 2 * U13 - 1
      V23 = 2 * U23 - 1
      S3 = V13 ^ 2 + V23 ^ 2
    Loop
      Ran_num3(iRow3 * 2 - 1) = (Sqr(-2 * Log(S3) / S3) * V13) * StdDev3 + Mean3
    If Amount3 Mod 2 = 0 Or iRow3 <> Count3 Then
      Ran_num3(iRow3 * 2) = (Sqr(-2 * Log(S3) / S3) * V23) * StdDev3 + Mean3
    End If
  Next iRow3
Cells(1, 15).Value = "#"
For iRow3 = 1 To Amount3
```

```
    Cells(iRow3 + 4010, 15).Value = iRow3
    Cells(iRow3 + 4010, iColumn3).Value = Format(Abs(Ran_num3(iRow3)), "0.000")

Next iRow3
Next iColumn3

'For the fourth Thickness mean
Dim Ran_num4(1 To 10000) As Double
Dim group4(0 To 30) As Double
Dim iRow4 As Double, jRow4 As Double, Count4 As Double, Amount4 As Double, n4 As Double
Dim Mean4 As Single, StdDev4 As Single
Dim U14 As Double, U24 As Double, V14 As Double, V24 As Double, S4 As Double

Mean4 = Range("G16").Value
StdDev4 = Range("D15").Value
Amount4 = 2000
n4 = Range("D17").Value
  If Amount4 Mod 2 = 0 Then
    Count4 = Amount4 / 2
  Else
    Count4 = (Amount4 + 1) / 2
  End If
  Randomize

  For iColumn4 = 16 To (16 + n4) - 1

    For iRow4 = 1 To Count4
      S4 = 2
    Do While S4 > 1
      U14 = Rnd
      U24 = Rnd
      V14 = 2 * U14 - 1
      V24 = 2 * U24 - 1
      S4 = V14 ^ 2 + V24 ^ 2
    Loop
      Ran_num4(iRow4 * 2 - 1) = (Sqr(-2 * Log(S4) / S4) * V14) * StdDev4 + Mean4
    If Amount4 Mod 2 = 0 Or iRow4 <> Count4 Then
      Ran_num4(iRow4 * 2) = (Sqr(-2 * Log(S4) / S4) * V24) * StdDev4 + Mean4
    End If
  Next iRow4
Cells(1, 15).Value = "#"
For iRow4 = 1 To Amount4
    Cells(iRow4 + 6014, 15).Value = iRow4
    Cells(iRow4 + 6014, iColumn4).Value = Format(Abs(Ran_num4(iRow4)), "0.000")

Next iRow4
Next iColumn4
'For the fifth Thickness mean
Dim Ran_num5(1 To 10000) As Double
Dim group5(0 To 30) As Double
Dim iRow5 As Double, jRow5 As Double, Count5 As Double, Amount5 As Double, n5 As Double
Dim Mean5 As Single, StdDev5 As Single
Dim U15 As Double, U25 As Double, V15 As Double, V25 As Double, S5 As Double

Mean5 = Range("G17").Value
StdDev5 = Range("D15").Value
```

```
Amount5 = 2000
n5 = Range("D17").Value
  If Amount5 Mod 2 = 0 Then
    Count5 = Amount5 / 2
  Else
    Count5 = (Amount5 + 1) / 2
  End If
  Randomize

  For iColumn5 = 16 To (16 + n5) - 1

    For iRow5 = 1 To Count5
      S5 = 2
    Do While S5 > 1
      U15 = Rnd
      U25 = Rnd
      V15 = 2 * U15 - 1
      V25 = 2 * U25 - 1
      S5 = V15 ^ 2 + V25 ^ 2
    Loop
      Ran_num5(iRow5 * 2 - 1) = (Sqr(-2 * Log(S5) / S5) * V15) * StdDev5 + Mean5
    If Amount5 Mod 2 = 0 Or iRow5 <> Count5 Then
      Ran_num5(iRow5 * 2) = (Sqr(-2 * Log(S5) / S5) * V25) * StdDev5 + Mean5
    End If
  Next iRow5
Cells(1, 15).Value = "#"
For iRow5 = 1 To Amount5
    Cells(iRow5 + 8018, 15).Value = iRow5
    Cells(iRow5 + 8018, iColumn5).Value = Format(Abs(Ran_num5(iRow5)), "0.000")

Next iRow5
Next iColumn5

'___STRENGTH_____________________________
"For the first Strength mean
Dim Ran_numSt(1 To 10000) As Double
Dim groupSt(0 To 30) As Double
Dim iRowSt As Double, jRowSt As Double, CountSt As Double, AmountSt As Double, nSt As Double
Dim MeanSt As Single, StdDevSt As Single
Dim U1St As Double, U2St As Double, V1St As Double, V2St As Double, SSt As Double
MeanSt = Range("G27").Value
StdDevSt = Range("D30").Value
AmountSt = 2000
nSt = Range("D32").Value
  If AmountSt Mod 2 = 0 Then
    CountSt = AmountSt / 2
  Else
    CountSt = (AmountSt + 1) / 2
  End If
  Randomize

  For iColumnSt = 60 To (60 + nSt) - 1

    For iRowSt = 1 To CountSt
      SSt = 2
    Do While SSt > 1
```

```
      U1St = Rnd
      U2St = Rnd
      V1St = 2 * U1St - 1
      V2St = 2 * U2St - 1
      SSt = V1St ^ 2 + V2St ^ 2
    Loop
      Ran_numSt(iRowSt * 2 - 1) = (Sqr(-2 * Log(SSt) / SSt) * V1St) * StdDevSt + MeanSt
    If AmountSt Mod 2 = 0 Or iRowSt <> CountSt Then
      Ran_numSt(iRowSt * 2) = (Sqr(-2 * Log(SSt) / SSt) * V2St) * StdDevSt + MeanSt
    End If
  Next iRowSt
Cells(1, 59).Value = "#"
For iRowSt = 1 To AmountSt
    Cells(iRowSt + 2, 59).Value = iRowSt
    Cells(iRowSt + 2, iColumnSt).Value = Format(Abs(Ran_numSt(iRowSt)), "0.000")
Next iRowSt
Next iColumnSt

'For the second Strength mean
Dim Ran_numSt2(1 To 10000) As Double
Dim groupSt2(0 To 30) As Double
Dim iRowSt2 As Double, jRowSt2 As Double, CountSt2 As Double, AmountSt2 As Double, nSt2 As
Double
Dim MeanSt2 As Single, StdDevSt2 As Single
Dim U1St2 As Double, U2St2 As Double, V1St2 As Double, V2St2 As Double, SSt2 As Double
MeanSt2 = Range("G28").Value
StdDevSt2 = Range("D30").Value
AmountSt2 = 2000
nSt2 = Range("D32").Value
  If AmountSt2 Mod 2 = 0 Then
    CountSt2 = AmountSt2 / 2
  Else
    CountSt2 = (AmountSt2 + 1) / 2
  End If
  Randomize

  For iColumnSt2 = 60 To (60 + nSt2) - 1

    For iRowSt2 = 1 To CountSt2
      SSt2 = 2
    Do While SSt2 > 1
      U1St2 = Rnd
      U2St2 = Rnd
      V1St2 = 2 * U1St2 - 1
      V2St2 = 2 * U2St2 - 1
      SSt2 = V1St2 ^ 2 + V2St2 ^ 2
    Loop
      Ran_numSt2(iRowSt2 * 2 - 1) = (Sqr(-2 * Log(SSt2) / SSt2) * V1St2) * StdDevSt2 + MeanSt2
    If AmountSt2 Mod 2 = 0 Or iRowSt2 <> CountSt2 Then
      Ran_numSt2(iRowSt2 * 2) = (Sqr(-2 * Log(SSt2) / SSt2) * V2St2) * StdDevSt2 + MeanSt2
    End If
  Next iRowSt2
Cells(1, 59).Value = "#"
For iRowSt2 = 1 To AmountSt2
    Cells(iRowSt2 + 2006, 59).Value = iRowSt2
    Cells(iRowSt2 + 2006, iColumnSt2).Value = Format(Abs(Ran_numSt2(iRowSt2)), "0.000")
```

```
Next iRowSt2
Next iColumnSt2

'For the third Strength mean
Dim Ran_numSt3(1 To 10000) As Double
Dim groupSt3(0 To 30) As Double
Dim iRowSt3 As Double, jRowSt3 As Double, CountSt3 As Double, AmountSt3 As Double, nSt3 As
Double
Dim MeanSt3 As Single, StdDevSt3 As Single
Dim U1St3 As Double, U3St3 As Double, V1St3 As Double, V3St3 As Double, SSt3 As Double
MeanSt3 = Range("G29").Value
StdDevSt3 = Range("D30").Value
AmountSt3 = 2000
nSt3 = Range("D32").Value
  If AmountSt3 Mod 2 = 0 Then
    CountSt3 = AmountSt3 / 2
  Else
    CountSt3 = (AmountSt3 + 1) / 2
  End If
  Randomize

  For iColumnSt3 = 60 To (60 + nSt3) - 1

    For iRowSt3 = 1 To CountSt3
      SSt3 = 2
    Do While SSt3 > 1
      U1St3 = Rnd
      U2St3 = Rnd
      V1St3 = 2 * U1St3 - 1
      V2St3 = 2 * U2St3 - 1
      SSt3 = V1St3 ^ 2 + V2St3 ^ 2
    Loop
      Ran_numSt3(iRowSt3 * 2 - 1) = (Sqr(-2 * Log(SSt3) / SSt3) * V1St3) * StdDevSt3 + MeanSt3
    If AmountSt3 Mod 2 = 0 Or iRowSt3 <> CountSt3 Then
      Ran_numSt3(iRowSt3 * 2) = (Sqr(-2 * Log(SSt3) / SSt3) * V2St3) * StdDevSt3 + MeanSt3
    End If
  Next iRowSt3
Cells(1, 59).Value = "#"
For iRowSt3 = 1 To AmountSt3
    Cells(iRowSt3 + 4010, 59).Value = iRowSt3
    Cells(iRowSt3 + 4010, iColumnSt3).Value = Format(Abs(Ran_numSt3(iRowSt3)), "0.000")
Next iRowSt3
Next iColumnSt3

'For the fourth Strength mean
Dim Ran_numSt4(1 To 10000) As Double
Dim groupSt4(0 To 30) As Double
Dim iRowSt4 As Double, jRowSt4 As Double, CountSt4 As Double, AmountSt4 As Double, nSt4 As
Double
Dim MeanSt4 As Single, StdDevSt4 As Single
Dim U1St4 As Double, U3St4 As Double, V1St4 As Double, V3St4 As Double, SSt4 As Double
MeanSt4 = Range("G30").Value
StdDevSt4 = Range("D30").Value
AmountSt4 = 2000
nSt4 = Range("D32").Value
  If AmountSt4 Mod 2 = 0 Then
```

```
    CountSt4 = AmountSt4 / 2
  Else
    CountSt4 = (AmountSt4 + 1) / 2
  End If
  Randomize

  For iColumnSt4 = 60 To (60 + nSt4) - 1

    For iRowSt4 = 1 To CountSt4
      SSt4 = 2
    Do While SSt4 > 1
      U1St4 = Rnd
      U2St4 = Rnd
      V1St4 = 2 * U1St4 - 1
      V2St4 = 2 * U2St4 - 1
      SSt4 = V1St4 ^ 2 + V2St4 ^ 2
    Loop
      Ran_numSt4(iRowSt4 * 2 - 1) = (Sqr(-2 * Log(SSt4) / SSt4) * V1St4) * StdDevSt4 + MeanSt4
    If AmountSt4 Mod 2 = 0 Or iRowSt4 <> CountSt4 Then
      Ran_numSt4(iRowSt4 * 2) = (Sqr(-2 * Log(SSt4) / SSt4) * V2St4) * StdDevSt4 + MeanSt4
    End If
  Next iRowSt4
Cells(1, 59).Value = "#"
For iRowSt4 = 1 To AmountSt4
    Cells(iRowSt4 + 6014, 59).Value = iRowSt4
    Cells(iRowSt4 + 6014, iColumnSt4).Value = Format(Abs(Ran_numSt4(iRowSt4)), "0.000")
Next iRowSt4
Next iColumnSt4

'For the fifth Strength mean
Dim Ran_numSt5(1 To 10000) As Double
Dim groupSt5(0 To 30) As Double
Dim iRowSt5 As Double, jRowSt5 As Double, CountSt5 As Double, AmountSt5 As Double, nSt5 As
Double
Dim MeanSt5 As Single, StdDevSt5 As Single
Dim U1St5 As Double, U2St5 As Double, V1St5 As Double, V2St5 As Double, SSt5 As Double
MeanSt5 = Range("G31").Value
StdDevSt5 = Range("D30").Value
AmountSt5 = 2000
nSt5 = Range("D32").Value
  If AmountSt5 Mod 2 = 0 Then
    CountSt5 = AmountSt5 / 2
  Else
    CountSt5 = (AmountSt5 + 1) / 2
  End If
  Randomize
  For iColumnSt5 = 60 To (60 + nSt5) - 1

    For iRowSt5 = 1 To CountSt5
      SSt5 = 2
    Do While SSt5 > 1
      U1St5 = Rnd
      U2St5 = Rnd
      V1St5 = 2 * U1St5 - 1
      V2St5 = 2 * U2St5 - 1
      SSt5 = V1St5 ^ 2 + V2St5 ^ 2
```

```
    Loop
      Ran_numSt5(iRowSt5 * 2 - 1) = (Sqr(-2 * Log(SSt5) / SSt5) * V1St5) * StdDevSt5 + MeanSt5
    If AmountSt5 Mod 2 = 0 Or iRowSt5 <> CountSt5 Then
      Ran_numSt5(iRowSt5 * 2) = (Sqr(-2 * Log(SSt5) / SSt5) * V2St5) * StdDevSt5 + MeanSt5
    End If
  Next iRowSt5
Cells(1, 59).Value = "#"
For iRowSt5 = 1 To AmountSt5
    Cells(iRowSt5 + 8018, 59).Value = iRowSt5
    Cells(iRowSt5 + 8018, iColumnSt5).Value = Format(Abs(Ran_numSt5(iRowSt5)), "0.000")
Next iRowSt5
Next iColumnSt5

'____SMOOTHNESS_____________________________________________
'For the first Smoothness mean
Dim Ran_numSm(1 To 10000) As Double
Dim groupSm(0 To 30) As Double
Dim iRowSm As Double, jRowSm As Double, CountSm As Double, AmountSm As Double, nSm As
Double
Dim MeanSm As Single, StdDevSm As Single
Dim U1Sm As Double, U2Sm As Double, V1Sm As Double, V2Sm As Double, SSm As Double
MeanSm = Range("G41").Value
StdDevSm = Range("D43").Value
AmountSm = 2000
nSm = Range("D45").Value
  If AmountSm Mod 2 = 0 Then
    CountSm = AmountSm / 2
  Else
    CountSm = (AmountSm + 1) / 2
  End If
  Randomize
    For iColumnSm = 103 To (103 + nSm) - 1

    For iRowSm = 1 To CountSm
      SSm = 2
    Do While SSm > 1
      U1Sm = Rnd
      U2Sm = Rnd
      V1Sm = 2 * U1Sm - 1
      V2Sm = 2 * U2Sm - 1
      SSm = V1Sm ^ 2 + V2Sm ^ 2
    Loop
      Ran_numSm(iRowSm * 2 - 1) = (Sqr(-2 * Log(SSm) / SSm) * V1Sm) * StdDevSm + MeanSm
    If AmountSm Mod 2 = 0 Or iRowSm <> CountSm Then
      Ran_numSm(iRowSm * 2) = (Sqr(-2 * Log(SSm) / SSm) * V2Sm) * StdDevSm + MeanSm
    End If
  Next iRowSm
Cells(1, 102).Value = "#"
For iRowSm = 1 To AmountSm
    Cells(iRowSm + 2, 102).Value = iRowSm
    Cells(iRowSm + 2, iColumnSm).Value = Format(Abs(Ran_numSm(iRowSm)), "0.000")
Next iRowSm
Next iColumnSm

'For the second Smoothness mean
Dim Ran_numSm2(1 To 10000) As Double
```

```
Dim groupSm2(0 To 70) As Double
Dim iRowSm2 As Double, jRowSm2 As Double, CountSm2 As Double, AmountSm2 As Double, nSm2
As Double
Dim MeanSm2 As Single, StdDevSm2 As Single
Dim U1Sm2 As Double, U2Sm2 As Double, V1Sm2 As Double, V2Sm2 As Double, SSm2 As Double
MeanSm2 = Range("G42").Value
StdDevSm2 = Range("D43").Value
AmountSm2 = 2000
nSm2 = Range("D45").Value
  If AmountSm2 Mod 2 = 0 Then
    CountSm2 = AmountSm2 / 2
  Else
    CountSm2 = (AmountSm2 + 1) / 2
  End If
  Randomize
    For iColumnSm2 = 103 To (103 + nSm2) - 1

    For iRowSm2 = 1 To CountSm2
      SSm2 = 2
    Do While SSm2 > 1
      U1Sm2 = Rnd
      U2Sm2 = Rnd
      V1Sm2 = 2 * U1Sm2 - 1
      V2Sm2 = 2 * U2Sm2 - 1
      SSm2 = V1Sm2 ^ 2 + V2Sm2 ^ 2
    Loop
      Ran_numSm2(iRowSm2 * 2 - 1) = (Sqr(-2 * Log(SSm2) / SSm2) * V1Sm2) * StdDevSm2 +
MeanSm2
    If AmountSm2 Mod 2 = 0 Or iRowSm2 <> CountSm2 Then
      Ran_numSm2(iRowSm2 * 2) = (Sqr(-2 * Log(SSm2) / SSm2) * V2Sm2) * StdDevSm2 + MeanSm2
    End If
  Next iRowSm2
Cells(1, 102).Value = "#"
For iRowSm2 = 1 To AmountSm2
    Cells(iRowSm2 + 2006, 102).Value = iRowSm2
    Cells(iRowSm2 + 2006, iColumnSm2).Value = Format(Abs(Ran_numSm2(iRowSm2)), "0.000")
Next iRowSm2
Next iColumnSm2

'For the third Smoothness mean
Dim Ran_numSm3(1 To 10000) As Double
Dim groupSm3(0 To 70) As Double
Dim iRowSm3 As Double, jRowSm3 As Double, CountSm3 As Double, AmountSm3 As Double, nSm3
As Double
Dim MeanSm3 As Single, StdDevSm3 As Single
Dim U1Sm3 As Double, U2Sm3 As Double, V1Sm3 As Double, V2Sm3 As Double, SSm3 As Double
MeanSm3 = Range("G43").Value
StdDevSm3 = Range("D43").Value
AmountSm3 = 2000
nSm3 = Range("D45").Value
  If AmountSm3 Mod 2 = 0 Then
    CountSm3 = AmountSm3 / 2
  Else
    CountSm3 = (AmountSm3 + 1) / 2
  End If
  Randomize
```

```
   For iColumnSm3 = 103 To (103 + nSm3) - 1

   For iRowSm3 = 1 To CountSm3
     SSm3 = 2
   Do While SSm3 > 1
     U1Sm3 = Rnd
     U2Sm3 = Rnd
     V1Sm3 = 2 * U1Sm3 - 1
     V2Sm3 = 2 * U2Sm3 - 1
     SSm3 = V1Sm3 ^ 2 + V2Sm3 ^ 2
   Loop
     Ran_numSm3(iRowSm3 * 2 - 1) = (Sqr(-2 * Log(SSm3) / SSm3) * V1Sm3) * StdDevSm3 +
MeanSm3
   If AmountSm3 Mod 2 = 0 Or iRowSm3 <> CountSm3 Then
     Ran_numSm3(iRowSm3 * 2) = (Sqr(-2 * Log(SSm3) / SSm3) * V2Sm3) * StdDevSm3 + MeanSm3
   End If
  Next iRowSm3
Cells(1, 102).Value = "#"
For iRowSm3 = 1 To AmountSm3
   Cells(iRowSm3 + 4010, 102).Value = iRowSm3
   Cells(iRowSm3 + 4010, iColumnSm3).Value = Format(Abs(Ran_numSm3(iRowSm3)), "0.000")
Next iRowSm3
Next iColumnSm3

'For the fourth Smoothness mean
Dim Ran_numSm4(1 To 10000) As Double
Dim groupSm4(0 To 70) As Double
Dim iRowSm4 As Double, jRowSm4 As Double, CountSm4 As Double, AmountSm4 As Double, nSm4
As Double
Dim MeanSm4 As Single, StdDevSm4 As Single
Dim U1Sm4 As Double, U2Sm4 As Double, V1Sm4 As Double, V2Sm4 As Double, SSm4 As Double
MeanSm4 = Range("G44").Value
StdDevSm4 = Range("D43").Value
AmountSm4 = 2000
nSm4 = Range("D45").Value
  If AmountSm4 Mod 2 = 0 Then
    CountSm4 = AmountSm4 / 2
  Else
    CountSm4 = (AmountSm4 + 1) / 2
  End If
  Randomize
   For iColumnSm4 = 103 To (103 + nSm4) - 1

   For iRowSm4 = 1 To CountSm4
     SSm4 = 2
   Do While SSm4 > 1
     U1Sm4 = Rnd
     U2Sm4 = Rnd
     V1Sm4 = 2 * U1Sm4 - 1
     V2Sm4 = 2 * U2Sm4 - 1
     SSm4 = V1Sm4 ^ 2 + V2Sm4 ^ 2
   Loop
     Ran_numSm4(iRowSm4 * 2 - 1) = (Sqr(-2 * Log(SSm4) / SSm4) * V1Sm4) * StdDevSm4 +
MeanSm4
   If AmountSm4 Mod 2 = 0 Or iRowSm4 <> CountSm4 Then
     Ran_numSm4(iRowSm4 * 2) = (Sqr(-2 * Log(SSm4) / SSm4) * V2Sm4) * StdDevSm4 + MeanSm4
```

```
    End If
  Next iRowSm4
Cells(1, 102).Value = "#"
For iRowSm4 = 1 To AmountSm4
    Cells(iRowSm4 + 6014, 102).Value = iRowSm4
    Cells(iRowSm4 + 6014, iColumnSm4).Value = Format(Abs(Ran_numSm4(iRowSm4)), "0.000")
Next iRowSm4
Next iColumnSm4

'For the fifth Smoothness mean
Dim Ran_numSm5(1 To 10000) As Double
Dim groupSm5(0 To 70) As Double
Dim iRowSm5 As Double, jRowSm5 As Double, CountSm5 As Double, AmountSm5 As Double, nSm5
As Double
Dim MeanSm5 As Single, StdDevSm5 As Single
Dim U1Sm5 As Double, U2Sm5 As Double, V1Sm5 As Double, V2Sm5 As Double, SSm5 As Double
MeanSm5 = Range("G45").Value
StdDevSm5 = Range("D43").Value
AmountSm5 = 2000
nSm5 = Range("D45").Value
  If AmountSm5 Mod 2 = 0 Then
    CountSm5 = AmountSm5 / 2
  Else
    CountSm5 = (AmountSm5 + 1) / 2
  End If
  Randomize
    For iColumnSm5 = 103 To (103 + nSm5) - 1

    For iRowSm5 = 1 To CountSm5
      SSm5 = 2
    Do While SSm5 > 1
      U1Sm5 = Rnd
      U2Sm5 = Rnd
      V1Sm5 = 2 * U1Sm5 - 1
      V2Sm5 = 2 * U2Sm5 - 1
      SSm5 = V1Sm5 ^ 2 + V2Sm5 ^ 2
    Loop
      Ran_numSm5(iRowSm5 * 2 - 1) = (Sqr(-2 * Log(SSm5) / SSm5) * V1Sm5) * StdDevSm5 +
MeanSm5
    If AmountSm5 Mod 2 = 0 Or iRowSm5 <> CountSm5 Then
      Ran_numSm5(iRowSm5 * 2) = (Sqr(-2 * Log(SSm5) / SSm5) * V2Sm5) * StdDevSm5 + MeanSm5
    End If
  Next iRowSm5
Cells(1, 102).Value = "#"
For iRowSm5 = 1 To AmountSm5
    Cells(iRowSm5 + 8018, 102).Value = iRowSm5
    Cells(iRowSm5 + 8018, iColumnSm5).Value = Format(Abs(Ran_numSm5(iRowSm5)), "0.000")
Next iRowSm5
Next iColumnSm5

'_______THICKNESS-QI_____________________
Range("AX3:AX2002").Formula = "=(AVERAGE(P3:AS3)-($D$13))/(STDEV(P3:AS3))"
Range("AX2007:AX4006").Formula = "=(AVERAGE(P2007:AS2007)-
($D$13))/(STDEV(P2007:AS2007))"
Range("AX4011:AX6010").Formula = "=(AVERAGE(P4011:AS4011)-
($D$13))/(STDEV(P4011:AS4011))"
```

```
Range("AX6015:AX8014").Formula = "=(AVERAGE(P6015:AS6015)-
($D$13))/(STDEV(P6015:AS6015))"
Range("AX8019:AX10018").Formula = "=(AVERAGE(P8019:AS8019)-
($D$13))/(STDEV(P8019:AS8019))"

'_______QI-Descending-Thickness___________
 'If Range("D11") = " " Then
 'Range("AY3:AY8014") = " "
 'Else:
 Range("AY3:AY2002") = Range("AX3:AX2002").Value
 Range("AY3:AY2002").Sort Key1:=Range("AY3:AY2002"), Order1:=xlDescending, Header:=xlNo,
OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
 Range("AY2007:AY4006") = Range("AX2007:AX4006").Value
 Range("AY2007:AY4006").Sort Key1:=Range("AY2007:AY4006"), Order1:=xlDescending,
Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
 Range("AY4011:AY6010") = Range("AX4011:AX6010").Value
 Range("AY4011:AY6010").Sort Key1:=Range("AY4011:AY6010"), Order1:=xlDescending,
Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
 Range("AY6015:AY8014") = Range("AX6015:AX8014").Value
 Range("AY6015:AY8014").Sort Key1:=Range("AY6015:AY8014"), Order1:=xlDescending,
Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
 Range("AY8019:AY10018") = Range("AX8019:AX10018").Value
 Range("AY8019:AY10018").Sort Key1:=Range("AY8019:AY10018"), Order1:=xlDescending,
Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
'End If

