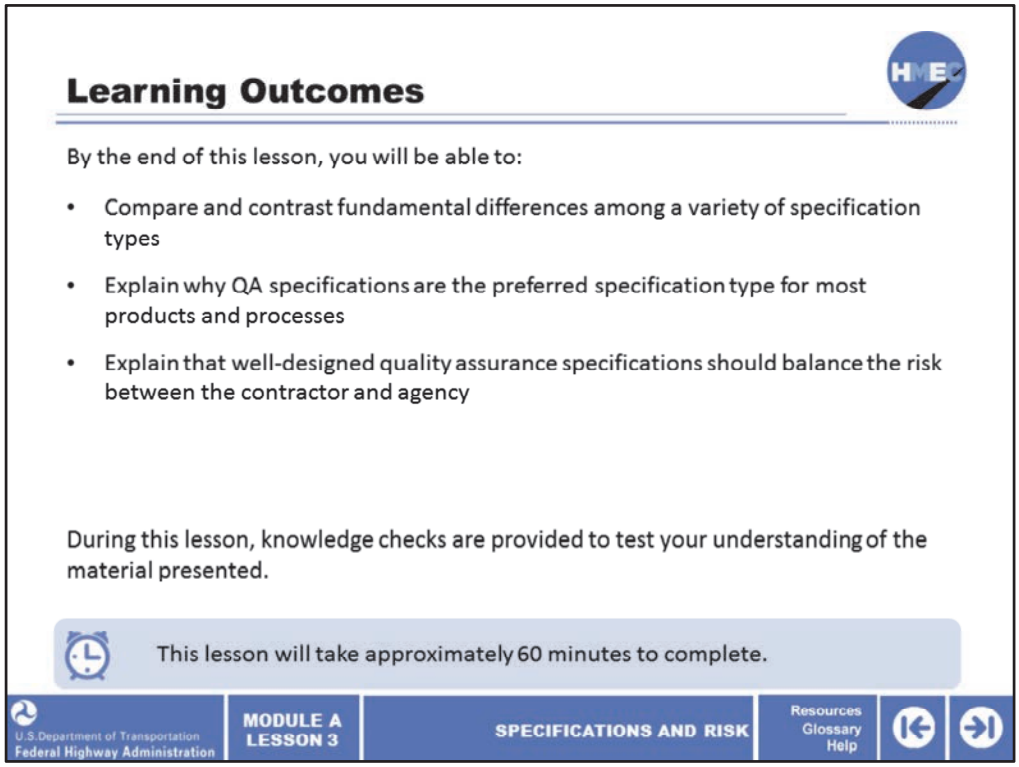
Welcome to the Highway Materials Engineering Course Module A, Lesson 3: Specifications and Risk. This lesson provides an understanding of the basic elements of a statistically-based quality assurance (QA) program and includes an introduction to quality assurance as well as techniques for collecting, organizing, and analyzing data.

A printer-friendly version of the lesson materials can be downloaded by selecting the paperclip icon. A copy of the slides and narration are provided for download.

If you need technical assistance during the training, please select the Help link in the upper right-hand corner of the screen.

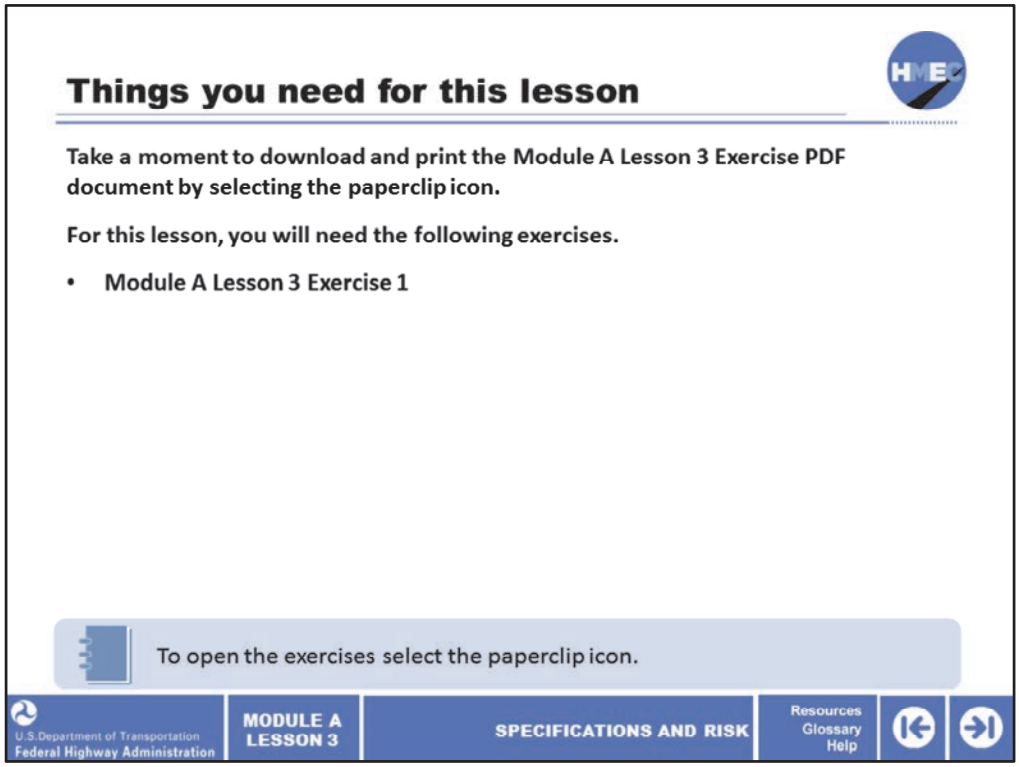


By the end of this lesson, you will be able to:

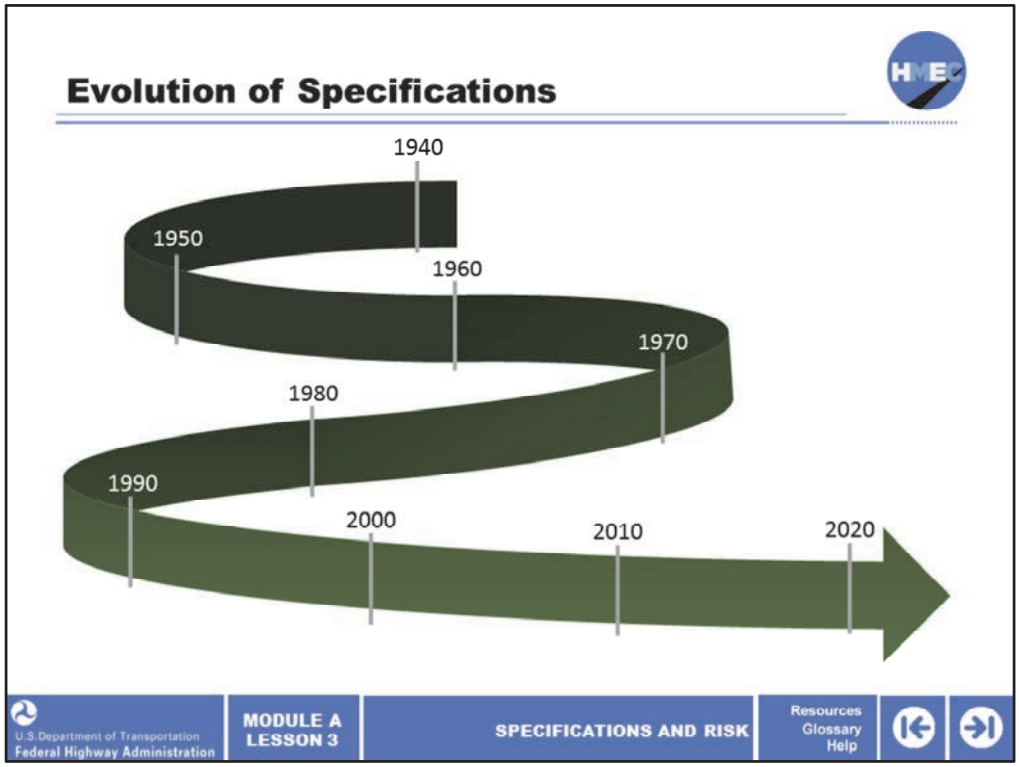
• Compare and contrast fundamental differences among a variety of specification types;
• Explain why QA specifications are the preferred specification type for most products and processes; and
• Explain that well-designed quality assurance specifications should balance the risk between the contractor and agency.

During this lesson, knowledge checks are provided to test your understanding of the material presented.

This lesson will take approximately 60 minutes to complete.



During this lesson, you will be prompted to reference the lesson exercise document. The documents referenced during this lesson are attached to the lesson in the paperclip icon. Please take a moment to open and print the document.



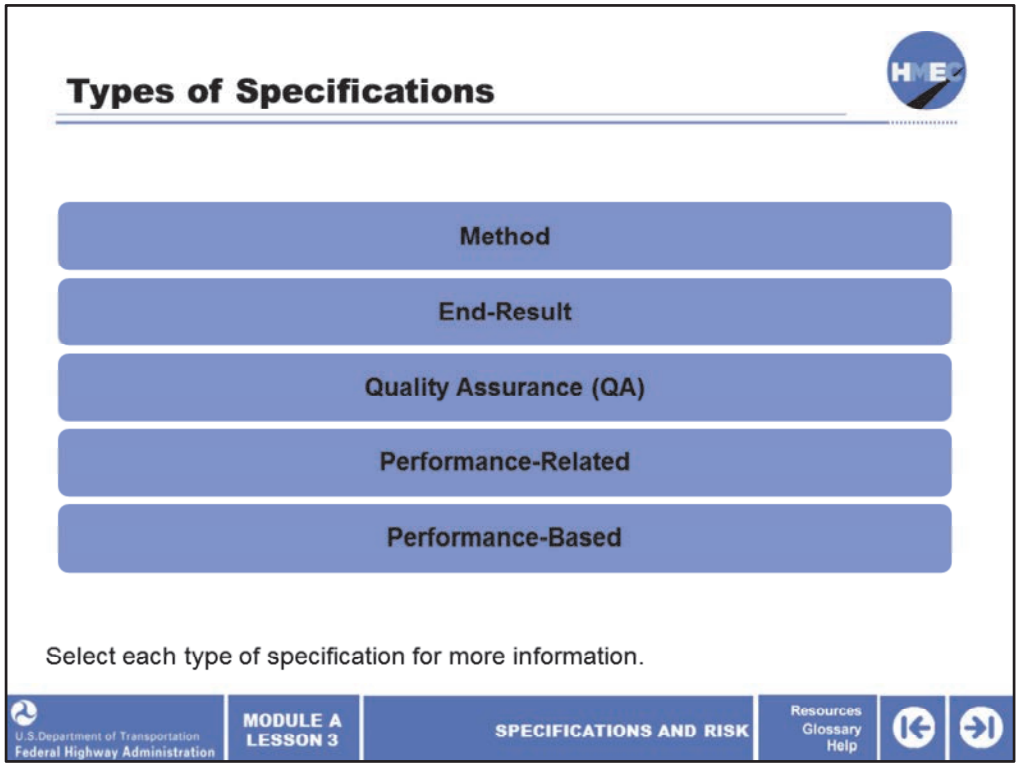
Specifications have evolved considerably over the last several decades.

Specifications complement project plans and serve an important purpose in constructing a quality project. Specifications tell us what criteria each component and the finished product must meet. The purpose of specifications has been the same since the 1940's but the method of detailing those specifications has changed and continues to change.

Specifications are intended to ensure that the requirements of the agency have been met and they detail particular requirements for each project. They provide the agency with a standard set of procedures for managing and executing a project, and they serve as written standards for the work items to be completed by the contractor. In a balanced approach, the parties share some elements of risk as they attempt to make a product for a reasonable cost that performs well and lasts a long time.

Prior to discussing the many ways of conducting materials control and acceptance procedures, we will first discuss the many specification types that exist and how they have evolved over the last several decades.

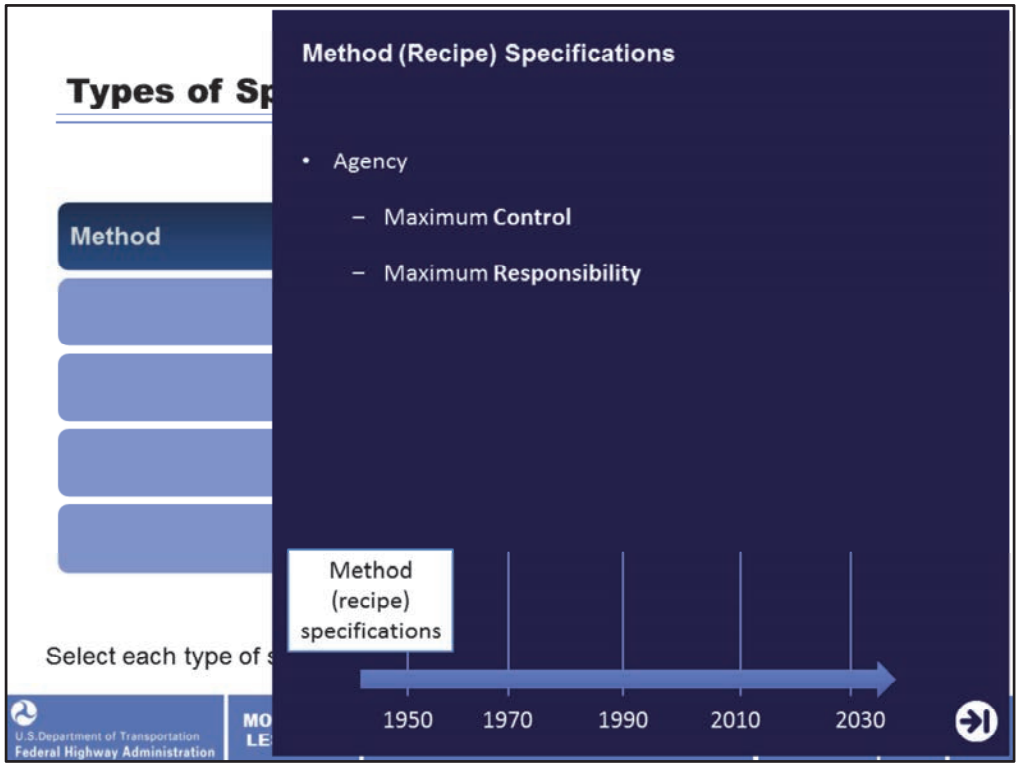
Image description: A ribbon with an arrow on the end and dates ranging from 1940 to 2020.



There are many types of specifications. They include:

- Method;
- End-Result;
- Quality Assurance;
- Performance-Related; and
- Performance-Based.

Select each type of specification for more information.



First, we'll look at method specifications. The method specification puts maximum control and responsibility in the hands of the specifying agency.

Going back to the 1940s and 1950s, method (recipe) specifications were used.

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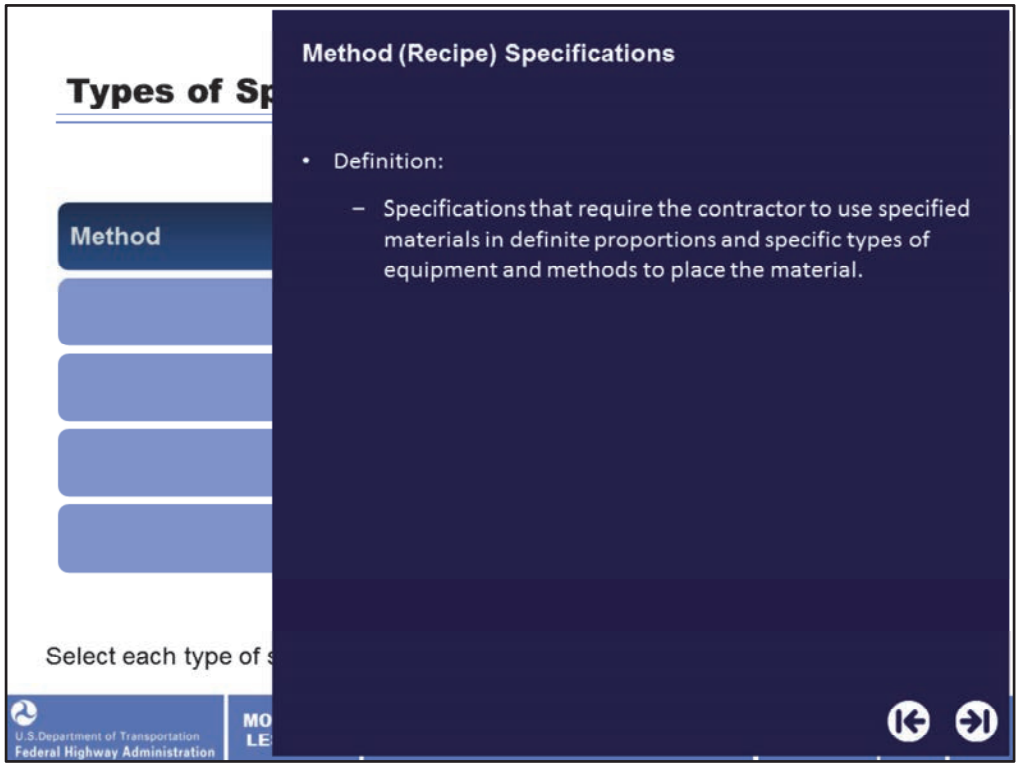
Image description: An arrow with dates ranging from 1950 to 2030 and labeled method (recipe) specifications.



The definition of method specifications is: Specifications that require the contractor procedures to use specified materials in definite proportions and specific types of equipment and methods to place the material. Each step is directed by a representative of the transportation agency.

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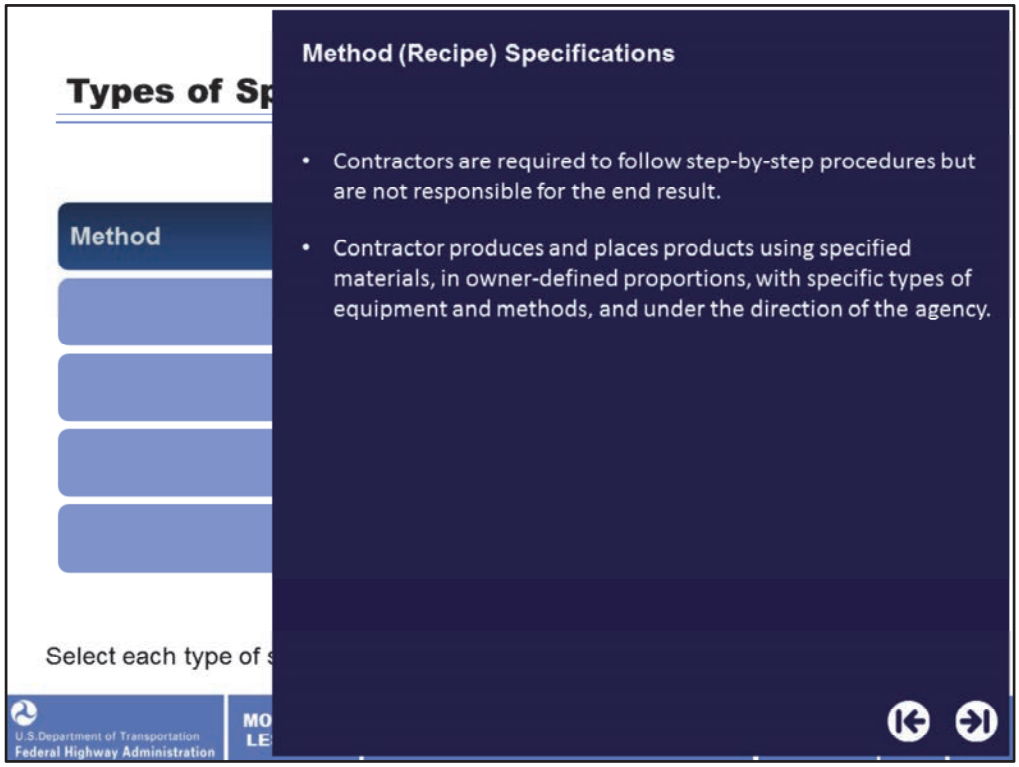

Contractors are required to follow step-by-step procedures but are not responsible for the end result. If the finished product does not perform as desired, it becomes the agency's problem.

The contractor produces and places products using specified materials, in owner-defined proportions, with specific types of equipment and methods, and under the direction of the agency.

Method specifications can still be used when a measure of quality is difficult to define. For example, take the texture of the finished pavement. This property is important but hard to define in a specification. Often agencies will use a method specification to specify what a contractor must do to provide a desirable texture.

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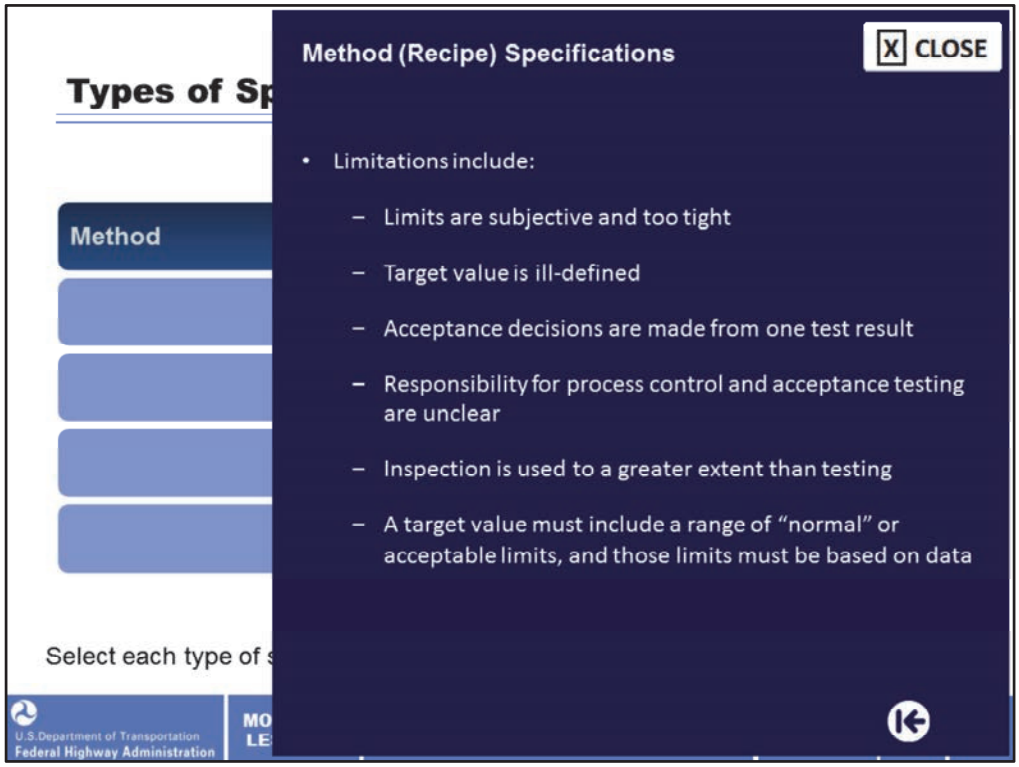

Method specifications have significant limitations. Some of these include:

• Limits are subjective and too tight;
• Target value is often ill-defined;
• Acceptance decisions are made from one test result, which is not adequate for ensuring quality;
• Responsibility for quality control (QC) and acceptance testing are unclear and, in fact, the contractor has little responsibility in either area;
• Inspection is used to a greater extent than testing, and with reduced agency personnel, it is difficult to accomplish effectively; and
• A target value must include a range of "normal" or acceptable limits, and those limits must be based on data.

These limitations were a large factor in seeking a better way of specifying a quality product.

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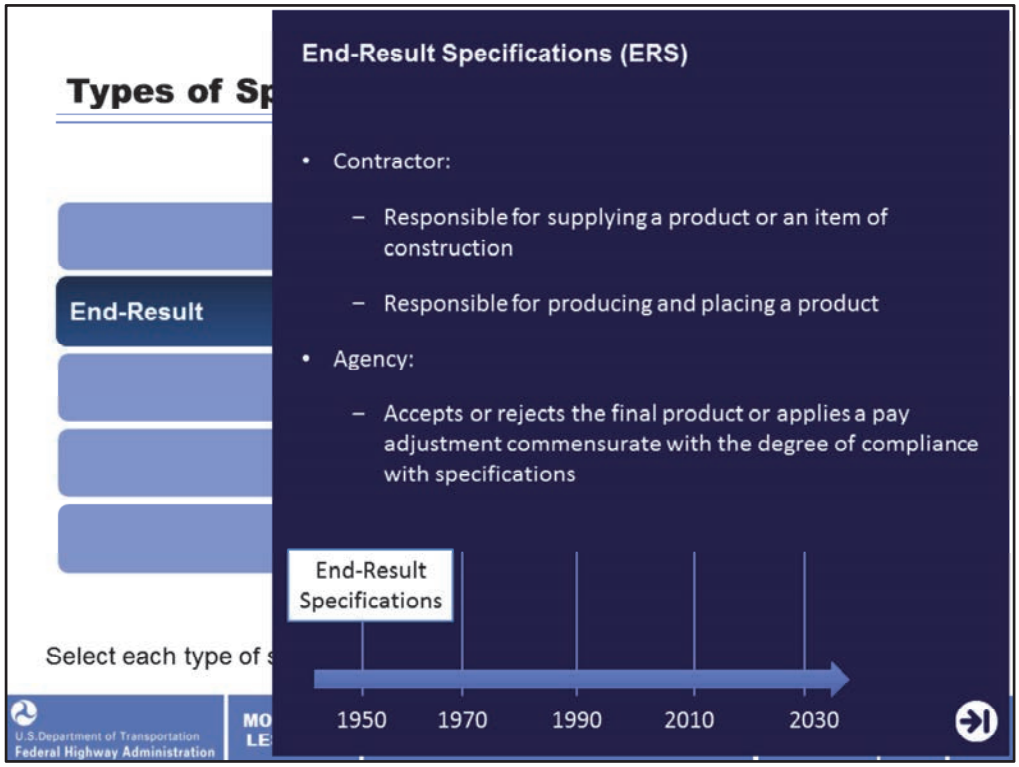

The disadvantages associated with method specifications led to the development of end-result specifications (ERS).

The first national use of this type of specification was the construction of the American Association of State Highway Officials (AASHO) Road Test in 1958. Since that time, the use of ERS specifications have grown and evolved into various forms. These were created to try to mitigate disadvantages of method specifications. End-result specifications are currently used in most States for specific work items.

Contractor:
• Responsible for supplying a product or an item of construction; and
• Responsible for producing and placing a product.

Agency:
• Accepts or rejects the final product or applies a pay adjustment commensurate with the degree of compliance with specifications.

The “final product” means that it’s the last place a product can be reasonably sampled and tested. This type spec is still used by some agencies, especially in the area of soil density. Indiana, Mississippi, and Utah are examples of three agencies that use ERS for acceptance of embankment density. After the contractor has completed compaction of the embankment the agency tests for compliance to the spec.

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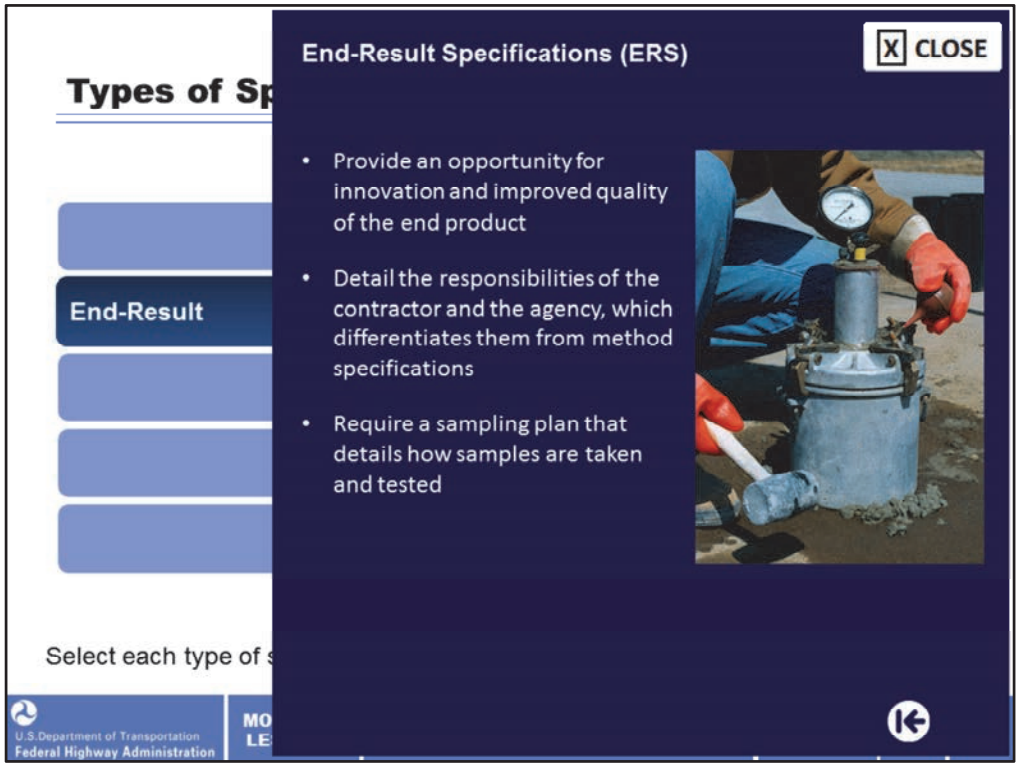
Image description: An arrow with dates ranging from 1950 to 2030 and labeled end-result specifications.



End-result specifications:

• Provide an opportunity for innovation and improved quality of the end product;
• Detail the responsibilities of the contractor and the agency, which differentiates them from method specifications; and
• Require a sampling plan that details how samples are taken and tested. While the use of ERS was an improvement over method type specifications, a further evolution was needed to better define the product desired.

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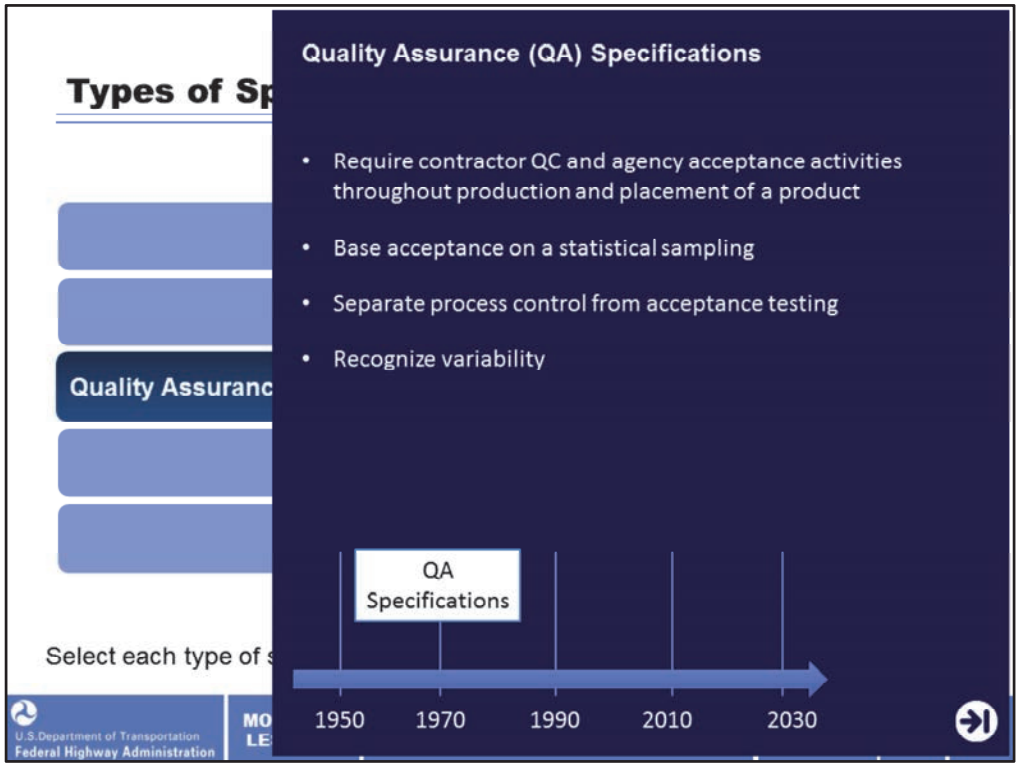
Image Description: Photo of testing equipment.



A specific type of end-result specification is a quality assurance, or QA, specification, which has been used in some States since the 1970's. QA specifications use proven mathematical concepts, and are commonly used today.

A quality characteristic is a characteristic of a product that is measured to determine conformance with a given requirement.

QA specifications:

• Require contractor QC and agency acceptance activities throughout the production and placement of a product;
• Base acceptance on a statistical sampling of the measured quality level for key quality characteristics;
• Separate QC from acceptance testing. It is stated in the contract which party is responsible for each phase throughout production and placement of the product; and
• Recognize variability and makes accommodations for it in the acceptance procedures. The acceptance procedures are established to balance the risks to the contractor and to the specifying agency, which is not possible with the method specifications.

Final acceptance of the product is based on a statistical sampling of the measured quality level for key quality characteristics. These specifications are used currently and are a recommended practice for most materials and processes.

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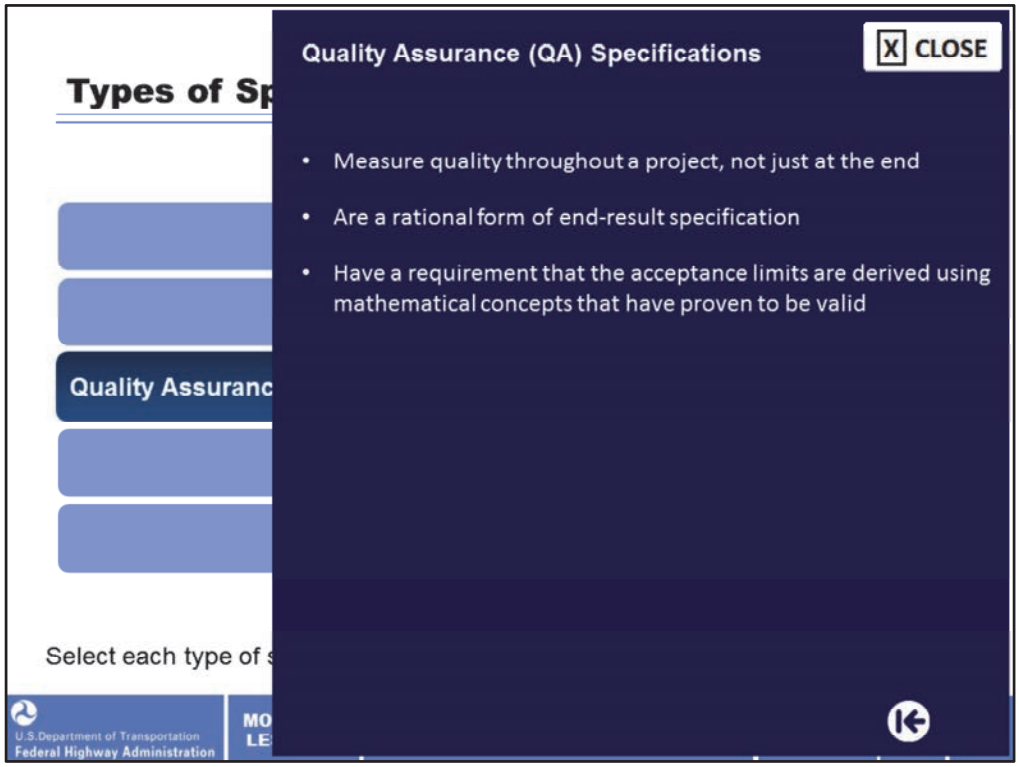
Image description: An arrow with dates ranging from 1950 to 2030 and labeled QA specifications.



QA specifications:

• Measure quality throughout a project, not just at the end;
• Are a rational form of end-result specification; and
• Use acceptance limits that are derived using mathematical concepts that have been proven to be valid. One procedure was developed for writing defense specifications. (Derived from Military Standard 414 “Sampling Procedures & Tables for Inspection by Variables for Percent Defective,” U.S. Dept. of Defense, 1958)*.

The specification may include equipment requirements that do not compromise other requirements in the specification, such as Materials Transfer Device.

The reason that specifications have evolved as they have is because the specification in use at the time had limitations. QA specifications in themselves have evolved as more has been learned through their usage. For example, the analysis of risks was not well understood in the 1960s when the first QA specifications were developed. Risk analysis is now an integral part of specification development.

So the proper development of a QA specification requires knowledge of the material and construction item being specified. For instance, it’s important to know:

• The contractor’s capabilities in controlling their product;
• The agency’s capability in accepting the product;

- The definition of what is an “acceptable“ product; and
- The definition of what is an “unacceptable” product.

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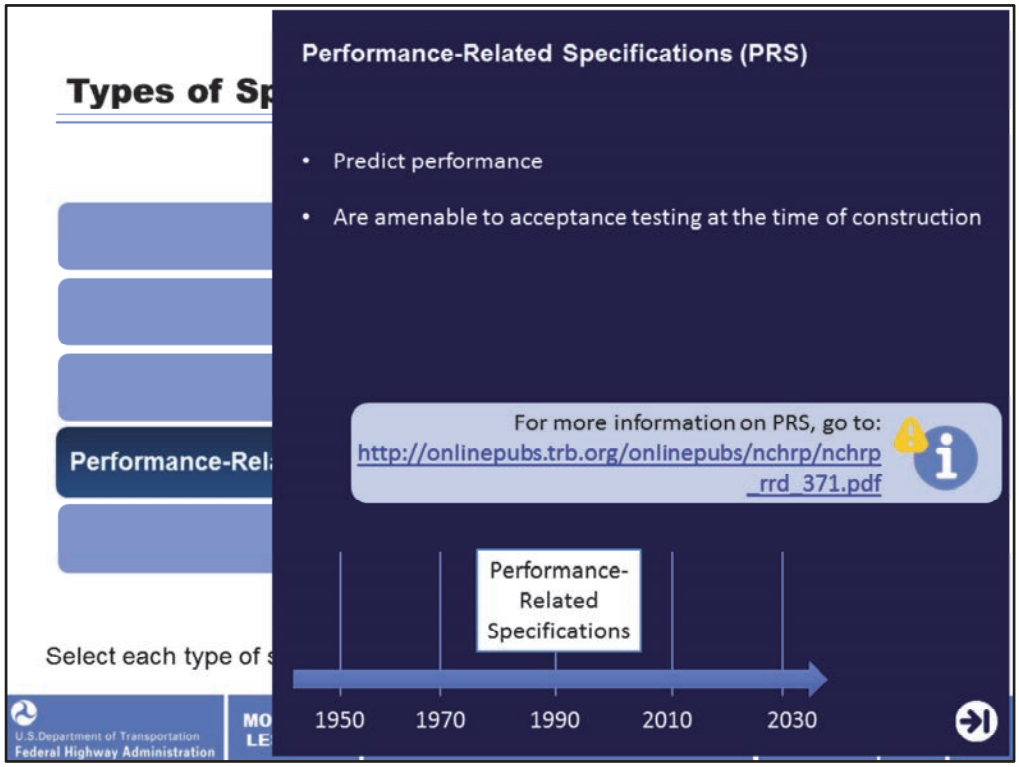


Performance-related specifications (PRS):

• Predict performance by using desired levels of key materials and construction quality characteristics that have been found to correlate with fundamental engineering properties; and
• Have characteristics that are amenable to acceptance testing at the time of construction.

These types of specifications are enhanced QA specs that use quality characteristics and lifecycle cost relationships correlated to product performance.

Today, specifications may be empirically (based on experience) related to performance. These specifications may be fully developed and used more consistently in the future.

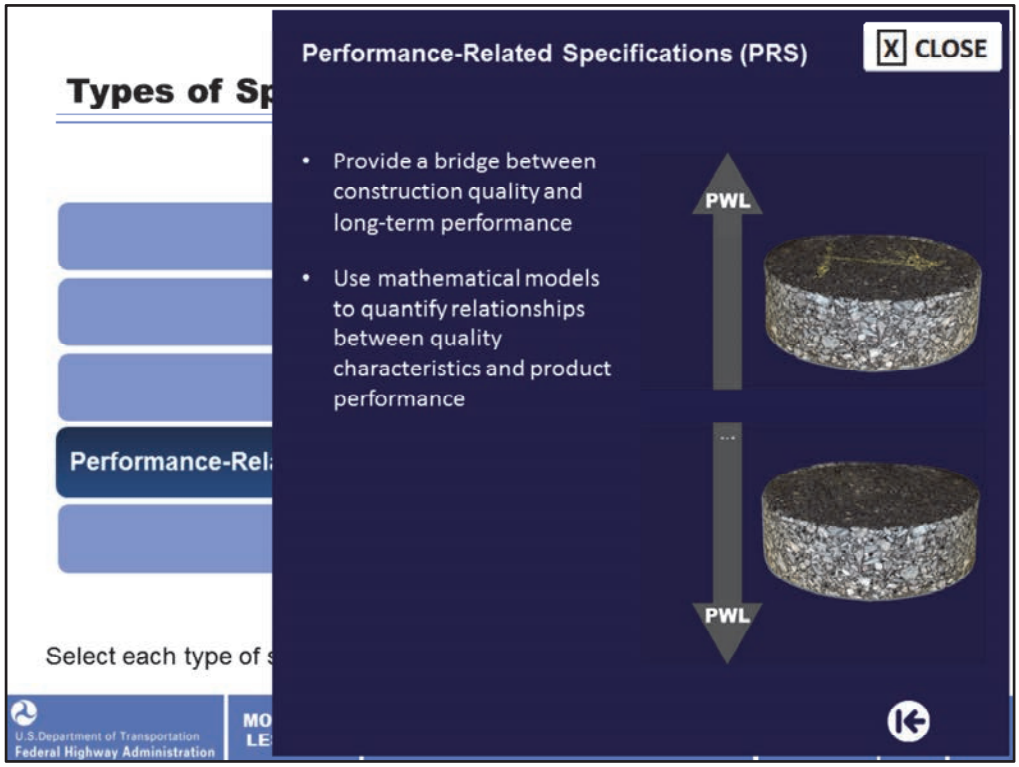
For more information on PRS, go to:
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rrd_371.pdf

Please use the forward button on the bottom right of the screen for more related information.

Image description: Important information icon with hyperlink.

Hyperlink: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rrd_371.pdf

Image description: An arrow with dates ranging from 1950 to 2030 and labeled performance related specifications.



Performance-related specifications:

• Provide a bridge between construction quality and long-term performance; and
• Use mathematical models to quantify relationships between quality characteristics, for example smoothness and permeability, and product performance.

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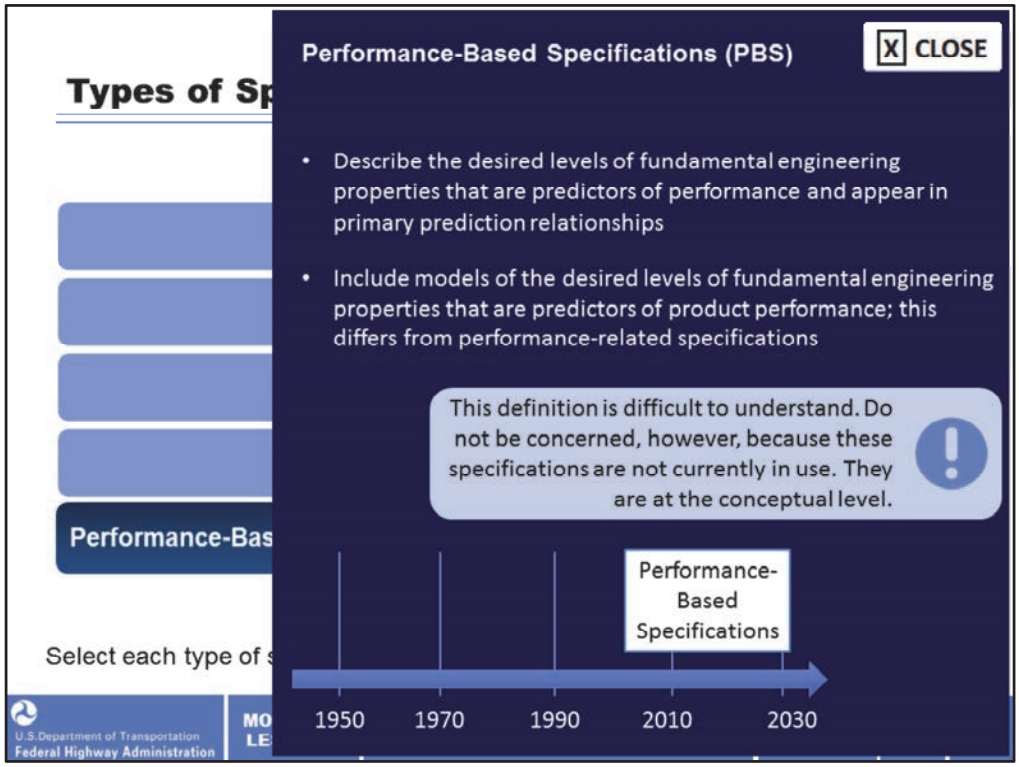
Image Description: Two core samples with one arrow pointing up showing PWL and one arrow pointing down showing PWL.



Performance-based specifications:

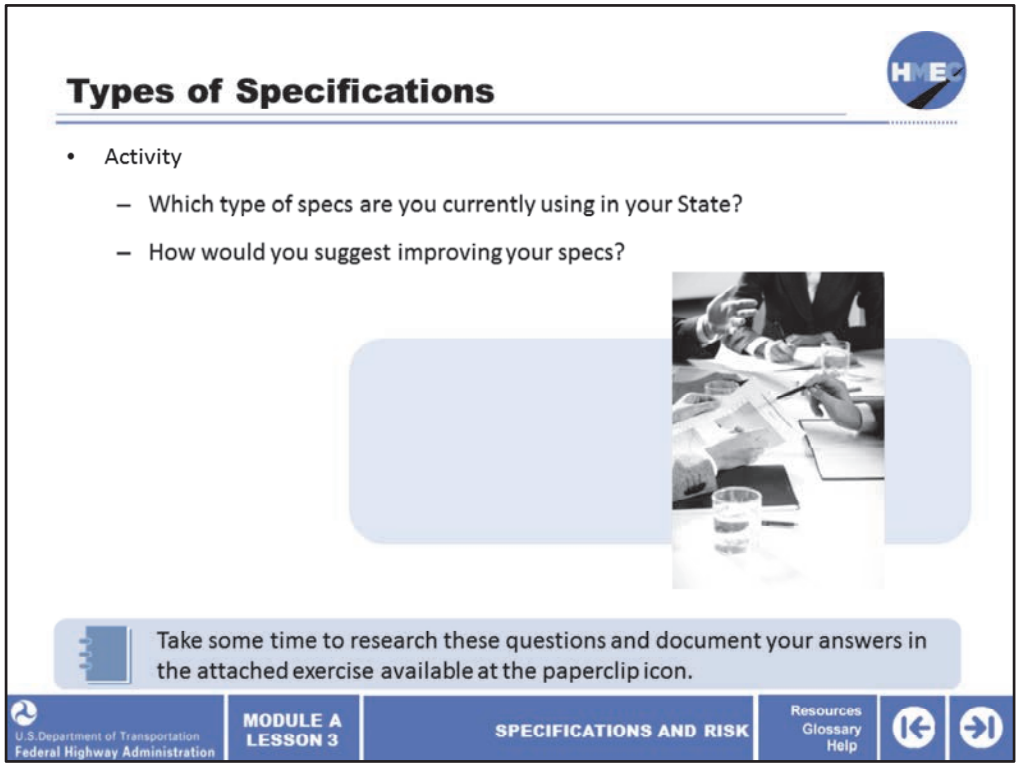
• Describe the desired levels of fundamental engineering properties that are predictors of performance and appear in primary prediction relationships. For example, the dynamic complex modulus of an asphalt mixture can be measured by the AMPT and the results can be directly input into the mechanistic-empirical software to design the pavement, and;
• Include models of the desired levels of fundamental engineering properties that are predictors of product performance. This differs from performance-related specifications.

Performance-based specifications are in their initial stages of development.

Select the close button to go back to the main screen.

Image description: An arrow with dates ranging from 1950 to 2030 and labeled performance based specifications.

Image description: Information box with exclamation icon, reading, This definition is difficult to understand. Do not be concerned, however, because these specifications are not currently in use. They are at the conceptual level.

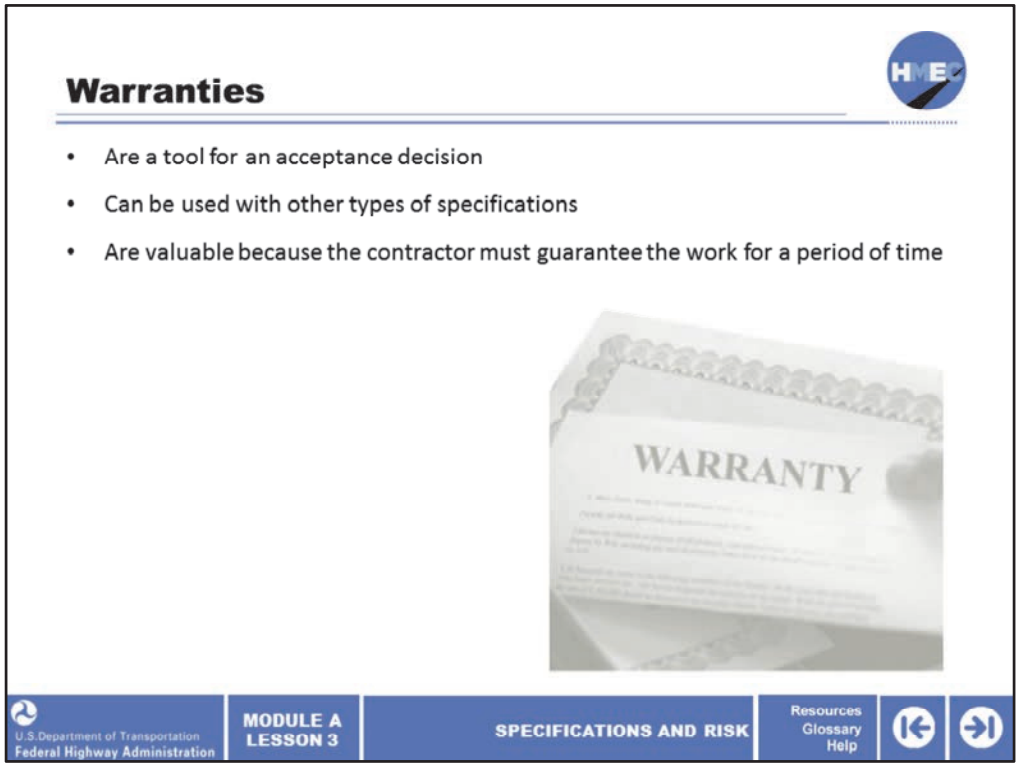


Consider the following questions: Which type of specs are you currently using in your State? How would you suggest improving your specs?

Take some time to research these questions and document your answers in the attached PDF exercise available at the paperclip icon. We'll discuss these questions in the classroom-based portion of Module A.

You can either add your comments to the PDF or printout the exercise and to bring it to class.

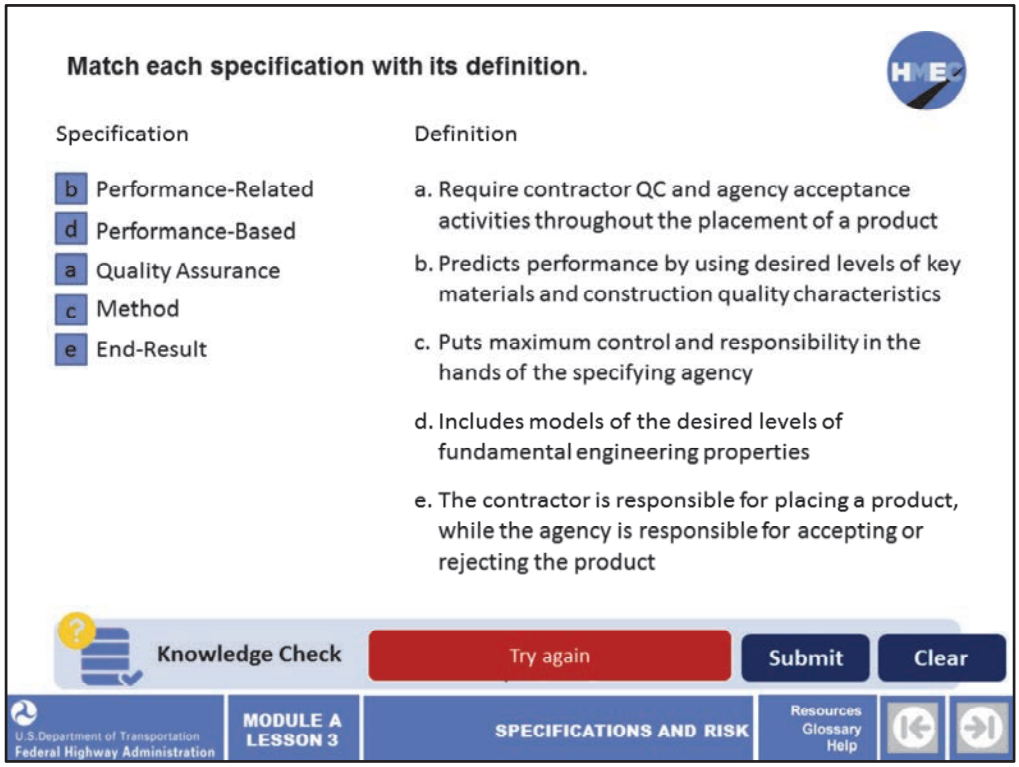
Image Description: Close up on a meeting showing a table with documents and hands expressing and pointing to documents.



You might have heard about warranties and wonder why we don't include them in the list of specification types. They are a tool for acceptance and, generally, are not the only tool used for an acceptance decision. Thus, they can be used with other types of specifications.

Warranties are valuable for assigning some future risks to the contractor because the contractor must guarantee the work for a period of time.

Image Description: Photo of Warranty Certificate.



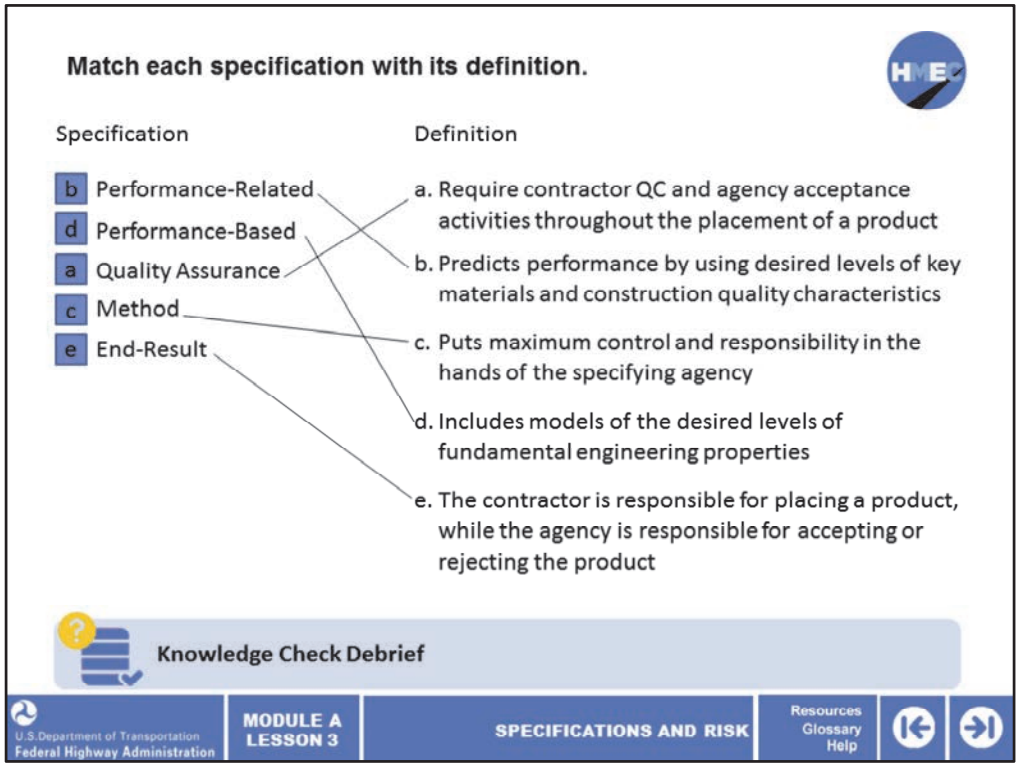
Match each specification with its definition.

Specifications:

1. Performance-Related;
2. Performance-Based;
3. Quality Assurance;
4. Method; and
5. End-Result.

Definitions:

a) Require contractor QC and agency acceptance activities throughout the placement of a product;
b) Predicts performance by using desired levels of key materials and construction quality characteristics;
c) Puts maximum control and responsibility in the hands of the specifying agency;
d) Includes models of the desired levels of fundamental engineering properties; and
e) The contractor is responsible for placing a product, while the agency is responsible for accepting or rejecting the product.



The correct answers are:

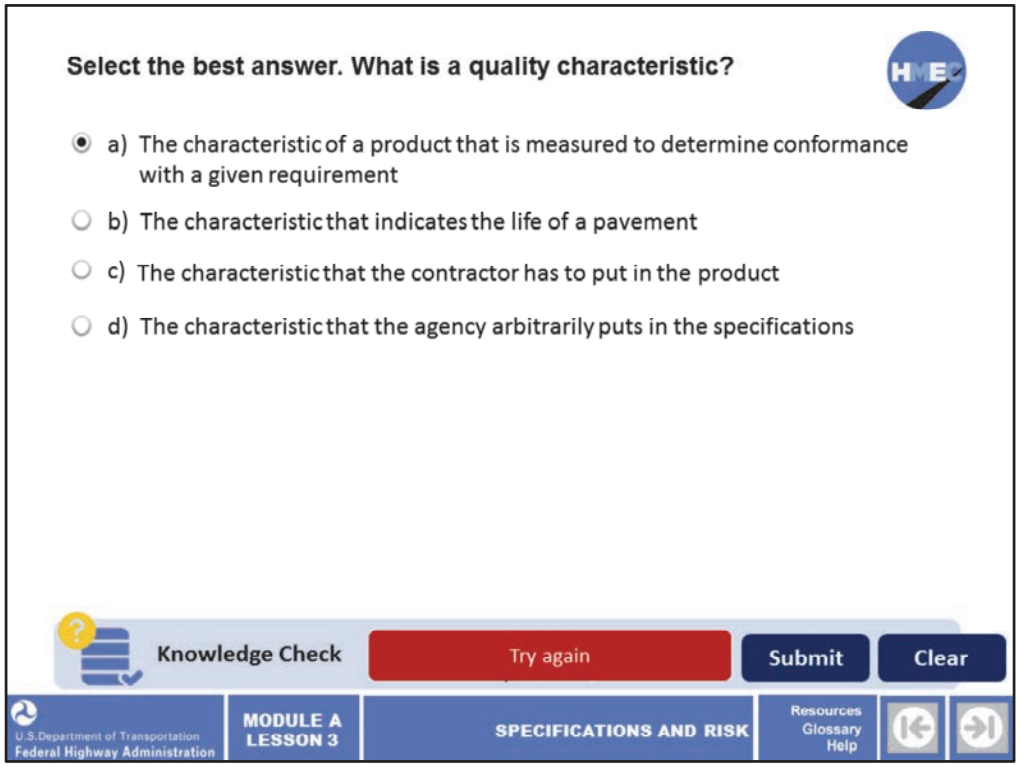
Performance-Related is b) Predicts performance by using desired levels of key materials and construction quality characteristics;

Performance-Based is d) Includes models of the desired levels of fundamental engineering properties;

Quality Assurance is a) Require contractor QC and agency acceptance activities throughout the placement of a product;

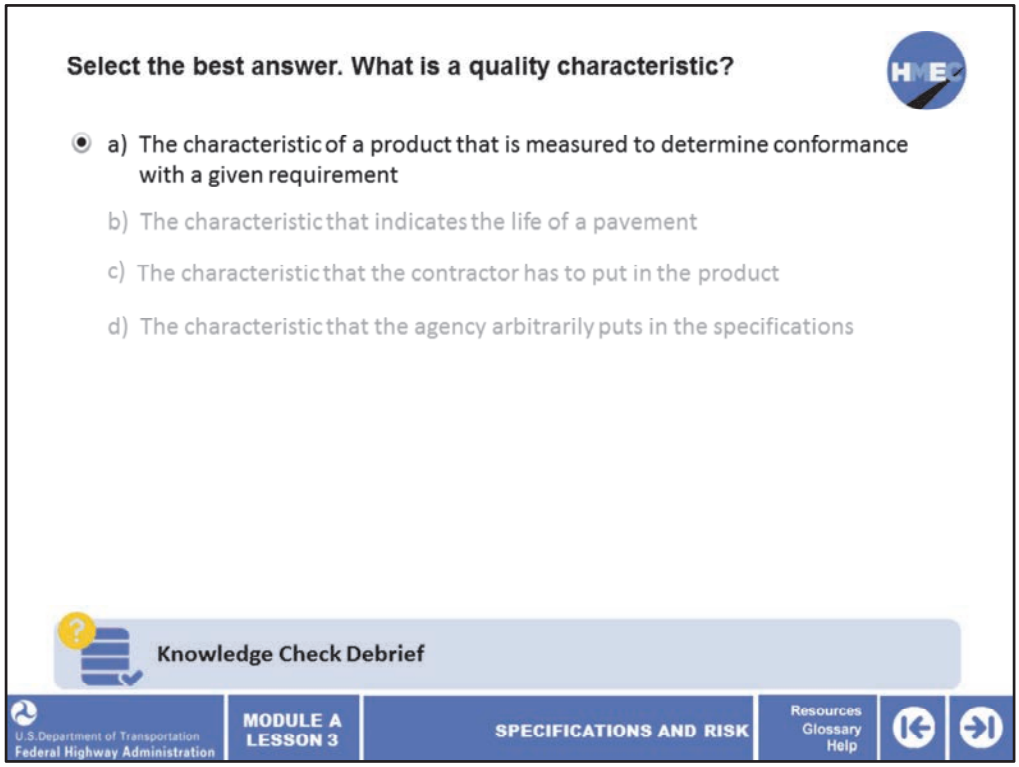
Method is c) