detailed design. This could lead to unrealistic expectations of the eventual users because of practical and fiscal limitations to the program. A product that doesn't live up to the promotional campaign will destroy the credibility of both the producer and advertising agency.

Since I am speaking as a representative of both the producer and the advertiser, I have to be especially careful of my credibility. In this case I am sure that this spin-off from developing statistically based specifications will deliver as advertised. You will be hearing a lot more about MISTIC in the future.

CALIFORNIA'S EXPERIENCE WITH THE USE OF STATISTICAL SPECIFICATIONS

Wallace H. Ames, Supervising Materials and Research Engineer, and Carl R. Sundquist, Senior Materials and Research Engineer, California Department of Transportation

This paper presents a summary of California's experience with the use of statistical specifications for the control of highway construction quality. The paper outlines the research, initiated in early 1965, emphasizing the need for statistically based specifications. The early development of a moving average specification, the problems resulting from its implementation, and later revisions to the original specification are discussed. A subsequent study, initiated in 1972, comparing materials quality control under the original moving average specification with that derived from the previous finite limit specifications is also discussed, and the findings of the investigation are summarized. The conclusions of these studies are: The moving average specifications work well and are thought to be practical, and that administrative problems preclude the use of purely statistical based specifications.
Key Words: Moving Average, Statistical Specifications, Quality Control, Mean, Standard Deviation, Normal Distribution, Research, Implementation, Material Quality.

Developing practical and reliable specifications for highway construction has always been one of California's goals. Specifications that are unnecessarily restrictive or arbitrary tend to raise costs, create delays, and strain relations between construction engineers and contractors. Conversely, excessively broad specifications lead to significant variations in quality, inordinate maintenance costs, and reduced public convenience and safety. Rapid evolution in construction methods and materials has made it necessary to constantly review and update specifications.

Prior to 1969, in California, our specifications generally had finite limits outside of which material was theoretically rejected. In many cases, however, it was often difficult and costly to reject material.

About 1964, the Federal Highway Administration began encouraging state highway agencies to develop specifications that recognize and allow for normal testing and materials variation. We initiated a research project in early 1965 to evaluate what some of these variations were (1). As an example, this research indicated that we had purchased material with a relative compaction ranging from 90 to 100 percent under a specification requiring a relative compaction of 95 percent. Between 1965 and 1968 a series of reports were released presenting the findings of this research (1-9).

The results of these studies indicated that we were accepting material that was represented by a normal distribution curve and that the test results ranged from slightly below or outside to varying amounts above or within the specification limits. This evaluation indicated two things: we were accepting material that was not one hundred percent within the specifications; and, that the contractors, to allow for inevitable statistical variation must aim for a value above or a quality higher than the minimum specificatin required to assure substantial compliance with finite specification limits.

Based on satisfactory past performance of work constructed under the then current specifications, it was decided that the specifications should be revised to reflect that practice. A research program was implemented to develop statistically based specifications. After some study, use of the moving average of 5 test results was initiated to determine specification compliance. The moving average of 5 tests was believed to be sensitive enough to indicate change and not so sensitive as to prohibit the contractor from making timely changes when changes were indicated to be necessary by the moving average trend. Since the moving average is technically valid only when applied to a process that is not time dependent, it was found to be most applicable to a production like PCC or AC from a batch plant or processed aggregate.

The moving average specification adopted consisted of averaging the 4 most recent test results with the test representing the material being tested. The moving average limit was generally established as the limit or tolerance which had previously been used under finite specification limits as the accept or reject limit. An individual test limit was established generally between 2 and 5 test units below or above the moving average limit using a 5% risk factor of accepting failing material, if the moving average limit was being met.

The use of the moving average specification brought about some contract administration problems. These problems were apparently non-uniform enforcement of the specifications due to individual choice or lack of clarity in the specifications. It was felt by some construction engineers that contractor manipulation of some materials was encouraged by the use of these specifications. For instance, in determining the cement content of cement treated base, a contractor on one specific day or half day could, as we say, "salt the mine" by "upping" the cement content to get his moving average up to a high level. Then he could run with a lower cement content until his moving average was about to drop below the limit before putting in another large surge of cement. Some Resident Engineers felt that the quality of material being purchased under these specifications was lower than we had purchased under the "old" 1969 specifications.

In an attempt to rectify such contract administration problems special provisions were prepared to modify the moving average specification. The moving average calculation was changed from being an average to what we might term a continuous moving average. The "moving average" under this specification is calculated by taking the existing moving average, multiplying by 4, adding the current test result, and then dividing by 5. Under this system, which admittedly is not completely sound from a statistical standpoint, all tests representing material used in the project have a diminishing influence on the "moving average" as the job progresses. A clause was also incorporated where material represented by an individual test which is outside the moving average limit and within the individual limit can be accepted. The contractor's production, however, must be stopped and corrections must be made to his operation before proceeding, if assuming the next individual test result would be at the same level, would cause the moving average to fall outside the moving average limit. A change was also made requiring the first test result to meet the moving average limit.

These changes lead to a more uniform application of the specifications and take away much of the engineering judgment. This current "moving average" specification is a compromise to satisfy both quality assurance and contract administration problems which are not totally compatible.

For some asphalt specifications we have developed an informal tolerance range to account for the precision of the tests and normal variability of the materials. This range has been developed by keeping records of test results and making comparisons over many years.

Concrete purchased on compressive strength requirements was an exception to the new specification until January 1, 1975 when they were incorporated. There is still a range between 80 and 95% of the specified compressive strength where the resident engineer has an option to accept or reject depending on the strength and specific use of the concrete.

A research project was initiated in 1972 to compare materials quality control under the 1971 moving average specifications and the "old" 1969 finite limit specifications. This evaluation was to include:

1. Determining the extent of materials compliance with moving average specifications.
2. Comparing current specification compliance with that under 1969 finite limit specifications.
3. Determining the ramifications of the moving average specification and evaluating its

implementation from an operational standpoint.
4. Determining if the quality of construction materials is being adequately controlled by the moving average specification.

Test data gathered from Transportation Laboratory files, district construction office files, and resident engineer's files to obtain the information to base the analysis on. Test data for each material was summarized by project, by district, and then statewide. The mean, standard deviation, and variance for test results obtained from the 1969 standard specifications were calculated for 50 different property tests for various materials. Only 4 were found to be in less than 90% compliance and eight others were between 90 to 95 percent compliance. The remaining 38 properties tested were found to have compliance rates of 95% or more. This indicates that the specifications are generally being met. In some cases, however, specification limit adjustments may be appropriate. It was apparent that the arithmetic means or quality levels have remained essentially the same under the moving average specifications. Although the report has not yet been completed, the findings of this study are essentially that:
1. Functionally the moving average works well and is generally thought to be practical by the engineers and technicians working with it. It does help to better evaluate materials quality, to recognize trends, and to administer contracts more fairly.
2. Finite specification limits often lead to arbitrary decisions in acceptance or rejection which are not consistent from one job to the next, thereby creating contract administration problems.
3. Due to the many inherent variables and administrative factors involved in contract control, it is highly unlikely that we will ever use a purely statistical specification. However, it is inevitable that statistics will play an increasingly important part in our specifications in the future.

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The contents of this article reflect the view of the California Department of Transportation Laboratory which is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the state of California or the Federal Highway Administration. This article does not constitute a standard specification or regulation.

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