'_____PWL - Thickness_____________________________
Range("BA3:BA2002").Formula =
"=IF(AY3>0,INDEX(Output!$X$3:$AY$403,MATCH(AY3,Output!$W$3:$W$403),MATCH($D$17,Out
put!$X$2:$AY$2)), IF(AY3<=0,(100-
INDEX(Output!$X$3:$AY$403,MATCH(ABS(AY3),Output!$W$3:$W$403),MATCH($D$17,Output!$X
$2:$AY$2)))))"
Range("BA2007:BA4006").Formula =
"=IF(AY2007>0,INDEX(Output!$X$3:$AY$403,MATCH(AY2007,Output!$W$3:$W$403),MATCH($D
$17,Output!$X$2:$AY$2)), IF(AY2007<=0,(100-
INDEX(Output!$X$3:$AY$403,MATCH(ABS(AY2007),Output!$W$3:$W$403),MATCH($D$17,Output
!$X$2:$AY$2)))))"
Range("BA4011:BA6010").Formula =
"=IF(AY4011>0,INDEX(Output!$X$3:$AY$403,MATCH(AY4011,Output!$W$3:$W$403),MATCH($D
$17,Output!$X$2:$AY$2)), IF(AY4011<=0,(100-
INDEX(Output!$X$3:$AY$403,MATCH(ABS(AY4011),Output!$W$3:$W$403),MATCH($D$17,Output
!$X$2:$AY$2)))))"
Range("BA6015:BA8014").Formula =
"=IF(AY6015>0,INDEX(Output!$X$3:$AY$403,MATCH(AY6015,Output!$W$3:$W$403),MATCH($D
$17,Output!$X$2:$AY$2)), IF(AY6015<=0,(100-
INDEX(Output!$X$3:$AY$403,MATCH(ABS(AY6015),Output!$W$3:$W$403),MATCH($D$17,Output
!$X$2:$AY$2)))))"
Range("BA8019:BA10018").Formula =
"=IF(AY8019>0,INDEX(Output!$X$3:$AY$403,MATCH(AY8019,Output!$W$3:$W$403),MATCH($D
$17,Output!$X$2:$AY$2)), IF(AY8019<=0,(100-
INDEX(Output!$X$3:$AY$403,MATCH(ABS(AY8019),Output!$W$3:$W$403),MATCH($D$17,Output
!$X$2:$AY$2)))))"

'_______PF - Thickness_____________________________
Range("BB3:BB2002").Formula = "=IF(BA3<=60,(0.75*(55+(0.5*BA3))),IF(BA3>60,55+(0.5*BA3)))"
```

```
Range("BB2007:BB4006").Formula =
"=IF(BA2007<=60,(0.75*(55+(0.5*BA2007))),IF(BA2007>60,55+(0.5*BA2007)))"
Range("BB4011:BB6010").Formula =
"=IF(BA4011<=60,(0.75*(55+(0.5*BA4011))),IF(BA4011>60,55+(0.5*BA4011)))"
Range("BB6015:BB8014").Formula =
"=IF(BA6015<=60,(0.75*(55+(0.5*BA6015))),IF(BA6015>60,55+(0.5*BA6015)))"
Range("BB8019:BB10018").Formula =
"=IF(BA8019<=60,(0.75*(55+(0.5*BA8019))),IF(BA8019>60,55+(0.5*BA8019)))"

'_____% Probability - Thickness_________________
 Range("BD3").Formula = "=(BB501+BB502)/2"
 Range("BD4").Formula = "=(BB1001+BB1002)/2"
 Range("BD5").Formula = "=(BB1501+BB1502)/2"
 Range("BD6").Formula = "=(BB1901+BB1902)/2"

 Range("BD2007").Formula = "=(BB2505+BB2506)/2"
 Range("BD2008").Formula = "=(BB3005+BB3006)/2"
 Range("BD2009").Formula = "=(BB3505+BB3506)/2"
 Range("BD2010").Formula = "=(BB3905+BB3906)/2"

 Range("BD4011").Formula = "=(BB4509+BB4510)/2"
 Range("BD4012").Formula = "=(BB5009+BB5010)/2"
 Range("BD4013").Formula = "=(BB5509+BB5510)/2"
 Range("BD4014").Formula = "=(BB5909+BB5910)/2"

 Range("BD6015").Formula = "=(BB6513+BB6514)/2"
 Range("BD6016").Formula = "=(BB7013+BB7014)/2"
 Range("BD6017").Formula = "=(BB7513+BB7514)/2"
 Range("BD6018").Formula = "=(BB7913+BB7914)/2"

 Range("BD8019").Formula = "=(BB8517+BB8518)/2"
 Range("BD8020").Formula = "=(BB9017+BB9018)/2"
 Range("BD8021").Formula = "=(BB9517+BB9518)/2"
 Range("BD8022").Formula = "=(BB9917+BB9918)/2"

'_______STRENGTH-QI_____________________
Range("CP3:CP2002").Formula = "=((AVERAGE(BH3:CK3))-($D$28))/(STDEV(BH3:CK3))"
Range("CP2007:CP4006").Formula = "=((AVERAGE(BH2007:CK2007))-
($D$28))/(STDEV(BH2007:CK2007))"
Range("CP4011:CP6010").Formula = "=((AVERAGE(BH4011:CK4011))-
($D$28))/(STDEV(BH4011:CK4011))"
Range("CP6015:CP8014").Formula = "=((AVERAGE(BH6015:CK6015))-
($D$28))/(STDEV(BH6015:CK6015))"
Range("CP8019:CP10018").Formula = "=((AVERAGE(BH8019:CK8019))-
($D$28))/(STDEV(BH8019:CK8019))"

'______QI- Descending - Strength___________
 Range("CQ3:CQ2002") = Range("CP3:CP2002").Value
 Range("CQ3:CQ2002").Sort Key1:=Range("CQ3:CQ2002"), Order1:=xlDescending, Header:=xlNo,
OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

 Range("CQ2007:CQ4006") = Range("CP2007:CP4006").Value
 Range("CQ2007:CQ4006").Sort Key1:=Range("CQ2007:CQ4006"), Order1:=xlDescending,
Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

 Range("CQ4011:CQ6010") = Range("CP4001:CP6010").Value
```

```
 Range("CQ4011:CQ6010").Sort Key1:=Range("CQ4001:CQ6010"), Order1:=xlDescending,
Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

 Range("CQ6015:CQ8014") = Range("CP6015:CP8014").Value
 Range("CQ6015:CQ8014").Sort Key1:=Range("CQ6015:CQ8014"), Order1:=xlDescending,
Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

 Range("CQ8019:CQ10018") = Range("CP8019:CP10018").Value
 Range("CQ8019:CQ10018").Sort Key1:=Range("CQ8019:CQ10018"), Order1:=xlDescending,
Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

'_____PWL - Strength_____________________________
Range("CS3:CS2002").Formula =
"=IF(CQ3>0,INDEX(Output!$X$3:$AY$403,MATCH(CQ3,Output!$W$3:$W$403),MATCH($D$32,Out
put!$X$2:$AY$2)), IF(CQ3<=0,(100-
INDEX(Output!$X$3:$CQ$403,MATCH(ABS(CQ3),Output!$W$3:$W$403),MATCH($D$32,Output!$X
$2:$AT$2)))))"
Range("CS2007:CS4006").Formula =
"=IF(CQ2007>0,INDEX(Output!$X$3:$AY$403,MATCH(CQ2007,Output!$W$3:$W$403),MATCH($D
$32,Output!$X$2:$AY$2)), IF(CQ2007<=0,(100-
INDEX(Output!$X$3:$AY$403,MATCH(ABS(CQ2007),Output!$W$3:$W$403),MATCH($D$32,Output
!$X$2:$AY$2)))))"
Range("CS4011:CS6010").Formula =
"=IF(CQ4011>0,INDEX(Output!$X$3:$AY$403,MATCH(CQ4011,Output!$W$3:$W$403),MATCH($D
$32,Output!$X$2:$AY$2)), IF(CQ4011<=0,(100-
INDEX(Output!$X$3:$AY$403,MATCH(ABS(CQ4011),Output!$W$3:$W$403),MATCH($D$32,Output
!$X$2:$AY$2)))))"
Range("CS6015:CS8014").Formula =
"=IF(CQ6015>0,INDEX(Output!$X$3:$AY$403,MATCH(CQ6015,Output!$W$3:$W$403),MATCH($D
$32,Output!$X$2:$AY$2)), IF(CQ6015<=0,(100-
INDEX(Output!$X$3:$AY$403,MATCH(ABS(CQ6015),Output!$W$3:$W$403),MATCH($D$32,Output
!$X$2:$AY$2)))))"
Range("CS8019:CS10018").Formula =
"=IF(CQ8019>0,INDEX(Output!$X$3:$AY$403,MATCH(CQ8019,Output!$W$3:$W$403),MATCH($D
$32,Output!$X$2:$AY$2)), IF(CQ8019<=0,(100-
INDEX(Output!$X$3:$AY$403,MATCH(ABS(CQ8019),Output!$W$3:$W$403),MATCH($D$32,Output
!$X$2:$AY$2)))))"

'_______PF - Strength_____________________________
Range("CT3:CT2002").Formula = "=IF(CS3<=60,(0.75*(55+(0.5*CS3))),IF(CS3>60,55+(0.5*CS3)))"
Range("CT2007:CT4006").Formula =
"=IF(CS2007<=60,(0.75*(55+(0.5*CS2007))),IF(CS2007>60,55+(0.5*CS2007)))"
Range("CT4011:CT6010").Formula =
"=IF(CS4011<=60,(0.75*(55+(0.5*CS4011))),IF(CS4011>60,55+(0.5*CS4011)))"
Range("CT6015:CT8014").Formula =
"=IF(CS6015<=60,(0.75*(55+(0.5*CS6015))),IF(CS6015>60,55+(0.5*CS6015)))"
Range("CT8019:CT10018").Formula =
"=IF(CS8019<=60,(0.75*(55+(0.5*CS8019))),IF(CS8019>60,55+(0.5*CS8019)))"

'_____% Probability - Strength_____________________
 Range("CV3").Formula = "=(CT501+CT502)/2"
 Range("CV4").Formula = "=(CT1001+CT1002)/2"
 Range("CV5").Formula = "=(CT1501+CT1502)/2"
 Range("CV6").Formula = "=(CT1901+CT1902)/2"
 Range("CV2007").Formula = "=(CT2505+CT2506)/2"
 Range("CV2008").Formula = "=(CT3005+CT3006)/2"
```

```
 Range("CV2009").Formula = "=(CT3505+CT3506)/2"
 Range("CV2010").Formula = "=(CT3905+CT3906)/2"

 Range("CV4011").Formula = "=(CT4509+CT4510)/2"
 Range("CV4012").Formula = "=(CT5009+CT5010)/2"
 Range("CV4013").Formula = "=(CT5509+CT5510)/2"
 Range("CV4014").Formula = "=(CT5909+CT5910)/2"

 Range("CV6015").Formula = "=(CT6513+CT6514)/2"
 Range("CV6016").Formula = "=(CT7013+CT7014)/2"
 Range("CV6017").Formula = "=(CT7513+CT7514)/2"
 Range("CV6018").Formula = "=(CT7913+CT7914)/2"

 Range("CV8019").Formula = "=(CT8517+CT8518)/2"
 Range("CV8020").Formula = "=(CT9017+CT9018)/2"
 Range("CV8021").Formula = "=(CT9517+CT9518)/2"
 Range("CV8022").Formula = "=(CT9917+CT9918)/2"

'_____Smoothness-PF_____________________
'If Worksheets("Output").Range("BC4") = 3 And Worksheets("Output").Range("BD4") = 1 Then
'Range("FR3:II2002").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY3,Output!$BG$2:$BG$142),MATCH($D$45,Output!$B
K$1:$EB$1))"
'Range("FR2007:II4006").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY2007,Output!$BG$2:$BG$142),MATCH($D$45,Output!
$BK$1:$EB$1))"
'Range("FR4011:II6010").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY4011,Output!$BG$2:$BG$142),MATCH($D$45,Output!
$BK$1:$EB$1))"
'Range("FR6015:II8014").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY6015,Output!$BG$2:$BG$142),MATCH($D$45,Output!
$BK$1:$EB$1))"
'Range("FR8019:II10018").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY8019,Output!$BG$2:$BG$142),MATCH($D$45,Output!
$BK$1:$EB$1))"
'End If

'If Worksheets("Output").Range("BC4") = 2 And
If Worksheets("Output").Range("BD4") = 2 Then
Range("FR3:II2002").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY3,Output!$BH$2:$BH$142),MATCH($D$45,Output!$B
K$1:$EB$1))"
Range("FR2007:II4006").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY2007,Output!$BH$2:$BH$142),MATCH($D$45,Output!
$BK$1:$EB$1))"
Range("FR4011:II6010").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY4011,Output!$BH$2:$BH$142),MATCH($D$45,Output!
$BK$1:$EB$1))"
Range("FR6015:II8014").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY6015,Output!$BH$2:$BH$142),MATCH($D$45,Output!
$BK$1:$EB$1))"
Range("FR8019:II10018").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY8019,Output!$BH$2:$BH$142),MATCH($D$45,Output!
$BK$1:$CJ$1))"
End If
'If Worksheets("Output").Range("BC4") = 3 And Worksheets("Output").Range("BD4") = 2 Then
```

```
'Range("FR3:II2002").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY3,Output!$BI$2:$BI$142),MATCH($D$45,Output!$BK$
1:$EB$1))"
'Range("FR2007:II4006").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY2007,Output!$BI$2:$BI$142),MATCH($D$45,Output!$
BK$1:$EB$1))"
'Range("FR4011:II6010").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY4011,Output!$BI$2:$BI$142),MATCH($D$45,Output!$
BK$1:$EB$1))"
'Range("FR6015:II8014").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY6015,Output!$BI$2:$BI$142),MATCH($D$45,Output!$
BK$1:$EB$1))"
'Range("FR8019:II10018").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY8019,Output!$BI$2:$BI$142),MATCH($D$45,Output!$
BK$1:$EB$1))"
'End If

'If Worksheets("Output").Range("BC4") = 2 And
If Worksheets("Output").Range("BD4") = 1 Then
Range("FR3:II2002").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY3,Output!$BJ$2:$BJ$142),MATCH($D$45,Output!$BK
$1:$EB$1))"
Range("FR2007:II4006").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY2007,Output!$BJ$2:$BJ$142),MATCH($D$45,Output!$
BK$1:$EB$1))"
Range("FR4011:II6010").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY4011,Output!$BJ$2:$BJ$142),MATCH($D$45,Output!$
BK$1:$EB$1))"
Range("FR6015:II8014").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY6015,Output!$BJ$2:$BJ$142),MATCH($D$45,Output!$
BK$1:$EB$1))"
Range("FR8019:II10018").Formula =
"=INDEX(Output!$BK$2:$EB$142,MATCH(CY8019,Output!$BJ$2:$BJ$142),MATCH($D$45,Output!$
BK$1:$EB$1))"
End If

'_____PF Descending - Smoothness_____
 Range("IL3:IL2002") = Range("IK3:IK2002").Value
 Range("IL3:IL2002").Sort Key1:=Range("IL3:IL2002"), Order1:=xlDescending, Header:=xlNo,
OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

 Range("IL2007:IL4006") = Range("IK2007:IK4006").Value
 Range("IL2007:IL4006").Sort Key1:=Range("IL2007:IL4006"), Order1:=xlDescending, Header:=xlNo,
OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

 Range("IL4011:IL6010") = Range("IK4011:IK6010").Value
 Range("IL4011:IL6010").Sort Key1:=Range("IL4011:IL6010"), Order1:=xlDescending, Header:=xlNo,
OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

 Range("IL6015:IL8014") = Range("IK6015:IK8014").Value
 Range("IL6015:IL8014").Sort Key1:=Range("IL6015:IL8014"), Order1:=xlDescending, Header:=xlNo,
OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

 Range("IL8019:IL10018") = Range("IK8019:IK10018").Value
 Range("IL8019:IL10018").Sort Key1:=Range("IL8019:IL10018"), Order1:=xlDescending, Header:=xlNo,
OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
```

```
'_______PF for % Probability - Smoothness_____________________________
 Range("IN3").Formula = "=(IL501+IL502)/2"
 Range("IN4").Formula = "=(IL1001+IL1002)/2"
 Range("IN5").Formula = "=(IL1501+IL1502)/2"
 Range("IN6").Formula = "=(IL1901+IL1902)/2"

 Range("IN2007").Formula = "=(IL2505+IL2506)/2"
 Range("IN2008").Formula = "=(IL3005+IL3006)/2"
 Range("IN2009").Formula = "=(IL3505+IL3506)/2"
 Range("IN2010").Formula = "=(IL3905+IL3906)/2"
 Range("IN4011").Formula = "=(IL4509+IL4510)/2"
 Range("IN4012").Formula = "=(IL5009+IL5010)/2"
 Range("IN4013").Formula = "=(IL5509+IL5510)/2"
 Range("IN4014").Formula = "=(IL5909+IL5910)/2"

 Range("IN6015").Formula = "=(IL6513+IL6514)/2"
 Range("IN6016").Formula = "=(IL7013+IL7014)/2"
 Range("IN6017").Formula = "=(IL7513+IL7514)/2"
 Range("IN6018").Formula = "=(IL7913+IL7914)/2"

 Range("IN8019").Formula = "=(IL8517+IL8518)/2"
 Range("IN8020").Formula = "=(IL9017+IL9018)/2"
 Range("IN8021").Formula = "=(IL9517+IL9518)/2"
 Range("IN8022").Formula = "=(IL9917+IL9918)/2"

'_________OUTPUT_____________________________________
'_________Thickness_____________________________________
Dim G13 As Double, G14 As Double, G15 As Double, G16 As Double, G17 As Double
Dim I13 As Double, I14 As Double, I15 As Double, I16 As Double, I17 As Double

G13 = Worksheets("Input").Range("G13")
G14 = Worksheets("Input").Range("G14")
G15 = Worksheets("Input").Range("G15")
G16 = Worksheets("Input").Range("G16")
G17 = Worksheets("Input").Range("G17")

I13 = Worksheets("Input").Range("I13")
I14 = Worksheets("Input").Range("I14")
I15 = Worksheets("Input").Range("I15")
I16 = Worksheets("Input").Range("I16")
I17 = Worksheets("Input").Range("I17")

Worksheets("Output").Range("B5") = G13
Worksheets("Output").Range("B6") = G14
Worksheets("Output").Range("B7") = G15
Worksheets("Output").Range("B8") = G16
Worksheets("Output").Range("B9") = G17

Worksheets("Output").Range("C5") = I13
Worksheets("Output").Range("C6") = I14
Worksheets("Output").Range("C7") = I15
Worksheets("Output").Range("C8") = I16
Worksheets("Output").Range("C9") = I17

'____________Thickness % Pay_____________________________
'If Range("D13").Value = " " Then
```

```
'Range("BD3:BD8019").Value = " "
'Else:
BD6 = Worksheets("Input").Range("BD6")
BD2010 = Worksheets("Input").Range("BD2010")
BD4014 = Worksheets("Input").Range("BD4014")
BD6018 = Worksheets("Input").Range("BD6018")
BD8022 = Worksheets("Input").Range("BD8022")

BD5 = Worksheets("Input").Range("BD5")
BD2009 = Worksheets("Input").Range("BD2009")
BD4013 = Worksheets("Input").Range("BD4013")
BD6017 = Worksheets("Input").Range("BD6017")
BD8021 = Worksheets("Input").Range("BD8021")

BD4 = Worksheets("Input").Range("BD4")
BD2008 = Worksheets("Input").Range("BD2008")
BD4012 = Worksheets("Input").Range("BD4012")
BD6016 = Worksheets("Input").Range("BD6016")
BD8020 = Worksheets("Input").Range("BD8020")

BD3 = Worksheets("Input").Range("BD3")
BD2007 = Worksheets("Input").Range("BD2007")
BD4011 = Worksheets("Input").Range("BD4011")
BD6015 = Worksheets("Input").Range("BD6015")
BD8019 = Worksheets("Input").Range("BD8019")

If Worksheets("Input").Range("D11") = "" Then
Worksheets("Output").Range("B5:K9") = ""
Else: Worksheets("Output").Range("D5") = BD6 - 100
Worksheets("Output").Range("D6") = BD2010 - 100
Worksheets("Output").Range("D7") = BD4014 - 100
Worksheets("Output").Range("D8") = BD6018 - 100
Worksheets("Output").Range("D9") = BD8022 - 100
Worksheets("Output").Range("E5") = BD5 - 100
Worksheets("Output").Range("E6") = BD2009 - 100
Worksheets("Output").Range("E7") = BD4013 - 100
Worksheets("Output").Range("E8") = BD6017 - 100
Worksheets("Output").Range("E9") = BD8021 - 100
Worksheets("Output").Range("F5") = BD4 - 100
Worksheets("Output").Range("F6") = BD2008 - 100
Worksheets("Output").Range("F7") = BD4012 - 100
Worksheets("Output").Range("F8") = BD6016 - 100
Worksheets("Output").Range("F9") = BD8020 - 100
Worksheets("Output").Range("G5") = BD3 - 100
Worksheets("Output").Range("G6") = BD2007 - 100
Worksheets("Output").Range("G7") = BD4011 - 100
Worksheets("Output").Range("G8") = BD6015 - 100
Worksheets("Output").Range("G9") = BD8019 - 100
End If
'_________Thickness % Profit_____________________
Dim C5 As Double, C6 As Double, C7 As Double, C8 As Double, C9 As Double
Dim D5 As Double, D6 As Double, D7 As Double, D8 As Double, D9 As Double
Dim E5 As Double, E6 As Double, E7 As Double, E8 As Double, E9 As Double
Dim F5 As Double, F6 As Double, F7 As Double, F8 As Double, F9 As Double
Dim G5 As Double, G6 As Double, G7 As Double, G8 As Double, G9 As Double
```

```
C5 = Worksheets("Output").Range("C5")
C6 = Worksheets("Output").Range("C6")
C7 = Worksheets("Output").Range("C7")
C8 = Worksheets("Output").Range("C8")
C9 = Worksheets("Output").Range("C9")
D5 = Worksheets("Output").Range("D5")
D6 = Worksheets("Output").Range("D6")
D7 = Worksheets("Output").Range("D7")
D8 = Worksheets("Output").Range("D8")
D9 = Worksheets("Output").Range("D9")
E5 = Worksheets("Output").Range("E5")
E6 = Worksheets("Output").Range("E6")
E7 = Worksheets("Output").Range("E7")
E8 = Worksheets("Output").Range("E8")
E9 = Worksheets("Output").Range("E9")
F5 = Worksheets("Output").Range("F5")
F6 = Worksheets("Output").Range("F6")
F7 = Worksheets("Output").Range("F7")
F8 = Worksheets("Output").Range("F8")
F9 = Worksheets("Output").Range("F9")
G5 = Worksheets("Output").Range("G5")
G6 = Worksheets("Output").Range("G6")
G7 = Worksheets("Output").Range("G7")
G8 = Worksheets("Output").Range("G8")
G9 = Worksheets("Output").Range("G9")

If Worksheets("Output").Range("B5") = "" Then
Worksheets("Output").Range("D5:K9") = ""
Else: Worksheets("Output").Range("H5") = D5 - C5
Worksheets("Output").Range("H6") = D6 - C6
Worksheets("Output").Range("H7") = D7 - C7
Worksheets("Output").Range("H8") = D8 - C8
Worksheets("Output").Range("H9") = D9 - C9

Worksheets("Output").Range("I5") = E5 - C5
Worksheets("Output").Range("I6") = E6 - C6
Worksheets("Output").Range("I7") = E7 - C7
Worksheets("Output").Range("I8") = E8 - C8
Worksheets("Output").Range("I9") = E9 - C9

Worksheets("Output").Range("J5") = F5 - C5
Worksheets("Output").Range("J6") = F6 - C6
Worksheets("Output").Range("J7") = F7 - C7
Worksheets("Output").Range("J8") = F8 - C8
Worksheets("Output").Range("J9") = F9 - C9

Worksheets("Output").Range("K5") = G5 - C5
Worksheets("Output").Range("K6") = G6 - C6
Worksheets("Output").Range("K7") = G7 - C7
Worksheets("Output").Range("K8") = G8 - C8
Worksheets("Output").Range("K9") = G9 - C9
End If

'________Strength ________________________________
Worksheets("Output").Range("B14") = Worksheets("Input").Range("G27")
Worksheets("Output").Range("B15") = Worksheets("Input").Range("G28")
```

```
Worksheets("Output").Range("B16") = Worksheets("Input").Range("G29")
Worksheets("Output").Range("B17") = Worksheets("Input").Range("G30")
Worksheets("Output").Range("B18") = Worksheets("Input").Range("G31")
Worksheets("Output").Range("C14") = Worksheets("Input").Range("I27")
Worksheets("Output").Range("C15") = Worksheets("Input").Range("I28")
Worksheets("Output").Range("C16") = Worksheets("Input").Range("I29")
Worksheets("Output").Range("C17") = Worksheets("Input").Range("I30")
Worksheets("Output").Range("C18") = Worksheets("Input").Range("I31")

'____________Strength % Pay_____________________________________________
If Range("D26").Value = "" Then
Worksheets("Output").Range("B14:K18") = ""
Else: Dim CV3 As Double, CV4 As Double, CV5 As Double, CV6 As Double
Dim CV2007 As Double, CV2008 As Double, CV2009 As Double, CV2010 As Double
Dim CV4011 As Double, CV4012 As Double, CV4013 As Double, CV4014 As Double
Dim CV6015 As Double, CV6016 As Double, CV6017 As Double, CV6018 As Double
Dim CV8019 As Double, CV8020 As Double, CV8021 As Double, CV8022 As Double

CV6 = Worksheets("Input").Range("CV6")
CV2010 = Worksheets("Input").Range("CV2010")
CV4014 = Worksheets("Input").Range("CV4014")
CV6018 = Worksheets("Input").Range("CV6018")
CV8022 = Worksheets("Input").Range("CV8022")

CV5 = Worksheets("Input").Range("CV5")
CV2009 = Worksheets("Input").Range("CV2009")
CV4013 = Worksheets("Input").Range("CV4013")
CV6017 = Worksheets("Input").Range("CV6017")
CV8021 = Worksheets("Input").Range("CV8021")

CV4 = Worksheets("Input").Range("CV4")
CV2008 = Worksheets("Input").Range("CV2008")
CV4012 = Worksheets("Input").Range("CV4012")
CV6016 = Worksheets("Input").Range("CV6016")
CV8020 = Worksheets("Input").Range("CV8020")

CV3 = Worksheets("Input").Range("CV3")
CV2007 = Worksheets("Input").Range("CV2007")
CV4011 = Worksheets("Input").Range("CV4011")
CV6015 = Worksheets("Input").Range("CV6015")
CV8019 = Worksheets("Input").Range("CV8019")
End If

If Worksheets("Input").Range("D26").Value = "" Then
Worksheets("Output").Range("B14:K18").Value = ""
Else: Worksheets("Output").Range("D14") = CV6 - 100
Worksheets("Output").Range("D15") = CV2010 - 100
Worksheets("Output").Range("D16") = CV4014 - 100
Worksheets("Output").Range("D17") = CV6018 - 100
Worksheets("Output").Range("D18") = CV8022 - 100

Worksheets("Output").Range("E14") = CV5 - 100
Worksheets("Output").Range("E15") = CV2009 - 100
Worksheets("Output").Range("E16") = CV4013 - 100
Worksheets("Output").Range("E17") = CV6017 - 100
Worksheets("Output").Range("E18") = CV8021 - 100
```

```
Worksheets("Output").Range("F14") = CV4 - 100
Worksheets("Output").Range("F15") = CV2008 - 100
Worksheets("Output").Range("F16") = CV4012 - 100
Worksheets("Output").Range("F17") = CV6016 - 100
Worksheets("Output").Range("F18") = CV8020 - 100

Worksheets("Output").Range("G14") = CV3 - 100
Worksheets("Output").Range("G15") = CV2007 - 100
Worksheets("Output").Range("G16") = CV4011 - 100
Worksheets("Output").Range("G17") = CV6015 - 100
Worksheets("Output").Range("G18") = CV8019 - 100
End If
'_________Strength % Profit____________________
Dim C14 As Double, C15 As Double, C16 As Double, C17 As Double, C18 As Double
Dim D14 As Double, D15 As Double, D16 As Double, D17 As Double, D18 As Double
Dim E14 As Double, E15 As Double, E16 As Double, E17 As Double, E18 As Double
Dim F14 As Double, F15 As Double, F16 As Double, F17 As Double, F18 As Double
Dim OG14 As Double, OG15 As Double, OG16 As Double, OG17 As Double, OG18 As Double

C14 = Worksheets("Output").Range("C14")
C15 = Worksheets("Output").Range("C15")
C16 = Worksheets("Output").Range("C16")
C17 = Worksheets("Output").Range("C17")
C18 = Worksheets("Output").Range("C18")
D14 = Worksheets("Output").Range("D14")
D15 = Worksheets("Output").Range("D15")
D16 = Worksheets("Output").Range("D16")
D17 = Worksheets("Output").Range("D17")
D18 = Worksheets("Output").Range("D18")
E14 = Worksheets("Output").Range("E14")
E15 = Worksheets("Output").Range("E15")
E16 = Worksheets("Output").Range("E16")
E17 = Worksheets("Output").Range("E17")
E18 = Worksheets("Output").Range("E18")
F14 = Worksheets("Output").Range("F14")
F15 = Worksheets("Output").Range("F15")
F16 = Worksheets("Output").Range("F16")
F17 = Worksheets("Output").Range("F17")
F18 = Worksheets("Output").Range("F18")
OG14 = Worksheets("Output").Range("G14")
OG15 = Worksheets("Output").Range("G15")
OG16 = Worksheets("Output").Range("G16")
OG17 = Worksheets("Output").Range("G17")
OG18 = Worksheets("Output").Range("G18")

If Worksheets("Input").Range("D26").Value = "" Then
Worksheets("Output").Range("B14:K18").Value = ""
Else: Worksheets("Output").Range("H14") = D14 - C14
Worksheets("Output").Range("H15") = D15 - C15
Worksheets("Output").Range("H16") = D16 - C16
Worksheets("Output").Range("H17") = D17 - C17
Worksheets("Output").Range("H18") = D18 - C18
Worksheets("Output").Range("I14") = E14 - C14
Worksheets("Output").Range("I15") = E15 - C15
Worksheets("Output").Range("I16") = E16 - C16
```

```
Worksheets("Output").Range("I17") = E17 - C17
Worksheets("Output").Range("I18") = E18 - C18
Worksheets("Output").Range("J14") = F14 - C14
Worksheets("Output").Range("J15") = F15 - C15
Worksheets("Output").Range("J16") = F16 - C16
Worksheets("Output").Range("J17") = F17 - C17
Worksheets("Output").Range("J18") = F18 - C18
Worksheets("Output").Range("K14") = OG14 - C14
Worksheets("Output").Range("K15") = OG15 - C15
Worksheets("Output").Range("K16") = OG16 - C16
Worksheets("Output").Range("K17") = OG17 - C17
Worksheets("Output").Range("K18") = OG18 - C18
End If
'________Smoothness_____________________________
Worksheets("Output").Range("B23") = Worksheets("Input").Range("G41")
Worksheets("Output").Range("B24") = Worksheets("Input").Range("G42")
Worksheets("Output").Range("B25") = Worksheets("Input").Range("G43")
Worksheets("Output").Range("B26") = Worksheets("Input").Range("G44")
Worksheets("Output").Range("B27") = Worksheets("Input").Range("G45")

Worksheets("Output").Range("C23") = Worksheets("Input").Range("I41")
Worksheets("Output").Range("C24") = Worksheets("Input").Range("I42")
Worksheets("Output").Range("C25") = Worksheets("Input").Range("I43")
Worksheets("Output").Range("C26") = Worksheets("Input").Range("I44")
Worksheets("Output").Range("C27") = Worksheets("Input").Range("I45")

'____________Smoothness % Pay_____________________
Dim IN3 As Double, IN4 As Double, IN5 As Double, IN6 As Double
Dim IN2007 As Double, IN2008 As Double, IN2009 As Double, IN2010 As Double
Dim IN4011 As Double, IN4012 As Double, IN4013 As Double, IN4014 As Double
Dim IN6015 As Double, IN6016 As Double, IN6017 As Double, IN6018 As Double
Dim IN8019 As Double, IN8020 As Double, IN8021 As Double, IN8022 As Double

IN6 = Worksheets("Input").Range("IN6")
IN2010 = Worksheets("Input").Range("IN2010")
IN4014 = Worksheets("Input").Range("IN4014")
IN6018 = Worksheets("Input").Range("IN6018")
IN8022 = Worksheets("Input").Range("IN8022")

IN5 = Worksheets("Input").Range("IN5")
IN2009 = Worksheets("Input").Range("IN2009")
IN4013 = Worksheets("Input").Range("IN4013")
IN6017 = Worksheets("Input").Range("IN6017")
IN8021 = Worksheets("Input").Range("IN8021")

IN4 = Worksheets("Input").Range("IN4")
IN2008 = Worksheets("Input").Range("IN2008")
IN4012 = Worksheets("Input").Range("IN4012")
IN6016 = Worksheets("Input").Range("IN6016")
IN8020 = Worksheets("Input").Range("IN8020")

IN3 = Worksheets("Input").Range("IN3")
IN2007 = Worksheets("Input").Range("IN2007")
IN4011 = Worksheets("Input").Range("IN4011")
IN6015 = Worksheets("Input").Range("IN6015")
IN8019 = Worksheets("Input").Range("IN8019")
```

```
If Worksheets("Output").Range("B23") = "" Then
Worksheets("Output").Range("D23:K27") = ""
Else: Worksheets("Output").Range("D23") = IN6 - 100
Worksheets("Output").Range("D24") = IN2010 - 100
Worksheets("Output").Range("D25") = IN4014 - 100
Worksheets("Output").Range("D26") = IN6018 - 100
Worksheets("Output").Range("D27") = IN8022 - 100

Worksheets("Output").Range("E23") = IN5 - 100
Worksheets("Output").Range("E24") = IN2009 - 100
Worksheets("Output").Range("E25") = IN4013 - 100
Worksheets("Output").Range("E26") = IN6017 - 100
Worksheets("Output").Range("E27") = IN8021 - 100

Worksheets("Output").Range("F23") = IN4 - 100
Worksheets("Output").Range("F24") = IN2008 - 100
Worksheets("Output").Range("F25") = IN4012 - 100
Worksheets("Output").Range("F26") = IN6016 - 100
Worksheets("Output").Range("F27") = IN8020 - 100

Worksheets("Output").Range("G23") = IN3 - 100
Worksheets("Output").Range("G24") = IN2007 - 100
Worksheets("Output").Range("G25") = IN4011 - 100
Worksheets("Output").Range("G26") = IN6015 - 100
Worksheets("Output").Range("G27") = IN8019 - 100
End If
'_________Smoothness % Profit_____________________
Dim C23 As Double, C24 As Double, C25 As Double, C26 As Double, C27 As Double
Dim D23 As Double, D24 As Double, D25 As Double, D26 As Double, D27 As Double
Dim E23 As Double, E24 As Double, E25 As Double, E26 As Double, E27 As Double
Dim F23 As Double, F24 As Double, F25 As Double, F26 As Double, F27 As Double
Dim G23 As Double, G24 As Double, G25 As Double, G26 As Double, G27 As Double

C23 = Worksheets("Output").Range("C23")
C24 = Worksheets("Output").Range("C24")
C25 = Worksheets("Output").Range("C25")
C26 = Worksheets("Output").Range("C26")
C27 = Worksheets("Output").Range("C27")
D23 = Worksheets("Output").Range("D23")
D24 = Worksheets("Output").Range("D24")
D25 = Worksheets("Output").Range("D25")
D26 = Worksheets("Output").Range("D26")
D27 = Worksheets("Output").Range("D27")
E23 = Worksheets("Output").Range("E23")
E24 = Worksheets("Output").Range("E24")
E25 = Worksheets("Output").Range("E25")
E26 = Worksheets("Output").Range("E26")
E27 = Worksheets("Output").Range("E27")
F23 = Worksheets("Output").Range("F23")
F24 = Worksheets("Output").Range("F24")
F25 = Worksheets("Output").Range("F25")
F26 = Worksheets("Output").Range("F26")
F27 = Worksheets("Output").Range("F27")
G23 = Worksheets("Output").Range("G23")
G24 = Worksheets("Output").Range("G24")
```

```
G25 = Worksheets("Output").Range("G25")
G26 = Worksheets("Output").Range("G26")
G27 = Worksheets("Output").Range("G27")

If Worksheets("Output").Range("B23") = "" Then
Worksheets("Output").Range("D23:K27") = ""
Else:
Worksheets("Output").Range("H23") = D23 - C23
Worksheets("Output").Range("H24") = D24 - C24
Worksheets("Output").Range("H25") = D25 - C25
Worksheets("Output").Range("H26") = D26 - C26
Worksheets("Output").Range("H27") = D27 - C27
Worksheets("Output").Range("I23") = E23 - C23
Worksheets("Output").Range("I24") = E24 - C24
Worksheets("Output").Range("I25") = E25 - C25
Worksheets("Output").Range("I26") = E26 - C26
Worksheets("Output").Range("I27") = E27 - C27
Worksheets("Output").Range("J23") = F23 - C23
Worksheets("Output").Range("J24") = F24 - C24
Worksheets("Output").Range("J25") = F25 - C25
Worksheets("Output").Range("J26") = F26 - C26
Worksheets("Output").Range("J27") = F27 - C27
Worksheets("Output").Range("K23") = G23 - C23
Worksheets("Output").Range("K24") = G24 - C24
Worksheets("Output").Range("K25") = G25 - C25
Worksheets("Output").Range("K26") = G26 - C26
Worksheets("Output").Range("K27") = G27 - C27
End If
'__________CPF - Profit_____________________
Worksheets("Output").Range("EG3:EG7") = Worksheets("Output").Range("H5:H9").Value
Worksheets("Output").Range("EG3:EG7").Sort Key1:=Worksheets("Output").Range("EG3:EG7"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("EH3:EH7") = Worksheets("Output").Range("I5:I9").Value
Worksheets("Output").Range("EH3:EH7").Sort Key1:=Worksheets("Output").Range("EH3:EH7"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("EI3:EI7") = Worksheets("Output").Range("J5:J9").Value
Worksheets("Output").Range("EI3:EI7").Sort Key1:=Worksheets("Output").Range("EI3:EI7"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("EJ3:EJ7") = Worksheets("Output").Range("K5:K9").Value
Worksheets("Output").Range("EJ3:EJ7").Sort Key1:=Worksheets("Output").Range("EJ3:EJ7"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("EG10:EG14") = Worksheets("Output").Range("H14:H18").Value
Worksheets("Output").Range("EG10:EG14").Sort Key1:=Worksheets("Output").Range("EG10:EG14"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("EH10:EH14") = Worksheets("Output").Range("I14:I18").Value
Worksheets("Output").Range("EH10:EH14").Sort Key1:=Worksheets("Output").Range("EH10:EH14"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("EI10:EI14") = Worksheets("Output").Range("J14:J18").Value
Worksheets("Output").Range("EI10:EI14").Sort Key1:=Worksheets("Output").Range("EI10:EI14"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
```

```
Worksheets("Output").Range("EJ10:EJ14") = Worksheets("Output").Range("K14:K18").Value
Worksheets("Output").Range("EJ10:EJ14").Sort Key1:=Worksheets("Output").Range("EJ10:EJ14"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("EG17:EG21") = Worksheets("Output").Range("H23:H27").Value
Worksheets("Output").Range("EG17:EG21").Sort Key1:=Worksheets("Output").Range("EG17:EG21"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("EH17:EH21") = Worksheets("Output").Range("I23:I27").Value
Worksheets("Output").Range("EH17:EH21").Sort Key1:=Worksheets("Output").Range("EH17:EH21"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("EI17:EI21") = Worksheets("Output").Range("J23:J27").Value
Worksheets("Output").Range("EI17:EI21").Sort Key1:=Worksheets("Output").Range("EI17:EI21"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("EJ17:EJ21") = Worksheets("Output").Range("K23:K27").Value
Worksheets("Output").Range("EJ17:EJ21").Sort Key1:=Worksheets("Output").Range("EJ17:EJ21"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

'___________CPF - Pay___________________________
Worksheets("Output").Range("FF3:FF7") = Worksheets("Output").Range("D5:D9").Value
Worksheets("Output").Range("FF3:FF7").Sort Key1:=Worksheets("Output").Range("FF3:FF7"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("FG3:FG7") = Worksheets("Output").Range("E5:E9").Value
Worksheets("Output").Range("FG3:FG7").Sort Key1:=Worksheets("Output").Range("FG3:FG7"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("FH3:FH7") = Worksheets("Output").Range("F5:F9").Value
Worksheets("Output").Range("FH3:FH7").Sort Key1:=Worksheets("Output").Range("FH3:FH7"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("FI3:FI7") = Worksheets("Output").Range("G5:G9").Value
Worksheets("Output").Range("FI3:FI7").Sort Key1:=Worksheets("Output").Range("FI3:FI7"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("FF10:FF14") = Worksheets("Output").Range("D14:D18").Value
Worksheets("Output").Range("FF10:FF14").Sort Key1:=Worksheets("Output").Range("FF10:FF14"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("FG10:FG14") = Worksheets("Output").Range("E14:E18").Value
Worksheets("Output").Range("FG10:FG14").Sort Key1:=Worksheets("Output").Range("FG10:FG14"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("FH10:FH14") = Worksheets("Output").Range("F14:F18").Value
Worksheets("Output").Range("FH10:FH14").Sort Key1:=Worksheets("Output").Range("FH10:FH14"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("FI10:FI14") = Worksheets("Output").Range("G14:G18").Value
Worksheets("Output").Range("FI10:FI14").Sort Key1:=Worksheets("Output").Range("FI10:FI14"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
Worksheets("Output").Range("FF17:FF21") = Worksheets("Output").Range("D23:D27").Value
Worksheets("Output").Range("FF17:FF21").Sort Key1:=Worksheets("Output").Range("FF17:FF21"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
```

```
Worksheets("Output").Range("FG17:FG21") = Worksheets("Output").Range("E23:E27").Value
Worksheets("Output").Range("FG17:FG21").Sort Key1:=Worksheets("Output").Range("FG17:FG21"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("FH17:FH21") = Worksheets("Output").Range("F23:F27").Value
Worksheets("Output").Range("FH17:FH21").Sort Key1:=Worksheets("Output").Range("FH17:FH21"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("FI17:FI21") = Worksheets("Output").Range("G23:G27").Value
Worksheets("Output").Range("FI17:FI21").Sort Key1:=Worksheets("Output").Range("FI17:FI21"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

'____PAY FACTOR (PAY + 100)_____________
If Worksheets("Output").Range("B5") = "" Then
Worksheets("Output").Range("EL3:EO7,EV3:EY7") = ""
Else: Worksheets("Output").Range("EL25:EL29").Formula = "=D5+100"
Worksheets("Output").Range("EM25:EM29").Formula = "=E5+100"
Worksheets("Output").Range("EN25:EN29").Formula = "=F5+100"
Worksheets("Output").Range("EO25:EO29").Formula = "=G5+100"
Worksheets("Output").Range("EV3:EY7").Formula = "=EL3-100"
End If

If Worksheets("Output").Range("B14") = "" Then
Worksheets("Output").Range("EL10:EO14,EV10:EY14") = ""
Else: Worksheets("Output").Range("EL32:EL36").Formula = "=D14+100"
Worksheets("Output").Range("EM32:EM36").Formula = "=E14+100"
Worksheets("Output").Range("EN32:EN36").Formula = "=F14+100"
Worksheets("Output").Range("EO32:EO36").Formula = "=G14+100"
Worksheets("Output").Range("EV10:EY14").Formula = "=EL10-100"
End If

If Worksheets("Output").Range("B23") = "" Then
Worksheets("Output").Range("EL17:EO21,EV17:EY21") = ""
Else: Worksheets("Output").Range("EL39:EL43").Formula = "=D23+100"
Worksheets("Output").Range("EM39:EM43").Formula = "=E23+100"
Worksheets("Output").Range("EN39:EN43").Formula = "=F23+100"
Worksheets("Output").Range("EO39:EO43").Formula = "=G23+100"
Worksheets("Output").Range("EV17:EY21").Formula = "=EL17-100"
End If

'______PAY FACTOR (PAY + 100) IN DESCENDING ORDER____
Worksheets("Output").Range("EL3:EL7") = Worksheets("Output").Range("EL25:EL29").Value
Worksheets("Output").Range("EL3:EL7").Sort Key1:=Worksheets("Output").Range("EL3:EL7"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
Worksheets("Output").Range("EL10:EL14") = Worksheets("Output").Range("EL32:EL36").Value
Worksheets("Output").Range("EL10:EL14").Sort Key1:=Worksheets("Output").Range("EL10:EL14"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
Worksheets("Output").Range("EL17:EL21") = Worksheets("Output").Range("EL39:EL43").Value
Worksheets("Output").Range("EL17:EL21").Sort Key1:=Worksheets("Output").Range("EL17:EL21"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("EM3:EM7") = Worksheets("Output").Range("EM25:EM29").Value
Worksheets("Output").Range("EM3:EM7").Sort Key1:=Worksheets("Output").Range("EM3:EM7"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
Worksheets("Output").Range("EM10:EM14") = Worksheets("Output").Range("EM32:EM36").Value
```

```
Worksheets("Output").Range("EM10:EM14").Sort Key1:=Worksheets("Output").Range("EM10:EM14"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
Worksheets("Output").Range("EM17:EM21") = Worksheets("Output").Range("EM39:EM43").Value
Worksheets("Output").Range("EM17:EM21").Sort Key1:=Worksheets("Output").Range("EM17:EM21"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("EN3:EN7") = Worksheets("Output").Range("EN25:EN29").Value
Worksheets("Output").Range("EN3:EN7").Sort Key1:=Worksheets("Output").Range("EN3:EN7"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
Worksheets("Output").Range("EN10:EN14") = Worksheets("Output").Range("EN32:EN36").Value
Worksheets("Output").Range("EN10:EN14").Sort Key1:=Worksheets("Output").Range("EN10:EN14"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
Worksheets("Output").Range("EN17:EN21") = Worksheets("Output").Range("EN39:EN43").Value
Worksheets("Output").Range("EN17:EN21").Sort Key1:=Worksheets("Output").Range("EN17:EN21"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("EO3:EO7") = Worksheets("Output").Range("EO25:EO29").Value
Worksheets("Output").Range("EO3:EO7").Sort Key1:=Worksheets("Output").Range("EO3:EO7"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
Worksheets("Output").Range("EO10:EO14") = Worksheets("Output").Range("EO32:EO36").Value
Worksheets("Output").Range("EO10:EO14").Sort Key1:=Worksheets("Output").Range("EO10:EO14"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
Worksheets("Output").Range("EO17:EO21") = Worksheets("Output").Range("EO39:EO43").Value
Worksheets("Output").Range("EO17:EO21").Sort Key1:=Worksheets("Output").Range("EO17:EO21"),
Order1:=xlDescending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

'_______Quality Factor_____________________________
Worksheets("Output").Range("EQ3:EQ7").Formula = "=IF(EG3=$H$5, $B$5, IF(EG3=$H$6,$B$6,
IF(EG3=$H$7, $B$7, IF(EG3=$H$8,$B$8, IF(EG3=$H$9,$B$9)))))"
Worksheets("Output").Range("ER3:ER7").Formula = "=IF(EH3=$I$5, $B$5, IF(EH3=$I$6,$B$6,
IF(EH3=$I$7, $B$7, IF(EH3=$I$8,$B$8, IF(EH3=$I$9,$B$9)))))"
Worksheets("Output").Range("ES3:ES7").Formula = "=IF(EI3=$J$5, $B$5, IF(EI3=$J$6,$B$6,
IF(EI3=$J$7, $B$7, IF(EI3=$J$8,$B$8, IF(EI3=$J$9,$B$9)))))"
Worksheets("Output").Range("ET3:ET7").Formula = "=IF(EJ3=$K$5, $B$5, IF(EJ3=$K$6,$B$6,
IF(EJ3=$K$7, $B$7, IF(EJ3=$K$8,$B$8, IF(EJ3=$K$9,$B$9)))))"

Worksheets("Output").Range("EQ10:EQ14").Formula = "=IF(EG10=$H$14, $B$14,
IF(EG10=$H$15,$B$15, IF(EG10=$H$16, $B$16, IF(EG10=$H$17,$B$17, IF(EG10=$H$18,$B$18)))))"
Worksheets("Output").Range("ER10:ER14").Formula = "=IF(EH10=$I$14, $B$14,
IF(EH10=$I$15,$B$15, IF(EH10=$I$16, $B$16, IF(EH10=$I$17,$B$17, IF(EH10=$I$18,$B$18)))))"
Worksheets("Output").Range("ES10:ES14").Formula = "=IF(EI10=$J$14, $B$14, IF(EI10=$J$15,$B$15,
IF(EI10=$J$16, $B$16, IF(EI10=$J$17,$B$17, IF(EI10=$J$18,$B$18)))))"
Worksheets("Output").Range("ET10:ET14").Formula = "=IF(EJ10=$K$14, $B$14,
IF(EJ10=$K$15,$B$15, IF(EJ10=$K$16, $B$16, IF(EJ10=$K$17,$B$17, IF(EJ10=$K$18,$B$18)))))"

'Worksheets("Output").Range("ES17").Formula = "=IF(EI17=$F$23, $B$23, IF(FH17=$F$24,$B$24,
IF(FH17=$F$25, $B$25, IF(FH17=$F$26,$B$26, IF(FH17=$F$27,$B$27)))))"
'Worksheets("Output").Range("ET17").Formula = "=IF(FI17=$G$23, $B$23, IF(FI17=$G$24,$B$24,
IF(FI17=$G$25, $B$25, IF(FI17=$G$26,$B$26, IF(FI17=$G$27,$B$27)))))"

Worksheets("Output").Range("EQ17:EQ21").Formula = "=IF(EG17=$H$23, $B$23,
IF(EG17=$H$24,$B$24, IF(EG17=$H$25, $B$25, IF(EG17=$H$26,$B$26, IF(EG17=$H$27,$B$27)))))"
Worksheets("Output").Range("ER17:ER21").Formula = "=IF(EH17=$I$23, $B$23,
IF(EH17=$I$24,$B$24, IF(EH17=$I$25, $B$25, IF(EH17=$I$26,$B$26, IF(EH17=$I$27,$B$27)))))"
Worksheets("Output").Range("ES17:ES21").Formula = "=IF(EI17=$J$23,$B$23, IF(EI17=$J$24, $B$24,
IF(EI17=$J$25,$B$25, IF(EI17=$J$26,$B$26,IF(EI17=$J$27,$B$27)))))"
```

```
Worksheets("Output").Range("ET17:ET21").Formula = "=IF(EJ17=$K$23,$B$23, IF(EJ17=$K$24,
$B$24, IF(EJ17=$K$25,$B$25, IF(EJ17=$K$26,$B$26,IF(EJ17=$K$27,$B$27)))))"

If Worksheets("Output").Range("B5").Value = "  " Then
Worksheets("Output").Range("EG3:ET7,D5:K9").Value = "  "
End If

If Worksheets("Output").Range("B14").Value = "  " Then
Worksheets("Output").Range("EG10:ET14,D14:K18").Value = "  "
End If
If Worksheets("Output").Range("B23").Value = "  " Then
Worksheets("Output").Range("EG17:E21,D23:K27").Value = "  "
End If

If Worksheets("Output").Range("B5") = "" Then
Worksheets("Output").Range("FA3:FD7") = 1
Else: Worksheets("Output").Range("FA3:FD7").Formula = "=EL3/100"
End If

If Worksheets("Output").Range("B14") = "" Then
Worksheets("Output").Range("FA10:FD14") = 1
Else: Worksheets("Output").Range("FA10:FD14").Formula = "=EL10/100"
End If

If Worksheets("Output").Range("B23") = "" Then
Worksheets("Output").Range("FA17:FD21") = 1
Else: Worksheets("Output").Range("FA17:FD21").Formula = "=EL17/100"
End If
Worksheets("Output").Activate
End If
End Sub
```

```
Sub Button6_Click()
Worksheets("Input").Activate
ActiveSheet.PrintOut , 1, 1
Worksheets("Output").Activate
ActiveSheet.PrintOut , 2, 1
End Sub
```

```
Sub DropDown3_Change()
Dim DVT As Double, LSLT As Double, SDT As Double, TVT As Double
Dim T1 As Double, T2 As Double, T3 As Double, T4 As Double, T5 As Double
Dim BV As Double
Dim w As Double
DVT = Range("D11").Value
LSLT = Range("D13").Value
SDT = Range("D15").Value
w = Range("M9").Value

T1 = Range("G13").Value
T2 = Range("G14").Value
T3 = Range("G15").Value
T4 = Range("G16").Value
T5 = Range("G17").Value

'BV = Val(TextBox1.Text)
```

```
If Worksheets("Output").Range("BA4") = 3 Then
   'TextBox1.Value = DVT
   Worksheets("Input").Range("D11") = DVT * 0.0254
   Worksheets("Input").Range("D13") = LSLT * 0.0254
   Worksheets("Input").Range("D15") = SDT * 0.0254
   Worksheets("Input").Range("G13") = T1 * 0.0254
   Worksheets("Input").Range("G14") = T2 * 0.0254
   Worksheets("Input").Range("G15") = T3 * 0.0254
   Worksheets("Input").Range("G16") = T4 * 0.0254
   Worksheets("Input").Range("G17") = T5 * 0.0254
ElseIf Worksheets("Output").Range("BA4") = 2 Then
   Worksheets("Input").Range("D11") = DVT / 0.0254
   Worksheets("Input").Range("D13") = LSLT / 0.0254
   Worksheets("Input").Range("D15") = SDT / 0.0254
   Worksheets("Input").Range("G13") = T1 / 0.0254
   Worksheets("Input").Range("G14") = T2 / 0.0254
   Worksheets("Input").Range("G15") = T3 / 0.0254
   Worksheets("Input").Range("G16") = T4 / 0.0254
   Worksheets("Input").Range("G17") = T5 / 0.0254
End If
End Sub
```

```
Sub DropDown6_Change()
Dim D30 As Double
Dim EG3 As Double, EG4 As Double, EG5 As Double, EG6 As Double, EG7 As Double
Dim EH3 As Double, EH4 As Double, EH5 As Double, EH6 As Double, EH7 As Double
Dim EI3 As Double, EI4 As Double, EI5 As Double, EI6 As Double, EI7 As Double
Dim EJ3 As Double, EJ4 As Double, EJ5 As Double, EJ6 As Double, EJ7 As Double
Dim EL3 As Double, EL4 As Double, EL5 As Double, EL6 As Double, EL7 As Double
Dim EM3 As Double, EM4 As Double, EM5 As Double, EM6 As Double, EM7 As Double
Dim EN3 As Double, EN4 As Double, EN5 As Double, EN6 As Double, EN7 As Double
Dim EO3 As Double, EO4 As Double, EO5 As Double, EO6 As Double, EO7 As Double
Dim EQ3 As Double, EQ4 As Double, EQ5 As Double, EQ6 As Double, EQ7 As Double
Dim ER3 As Double, ER4 As Double, ER5 As Double, ER6 As Double, ER7 As Double
Dim ES3 As Double, ES4 As Double, ES5 As Double, ES6 As Double, ES7 As Double
Dim ET3 As Double, ET4 As Double, ET5 As Double, ET6 As Double, ET7 As Double
Dim EG10 As Double, EG11 As Double, EG12 As Double, EG13 As Double, EG14 As Double
Dim EH10 As Double, EH11 As Double, EH12 As Double, EH13 As Double, EH14 As Double
Dim EI10 As Double, EI11 As Double, EI12 As Double, EI13 As Double, EI14 As Double
Dim EJ10 As Double, EJ11 As Double, EJ12 As Double, EJ13 As Double, EJ14 As Double
Dim EL10 As Double, EL11 As Double, EL12 As Double, EL13 As Double, EL14 As Double
Dim EM10 As Double, EM11 As Double, EM12 As Double, EM13 As Double, EM14 As Double
Dim EN10 As Double, EN11 As Double, EN12 As Double, EN13 As Double, EN14 As Double
Dim EO10 As Double, EO11 As Double, EO12 As Double, EO13 As Double, EO14 As Double
Dim EQ10 As Double, EQ11 As Double, EQ12 As Double, EQ13 As Double, EQ14 As Double
Dim ER10 As Double, ER11 As Double, ER12 As Double, ER13 As Double, ER14 As Double
Dim ES10 As Double, ES11 As Double, ES12 As Double, ES13 As Double, ES14 As Double
Dim ET10 As Double, ET11 As Double, ET12 As Double, ET13 As Double, ET14 As Double
Dim EG17 As Double, EG18 As Double, EG19 As Double, EG20 As Double, EG21 As Double
Dim EH17 As Double, EH18 As Double, EH19 As Double, EH20 As Double, EH21 As Double
Dim EI17 As Double, EI18 As Double, EI19 As Double, EI20 As Double, EI21 As Double
Dim EJ17 As Double, EJ18 As Double, EJ19 As Double, EJ20 As Double, EJ21 As Double
Dim EL17 As Double, EL18 As Double, EL19 As Double, EL20 As Double, EL21 As Double
Dim EM17 As Double, EM18 As Double, EM19 As Double, EM20 As Double, EM21 As Double
Dim EN17 As Double, EN18 As Double, EN19 As Double, EN20 As Double, EN21 As Double
```

```
Dim EO17 As Double, EO18 As Double, EO19 As Double, EO20 As Double, EO21 As Double
Dim EQ17 As Double, EQ18 As Double, EQ19 As Double, EQ20 As Double, EQ21 As Double
Dim ER17 As Double, ER18 As Double, ER19 As Double, ER20 As Double, ER21 As Double
Dim ES17 As Double, ES18 As Double, ES19 As Double, ES20 As Double, ES21 As Double
Dim ET17 As Double, ET18 As Double, ET19 As Double, ET20 As Double, ET21 As Double
Dim E35 As Double, E37 As Double, E39 As Double, N6 As Double
Dim EV3 As Double, EV4 As Double, EV5 As Double, EV6 As Double, EV7 As Double
Dim EW3 As Double, EW4 As Double, EW5 As Double, EW6 As Double, EW7 As Double
Dim EX3 As Double, EX4 As Double, EX5 As Double, EX6 As Double, EX7 As Double
Dim EY3 As Double, EY4 As Double, EY5 As Double, EY6 As Double, EY7 As Double
Dim EV10 As Double, EV11 As Double, EV12 As Double, EV13 As Double, EV14 As Double
Dim EW10 As Double, EW11 As Double, EW12 As Double, EW13 As Double, EW14 As Double
Dim EX10 As Double, EX11 As Double, EX12 As Double, EX13 As Double, EX14 As Double
Dim EY10 As Double, EY11 As Double, EY12 As Double, EY13 As Double, EY14 As Double
Dim EV17 As Double, EV18 As Double, EV19 As Double, EV20 As Double, EV21 As Double
Dim EW17 As Double, EW18 As Double, EW19 As Double, EW20 As Double, EW21 As Double
Dim EX17 As Double, EX18 As Double, EX19 As Double, EX20 As Double, EX21 As Double
Dim EY17 As Double, EY18 As Double, EY19 As Double, EY20 As Double, EY21 As Double
Dim FA3 As Double, FA4 As Double, FA5 As Double, FA6 As Double, FA7 As Double
Dim FB3 As Double, FB4 As Double, FB5 As Double, FB6 As Double, FB7 As Double
Dim FC3 As Double, FC4 As Double, FC5 As Double, FC6 As Double, FC7 As Double
Dim FD3 As Double, FD4 As Double, FD5 As Double, FD6 As Double, FD7 As Double
Dim FA10 As Double, FA11 As Double, FA12 As Double, FA13 As Double, FA14 As Double
Dim FB10 As Double, FB11 As Double, FB12 As Double, FB13 As Double, FB14 As Double
Dim FC10 As Double, FC11 As Double, FC12 As Double, FC13 As Double, FC14 As Double
Dim FD10 As Double, FD11 As Double, FD12 As Double, FD13 As Double, FD14 As Double
Dim FA17 As Double, FA18 As Double, FA19 As Double, FA20 As Double, FA21 As Double
Dim FB17 As Double, FB18 As Double, FB19 As Double, FB20 As Double, FB21 As Double
Dim FC17 As Double, FC18 As Double, FC19 As Double, FC20 As Double, FC21 As Double
Dim FD17 As Double, FD18 As Double, FD19 As Double, FD20 As Double, FD21 As Double

EV3 = Range("EV3").Value
EV4 = Range("EV4").Value
EV5 = Range("EV5").Value
EV6 = Range("EV6").Value
EV7 = Range("EV7").Value
EW3 = Range("EW3").Value
EW4 = Range("EW4").Value
EW5 = Range("EW5").Value
EW6 = Range("EW6").Value
EW7 = Range("EW7").Value
EX3 = Range("EX3").Value
EX4 = Range("EX4").Value
EX5 = Range("EX5").Value
EX6 = Range("EX6").Value
EX7 = Range("EX7").Value
EY3 = Range("EY3").Value
EY4 = Range("EY4").Value
EY5 = Range("EY5").Value
EY6 = Range("EY6").Value
EY7 = Range("EY7").Value
EV10 = Range("EV10").Value
EV11 = Range("EV11").Value
EV12 = Range("EV12").Value
EV13 = Range("EV13").Value
EV14 = Range("EV14").Value
```

```
EW10 = Range("EW10").Value
EW11 = Range("EW11").Value
EW12 = Range("EW12").Value
EW13 = Range("EW13").Value
EW14 = Range("EW14").Value
EX10 = Range("EX10").Value
EX11 = Range("EX11").Value
EX12 = Range("EX12").Value
EX13 = Range("EX13").Value
EX14 = Range("EX14").Value
EY10 = Range("EY10").Value
EY11 = Range("EY11").Value
EY12 = Range("EY12").Value
EY13 = Range("EY13").Value
EY14 = Range("EY14").Value
EV17 = Range("EV17").Value
EV18 = Range("EV18").Value
EV19 = Range("EV19").Value
EV20 = Range("EV20").Value
EV21 = Range("EV21").Value
EW17 = Range("EW17").Value
EW18 = Range("EW18").Value
EW19 = Range("EW19").Value
EW20 = Range("EW20").Value
EW21 = Range("EW21").Value
EX17 = Range("EX17").Value
EX18 = Range("EX18").Value
EX19 = Range("EX19").Value
EX20 = Range("EX20").Value
EX21 = Range("EX21").Value
EY17 = Range("EY17").Value
EY18 = Range("EY18").Value
EY19 = Range("EY19").Value
EY20 = Range("EY20").Value
EY21 = Range("EY21").Value
EG3 = Range("EG3").Value
EG4 = Range("EG4").Value
EG5 = Range("EG5").Value
EG6 = Range("EG6").Value
EG7 = Range("EG7").Value
EH3 = Range("EH3").Value
EH4 = Range("EH4").Value
EH5 = Range("EH5").Value
EH6 = Range("EH6").Value
EH7 = Range("EH7").Value
EI3 = Range("EI3").Value
EI4 = Range("EI4").Value
EI5 = Range("EI5").Value
EI6 = Range("EI6").Value
EI7 = Range("EI7").Value
EJ3 = Range("EJ3").Value
EJ4 = Range("EJ4").Value
EJ5 = Range("EJ5").Value
EJ6 = Range("EJ6").Value
EJ7 = Range("EJ7").Value
EL3 = Range("EL3").Value
```

```
EL4 = Range("EL4").Value
EL5 = Range("EL5").Value
EL6 = Range("EL6").Value
EL7 = Range("EL7").Value
EM3 = Range("EM3").Value
EM4 = Range("EM4").Value
EM5 = Range("EM5").Value
EM6 = Range("EM6").Value
EM7 = Range("EM7").Value
EN3 = Range("EN3").Value
EN4 = Range("EN4").Value
EN5 = Range("EN5").Value
EN6 = Range("EN6").Value
EN7 = Range("EN7").Value
EO3 = Range("EO3").Value
EO4 = Range("EO4").Value
EO5 = Range("EO5").Value
EO6 = Range("EO6").Value
EO7 = Range("EO7").Value
EQ3 = Range("EQ3").Value
EQ4 = Range("EQ4").Value
EQ5 = Range("EQ5").Value
EQ6 = Range("EQ6").Value
EQ7 = Range("EQ7").Value
ER3 = Range("ER3").Value
ER4 = Range("ER4").Value
ER5 = Range("ER5").Value
ER6 = Range("ER6").Value
ER7 = Range("ER7").Value
ES3 = Range("ES3").Value
ES4 = Range("ES4").Value
ES5 = Range("ES5").Value
ES6 = Range("ES6").Value
ES7 = Range("ES7").Value
ET3 = Range("ET3").Value
ET4 = Range("ET4").Value
ET5 = Range("ET5").Value
ET6 = Range("ET6").Value
ET7 = Range("ET7").Value
EG10 = Range("EG10").Value
EG11 = Range("EG11").Value
EG12 = Range("EG12").Value
EG13 = Range("EG13").Value
EG14 = Range("EG14").Value
EH10 = Range("EH10").Value
EH11 = Range("EH11").Value
EH12 = Range("EH12").Value
EH13 = Range("EH13").Value
EH14 = Range("EH14").Value
EI10 = Range("EI10").Value
EI11 = Range("EI11").Value
EI12 = Range("EI12").Value
EI13 = Range("EI13").Value
EI14 = Range("EI14").Value
EJ10 = Range("EJ10").Value
EJ11 = Range("EJ11").Value
```

```
EJ12 = Range("EJ12").Value
EJ13 = Range("EJ13").Value
EJ14 = Range("EJ14").Value
EL10 = Range("EL10").Value
EL11 = Range("EL11").Value
EL12 = Range("EL12").Value
EL13 = Range("EL13").Value
EL14 = Range("EL14").Value
EM10 = Range("EM10").Value
EM11 = Range("EM11").Value
EM12 = Range("EM12").Value
EM13 = Range("EM13").Value
EM14 = Range("EM14").Value
EN10 = Range("EN10").Value
EN11 = Range("EN11").Value
EN12 = Range("EN12").Value
EN13 = Range("EN13").Value
EN14 = Range("EN14").Value
EO10 = Range("EO10").Value
EO11 = Range("EO11").Value
EO12 = Range("EO12").Value
EO13 = Range("EO13").Value
EO14 = Range("EO14").Value
EQ10 = Range("EQ10").Value
EQ11 = Range("EQ11").Value
EQ12 = Range("EQ12").Value
EQ13 = Range("EQ13").Value
EQ14 = Range("EQ14").Value
ER10 = Range("ER10").Value
ER11 = Range("ER11").Value
ER12 = Range("ER12").Value
ER13 = Range("ER13").Value
ER14 = Range("ER14").Value
ES10 = Range("ES10").Value
ES11 = Range("ES11").Value
ES12 = Range("ES12").Value
ES13 = Range("ES13").Value
ES14 = Range("ES14").Value
ET10 = Range("ET10").Value
ET11 = Range("ET11").Value
ET12 = Range("ET12").Value
ET13 = Range("ET13").Value
ET14 = Range("ET14").Value
EG17 = Range("EG17").Value
EG18 = Range("EG18").Value
EG19 = Range("EG19").Value
EG20 = Range("EG20").Value
EG21 = Range("EG21").Value
EH17 = Range("EH17").Value
EH18 = Range("EH18").Value
EH19 = Range("EH19").Value
EH20 = Range("EH20").Value
EH21 = Range("EH21").Value
EI17 = Range("EI17").Value
EI18 = Range("EI18").Value
EI19 = Range("EI19").Value
```

```
EI20 = Range("EI20").Value
EI21 = Range("EI21").Value
EJ17 = Range("EJ17").Value
EJ18 = Range("EJ18").Value
EJ19 = Range("EJ19").Value
EJ20 = Range("EJ20").Value
EJ21 = Range("EJ21").Value
EL17 = Range("EL17").Value
EL18 = Range("EL18").Value
EL19 = Range("EL19").Value
EL20 = Range("EL20").Value
EL21 = Range("EL21").Value
EM17 = Range("EM17").Value
EM18 = Range("EM18").Value
EM19 = Range("EM19").Value
EM20 = Range("EM20").Value
EM21 = Range("EM21").Value
EN17 = Range("EN17").Value
EN18 = Range("EN18").Value
EN19 = Range("EN19").Value
EN20 = Range("EN20").Value
EN21 = Range("EN21").Value
EO17 = Range("EO17").Value
EO18 = Range("EO18").Value
EO19 = Range("EO19").Value
EO20 = Range("EO20").Value
EO21 = Range("EO21").Value
EQ17 = Range("EQ17").Value
EQ18 = Range("EQ18").Value
EQ19 = Range("EQ19").Value
EQ20 = Range("EQ20").Value
EQ21 = Range("EQ21").Value
ER17 = Range("ER17").Value
ER18 = Range("ER18").Value
ER19 = Range("ER19").Value
ER20 = Range("ER20").Value
ER21 = Range("ER21").Value
ES17 = Range("ES17").Value
ES18 = Range("ES18").Value
ES19 = Range("ES19").Value
ES20 = Range("ES20").Value
ES21 = Range("ES21").Value
ET17 = Range("ET17").Value
ET18 = Range("ET18").Value
ET19 = Range("ET19").Value
ET20 = Range("ET20").Value
ET21 = Range("ET21").Value
E35 = Range("E35").Value
E37 = Range("E37").Value
E37 = Range("E37").Value

Dim G4 As Double
G4 = Worksheets("Input").Range("G4").Value

FA3 = Range("FA3").Value
FA4 = Range("FA4").Value
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FA5 = Range("FA5").Value
FA6 = Range("FA6").Value
FA7 = Range("FA7").Value
FB3 = Range("FB3").Value
FB4 = Range("FB4").Value
FB5 = Range("FB5").Value
FB6 = Range("FB6").Value
FB7 = Range("FB7").Value
FC3 = Range("FC3").Value
FC4 = Range("FC4").Value
FC5 = Range("FC5").Value
FC6 = Range("FC6").Value
FC7 = Range("FC7").Value
FD3 = Range("FD3").Value
FD4 = Range("FD4").Value
FD5 = Range("FD5").Value
FD6 = Range("FD6").Value
FD7 = Range("FD7").Value
FA10 = Range("FA10").Value
FA11 = Range("FA11").Value
FA12 = Range("FA12").Value
FA13 = Range("FA13").Value
FA14 = Range("FA14").Value
FB10 = Range("FB10").Value
FB11 = Range("FB11").Value
FB12 = Range("FB12").Value
FB13 = Range("FB13").Value
FB14 = Range("FB14").Value
FC10 = Range("FC10").Value
FC11 = Range("FC11").Value
FC12 = Range("FC12").Value
FC13 = Range("FC13").Value
FC14 = Range("FC14").Value
FD10 = Range("FD10").Value
FD11 = Range("FD11").Value
FD12 = Range("FD12").Value
FD13 = Range("FD13").Value
FD14 = Range("FD14").Value
FA17 = Range("FA17").Value
FA18 = Range("FA18").Value
FA19 = Range("FA19").Value
FA20 = Range("FA20").Value
FA21 = Range("FA21").Value
FB17 = Range("FB17").Value
FB18 = Range("FB18").Value
FB19 = Range("FB19").Value
FB20 = Range("FB20").Value
FB21 = Range("FB21").Value
FC17 = Range("FC17").Value
FC18 = Range("FC18").Value
FC19 = Range("FC19").Value
FC20 = Range("FC20").Value
FC21 = Range("FC21").Value
FD17 = Range("FD17").Value
FD18 = Range("FD18").Value
FD19 = Range("FD19").Value
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FD20 = Range("FD20").Value
FD21 = Range("FD21").Value
D30 = Range("D30").Value

'_________95%_____________________________________
If Worksheets("Output").Range("AZ6") = 2 Then
Range("G48,EF48").Formula = ((EL3 * E35) + (EL10 * E37) + (EL17 * E39)) / (E35 + E37 + E39)
Range("G49, EF49").Formula = ((EL3 * E35) + (EL10 * E37) + (EL18 * E39)) / (E35 + E37 + E39)
Range("G50, EF50").Formula = ((EL4 * E35) + (EL10 * E37) + (EL17 * E39)) / (E35 + E37 + E39)
Range("G51, EF51").Formula = ((EL3 * E35) + (EL11 * E37) + (EL17 * E39)) / (E35 + E37 + E39)
Range("G52, EF52").Formula = ((EL3 * E35) + (EL11 * E37) + (EL18 * E39)) / (E35 + E37 + E39)
Range("G53, EF53").Formula = ((EL4 * E35) + (EL10 * E37) + (EL18 * E39)) / (E35 + E37 + E39)
Range("G54, EF54").Formula = ((EL3 * E35) + (EL10 * E37) + (EL19 * E39)) / (E35 + E37 + E39)
Range("G55, EF55").Formula = ((EL4 * E35) + (EL11 * E37) + (EL17 * E39)) / (E35 + E37 + E39)
Range("G56, EF56").Formula = ((EL4 * E35) + (EL11 * E37) + (EL18 * E39)) / (E35 + E37 + E39)
Range("G57, EF57").Formula = ((EL3 * E35) + (EL11 * E37) + (EL19 * E39)) / (E35 + E37 + E39)
Range("G58, EF58").Formula = ((EL3 * E35) + (EL10 * E37) + (EL20 * E39)) / (E35 + E37 + E39)
Range("G59, EF59").Formula = ((EL4 * E35) + (EL10 * E37) + (EL19 * E39)) / (E35 + E37 + E39)
Range("G60, EF60").Formula = ((EL4 * E35) + (EL11 * E37) + (EL19 * E39)) / (E35 + E37 + E39)
Range("G61, EF61").Formula = ((EL3 * E35) + (EL12 * E37) + (EL18 * E39)) / (E35 + E37 + E39)
Range("G62, EF62").Formula = ((EL3 * E35) + (EL12 * E37) + (EL17 * E39)) / (E35 + E37 + E39)
Range("G63, EF63").Formula = ((EL4 * E35) + (EL12 * E37) + (EL17 * E39)) / (E35 + E37 + E39)
Range("G64, EF64").Formula = ((EL4 * E35) + (EL12 * E37) + (EL18 * E39)) / (E35 + E37 + E39)
Range("G65, EF65").Formula = ((EL3 * E35) + (EL12 * E37) + (EL19 * E39)) / (E35 + E37 + E39)
Range("G66, EF66").Formula = ((EL4 * E35) + (EL12 * E37) + (EL19 * E39)) / (E35 + E37 + E39)
Range("G67, EF67").Formula = ((EL3 * E35) + (EL11 * E37) + (EL20 * E39)) / (E35 + E37 + E39)
Range("G68, EF68").Formula = ((EL4 * E35) + (EL10 * E37) + (EL20 * E39)) / (E35 + E37 + E39)
Range("G69, EF69").Formula = ((EL3 * E35) + (EL12 * E37) + (EL20 * E39)) / (E35 + E37 + E39)
Range("G70, EF70").Formula = ((EL4 * E35) + (EL11 * E37) + (EL20 * E39)) / (E35 + E37 + E39)
Range("G71, EF71").Formula = ((EL3 * E35) + (EL10 * E37) + (EL21 * E39)) / (E35 + E37 + E39)
Range("G72, EF72").Formula = ((EL3 * E35) + (EL13 * E37) + (EL17 * E39)) / (E35 + E37 + E39)
Range("G73, EF73").Formula = ((EL4 * E35) + (EL12 * E37) + (EL20 * E39)) / (E35 + E37 + E39)
Range("G74, EF74").Formula = ((EL3 * E35) + (EL13 * E37) + (EL18 * E39)) / (E35 + E37 + E39)
End If

If Worksheets("Output").Range("AZ6") = 3 Then
Range("G48, EF48").Formula = (((EL3 / 100) + (EL10 / 100) + (EL17 / 100)) / G4) * 100
Range("G49, EF49").Formula = (((EL3 / 100) + (EL10 / 100) + (EL18 / 100)) / G4) * 100
Range("G50, EF50").Formula = (((EL4 / 100) + (EL10 / 100) + (EL17 / 100)) / G4) * 100
Range("G51, EF51").Formula = (((EL3 / 100) + (EL11 / 100) + (EL17 / 100)) / G4) * 100
Range("G52, EF52").Formula = (((EL3 / 100) + (EL11 / 100) + (EL18 / 100)) / G4) * 100
Range("G53, EF53").Formula = (((EL4 / 100) + (EL10 / 100) + (EL18 / 100)) / G4) * 100
Range("G54, EF54").Formula = (((EL3 / 100) + (EL10 / 100) + (EL19 / 100)) / G4) * 100
Range("G55, EF55").Formula = (((EL4 / 100) + (EL11 / 100) + (EL17 / 100)) / G4) * 100
Range("G56, EF56").Formula = (((EL4 / 100) + (EL11 / 100) + (EL18 / 100)) / G4) * 100
Range("G57, EF57").Formula = (((EL3 / 100) + (EL11 / 100) + (EL19 / 100)) / G4) * 100
Range("G58, EF58").Formula = (((EL3 / 100) + (EL10 / 100) + (EL20 / 100)) / G4) * 100
Range("G59, EF59").Formula = (((EL4 / 100) + (EL10 / 100) + (EL19 / 100)) / G4) * 100
Range("G60, EF60").Formula = (((EL4 / 100) + (EL11 / 100) + (EL19 / 100)) / G4) * 100
Range("G61, EF61").Formula = (((EL3 / 100) + (EL11 / 100) + (EL18 / 100)) / G4) * 100
Range("G62, EF62").Formula = (((EL3 / 100) + (EL12 / 100) + (EL17 / 100)) / G4) * 100
Range("G63, EF63").Formula = (((EL4 / 100) + (EL12 / 100) + (EL17 / 100)) / G4) * 100
Range("G64, EF64").Formula = (((EL4 / 100) + (EL12 / 100) + (EL18 / 100)) / G4) * 100
Range("G65, EF65").Formula = (((EL3 / 100) + (EL12 / 100) + (EL19 / 100)) / G4) * 100
Range("G66, EF66").Formula = (((EL4 / 100) + (EL12 / 100) + (EL19 / 100)) / G4) * 100
Range("G67, EF67").Formula = (((EL3 / 100) + (EL11 / 100) + (EL20 / 100)) / G4) * 100
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Range("G68, EF68").Formula = (((EL4 / 100) + (EL10 / 100) + (EL20 / 100)) / G4) * 100
Range("G69, EF69").Formula = (((EL3 / 100) + (EL12 / 100) + (EL20 / 100)) / G4) * 100
Range("G70, EF70").Formula = (((EL4 / 100) + (EL11 / 100) + (EL20 / 100)) / G4) * 100
Range("G71, EF71").Formula = (((EL3 / 100) + (EL10 / 100) + (EL21 / 100)) / G4) * 100
Range("G72, EF72").Formula = (((EL3 / 100) + (EL13 / 100) + (EL17 / 100)) / G4) * 100
Range("G73, EF73").Formula = (((EL4 / 100) + (EL12 / 100) + (EL20 / 100)) / G4) * 100
Range("G74, EF74").Formula = (((EL3 / 100) + (EL13 / 100) + (EL18 / 100)) / G4) * 100
End If

If Worksheets("Output").Range("AZ6") = 4 Then
Range("G48, EF48").Formula = ((((EV3) / 100) + ((EV10) / 100) + ((EV17) / 100)) + 1) * 100
Range("G49, EF49").Formula = ((((EV3) / 100) + ((EV10) / 100) + ((EV18) / 100)) + 1) * 100
Range("G50, EF50").Formula = ((((EV4) / 100) + ((EV10) / 100) + ((EV17) / 100)) + 1) * 100
Range("G51, EF51").Formula = ((((EV3) / 100) + ((EV11) / 100) + ((EV17) / 100)) + 1) * 100
Range("G52, EF52").Formula = ((((EV3) / 100) + ((EV11) / 100) + ((EV18) / 100)) + 1) * 100
Range("G53, EF53").Formula = ((((EV4) / 100) + ((EV10) / 100) + ((EV18) / 100)) + 1) * 100
Range("G54, EF54").Formula = ((((EV3) / 100) + ((EV10) / 100) + ((EV19) / 100)) + 1) * 100
Range("G55, EF55").Formula = ((((EV4) / 100) + ((EV11) / 100) + ((EV17) / 100)) + 1) * 100
Range("G56, EF56").Formula = ((((EV4) / 100) + ((EV11) / 100) + ((EV18) / 100)) + 1) * 100
Range("G57, EF57").Formula = ((((EV3) / 100) + ((EV11) / 100) + ((EV19) / 100)) + 1) * 100
Range("G58, EF58").Formula = ((((EV3) / 100) + ((EV10) / 100) + ((EV20) / 100)) + 1) * 100
Range("G59, EF59").Formula = ((((EV4) / 100) + ((EV10) / 100) + ((EV19) / 100)) + 1) * 100
Range("G60, EF60").Formula = ((((EV4) / 100) + ((EV11) / 100) + ((EV19) / 100)) + 1) * 100
Range("G61, EF61").Formula = ((((EV3) / 100) + ((EV11) / 100) + ((EV18) / 100)) + 1) * 100
Range("G62, EF62").Formula = ((((EV3) / 100) + ((EV12) / 100) + ((EV17) / 100)) + 1) * 100
Range("G63, EF63").Formula = ((((EV4) / 100) + ((EV12) / 100) + ((EV17) / 100)) + 1) * 100
Range("G64, EF64").Formula = ((((EV4) / 100) + ((EV12) / 100) + ((EV18) / 100)) + 1) * 100
Range("G65, EF65").Formula = ((((EV3) / 100) + ((EV12) / 100) + ((EV19) / 100)) + 1) * 100
Range("G66, EF66").Formula = ((((EV4) / 100) + ((EV12) / 100) + ((EV19) / 100)) + 1) * 100
Range("G67, EF67").Formula = ((((EV3) / 100) + ((EV11) / 100) + ((EV20) / 100)) + 1) * 100
Range("G68, EF68").Formula = ((((EV4) / 100) + ((EV10) / 100) + ((EV20) / 100)) + 1) * 100
Range("G69, EF69").Formula = ((((EV3) / 100) + ((EV12) / 100) + ((EV20) / 100)) + 1) * 100
Range("G70, EF70").Formula = ((((EV4) / 100) + ((EV11) / 100) + ((EV20) / 100)) + 1) * 100
Range("G71, EF71").Formula = ((((EV3) / 100) + ((EV10) / 100) + ((EV21) / 100)) + 1) * 100
Range("G72, EF72").Formula = ((((EV3) / 100) + ((EV13) / 100) + ((EV17) / 100)) + 1) * 100
Range("G73, EF73").Formula = ((((EV4) / 100) + ((EV12) / 100) + ((EV20) / 100)) + 1) * 100
Range("G74, EF74").Formula = ((((EV3) / 100) + ((EV13) / 100) + ((EV18) / 100)) + 1) * 100
End If

If Worksheets("Output").Range("AZ6") = 5 Then
Range("G48, EF48").Formula = ((FA3) * (FA10) * (FA17)) * 100
Range("G49, EF49").Formula = ((FA3) * (FA10) * (FA18)) * 100
Range("G50, EF50").Formula = ((FA4) * (FA10) * (FA17)) * 100
Range("G51, EF51").Formula = ((FA3) * (FA11) * (FA17)) * 100
Range("G52, EF52").Formula = ((FA3) * (FA11) * (FA18)) * 100
Range("G53, EF53").Formula = ((FA4) * (FA10) * (FA18)) * 100
Range("G54, EF54").Formula = ((FA3) * (FA10) * (FA19)) * 100
Range("G55, EF55").Formula = ((FA4) * (FA11) * (FA17)) * 100
Range("G56, EF56").Formula = ((FA4) * (FA11) * (FA18)) * 100
Range("G57, EF57").Formula = ((FA3) * (FA11) * (FA19)) * 100
Range("G58, EF58").Formula = ((FA3) * (FA10) * (FA20)) * 100
Range("G59, EF59").Formula = ((FA4) * (FA10) * (FA19)) * 100
Range("G60, EF60").Formula = ((FA4) * (FA11) * (FA19)) * 100
Range("G61, EF61").Formula = ((FA3) * (FA11) * (FA18)) * 100
Range("G62, EF62").Formula = ((FA3) * (FA12) * (FA17)) * 100
Range("G63, EF63").Formula = ((FA4) * (FA12) * (FA17)) * 100
```

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Range("G64, EF64").Formula = ((FA4) * (FA12) * (FA18)) * 100
Range("G65, EF65").Formula = ((FA3) * (FA12) * (FA19)) * 100
Range("G66, EF66").Formula = ((FA4) * (FA12) * (FA19)) * 100
Range("G67, EF67").Formula = ((FA3) * (FA11) * (FA20)) * 100
Range("G68, EF68").Formula = ((FA4) * (FA10) * (FA20)) * 100
Range("G69, EF69").Formula = ((FA3) * (FA12) * (FA20)) * 100
Range("G70, EF70").Formula = ((FA4) * (FA11) * (FA20)) * 100
Range("G71, EF71").Formula = ((FA3) * (FA10) * (FA21)) * 100
Range("G72, EF72").Formula = ((FA3) * (FA13) * (FA17)) * 100
Range("G73, EF73").Formula = ((FA4) * (FA12) * (FA20)) * 100
Range("G74, EF74").Formula = ((FA3) * (FA13) * (FA18)) * 100
End If

'________75%_____________________________________
If Worksheets("Output").Range("AZ6") = 2 Then
Range("N48, EM48").Formula = ((EM3 * E35) + (EM10 * E37) + (EM17 * E39)) / (E35 + E37 + E39)
Range("N49, EM49").Formula = ((EM3 * E35) + (EM10 * E37) + (EM18 * E39)) / (E35 + E37 + E39)
Range("N50, EM50").Formula = ((EM4 * E35) + (EM10 * E37) + (EM17 * E39)) / (E35 + E37 + E39)
Range("N51, EM51").Formula = ((EM3 * E35) + (EM11 * E37) + (EM17 * E39)) / (E35 + E37 + E39)
Range("N52, EM52").Formula = ((EM3 * E35) + (EM11 * E37) + (EM18 * E39)) / (E35 + E37 + E39)
Range("N53, EM53").Formula = ((EM4 * E35) + (EM10 * E37) + (EM18 * E39)) / (E35 + E37 + E39)
Range("N54, EM54").Formula = ((EM3 * E35) + (EM10 * E37) + (EM19 * E39)) / (E35 + E37 + E39)
Range("N55, EM55").Formula = ((EM4 * E35) + (EM11 * E37) + (EM17 * E39)) / (E35 + E37 + E39)
Range("N56, EM56").Formula = ((EM4 * E35) + (EM11 * E37) + (EM18 * E39)) / (E35 + E37 + E39)
Range("N57, EM57").Formula = ((EM3 * E35) + (EM11 * E37) + (EM19 * E39)) / (E35 + E37 + E39)
Range("N58, EM58").Formula = ((EM3 * E35) + (EM10 * E37) + (EM20 * E39)) / (E35 + E37 + E39)
Range("N59, EM59").Formula = ((EM4 * E35) + (EM10 * E37) + (EM19 * E39)) / (E35 + E37 + E39)
Range("N60, EM60").Formula = ((EM4 * E35) + (EM11 * E37) + (EM19 * E39)) / (E35 + E37 + E39)
Range("N61, EM61").Formula = ((EM3 * E35) + (EM12 * E37) + (EM18 * E39)) / (E35 + E37 + E39)
Range("N62, EM62").Formula = ((EM3 * E35) + (EM12 * E37) + (EM17 * E39)) / (E35 + E37 + E39)
Range("N63, EM63").Formula = ((EM4 * E35) + (EM12 * E37) + (EM17 * E39)) / (E35 + E37 + E39)
Range("N64, EM64").Formula = ((EM4 * E35) + (EM12 * E37) + (EM18 * E39)) / (E35 + E37 + E39)
Range("N65, EM65").Formula = ((EM3 * E35) + (EM12 * E37) + (EM19 * E39)) / (E35 + E37 + E39)
Range("N66, EM66").Formula = ((EM4 * E35) + (EM12 * E37) + (EM19 * E39)) / (E35 + E37 + E39)
Range("N67, EM67").Formula = ((EM3 * E35) + (EM11 * E37) + (EM20 * E39)) / (E35 + E37 + E39)
Range("N68, EM68").Formula = ((EM4 * E35) + (EM10 * E37) + (EM20 * E39)) / (E35 + E37 + E39)
Range("N69, EM69").Formula = ((EM3 * E35) + (EM12 * E37) + (EM20 * E39)) / (E35 + E37 + E39)
Range("N70, EM70").Formula = ((EM4 * E35) + (EM11 * E37) + (EM20 * E39)) / (E35 + E37 + E39)
Range("N71, EM71").Formula = ((EM3 * E35) + (EM10 * E37) + (EM21 * E39)) / (E35 + E37 + E39)
Range("N72, EM72").Formula = ((EM3 * E35) + (EM13 * E37) + (EM17 * E39)) / (E35 + E37 + E39)
Range("N73, EM73").Formula = ((EM4 * E35) + (EM12 * E37) + (EM20 * E39)) / (E35 + E37 + E39)
Range("N74, EM74").Formula = ((EM3 * E35) + (EM13 * E37) + (EM18 * E39)) / (E35 + E37 + E39)
End If

If Worksheets("Output").Range("AZ6") = 3 Then
Range("N48, EM48").Formula = (((EM3 / 100) + (EM10 / 100) + (EM17 / 100)) / G4) * 100
Range("N49, EM49").Formula = (((EM3 / 100) + (EM10 / 100) + (EM18 / 100)) / G4) * 100
Range("N50, EM50").Formula = (((EM4 / 100) + (EM10 / 100) + (EM17 / 100)) / G4) * 100
Range("N51, EM51").Formula = (((EM3 / 100) + (EM11 / 100) + (EM17 / 100)) / G4) * 100
Range("N52, EM52").Formula = (((EM3 / 100) + (EM11 / 100) + (EM18 / 100)) / G4) * 100
Range("N53, EM53").Formula = (((EM4 / 100) + (EM10 / 100) + (EM18 / 100)) / G4) * 100
Range("N54, EM54").Formula = (((EM3 / 100) + (EM10 / 100) + (EM19 / 100)) / G4) * 100
Range("N55, EM55").Formula = (((EM4 / 100) + (EM11 / 100) + (EM17 / 100)) / G4) * 100
Range("N56, EM56").Formula = (((EM4 / 100) + (EM11 / 100) + (EM18 / 100)) / G4) * 100
Range("N57, EM57").Formula = (((EM3 / 100) + (EM11 / 100) + (EM19 / 100)) / G4) * 100
Range("N58, EM58").Formula = (((EM3 / 100) + (EM10 / 100) + (EM20 / 100)) / G4) * 100
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Range("N59, EM59").Formula = (((EM4 / 100) + (EM10 / 100) + (EM19 / 100)) / G4) * 100
Range("N60, EM60").Formula = (((EM4 / 100) + (EM11 / 100) + (EM19 / 100)) / G4) * 100
Range("N61, EM61").Formula = (((EM3 / 100) + (EM11 / 100) + (EM18 / 100)) / G4) * 100
Range("N62, EM62").Formula = (((EM3 / 100) + (EM12 / 100) + (EM17 / 100)) / G4) * 100
Range("N63, EM63").Formula = (((EM4 / 100) + (EM12 / 100) + (EM17 / 100)) / G4) * 100
Range("N64, EM64").Formula = (((EM4 / 100) + (EM12 / 100) + (EM18 / 100)) / G4) * 100
Range("N65, EM65").Formula = (((EM3 / 100) + (EM12 / 100) + (EM19 / 100)) / G4) * 100
Range("N66, EM66").Formula = (((EM4 / 100) + (EM12 / 100) + (EM19 / 100)) / G4) * 100
Range("N67, EM67").Formula = (((EM3 / 100) + (EM11 / 100) + (EM20 / 100)) / G4) * 100
Range("N68, EM68").Formula = (((EM4 / 100) + (EM10 / 100) + (EM20 / 100)) / G4) * 100
Range("N69, EM69").Formula = (((EM3 / 100) + (EM12 / 100) + (EM20 / 100)) / G4) * 100
Range("N70, EM70").Formula = (((EM4 / 100) + (EM11 / 100) + (EM20 / 100)) / G4) * 100
Range("N71, EM71").Formula = (((EM3 / 100) + (EM10 / 100) + (EM21 / 100)) / G4) * 100
Range("N72, EM72").Formula = (((EM3 / 100) + (EM13 / 100) + (EM17 / 100)) / G4) * 100
Range("N73, EM73").Formula = (((EM4 / 100) + (EM12 / 100) + (EM20 / 100)) / G4) * 100
Range("N74, EM74").Formula = (((EM3 / 100) + (EM13 / 100) + (EM18 / 100)) / G4) * 100
End If

If Worksheets("Output").Range("AZ6") = 4 Then
Range("N48, EM48").Formula = ((((EW3) / 100) + ((EW10) / 100) + ((EW17) / 100)) + 1) * 100
Range("N49, EM49").Formula = ((((EW3) / 100) + ((EW10) / 100) + ((EW18) / 100)) + 1) * 100
Range("N50, EM50").Formula = ((((EW4) / 100) + ((EW10) / 100) + ((EW17) / 100)) + 1) * 100
Range("N51, EM51").Formula = ((((EW3) / 100) + ((EW11) / 100) + ((EW17) / 100)) + 1) * 100
Range("N52, EM52").Formula = ((((EW3) / 100) + ((EW11) / 100) + ((EW18) / 100)) + 1) * 100
Range("N53, EM53").Formula = ((((EW4) / 100) + ((EW10) / 100) + ((EW18) / 100)) + 1) * 100
Range("N54, EM54").Formula = ((((EW3) / 100) + ((EW10) / 100) + ((EW19) / 100)) + 1) * 100
Range("N55, EM55").Formula = ((((EW4) / 100) + ((EW11) / 100) + ((EW17) / 100)) + 1) * 100
Range("N56, EM56").Formula = ((((EW4) / 100) + ((EW11) / 100) + ((EW18) / 100)) + 1) * 100
Range("N57, EM57").Formula = ((((EW3) / 100) + ((EW11) / 100) + ((EW19) / 100)) + 1) * 100
Range("N58, EM58").Formula = ((((EW3) / 100) + ((EW10) / 100) + ((EW20) / 100)) + 1) * 100
Range("N59, EM59").Formula = ((((EW4) / 100) + ((EW10) / 100) + ((EW19) / 100)) + 1) * 100
Range("N60, EM60").Formula = ((((EW4) / 100) + ((EW11) / 100) + ((EW19) / 100)) + 1) * 100
Range("N61, EM61").Formula = ((((EW3) / 100) + ((EW11) / 100) + ((EW18) / 100)) + 1) * 100
Range("N62, EM62").Formula = ((((EW3) / 100) + ((EW12) / 100) + ((EW17) / 100)) + 1) * 100
Range("N63, EM63").Formula = ((((EW4) / 100) + ((EW12) / 100) + ((EW17) / 100)) + 1) * 100
Range("N64, EM64").Formula = ((((EW4) / 100) + ((EW12) / 100) + ((EW18) / 100)) + 1) * 100
Range("N65, EM65").Formula = ((((EW3) / 100) + ((EW12) / 100) + ((EW19) / 100)) + 1) * 100
Range("N66, EM66").Formula = ((((EW4) / 100) + ((EW12) / 100) + ((EW19) / 100)) + 1) * 100
Range("N67, EM67").Formula = ((((EW3) / 100) + ((EW11) / 100) + ((EW20) / 100)) + 1) * 100
Range("N68, EM68").Formula = ((((EW4) / 100) + ((EW10) / 100) + ((EW20) / 100)) + 1) * 100
Range("N69, EM69").Formula = ((((EW3) / 100) + ((EW12) / 100) + ((EW20) / 100)) + 1) * 100
Range("N70, EM70").Formula = ((((EW4) / 100) + ((EW11) / 100) + ((EW20) / 100)) + 1) * 100
Range("N71, EM71").Formula = ((((EW3) / 100) + ((EW10) / 100) + ((EW21) / 100)) + 1) * 100
Range("N72, EM72").Formula = ((((EW3) / 100) + ((EW13) / 100) + ((EW17) / 100)) + 1) * 100
Range("N73, EM73").Formula = ((((EW4) / 100) + ((EW12) / 100) + ((EW20) / 100)) + 1) * 100
Range("N74, EM74").Formula = ((((EW3) / 100) + ((EW13) / 100) + ((EW18) / 100)) + 1) * 100
End If

If Worksheets("Output").Range("AZ6") = 5 Then
Range("N48, EM48").Formula = ((FB3) * (FB10) * (FB17)) * 100
Range("N49, EM49").Formula = ((FB3) * (FB10) * (FB18)) * 100
Range("N50, EM50").Formula = ((FB4) * (FB10) * (FB17)) * 100
Range("N51, EM51").Formula = ((FB3) * (FB11) * (FB17)) * 100
Range("N52, EM52").Formula = ((FB3) * (FB11) * (FB18)) * 100
Range("N53, EM53").Formula = ((FB4) * (FB10) * (FB18)) * 100
Range("N54, EM54").Formula = ((FB3) * (FB10) * (FB19)) * 100
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Range("N55, EM55").Formula = ((FB4) * (FB11) * (FB17)) * 100
Range("N56, EM56").Formula = ((FB4) * (FB11) * (FB18)) * 100
Range("N57, EM57").Formula = ((FB3) * (FB11) * (FB19)) * 100
Range("N58, EM58").Formula = ((FB3) * (FB10) * (FB20)) * 100
Range("N59, EM59").Formula = ((FB4) * (FB10) * (FB19)) * 100
Range("N60, EM60").Formula = ((FB4) * (FB11) * (FB19)) * 100
Range("N61, EM61").Formula = ((FB3) * (FB11) * (FB18)) * 100
Range("N62, EM62").Formula = ((FB3) * (FB12) * (FB17)) * 100
Range("N63, EM63").Formula = ((FB4) * (FB12) * (FB17)) * 100
Range("N64, EM64").Formula = ((FB4) * (FB12) * (FB18)) * 100
Range("N65, EM65").Formula = ((FB3) * (FB12) * (FB19)) * 100
Range("N66, EM66").Formula = ((FB4) * (FB12) * (FB19)) * 100
Range("N67, EM67").Formula = ((FB3) * (FB11) * (FB20)) * 100
Range("N68, EM68").Formula = ((FB4) * (FB10) * (FB20)) * 100
Range("N69, EM69").Formula = ((FB3) * (FB12) * (FB20)) * 100
Range("N70, EM70").Formula = ((FB4) * (FB11) * (FB20)) * 100
Range("N71, EM71").Formula = ((FB3) * (FB10) * (FB21)) * 100
Range("N72, EM72").Formula = ((FB3) * (FB13) * (FB17)) * 100
Range("N73, EM73").Formula = ((FB4) * (FB12) * (FB20)) * 100
Range("N74, EM74").Formula = ((FB3) * (FB13) * (FB18)) * 100
End If

'_________50%_____________________________________
If Worksheets("Output").Range("AZ6") = 2 Then
Range("G81,EF81").Formula = ((EN3 * E35) + (EN10 * E37) + (EN17 * E39)) / (E35 + E37 + E39)
Range("G82,EF82").Formula = ((EN3 * E35) + (EN10 * E37) + (EN18 * E39)) / (E35 + E37 + E39)
Range("G83,EF83").Formula = ((EN4 * E35) + (EN10 * E37) + (EN17 * E39)) / (E35 + E37 + E39)
Range("G84,EF84").Formula = ((EN3 * E35) + (EN11 * E37) + (EN17 * E39)) / (E35 + E37 + E39)
Range("G85,EF85").Formula = ((EN3 * E35) + (EN11 * E37) + (EN18 * E39)) / (E35 + E37 + E39)
Range("G86,EF86").Formula = ((EN4 * E35) + (EN10 * E37) + (EN18 * E39)) / (E35 + E37 + E39)
Range("G87,EF87").Formula = ((EN3 * E35) + (EN10 * E37) + (EN19 * E39)) / (E35 + E37 + E39)
Range("G88,EF88").Formula = ((EN4 * E35) + (EN11 * E37) + (EN17 * E39)) / (E35 + E37 + E39)
Range("G89,EF89").Formula = ((EN4 * E35) + (EN11 * E37) + (EN18 * E39)) / (E35 + E37 + E39)
Range("G90,EF90").Formula = ((EN3 * E35) + (EN11 * E37) + (EN19 * E39)) / (E35 + E37 + E39)
Range("G91,EF91").Formula = ((EN3 * E35) + (EN10 * E37) + (EN20 * E39)) / (E35 + E37 + E39)
Range("G92,EF92").Formula = ((EN4 * E35) + (EN10 * E37) + (EN19 * E39)) / (E35 + E37 + E39)
Range("G93,EF93").Formula = ((EN4 * E35) + (EN11 * E37) + (EN19 * E39)) / (E35 + E37 + E39)
Range("G94,EF94").Formula = ((EN3 * E35) + (EN12 * E37) + (EN18 * E39)) / (E35 + E37 + E39)
Range("G95,EF95").Formula = ((EN3 * E35) + (EN12 * E37) + (EN17 * E39)) / (E35 + E37 + E39)
Range("G96,EF96").Formula = ((EN4 * E35) + (EN12 * E37) + (EN17 * E39)) / (E35 + E37 + E39)
Range("G97,EF97").Formula = ((EN4 * E35) + (EN12 * E37) + (EN18 * E39)) / (E35 + E37 + E39)
Range("G98,EF98").Formula = ((EN3 * E35) + (EN12 * E37) + (EN19 * E39)) / (E35 + E37 + E39)
Range("G99,EF99").Formula = ((EN4 * E35) + (EN12 * E37) + (EN19 * E39)) / (E35 + E37 + E39)
Range("G100,EF100").Formula = ((EN3 * E35) + (EN11 * E37) + (EN20 * E39)) / (E35 + E37 + E39)
Range("G101,EF101").Formula = ((EN4 * E35) + (EN10 * E37) + (EN20 * E39)) / (E35 + E37 + E39)
Range("G102,EF102").Formula = ((EN3 * E35) + (EN12 * E37) + (EN20 * E39)) / (E35 + E37 + E39)
Range("G103,EF103").Formula = ((EN4 * E35) + (EN11 * E37) + (EN20 * E39)) / (E35 + E37 + E39)
Range("G104,EF104").Formula = ((EN3 * E35) + (EN10 * E37) + (EN21 * E39)) / (E35 + E37 + E39)
Range("G105,EF105").Formula = ((EN3 * E35) + (EN13 * E37) + (EN17 * E39)) / (E35 + E37 + E39)
Range("G106,EF106").Formula = ((EN4 * E35) + (EN12 * E37) + (EN20 * E39)) / (E35 + E37 + E39)
Range("G107,EF107").Formula = ((EN3 * E35) + (EN13 * E37) + (EN18 * E39)) / (E35 + E37 + E39)
End If
If Worksheets("Output").Range("AZ6") = 3 Then
Range("G81,EF81").Formula = (((EN3 / 100) + (EN10 / 100) + (EN17 / 100)) / G4) * 100
Range("G82,EF82").Formula = (((EN3 / 100) + (EN10 / 100) + (EN18 / 100)) / G4) * 100
Range("G83,EF83").Formula = (((EN4 / 100) + (EN10 / 100) + (EN17 / 100)) / G4) * 100
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Range("G84,EF84").Formula = (((EN3 / 100) + (EN11 / 100) + (EN17 / 100)) / G4) * 100
Range("G85,EF85").Formula = (((EN3 / 100) + (EN11 / 100) + (EN18 / 100)) / G4) * 100
Range("G86,EF86").Formula = (((EN4 / 100) + (EN10 / 100) + (EN18 / 100)) / G4) * 100
Range("G87,EF87").Formula = (((EN3 / 100) + (EN10 / 100) + (EN19 / 100)) / G4) * 100
Range("G88,EF88").Formula = (((EN4 / 100) + (EN11 / 100) + (EN17 / 100)) / G4) * 100
Range("G89,EF89").Formula = (((EN4 / 100) + (EN11 / 100) + (EN18 / 100)) / G4) * 100
Range("G90,EF90").Formula = (((EN3 / 100) + (EN11 / 100) + (EN19 / 100)) / G4) * 100
Range("G91,EF91").Formula = (((EN3 / 100) + (EN10 / 100) + (EN20 / 100)) / G4) * 100
Range("G92,EF92").Formula = (((EN4 / 100) + (EN10 / 100) + (EN19 / 100)) / G4) * 100
Range("G93,EF93").Formula = (((EN4 / 100) + (EN11 / 100) + (EN19 / 100)) / G4) * 100
Range("G94,EF94").Formula = (((EN3 / 100) + (EN11 / 100) + (EN18 / 100)) / G4) * 100
Range("G95,EF95").Formula = (((EN3 / 100) + (EN12 / 100) + (EN17 / 100)) / G4) * 100
Range("G96,EF96").Formula = (((EN4 / 100) + (EN12 / 100) + (EN17 / 100)) / G4) * 100
Range("G97,EF97").Formula = (((EN4 / 100) + (EN12 / 100) + (EN18 / 100)) / G4) * 100
Range("G98,EF98").Formula = (((EN3 / 100) + (EN12 / 100) + (EN19 / 100)) / G4) * 100
Range("G99,EF99").Formula = (((EN4 / 100) + (EN12 / 100) + (EN19 / 100)) / G4) * 100
Range("G100,EF100").Formula = (((EN3 / 100) + (EN11 / 100) + (EN20 / 100)) / G4) * 100
Range("G101,EF101").Formula = (((EN4 / 100) + (EN10 / 100) + (EN20 / 100)) / G4) * 100
Range("G102,EF102").Formula = (((EN3 / 100) + (EN12 / 100) + (EN20 / 100)) / G4) * 100
Range("G103,EF103").Formula = (((EN4 / 100) + (EN11 / 100) + (EN20 / 100)) / G4) * 100
Range("G104,EF104").Formula = (((EN3 / 100) + (EN10 / 100) + (EN21 / 100)) / G4) * 100
Range("G105,EF105").Formula = (((EN3 / 100) + (EN13 / 100) + (EN17 / 100)) / G4) * 100
Range("G106,EF106").Formula = (((EN4 / 100) + (EN12 / 100) + (EN20 / 100)) / G4) * 100
Range("G107,EF107").Formula = (((EN3 / 100) + (EN13 / 100) + (EN18 / 100)) / G4) * 100
End If

If Worksheets("Output").Range("AZ6") = 4 Then
Range("G81,EF81").Formula = ((((EX3) / 100) + ((EX10) / 100) + ((EX17) / 100)) + 1) * 100
Range("G82,EF82").Formula = ((((EX3) / 100) + ((EX10) / 100) + ((EX18) / 100)) + 1) * 100
Range("G83,EF83").Formula = ((((EX4) / 100) + ((EX10) / 100) + ((EX17) / 100)) + 1) * 100
Range("G84,EF84").Formula = ((((EX3) / 100) + ((EX11) / 100) + ((EX17) / 100)) + 1) * 100
Range("G85,EF85").Formula = ((((EX3) / 100) + ((EX11) / 100) + ((EX18) / 100)) + 1) * 100
Range("G86,EF86").Formula = ((((EX4) / 100) + ((EX10) / 100) + ((EX18) / 100)) + 1) * 100
Range("G87,EF87").Formula = ((((EX3) / 100) + ((EX10) / 100) + ((EX19) / 100)) + 1) * 100
Range("G88,EF88").Formula = ((((EX4) / 100) + ((EX11) / 100) + ((EX17) / 100)) + 1) * 100
Range("G89,EF89").Formula = ((((EX4) / 100) + ((EX11) / 100) + ((EX18) / 100)) + 1) * 100
Range("G90,EF90").Formula = ((((EX3) / 100) + ((EX11) / 100) + ((EX19) / 100)) + 1) * 100
Range("G91,EF91").Formula = ((((EX3) / 100) + ((EX10) / 100) + ((EX20) / 100)) + 1) * 100
Range("G92,EF92").Formula = ((((EX4) / 100) + ((EX10) / 100) + ((EX19) / 100)) + 1) * 100
Range("G93,EF93").Formula = ((((EX4) / 100) + ((EX11) / 100) + ((EX19) / 100)) + 1) * 100
Range("G94,EF94").Formula = ((((EX3) / 100) + ((EX11) / 100) + ((EX18) / 100)) + 1) * 100
Range("G95,EF95").Formula = ((((EX3) / 100) + ((EX12) / 100) + ((EX17) / 100)) + 1) * 100
Range("G96,EF96").Formula = ((((EX4) / 100) + ((EX12) / 100) + ((EX17) / 100)) + 1) * 100
Range("G97,EF97").Formula = ((((EX4) / 100) + ((EX12) / 100) + ((EX18) / 100)) + 1) * 100
Range("G98,EF98").Formula = ((((EX3) / 100) + ((EX12) / 100) + ((EX19) / 100)) + 1) * 100
Range("G99,EF99").Formula = ((((EX4) / 100) + ((EX12) / 100) + ((EX19) / 100)) + 1) * 100
Range("G100,EF100").Formula = ((((EX3) / 100) + ((EX11) / 100) + ((EX20) / 100)) + 1) * 100
Range("G101,EF101").Formula = ((((EX4) / 100) + ((EX10) / 100) + ((EX20) / 100)) + 1) * 100
Range("G102,EF102").Formula = ((((EX3) / 100) + ((EX12) / 100) + ((EX20) / 100)) + 1) * 100
Range("G103,EF103").Formula = ((((EX4) / 100) + ((EX11) / 100) + ((EX20) / 100)) + 1) * 100
Range("G104,EF104").Formula = ((((EX3) / 100) + ((EX10) / 100) + ((EX21) / 100)) + 1) * 100
Range("G105,EF105").Formula = ((((EX3) / 100) + ((EX13) / 100) + ((EX17) / 100)) + 1) * 100
Range("G106,EF106").Formula = ((((EX4) / 100) + ((EX12) / 100) + ((EX20) / 100)) + 1) * 100
Range("G107,EF107").Formula = ((((EX3) / 100) + ((EX13) / 100) + ((EX18) / 100)) + 1) * 100
End If
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If Worksheets("Output").Range("AZ6") = 5 Then
Range("G81,EF81").Formula = ((FC3) * (FC10) * (FC17)) * 100
Range("G82,EF82").Formula = ((FC3) * (FC10) * (FC18)) * 100
Range("G83,EF83").Formula = ((FC4) * (FC10) * (FC17)) * 100
Range("G84,EF84").Formula = ((FC3) * (FC11) * (FC17)) * 100
Range("G85,EF85").Formula = ((FC3) * (FC11) * (FC18)) * 100
Range("G86,EF86").Formula = ((FC4) * (FC10) * (FC18)) * 100
Range("G87,EF87").Formula = ((FC3) * (FC10) * (FC19)) * 100
Range("G88,EF88").Formula = ((FC4) * (FC11) * (FC17)) * 100
Range("G89,EF89").Formula = ((FC4) * (FC11) * (FC18)) * 100
Range("G90,EF90").Formula = ((FC3) * (FC11) * (FC19)) * 100
Range("G91,EF91").Formula = ((FC3) * (FC10) * (FC20)) * 100
Range("G92,EF92").Formula = ((FC4) * (FC10) * (FC19)) * 100
Range("G93,EF93").Formula = ((FC4) * (FC11) * (FC19)) * 100
Range("G94,EF94").Formula = ((FC3) * (FC11) * (FC18)) * 100
Range("G95,EF95").Formula = ((FC3) * (FC12) * (FC17)) * 100
Range("G96,EF96").Formula = ((FC4) * (FC12) * (FC17)) * 100
Range("G97,EF97").Formula = ((FC4) * (FC12) * (FC18)) * 100
Range("G98,EF98").Formula = ((FC3) * (FC12) * (FC19)) * 100
Range("G99,EF99").Formula = ((FC4) * (FC12) * (FC19)) * 100
Range("G100,EF100").Formula = ((FC3) * (FC11) * (FC20)) * 100
Range("G101,EF101").Formula = ((FC4) * (FC10) * (FC20)) * 100
Range("G102,EF102").Formula = ((FC3) * (FC12) * (FC20)) * 100
Range("G103,EF103").Formula = ((FC4) * (FC11) * (FC20)) * 100
Range("G104,EF104").Formula = ((FC3) * (FC10) * (FC21)) * 100
Range("G105,EF105").Formula = ((FC3) * (FC13) * (FC17)) * 100
Range("G106,EF106").Formula = ((FC4) * (FC12) * (FC20)) * 100
Range("G107,EF107").Formula = ((FC3) * (FC13) * (FC18)) * 100
End If

'_________25%_____________________________________
If Worksheets("Output").Range("AZ6") = 2 Then
Range("N81, EM81").Formula = ((EO3 * E35) + (EO10 * E37) + (EO17 * E39)) / (E35 + E37 + E39)
Range("N82, EM82").Formula = ((EO3 * E35) + (EO10 * E37) + (EO18 * E39)) / (E35 + E37 + E39)
Range("N83, EM83").Formula = ((EO4 * E35) + (EO10 * E37) + (EO17 * E39)) / (E35 + E37 + E39)
Range("N84, EM84").Formula = ((EO3 * E35) + (EO11 * E37) + (EO17 * E39)) / (E35 + E37 + E39)
Range("N85, EM85").Formula = ((EO3 * E35) + (EO11 * E37) + (EO18 * E39)) / (E35 + E37 + E39)
Range("N86, EM86").Formula = ((EO4 * E35) + (EO10 * E37) + (EO18 * E39)) / (E35 + E37 + E39)
Range("N87, EM87").Formula = ((EO3 * E35) + (EO10 * E37) + (EO19 * E39)) / (E35 + E37 + E39)
Range("N88, EM88").Formula = ((EO4 * E35) + (EO11 * E37) + (EO17 * E39)) / (E35 + E37 + E39)
Range("N89, EM89").Formula = ((EO4 * E35) + (EO11 * E37) + (EO18 * E39)) / (E35 + E37 + E39)
Range("N90, EM90").Formula = ((EO3 * E35) + (EO11 * E37) + (EO19 * E39)) / (E35 + E37 + E39)
Range("N91, EM91").Formula = ((EO3 * E35) + (EO10 * E37) + (EO20 * E39)) / (E35 + E37 + E39)
Range("N92, EM92").Formula = ((EO4 * E35) + (EO10 * E37) + (EO19 * E39)) / (E35 + E37 + E39)
Range("N93, EM93").Formula = ((EO4 * E35) + (EO11 * E37) + (EO19 * E39)) / (E35 + E37 + E39)
Range("N94, EM94").Formula = ((EO3 * E35) + (EO12 * E37) + (EO18 * E39)) / (E35 + E37 + E39)
Range("N95, EM95").Formula = ((EO3 * E35) + (EO12 * E37) + (EO17 * E39)) / (E35 + E37 + E39)
Range("N96, EM96").Formula = ((EO4 * E35) + (EO12 * E37) + (EO17 * E39)) / (E35 + E37 + E39)
Range("N97, EM97").Formula = ((EO4 * E35) + (EO12 * E37) + (EO18 * E39)) / (E35 + E37 + E39)
Range("N98, EM98").Formula = ((EO3 * E35) + (EO12 * E37) + (EO19 * E39)) / (E35 + E37 + E39)
Range("N99, EM99").Formula = ((EO4 * E35) + (EO12 * E37) + (EO19 * E39)) / (E35 + E37 + E39)
Range("N100, EM100").Formula = ((EO3 * E35) + (EO11 * E37) + (EO20 * E39)) / (E35 + E37 + E39)
Range("N101, EM101").Formula = ((EO4 * E35) + (EO10 * E37) + (EO20 * E39)) / (E35 + E37 + E39)
Range("N102, EM102").Formula = ((EO3 * E35) + (EO12 * E37) + (EO20 * E39)) / (E35 + E37 + E39)
Range("N103, EM103").Formula = ((EO4 * E35) + (EO11 * E37) + (EO20 * E39)) / (E35 + E37 + E39)
Range("N104, EM104").Formula = ((EO3 * E35) + (EO10 * E37) + (EO21 * E39)) / (E35 + E37 + E39)
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Range("N105, EM105").Formula = ((EO3 * E35) + (EO13 * E37) + (EO17 * E39)) / (E35 + E37 + E39)
Range("N106, EM106").Formula = ((EO4 * E35) + (EO12 * E37) + (EO20 * E39)) / (E35 + E37 + E39)
Range("N107, EM107").Formula = ((EO3 * E35) + (EO13 * E37) + (EO18 * E39)) / (E35 + E37 + E39)
End If

If Worksheets("Output").Range("AZ6") = 3 Then
Range("N81, EM81").Formula = (((EO3 / 100) + (EO10 / 100) + (EO17 / 100)) / G4) * 100
Range("N82, EM82").Formula = (((EO3 / 100) + (EO10 / 100) + (EO18 / 100)) / G4) * 100
Range("N83, EM83").Formula = (((EO4 / 100) + (EO10 / 100) + (EO17 / 100)) / G4) * 100
Range("N84, EM84").Formula = (((EO3 / 100) + (EO11 / 100) + (EO17 / 100)) / G4) * 100
Range("N85, EM85").Formula = (((EO3 / 100) + (EO11 / 100) + (EO18 / 100)) / G4) * 100
Range("N86, EM86").Formula = (((EO4 / 100) + (EO10 / 100) + (EO18 / 100)) / G4) * 100
Range("N87, EM87").Formula = (((EO3 / 100) + (EO10 / 100) + (EO19 / 100)) / G4) * 100
Range("N88, EM88").Formula = (((EO4 / 100) + (EO11 / 100) + (EO17 / 100)) / G4) * 100
Range("N89, EM89").Formula = (((EO4 / 100) + (EO11 / 100) + (EO18 / 100)) / G4) * 100
Range("N90, EM90").Formula = (((EO3 / 100) + (EO11 / 100) + (EO19 / 100)) / G4) * 100
Range("N91, EM91").Formula = (((EO3 / 100) + (EO10 / 100) + (EO20 / 100)) / G4) * 100
Range("N92, EM92").Formula = (((EO4 / 100) + (EO10 / 100) + (EO19 / 100)) / G4) * 100
Range("N93, EM93").Formula = (((EO4 / 100) + (EO11 / 100) + (EO19 / 100)) / G4) * 100
Range("N94, EM94").Formula = (((EO3 / 100) + (EO11 / 100) + (EO18 / 100)) / G4) * 100
Range("N95, EM95").Formula = (((EO3 / 100) + (EO12 / 100) + (EO17 / 100)) / G4) * 100
Range("N96, EM96").Formula = (((EO4 / 100) + (EO12 / 100) + (EO17 / 100)) / G4) * 100
Range("N97, EM97").Formula = (((EO4 / 100) + (EO12 / 100) + (EO18 / 100)) / G4) * 100
Range("N98, EM98").Formula = (((EO3 / 100) + (EO12 / 100) + (EO19 / 100)) / G4) * 100
Range("N99, EM98").Formula = (((EO4 / 100) + (EO12 / 100) + (EO19 / 100)) / G4) * 100
Range("N100, EM100").Formula = (((EO3 / 100) + (EO11 / 100) + (EO20 / 100)) / G4) * 100
Range("N101, EM101").Formula = (((EO4 / 100) + (EO10 / 100) + (EO20 / 100)) / G4) * 100
Range("N102, EM102").Formula = (((EO3 / 100) + (EO12 / 100) + (EO20 / 100)) / G4) * 100
Range("N103, EM103").Formula = (((EO4 / 100) + (EO11 / 100) + (EO20 / 100)) / G4) * 100
Range("N104, EM104").Formula = (((EO3 / 100) + (EO10 / 100) + (EO21 / 100)) / G4) * 100
Range("N105, EM105").Formula = (((EO3 / 100) + (EO13 / 100) + (EO17 / 100)) / G4) * 100
Range("N106, EM106").Formula = (((EO4 / 100) + (EO12 / 100) + (EO20 / 100)) / G4) * 100
Range("N107, EM107").Formula = (((EO3 / 100) + (EO13 / 100) + (EO18 / 100)) / G4) * 100
End If

If Worksheets("Output").Range("AZ6") = 4 Then
Range("N81,EM81").Formula = ((((EY3) / 100) + ((EY10) / 100) + ((EY17) / 100)) + 1) * 100
Range("N82,EM82").Formula = ((((EY3) / 100) + ((EY10) / 100) + ((EY18) / 100)) + 1) * 100
Range("N83,EM83").Formula = ((((EY4) / 100) + ((EY10) / 100) + ((EY17) / 100)) + 1) * 100
Range("N84,EM84").Formula = ((((EY3) / 100) + ((EY11) / 100) + ((EY17) / 100)) + 1) * 100
Range("N85,EM85").Formula = ((((EY3) / 100) + ((EY11) / 100) + ((EY18) / 100)) + 1) * 100
Range("N86,EM86").Formula = ((((EY4) / 100) + ((EY10) / 100) + ((EY18) / 100)) + 1) * 100
Range("N87,EM87").Formula = ((((EY3) / 100) + ((EY10) / 100) + ((EY19) / 100)) + 1) * 100
Range("N88,EM88").Formula = ((((EY4) / 100) + ((EY11) / 100) + ((EY17) / 100)) + 1) * 100
Range("N89,EM89").Formula = ((((EY4) / 100) + ((EY11) / 100) + ((EY18) / 100)) + 1) * 100
Range("N90,EM90").Formula = ((((EY3) / 100) + ((EY11) / 100) + ((EY19) / 100)) + 1) * 100
Range("N91,EM91").Formula = ((((EY3) / 100) + ((EY10) / 100) + ((EY20) / 100)) + 1) * 100
Range("N92,EM92").Formula = ((((EY4) / 100) + ((EY10) / 100) + ((EY19) / 100)) + 1) * 100
Range("N93,EM93").Formula = ((((EY4) / 100) + ((EY11) / 100) + ((EY19) / 100)) + 1) * 100
Range("N94,EM94").Formula = ((((EY3) / 100) + ((EY11) / 100) + ((EY18) / 100)) + 1) * 100
Range("N95,EM95").Formula = ((((EY3) / 100) + ((EY12) / 100) + ((EY17) / 100)) + 1) * 100
Range("N96,EM96").Formula = ((((EY4) / 100) + ((EY12) / 100) + ((EY17) / 100)) + 1) * 100
Range("N97,EM97").Formula = ((((EY4) / 100) + ((EY12) / 100) + ((EY18) / 100)) + 1) * 100
Range("N98,EM98").Formula = ((((EY3) / 100) + ((EY12) / 100) + ((EY19) / 100)) + 1) * 100
Range("N99,EM99").Formula = ((((EY4) / 100) + ((EY12) / 100) + ((EY19) / 100)) + 1) * 100
Range("N100,EM100").Formula = ((((EY3) / 100) + ((EY11) / 100) + ((EY20) / 100)) + 1) * 100
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Range("N101,EM101").Formula = ((((EY4) / 100) + ((EY10) / 100) + ((EY20) / 100)) + 1) * 100
Range("N102,EM102").Formula = ((((EY3) / 100) + ((EY12) / 100) + ((EY20) / 100)) + 1) * 100
Range("N103,EM103").Formula = ((((EY4) / 100) + ((EY11) / 100) + ((EY20) / 100)) + 1) * 100
Range("N104,EM104").Formula = ((((EY3) / 100) + ((EY10) / 100) + ((EY21) / 100)) + 1) * 100
Range("N105,EM105").Formula = ((((EY3) / 100) + ((EY13) / 100) + ((EY17) / 100)) + 1) * 100
Range("N106,EM106").Formula = ((((EY4) / 100) + ((EY12) / 100) + ((EY20) / 100)) + 1) * 100
Range("N107,EM107").Formula = ((((EY3) / 100) + ((EY13) / 100) + ((EY18) / 100)) + 1) * 100
End If

If Worksheets("Output").Range("AZ6") = 5 Then
Range("N81,EM81").Formula = ((FD3) * (FD10) * (FD17)) * 100
Range("N82,EM82").Formula = ((FD3) * (FD10) * (FD18)) * 100
Range("N83,EM83").Formula = ((FD4) * (FD10) * (FD17)) * 100
Range("N84,EM84").Formula = ((FD3) * (FD11) * (FD17)) * 100
Range("N85,EM85").Formula = ((FD3) * (FD11) * (FD18)) * 100
Range("N86,EM86").Formula = ((FD4) * (FD10) * (FD18)) * 100
Range("N87,EM87").Formula = ((FD3) * (FD10) * (FD19)) * 100
Range("N88,EM88").Formula = ((FD4) * (FD11) * (FD17)) * 100
Range("N89,EM89").Formula = ((FD4) * (FD11) * (FD18)) * 100
Range("N90,EM90").Formula = ((FD3) * (FD11) * (FD19)) * 100
Range("N91,EM91").Formula = ((FD3) * (FD10) * (FD20)) * 100
Range("N92,EM92").Formula = ((FD4) * (FD10) * (FD19)) * 100
Range("N93,EM93").Formula = ((FD4) * (FD11) * (FD19)) * 100
Range("N94,EM94").Formula = ((FD3) * (FD11) * (FD18)) * 100
Range("N95,EM95").Formula = ((FD3) * (FD12) * (FD17)) * 100
Range("N96,EM96").Formula = ((FD4) * (FD12) * (FD17)) * 100
Range("N97,EM97").Formula = ((FD4) * (FD12) * (FD18)) * 100
Range("N98,EM98").Formula = ((FD3) * (FD12) * (FD19)) * 100
Range("N99,EM99").Formula = ((FD4) * (FD12) * (FD19)) * 100
Range("N100,EM100").Formula = ((FD3) * (FD11) * (FD20)) * 100
Range("N101,EM101").Formula = ((FD4) * (FD10) * (FD20)) * 100
Range("N102,EM102").Formula = ((FD3) * (FD12) * (FD20)) * 100
Range("N103,EM103").Formula = ((FD4) * (FD11) * (FD20)) * 100
Range("N104,EM104").Formula = ((FD3) * (FD10) * (FD21)) * 100
Range("N105,EM105").Formula = ((FD3) * (FD13) * (FD17)) * 100
Range("N106,EM106").Formula = ((FD4) * (FD12) * (FD20)) * 100
Range("N107,EM107").Formula = ((FD3) * (FD13) * (FD18)) * 100
End If

'If Worksheets("Output").Range("AZ6") = 1 Then
'MsgBox "You must choose a composite pay factor method."
'End If
'
Dim T95 As Double, T75 As Double, T50 As Double, T25 As Double
Dim T952 As Double, T752 As Double, T502 As Double, T252 As Double
T95 = Range("EQ3").Value
T75 = Range("ER3").Value
T50 = Range("ES3").Value
T25 = Range("ET3").Value
T952 = Range("EQ4").Value
T752 = Range("ER4").Value
T502 = Range("ES4").Value
T252 = Range("ET4").Value

Range("D48,D49,D51,D52,D54,D57,D58,D61,D62,D65,D67,D69,D71,D72,D74") = T95
Range("K48,K49,K51,K52,K54,K57,K58,K61,K62,K65,K67,K69,K71,K72,K74") = T75
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Range("D81,D82,D84,D85,D87,D90,D91,D94,D95,D98,D100,D102,D104,D105,D107") = T50
Range("K81,K82,K84,K85,K87,K90,K91,K94,K95,K98,K100,K102,K104,K105,K107") = T25
Range("D50,D53,D55,D56,D59,D60,D63,D64,D66,D68,D70,D73") = T952
Range("K50,K53,K55,K56,K59,K60,K63,K64,K66,K68,K70,K73") = T752
Range("D83,D86,D88,D89,D92,D93,D96,D97,D99,D101,D103,D106") = T502
Range("K83,K86,K88,K89,K92,K93,K96,K97,K99,K101,K103,K106") = T252

Dim S95 As Double, S75 As Double, S50 As Double, S25 As Double
Dim S952 As Double, S752 As Double, S502 As Double, S252 As Double
Dim S953 As Double, S753 As Double, S503 As Double, S253 As Double
Dim S954 As Double, S754 As Double, S504 As Double, S254 As Double
S95 = Range("EQ10").Value
S75 = Range("ER10").Value
S50 = Range("ES10").Value
S25 = Range("ET10").Value
S952 = Range("EQ11").Value
S752 = Range("ER11").Value
S502 = Range("ES11").Value
S252 = Range("ET11").Value
S953 = Range("EQ12").Value
S753 = Range("ER12").Value
S503 = Range("ES12").Value
S253 = Range("ET12").Value
S954 = Range("EQ13").Value
S754 = Range("ER13").Value
S504 = Range("ES13").Value
S254 = Range("ET13").Value

Range("E48,E49,E50,E52,E54,E53,E58,E59,E68,E71") = S95
Range("L48,L49,L50,L52,L54,L53,L58,L59,L68,L71") = S75
Range("E81,E82,E83,E86,E90,E91,E92,E101,E104") = S50
Range("L81,L82,L83,L86,L87,L90,L91,L92,L101,L104") = S25
Range("E51,E52,E55,E56,E57,E60,E67,E70") = S952
Range("L51,L52,L55,L56,L57,L60,L67,L70") = S752
Range("E84,E85,E87,E88,E89,E90,E93,E100,E103") = S502
Range("L84,L85,L88,L89,L90,L93,L100,L103") = S252
Range("E62,E61,E63,E64,E65,E66,E69,E73") = S953
Range("L62,L63,L65,L66,L69,L73,L61,L64") = S753
Range("E94,E97,E95,E96,E98,E99,E102,E106") = S503
Range("L94,L97,L95,L96,L98,L99,L102,L106") = S253
Range("E72, E74") = S954
Range("L72, L74") = S754
Range("E105, E107") = S504
Range("L105, L107") = S254
Dim St95 As Double, St75 As Double, St50 As Double, St25 As Double
Dim St952 As Double, St752 As Double, St502 As Double, St252 As Double
Dim St953 As Double, St753 As Double, St503 As Double, St253 As Double
Dim St954 As Double, St754 As Double, St504 As Double, St254 As Double
Dim St955 As Double, St755 As Double, St505 As Double, St255 As Double
St95 = Range("EQ17").Value
St75 = Range("ER17").Value
St50 = Range("ES17").Value
St25 = Range("ET17").Value
St952 = Range("EQ18").Value
St752 = Range("ER18").Value
St502 = Range("ES18").Value
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St252 = Range("ET18").Value
St953 = Range("EQ19").Value
St753 = Range("ER19").Value
St503 = Range("ES19").Value
St253 = Range("ET19").Value
St954 = Range("EQ20").Value
St754 = Range("ER20").Value
St504 = Range("ES20").Value
St254 = Range("ET20").Value
St955 = Range("EQ21").Value
St755 = Range("ER21").Value
St505 = Range("ES21").Value
St255 = Range("ET21").Value
Range("F48,F51,F50,F55,F62,F63,F72") = St95
Range("M48,M51,M50,M55,M62,M63,M72") = St75
Range("F81,F83,F84,F88,F95,F96,F105") = St50
Range("M81,M83,M84,M88,M95,M96,M105") = St25
Range("F49,F52,F53,F56,F61,F64,F74") = St952
Range("M49,M52,M53,M56,M61,M64,M74") = St752
Range("F82,F85,F86,F89,F94,F97,F107") = St502
Range("M82,M85,M86,M89,M94,M97,M107") = St252
Range("F54,F57,F59,F60,F65,F66") = St953
Range("M54,M57,M59,M60,M65,M66") = St753
Range("F90,F92,F93,F98,F99") = St503
Range("M90,M92,M93,M98,M99") = St253
Range("F58,F67,F68,F69,F70,F73") = St954
Range("M58,M67,M68,M69,M70,M73") = St754
Range("F91,F100,F101,F102,F103,F106") = St504
Range("M91,M100,M101,M102,M103,M106") = St254
Range("F71") = St955
Range("M71") = St755
Range("F104,F87") = St505
Range("M104,M87") = St255

'_______Profit_____________________________
Dim PT95 As Double, PT75 As Double, PT50 As Double, PT25 As Double
Dim PT952 As Double, PT752 As Double, PT502 As Double, PT252 As Double
PT95 = Range("EG3").Value
PT75 = Range("EH3").Value
PT50 = Range("EI3").Value
PT25 = Range("EJ3").Value
PT952 = Range("EG4").Value
PT752 = Range("EH4").Value
PT502 = Range("EI4").Value
PT252 = Range("EJ4").Value

If Worksheets("Output").Range("B5") = "" Then
Range("EH48,EH49,EH51,EH52,EH54,EH57,EH58,EH61,EH62,EH65,EH67,EH69,EH71,EH72,EH74")
= ""
Range("EO48,EO49,EO51,EO52,EO54,EO57,EO58,EO61,EO62,EO65,EO67,EO69,EO71,EO72,EO74")
= ""
Range("EH81,EH82,EH84,EH85,EH87,EH90,EH91,EH94,EH95,EH98,EH100,EH102,EH104,EH105,EH
107") = ""
Range("EO81,EO82,EO84,EO85,EO87,EO90,EO91,EO94,EO95,EO98,EO100,EO102,EO104,EO105,EO
107") = ""
Range("EH50,EH53,EH55,EH56,EH59,EH60,EH63,EH64,EH66,EH68,EH70,EH73") = ""
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Range("EO50,EO53,EO55,EO56,EO59,EO60,EO63,EO64,EO66,EO68,EO70,EO73") = ""
Range("EH83,EH86,EH88,EH89,EH92,EH93,EH96,EH97,EH99,EH101,EH103,EH106") = ""
Range("EO83,EO86,EO88,EO89,EO92,EO93,EO96,EO97,EO99,EO101,EO103,EO106") = ""

Else:
Range("EH48,EH49,EH51,EH52,EH54,EH57,EH58,EH61,EH62,EH65,EH67,EH69,EH71,EH72,EH74")
= PT95
Range("EO48,EO49,EO51,EO52,EO54,EO57,EO58,EO61,EO62,EO65,EO67,EO69,EO71,EO72,EO74")
= PT75
Range("EH81,EH82,EH84,EH85,EH87,EH90,EH91,EH94,EH95,EH98,EH100,EH102,EH104,EH105,EH
107") = PT50
Range("EO81,EO82,EO84,EO85,EO87,EO90,EO91,EO94,EO95,EO98,EO100,EO102,EO104,EO105,EO
107") = PT25
Range("EH50,EH53,EH55,EH56,EH59,EH60,EH63,EH64,EH66,EH68,EH70,EH73") = PT952
Range("EO50,EO53,EO55,EO56,EO59,EO60,EO63,EO64,EO66,EO68,EO70,EO73") = PT752
Range("EH83,EH86,EH88,EH89,EH92,EH93,EH96,EH97,EH99,EH101,EH103,EH106") = PT502
Range("EO83,EO86,EO88,EO89,EO92,EO93,EO96,EO97,EO99,EO101,EO103,EO106") = PT252
End If

Dim PS95 As Double, PS75 As Double, PS50 As Double, PS25 As Double
Dim PS952 As Double, PS752 As Double, PS502 As Double, PS252 As Double
Dim PS953 As Double, PS753 As Double, PS503 As Double, PS253 As Double
Dim PS954 As Double, PS754 As Double, PS504 As Double, PS254 As Double
PS95 = Range("EG10").Value
PS75 = Range("EH10").Value
PS50 = Range("EI10").Value
PS25 = Range("EJ10").Value
PS952 = Range("EG11").Value
PS752 = Range("EH11").Value
PS502 = Range("EI11").Value
PS252 = Range("EJ11").Value
PS953 = Range("EG12").Value
PS753 = Range("EH12").Value
PS503 = Range("EI12").Value
PS253 = Range("EJ12").Value
PS954 = Range("EG13").Value
PS754 = Range("EH13").Value
PS504 = Range("EI13").Value
PS254 = Range("EJ13").Value

If Worksheets("Output").Range("B14") = "" Then
Range("EI48,EI49,EI50,EI52,EI54,EI53,EI58,EI59,EI68,EI71") = ""
Range("EP48,EP49,EP50,EP52,EP54,EP53,EP58,EP59,EP68,EP71") = ""
Range("EI81,EI82,EI83,EI86,EI87,EI90,EI91,EI92,EI101,EI104") = ""
Range("EP81,EP82,EP83,EP86,EP87,EP90,EP91,EP92,EP101,EP104") = ""
Range("EI51,EI52,EI55,EI56,EI57,EI60,EI61,EI64,EI67,EI70") = ""
Range("EP51,EP52,EP55,EP56,EP57,EP60,EP61,EP64,EP67,EP70") = ""
Range("EI84,EI85,EI88,EI89,EI90,EI93,EI94,EI97,EI100,EI103") = ""
Range("EP84,EP85,EP88,EP89,EP90,EP93,EP94,EP97,EP100,EP103") = ""
Range("EI62,EI63,EI65,EI66,EI69,EI73") = ""
Range("EP62,EP63,EP65,EP66,EP69,EP73") = ""
Range("EI95,EI96,EI98,EI99,EI102,EI106") = ""
Range("EP95,EP96,EP98,EP99,EP102,EP106") = ""
Range("EI72, EI74") = ""
Range("EP72, EP74") = ""
Range("EI105, EI107") = ""
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Range("EP105, EP107") = ""

Else: Range("EI48,EI49,EI50,EI52,EI54,EI53,EI58,EI59,EI68,EI71") = PS95
Range("EP48,EP49,EP50,EP52,EP54,EP53,EP58,EP59,EP68,EP71") = PS75
Range("EI82,EI81,EI83,EI86,EI90,EI91,EI92,EI101,EI104") = PS50
Range("EP81,EP82,EP83,EP86,EP90,EP91,EP92,EP101,EP104") = PS25
Range("EI51,EI52,EI55,EI56,EI57,EI60,EI67,EI70") = PS952
Range("EP51,EP52,EP55,EP56,EP57,EP60,EP67,EP70") = PS752
Range("EI84,EI85,EI88,EI87,EI89,EI90,EI93,EI100,EI103") = PS502
Range("EP84,EP85,EP88,EP89,EP90,EP93,EP100,EP103") = PS252
Range("EI62,EI61,EI63,EI64,EI65,EI66,EI69,EI73") = PS953
Range("EP62,EP63,EP65,EP66,EP69,EP73,EP64,EP61") = PS753
Range("EI95,EI96,EI98,EI99,EI102,EI106,EI94,EI97") = PS503
Range("EP95,EP96,EP98,EP99,EP102,EP106,EP94,EP97") = PS253
Range("EI72, EI74") = PS954
Range("EP72, EP74") = PS754
Range("EI105, EI107") = PS504
Range("EP105, EP107") = PS254
End If

Dim PSt95 As Double, PSt75 As Double, PSt50 As Double, PSt25 As Double
Dim PSt952 As Double, PSt752 As Double, PSt502 As Double, PSt252 As Double
Dim PSt953 As Double, PSt753 As Double, PSt503 As Double, PSt253 As Double
Dim PSt954 As Double, PSt754 As Double, PSt504 As Double, PSt254 As Double
Dim PSt955 As Double, PSt755 As Double, PSt505 As Double, PSt255 As Double
PSt95 = Range("EG17").Value
PSt75 = Range("EH17").Value
PSt50 = Range("EI17").Value
PSt25 = Range("EJ17").Value
PSt952 = Range("EG18").Value
PSt752 = Range("EH18").Value
PSt502 = Range("EI18").Value
PSt252 = Range("EJ18").Value
PSt953 = Range("EG19").Value
PSt753 = Range("EH19").Value
PSt503 = Range("EI19").Value
PSt253 = Range("EJ19").Value
PSt954 = Range("EG20").Value
PSt754 = Range("EH20").Value
PSt504 = Range("EI20").Value
PSt254 = Range("EJ20").Value
PSt955 = Range("EG21").Value
PSt755 = Range("EH21").Value
PSt505 = Range("EI21").Value
PSt255 = Range("EJ21").Value

If Worksheets("Output").Range("B23") = "" Then
Range("EJ48,EJ50,EJ51,EJ55,EJ62,EJ63,EJ72") = ""
Range("EQ48,EQ51,EQ50,EQ55,EQ62,EQ63,EQ72") = ""
Range("EJ81,EJ83,EJ84,EJ88,EJ95,EJ96,EJ105") = ""
Range("EQ81,EQ83,EQ84,EQ88,EQ95,EQ96,EQ105") = ""
Range("EJ49,EJ52,EJ53,EJ56,EJ61,EJ64,EJ74") = ""
Range("EQ49,EQ52,EQ53,EQ56,EQ61,EQ64,EQ74") = ""
Range("EJ82,EJ85,EJ86,EJ89,EJ94,EJ97,EJ107") = ""
Range("EQ82,EQ85,EQ86,EQ89,EQ94,EQ97,EQ107") = ""
Range("EJ54,EJ57,EJ59,EJ60,EJ65,EJ66") = ""
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Range("EQ54,EQ57,EQ59,EQ60,EQ65,EQ66") = ""
Range("EJ87,EJ90,EJ92,EJ93,EJ98,EJ99") = ""
Range("EQ87,EQ90,EQ92,EQ93,EQ98,EQ99") = ""
Range("EJ58,EJ67,EJ68,EJ69,EJ70,EJ73") = ""
Range("EQ58,EQ67,EQ68,EQ69,EQ70,EQ73") = ""
Range("EJ91,EJ100,EJ101,EJ102,EJ103,EJ106") = ""
Range("EQ91,EQ100,EQ101,EQ102,EQ103,EQ106") = ""
Range("EJ71") = ""
Range("EQ71") = ""
Range("EJ104") = ""
Range("EQ104") = ""

Else: Range("EJ48,EJ50,EJ51,EJ55,EJ62,EJ63,EJ72") = PSt95
Range("EQ48,EQ51,EQ50,EQ55,EQ62,EQ63,EQ72") = PSt75
Range("EJ81, EJ83,EJ84,EJ88,EJ95,EJ96,EJ105") = PSt50
Range("EQ81,EQ83,EQ84,EQ88,EQ95,EQ96,EQ105") = PSt25
Range("EJ49,EJ52,EJ53,EJ56,EJ61,EJ64,EJ74") = PSt952
Range("EQ49,EQ52,EQ53,EQ56,EQ61,EQ64,EQ74") = PSt752
Range("EJ82,EJ85,EJ86,EJ89,EJ94,EJ97,EJ107") = PSt502
Range("EQ82,EQ85,EQ86,EQ89,EQ94,EQ97,EQ107") = PSt252
Range("EJ54,EJ57,EJ59,EJ60,EJ65,EJ66") = PSt953
Range("EQ54,EQ57,EQ59,EQ60,EQ65,EQ66") = PSt753
Range("EJ87,EJ90,EJ92,EJ93,EJ98,EJ99") = PSt503
Range("EQ87,EQ90,EQ92,EQ93,EQ98,EQ99") = PSt253
Range("EJ58,EJ67,EJ68,EJ69,EJ70,EJ73") = PSt954
Range("EQ58,EQ67,EQ68,EQ69,EQ70,EQ73") = PSt754
Range("EJ91,EJ100,EJ101,EJ102,EJ103,EJ106") = PSt504
Range("EQ91,EQ100,EQ101,EQ102,EQ103,EQ106") = PSt254
Range("EJ71") = PSt955
Range("EQ71") = PSt755
Range("EJ104,EJ87") = PSt505
Range("EQ104,EQ87") = PSt255
End If

Range("EK48:EK74").Formula = "=sum(EH48:EJ48)"
Range("EK81:EK107").Formula = "=sum(EH81:EJ81)"
Range("ER48:ER74").Formula = "=sum(EO48:EQ48)"
Range("ER81:ER107").Formula = "=sum(EO81:EQ81)"

For Each cell In Range("G48:G74, N48:N74, G81:G107, N81:N107 ")
If cell > D30 Then
cell.Value = D30
End If
Next
Worksheets("Output").Range("EL48:EL74") = Worksheets("Output").Range("EU48:EU74").Value
Worksheets("Output").Range("EL48:EL74").Sort Key1:=Worksheets("Output").Range("EL48:EL74"),
Order1:=xlAscending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("EL81:EL107") = Worksheets("Output").Range("EW48:EW74").Value
Worksheets("Output").Range("EL81:EL107").Sort Key1:=Worksheets("Output").Range("EL81:EL107"),
Order1:=xlAscending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
Worksheets("Output").Range("ES48:ES74") = Worksheets("Output").Range("EV48:EV74").Value
Worksheets("Output").Range("ES48:ES74").Sort Key1:=Worksheets("Output").Range("ES48:ES74"),
Order1:=xlAscending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom

Worksheets("Output").Range("ES81:ES107") = Worksheets("Output").Range("EX48:EX74").Value
```

```
Worksheets("Output").Range("ES81:ES107").Sort Key1:=Worksheets("Output").Range("ES81:ES107"),
Order1:=xlAscending, Header:=xlNo, OrderCustom:=1, MatchCase:=False, Orientation:=xlTopToBottom
Range("C81:C107").Formula = "=INDEX($EG$81:$EG$107,MATCH(H81,$EL$81:$EL$107))"

Range("J81:J107").Formula = "=INDEX($EN$81:$EN$107,MATCH(O81,$ES$81:$ES$107))"

Range("C48:C74").Formula = "=INDEX($EG$48:$EG$74,MATCH(H48,$EL$48:$EL$74))"

Range("J48:J74").Formula = "=INDEX($EN$48:$EN$74,MATCH(O48,$ES$48:$ES$74))"

Range("H48") = Range("EU48")
Range("H49") = Range("EU49")
Range("H50") = Range("EU50")
Range("H51") = Range("EU51")
Range("H52") = Range("EU52")
Range("H53") = Range("EU53")
Range("H54") = Range("EU54")
Range("H55") = Range("EU55")
Range("H56") = Range("EU56")
Range("H57") = Range("EU57")
Range("H58") = Range("EU58")
Range("H59") = Range("EU59")
Range("H60") = Range("EU60")
Range("H61") = Range("EU61")
Range("H62") = Range("EU62")
Range("H63") = Range("EU63")
Range("H64") = Range("EU64")
Range("H65") = Range("EU65")
Range("H66") = Range("EU66")
Range("H67") = Range("EU67")
Range("H68") = Range("EU68")
Range("H69") = Range("EU69")
Range("H70") = Range("EU70")
Range("H71") = Range("EU71")
Range("H72") = Range("EU72")
Range("H73") = Range("EU73")
Range("H74") = Range("EU74")
Range("O48") = Range("EV48")
Range("O49") = Range("EV49")
Range("O50") = Range("EV50")
Range("O51") = Range("EV51")
Range("O52") = Range("EV52")
Range("O53") = Range("EV53")
Range("O54") = Range("EV54")
Range("O55") = Range("EV55")
Range("O56") = Range("EV56")
Range("O57") = Range("EV57")
Range("O58") = Range("EV58")
Range("O59") = Range("EV59")
Range("O60") = Range("EV60")
Range("O61") = Range("EV61")
Range("O62") = Range("EV62")
Range("O63") = Range("EV63")
Range("O64") = Range("EV64")
Range("O65") = Range("EV65")
Range("O66") = Range("EV66")
```

```
Range("O67") = Range("EV67")
Range("O68") = Range("EV68")
Range("O69") = Range("EV69")
Range("O70") = Range("EV70")
Range("O71") = Range("EV71")
Range("O72") = Range("EV72")
Range("O73") = Range("EV73")
Range("O74") = Range("EV74")
Range("H81") = Range("EW48")
Range("H82") = Range("EW49")
Range("H83") = Range("EW50")
Range("H84") = Range("EW51")
Range("H85") = Range("EW52")
Range("H86") = Range("EW53")
Range("H87") = Range("EW54")
Range("H88") = Range("EW55")
Range("H89") = Range("EW56")
Range("H90") = Range("EW57")
Range("H91") = Range("EW58")
Range("H92") = Range("EW59")
Range("H93") = Range("EW60")
Range("H94") = Range("EW61")
Range("H95") = Range("EW62")
Range("H96") = Range("EW63")
Range("H97") = Range("EW64")
Range("H98") = Range("EW65")
Range("H99") = Range("EW66")
Range("H100") = Range("EW67")
Range("H101") = Range("EW68")
Range("H102") = Range("EW69")
Range("H103") = Range("EW70")
Range("H104") = Range("EW71")
Range("H105") = Range("EW72")
Range("H106") = Range("EW73")
Range("H107") = Range("EW74")
Range("O81") = Range("EX48")
Range("O82") = Range("EX49")
Range("O83") = Range("EX50")
Range("O84") = Range("EX51")
Range("O85") = Range("EX52")
Range("O86") = Range("EX53")
Range("O87") = Range("EX54")
Range("O88") = Range("EX55")
Range("O89") = Range("EX56")
Range("O90") = Range("EX57")
Range("O91") = Range("EX58")
Range("O92") = Range("EX59")
Range("O93") = Range("EX60")
Range("O94") = Range("EX61")
Range("O95") = Range("EX62")
Range("O96") = Range("EX63")
Range("O97") = Range("EX64")
Range("O98") = Range("EX65")
Range("O99") = Range("EX66")
Range("O100") = Range("EX67")
Range("O101") = Range("EX68")
```

```
Range("O102") = Range("EX69")
Range("O103") = Range("EX70")
Range("O104") = Range("EX71")
Range("O105") = Range("EX72")
Range("O106") = Range("EX73")
Range("O107") = Range("EX74")

For Each cell In Range("C48:C74,C81:C107,J48:J74,J81:J107")
If cell = 3 Then
cell.Interior.ColorIndex = 50
End If
Next
For Each cell In Range("C48:C74,C81:C107,J48:J74,J81:J107")
If cell > 3 Then
cell.Interior.ColorIndex = 0
End If
Next

For Each cell In Range("C48:C74,C81:C107,J48:J74,J81:J107")
If cell = 2 Then
cell.Interior.ColorIndex = 43
End If
Next

For Each cell In Range("C48:C74,C81:C107,J48:J74,J81:J107")
If cell = 1 Then
cell.Interior.ColorIndex = 4
End If
Next
End Sub
```

```
Sub DropDown5_Change()

Dim DVS As Double, LSLS As Double, SDS As Double, TVS As Double
Dim S1 As Double, S2 As Double, S3 As Double, S4 As Double, S5 As Double
DVS = Range("D26").Value
LSLS = Range("D28").Value
SDS = Range("D30").Value

S1 = Range("G27").Value
S2 = Range("G28").Value
S3 = Range("G29").Value
S4 = Range("G30").Value
S5 = Range("G31").Value
If Worksheets("Output").Range("BB4") = 3 Then
   Worksheets("Input").Range("D26") = DVS * 0.07030696
   Worksheets("Input").Range("D28") = LSLS * 0.07030696
   Worksheets("Input").Range("D30") = SDS * 0.07030696
   Worksheets("Input").Range("G27") = S1 * 0.07030696
   Worksheets("Input").Range("G28") = S2 * 0.07030696
   Worksheets("Input").Range("G29") = S3 * 0.07030696
   Worksheets("Input").Range("G30") = S4 * 0.07030696
   Worksheets("Input").Range("G31") = S5 * 0.07030696
ElseIf Worksheets("Output").Range("BB4") = 2 Then
   Worksheets("Input").Range("D26") = DVS / 0.07030696
   Worksheets("Input").Range("D28") = LSLS / 0.07030696
```

```
   Worksheets("Input").Range("D30") = SDS / 0.07030696
   Worksheets("Input").Range("G27") = S1 / 0.07030696
   Worksheets("Input").Range("G28") = S2 / 0.07030696
   Worksheets("Input").Range("G29") = S3 / 0.07030696
   Worksheets("Input").Range("G30") = S4 / 0.07030696
   Worksheets("Input").Range("G31") = S5 / 0.07030696
End If
End Sub
```

```
Sub notools()
   ActiveWindow.DisplayHeadings = False
   Application.DisplayFormulaBar = False
   Dim cbar As CommandBar
   For Each cbar In CommandBars
      If cbar.Enabled And cbar.Type = msoBarTypeNormal Then
         cbar.Visible = False
      End If
   Next cbar
   CommandBars("Worksheet Menu Bar").Enabled = False
End Sub
Sub DropDown9_Change()

Dim DVS2 As Double, LSLS2 As Double, SDS2 As Double, TVS2 As Double
Dim S12 As Double, S22 As Double, S32 As Double, S42 As Double, S52 As Double
DVS2 = Range("D26").Value
LSLS2 = Range("D28").Value
SDS2 = Range("D30").Value

S12 = Range("G27").Value
S22 = Range("G28").Value
S32 = Range("G29").Value
S42 = Range("G30").Value
S52 = Range("G31").Value

If Worksheets("Output").Range("BE4") = 2 Then
   Worksheets("Input").OLEObjects("Textbox2").Object.Text = Round(9 *
(Worksheets("Input").OLEObjects("Textbox2").Object.Text) ^ (1 / 2))
   Worksheets("Input").Range("D26") = 9 * (DVS2) ^ (1 / 2)
   Worksheets("Input").Range("D28") = 9 * (LSLS2) ^ (1 / 2)
   Worksheets("Input").Range("D30") = 9 * (SDS2) ^ (1 / 2)
   Worksheets("Input").Range("G27") = 9 * (S12) ^ (1 / 2)
   Worksheets("Input").Range("G28") = 9 * (S22) ^ (1 / 2)
   Worksheets("Input").Range("G29") = 9 * (S32) ^ (1 / 2)
   Worksheets("Input").Range("G30") = 9 * (S42) ^ (1 / 2)
   Worksheets("Input").Range("G31") = 9 * (S52) ^ (1 / 2)
ElseIf Worksheets("Output").Range("BE4") = 1 Then
   Worksheets("Input").OLEObjects("Textbox2").Object.Text =
Round(((Worksheets("Input").OLEObjects("Textbox2").Object.Text) / 9) ^ 2)
   Worksheets("Input").Range("D26") = (DVS2 / 9) ^ 2
   Worksheets("Input").Range("D28") = (LSLS2 / 9) ^ 2
   Worksheets("Input").Range("D30") = (SDS2 / 9) ^ 2
   Worksheets("Input").Range("G27") = (S12 / 9) ^ 2
   Worksheets("Input").Range("G28") = (S22 / 9) ^ 2
   Worksheets("Input").Range("G29") = (S32 / 9) ^ 2
   Worksheets("Input").Range("G30") = (S42 / 9) ^ 2
   Worksheets("Input").Range("G31") = (S52 / 9) ^ 2
```

```
End If

End Sub
```

```
Sub DropDown4_Change()

Dim DVSt As Double, LSLSt As Double, SDSt As Double, TVSt As Double
Dim S1t As Double, S2t As Double, S3t As Double, S4t As Double, S5t As Double
DVSt = Range("D41").Value
SDSt = Range("D43").Value

S1t = Range("G41").Value
S2t = Range("G42").Value
S3t = Range("G43").Value
S4t = Range("G44").Value
S5t = Range("G45").Value

If Worksheets("Output").Range("BC4") = 3 Then
   Worksheets("Input").Range("D41") = DVSt * 15.78283
   Worksheets("Input").Range("D43") = SDSt * 15.78283
   Worksheets("Input").Range("G41") = S1t * 15.78283
   Worksheets("Input").Range("G42") = S2t * 15.78283
   Worksheets("Input").Range("G43") = S3t * 15.78283
   Worksheets("Input").Range("G44") = S4t * 15.78283
   Worksheets("Input").Range("G45") = S5t * 15.78283
ElseIf Worksheets("Output").Range("BC4") = 2 Then
   Worksheets("Input").Range("D41") = DVSt / 15.78283
   Worksheets("Input").Range("D43") = SDSt / 15.78283
   Worksheets("Input").Range("G41") = S1t / 15.78283
   Worksheets("Input").Range("G42") = S2t / 15.78283
   Worksheets("Input").Range("G43") = S3t / 15.78283
   Worksheets("Input").Range("G44") = S4t / 15.78283
   Worksheets("Input").Range("G45") = S5t / 15.78283
End If
End Sub
```

```
Sub Button442_Click()

Range("O3:BB10018").Select
   Selection.ClearContents

   Range("BD3:BD10018").Select
   Selection.ClearContents

   Range("BG1:CV10018").Select
   Selection.ClearContents

   Range("CX3:IK10018").Select
   Selection.ClearContents

   Range("IN3:IN10018").Select
   Selection.ClearContents

   Range("IL3:IL10018").Select
   Selection.ClearContents
Do
```

```
    fName = Application.GetSaveAsFilename
Loop Until fName <> False
ActiveWorkbook.SaveAs Filename:=fName
End Sub
```

```
Sub Button464_Click()
UserForm1.Show 0
End Sub
```

APPENDIX F
COMPUTER SOFTWARE PROGRAM (PROB.O.PROF) MANUAL

F.1 System Requirements and Recommendations

To effectively use this software program the user will need an IBM-compatible industry-standard personal computer with the following minimum characteristics:

- Intel Pentium Pro, Pentium, or 486 PC
- Microsoft ® Windows 98, Windows 95, Windows NT 4.0, or newer operating system
- Minimum of 16 Mb of RAM
- Pointing device
- Graphics adapter with at least 800 x 600 resolution
- Microsoft Excel (any version)

F.2 Software Installation

This software program is in an Excel worksheet. There is no installation required.

F.3 Starting the Software

When the user first opens the Excel worksheet program a message box will come up and ask the user to disable or enable macros. Click on “Enable Macros” to allow the program to run with Excel Macros and Visual Basic. The message box is shown in Figure F-1.

In addition, the user will also see two tabs on the bottom left side of the program: input and output. The input tab is used to input all the data and the output tab is to show the user the calculated output data.

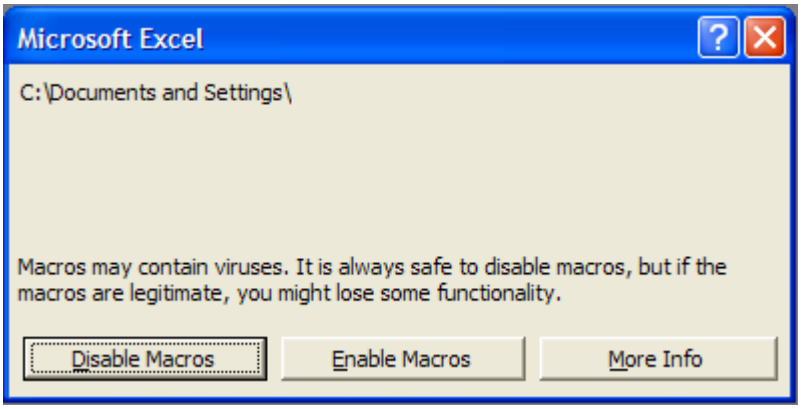

Figure F-1. Disable/Enable Macros Message Box

F.4 Buttons

There are five buttons in the program that are used, Figure F-2. The “RUN” button is to execute the program once the data has been inputted. The “CLEAR” button is to clear all inputted data and start from scratch. The “PRINT” button will print the users input numbers along with the output data, a total of three pages long. The “SAVE” button will allow the user to save the work done. Make sure when saving the program that it is saved under a different name. The “HELP” button opens up a search box to allow the user to search for a keyword. Figure F-3 shows the search tool box. The user can either type in the keyword or use the dropdown box to scroll to the keyword or their choice. In order to receive an explanation or definition of the keyword, the user should press the “GO” button on the right hand side. Then, a message box will pop out and give the information for that keyword.

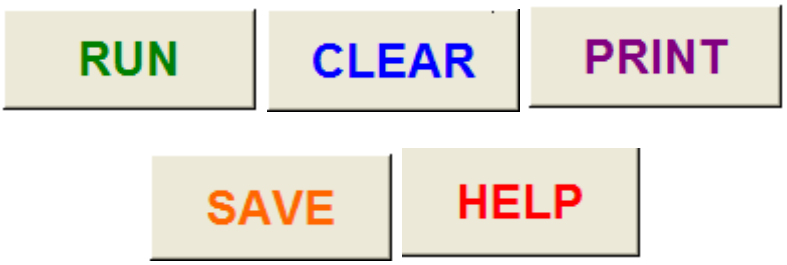

Figure F-2. The Five Buttons Used in the Software Program

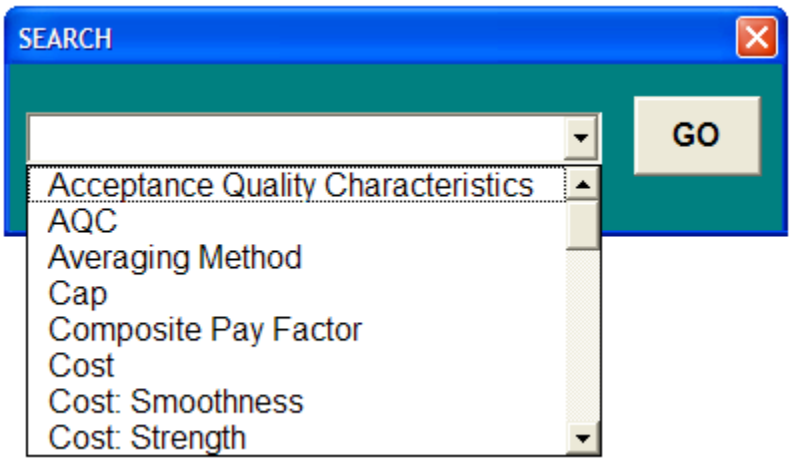

Figure F-3. Search Tool

F.4 Input Data

This software program provides the user with a tool for investigating the cost of quality, and target AQCs that will maximize profit. Specifically, the software allows the user to change concrete pavement design features for concrete pavement The first thing to do is input is the number of AQCs needed to analyze (e.g., 1, 2, or 3), Figure F-4.

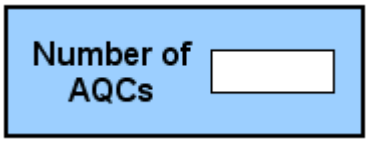

Figure F-4. Input the Number of AQCs for Analysis

If a number 1, 2, or 3 is not inputted in the box shown above, a message box will show asking the user to enter the number of AQCs used, Figure F-5.

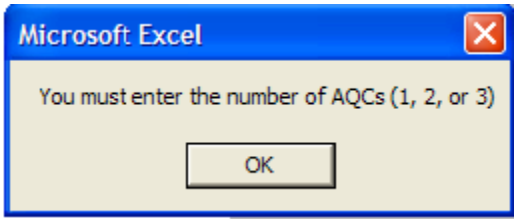

Figure F-5. Message Box if Number of AQCs is Not Entered

After the number of AQCs are entered, enter the values for each AQC (e.g., thickness, strength, and smoothness). Figures F-6 through F-8 show the boxes where the values for each AQC are entered.

In order to execute the thickness analysis, the user should input the design value, lower specification limit, standard deviation, samples per lot (for simulation and QI purposes), and the target value increment. Note that before inputting a number in the target value increment box, the user should click out of a cell first. The% cost values shown in the right hand side of Figure F-6 automatically changes to the default values when the user inputs the rest of the thickness variables. The user can change the percent cost values to meet their expected needs. The thickness input box is seen in Figure F-6.

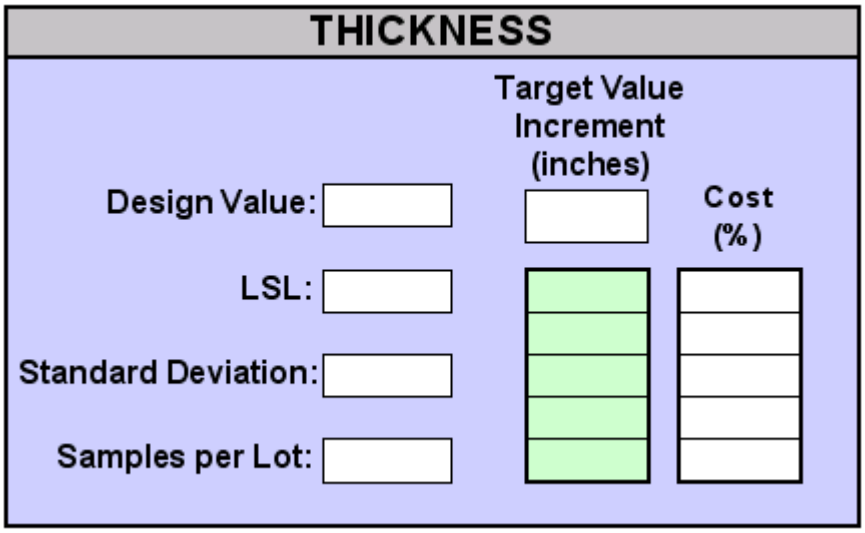

Figure F-6. Thickness Input Box

To execute the strength analysis, the user should first choose the test method used from the drop box (e.g., compressive or flexural). Then the user should input the design value, lower specification limit, standard deviation (for simulation and QI purposes), samples per lot, and target value increment. The percent cost values shown in the right hand side of Figure F-7 automatically changes to the default values when the user inputs

the rest of the strength variables. The user can change the percent cost values to meet their expected needs. The strength input box is seen in Figure F-7.

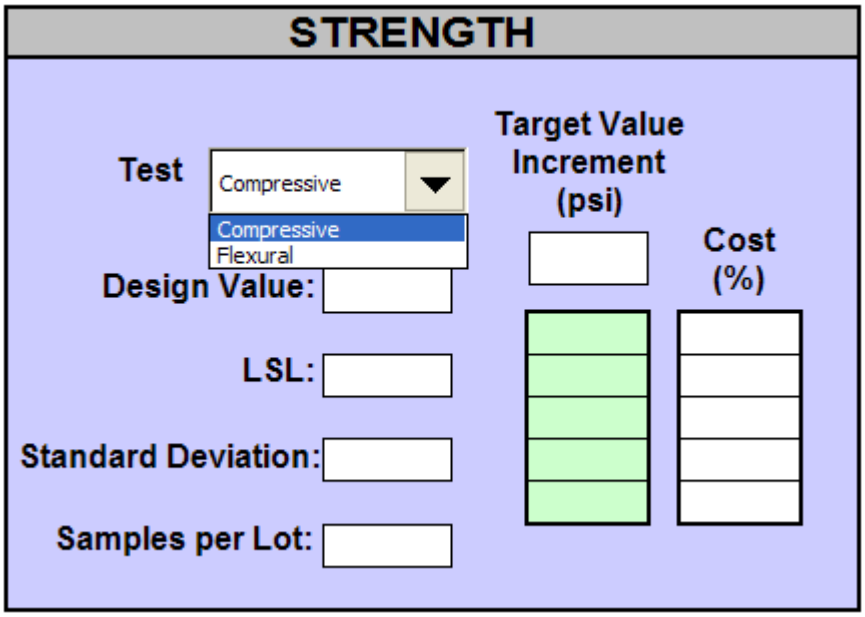

Figure F-7. Strength Input Box

To execute the smoothness analysis, the user should first choose the index measurement used from the drop box (e.g., $PI_{0.2\text{-}inch}$ or IRI). Then the user should input the design value, lower specification limit, standard deviation (for simulation purposes), total sub lots, and target value increment. The total sub lot measurement for smoothness is different than the samples per lot taken for thickness and strength. For example, five sub lots for smoothness is equivalent to half a mile of production, ten sub lots for smoothness is equivalent to one mile of production and twenty sub lot for smoothness is equivalent to two miles of production, etc. The user can input 5 to 70 total sub lots for analysis purposes, depending on how many miles of lots is produced per day. The percent cost values shown in the right hand side of Figure F-8 automatically changes to the default values when the user inputs the rest of the smoothness variables. The user can

change the percent cost values to meet their expected needs. The smoothness input box is seen in Figure F-8.

Once all the data has been inputted the user can run the program. The total run time for the execution take an estimated time of three minutes. In order to start from the beginning, the user should press the "CLEAR" button. All of the input variables will be cleared within an estimated time of three to five seconds.

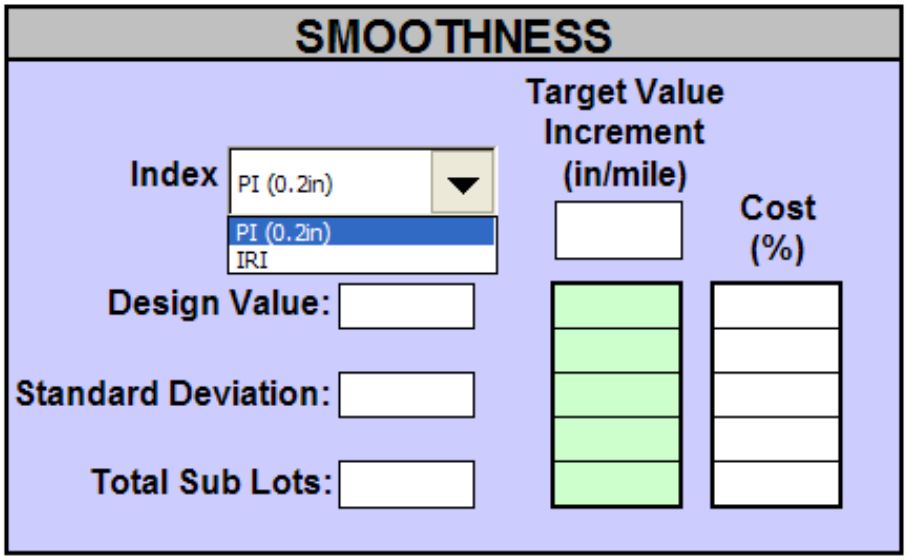

Figure F-8. Smoothness Input Box

F.5 Output Data

After the program has been executed, it will automatically switch to the output section to show the results. The outputs cost results are shown in three tables: thickness, strength, and smoothness. The three output tables are shown in Figures F-9 through F-11. Each table consists a target AQC increment. A cost, pay and profit value (in percent) associated to each AQC increment is also calculated and shown in the table. In addition the pay and profit are calculated for the four different types of risks: 95%, 75%, 50%, and 25%.

Target Thickness (inches)	COST (%)	PAY				PROFIT			
		95%	75%	50%	25%	95%	75%	50%	25%

Figure F-9. Thickness Output Table

Target Strength (psi)	COST (%)	PAY				PROFIT			
		95%	75%	50%	25%	95%	75%	50%	25%

Figure F-10. Strength Output Table

Target Smoothness (in/mile)	COST (%)	PAY				PROFIT			
		95%	75%	50%	25%	95%	75%	50%	25%

Figure F-11. Smoothness Output Table

The user has to input a cap value, in percent, for the maximum allowable composite pay factor. The default value is 108% that can be used. In addition, the user needs to choose a composite pay method to use. The user has four methods to choose from a drop box: Weighted Average, Averaging, Summation, and Product. The Weighted Average Method uses a weight for each AQC. The user should input a weight, in percent, before selecting this method from the drop box. These can be seen in Figures F-12 and F-13.

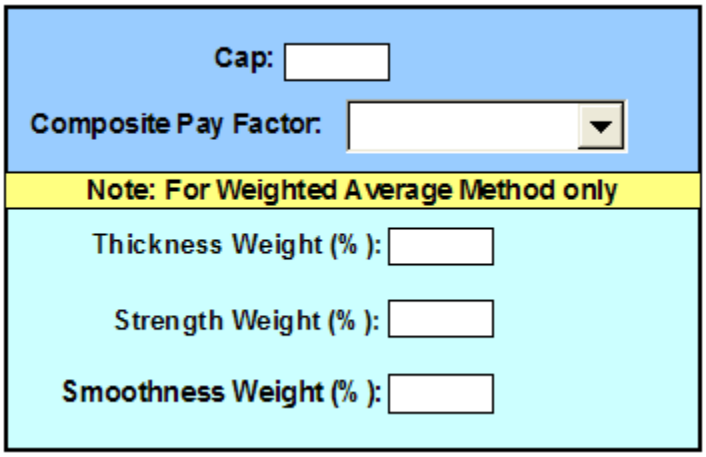

Figure F-12. Cap and Composite Pay Factor Inputs

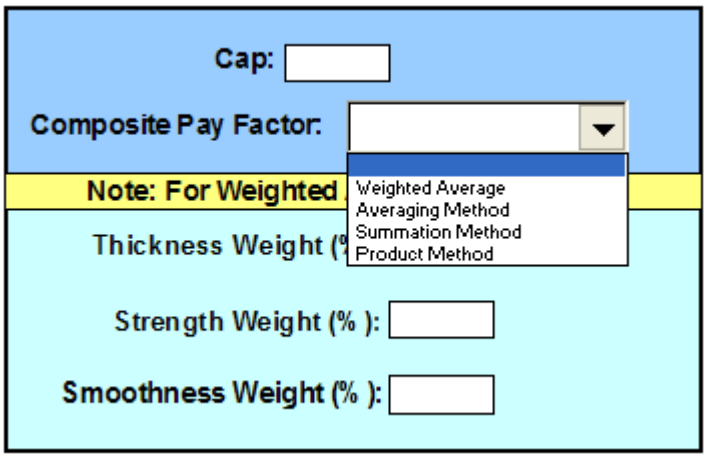

Figure F-13. Composite Pay Factor Drop Box of Different Methods Used

Once the user chooses a composite pay method, 27 combinations of combined AQCs are ranked for each risk percentile, Figure F-14. These tables show the rank number, AQCs used in the combination, the CPF, and the profit. The best three combinations that show the maximum profit are highlighted. This will help the user choose the best combined target AQCs that will maximize profit depending on the risk percentage.

95% Probability					
Rank	Target Quality Factor			CPF	Profit
	T	$t	$m	(%)	(%)
3	12	5000	5	108.00	6.40
2	12	5000	6	108.00	7.10
4	11.5	5000	5	106.05	-0.06
10	12	4500	5	104.99	-3.65
11	12	4500	6	102.91	-4.35
5	11.5	5000	6	103.95	-0.76
1	12	5000	7	108.00	8.00
13	11.5	4500	5	99.99	-5.31
14	11.5	4500	6	98.01	-6.01
12	12	4500	7	101.87	-5.25
6	12	5000	8	105.84	-1.30
7	11.5	5000	7	102.90	-1.66
16	11.5	4500	7	97.02	-6.91
19	12	4000	6	102.91	-14.76
18	12	4000	5	92.26	-14.06
21	11.5	4000	5	87.87	-15.72
22	11.5	4000	6	86.13	-16.42
20	12	4000	7	89.52	-15.66
24	11.5	4000	7	85.26	-17.32
15	12	4500	8	99.79	-6.55
9	11.5	5000	8	100.80	-2.96
23	12	4000	8	87.70	-16.96
17	11.5	4500	8	95.04	-8.21
8	12	5000	9	103.64	-2.80
26	12	3500	5	58.33	-44.96
25	11.5	4000	8	83.52	-18.62
27	12	3500	6	57.17	-45.66

75% Probability					
Rank	Target Quality Factor			CPF	Profit
	T	$t	$m	(%)	(%)
15	11.5	4500	5	108.00	2.00
13	11.5	4500	6	108.00	2.70
7	12	4500	5	108.00	5.00
12	11.5	5000	5	108.00	3.00
9	11.5	5000	6	108.00	3.70
6	12	4500	6	108.00	5.70
10	11.5	4500	7	108.00	3.40
5	12	5000	5	108.00	6.00
3	12	5000	6	108.00	6.70
8	11.5	5000	7	108.00	4.40
11	11.5	4500	8	106.94	3.30
4	12	4500	7	108.00	6.40
2	12	5000	7	108.00	7.40
1	11.5	4000	6	108.00	10.36
19	11.5	4000	5	101.81	-1.66
22	12	4000	5	101.81	-4.66
23	12	4000	6	100.80	-5.36
20	11.5	4000	7	99.79	-3.06
24	12	4000	7	99.79	-6.06
14	11.5	5000	8	106.94	2.30
17	12	4500	8	106.94	0.30
21	11.5	4000	8	97.78	-4.36
18	12	5000	8	106.94	-0.70
16	11.5	4500	9	104.74	1.80
26	11.5	3500	5	65.75	-34.75
25	12	4000	8	97.78	-7.36
27	11.5	3500	6	65.10	-35.45

50% Probability					
Rank	Target Quality Factor			CPF	Profit
	T	$t	$m	(%)	(%)
22	11.5	4000	5	108.00	1.26
20	11.5	4000	6	108.00	1.96
10	12	4000	5	108.00	4.26
21	11.5	4500	5	108.00	1.60
19	11.5	4500	6	108.00	2.30
8	12	4000	6	108.00	4.96
5	11.5	4500	9	108.00	5.80
9	12	4500	5	108.00	4.60
7	12	4500	6	108.00	5.30
15	11.5	4500	7	108.00	3.20
12	11.5	4000	8	106.94	4.04
4	12	4000	7	108.00	5.86
3	12	4500	7	108.00	6.20
14	11.5	5000	6	108.00	3.30
17	11.5	5000	5	108.00	2.60
6	12	5000	5	108.00	5.60
2	12	5000	6	108.00	6.30
11	11.5	5000	7	108.00	4.20
1	12	5000	7	108.00	7.20
13	11.5	4500	8	106.94	3.70
23	12	4000	8	106.94	1.04
16	11.5	5000	8	105.92	2.70
24	12	4500	8	106.94	0.70
18	11.5	4000	9	104.74	2.54
26	11.5	3500	5	94.38	-7.60
25	12	5000	8	105.92	-0.30
27	11.5	3500	6	93.45	-8.30

25% Probability					
Rank	Target Quality Factor			CPF	Profit
	T	$t	$m	(%)	(%)
25	11.5	4000	5	108.00	0.30
23	11.5	4000	6	108.00	1.10
24	11	4000	5	108.00	0.96
22	11.5	4500	5	108.00	1.30
19	11.5	4500	6	108.00	2.10
21	11	4000	6	108.00	1.76
1	11.5	4000	9	108.00	9.40
20	11	4500	5	108.00	1.96
16	11	4500	6	108.00	2.76
15	11.5	4500	7	108.00	2.80
14	11.5	4000	8	108.00	2.90
17	11	4000	7	108.00	2.46
11	11	4500	7	108.00	3.46
12	11.5	5000	6	108.00	3.10
18	11.5	5000	5	108.00	2.30
13	11	5000	5	108.00	2.96
8	11	5000	6	108.00	3.76
7	11.5	5000	7	108.00	3.80
5	11	5000	7	108.00	4.46
6	11.5	4500	8	108.00	3.90
10	11	4000	8	108.00	3.56
3	11.5	5000	8	108.00	4.90
4	11	4500	8	108.00	4.56
9	11.5	4000	9	105.84	3.60
26	11.5	3500	5	102.82	0.04
2	11	5000	8	108.00	5.56
27	11.5	3500	6	100.80	-0.76

Figure F-14. Combinations of Target AQCs for Different Risks

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BIOGRAPHICAL SKETCH

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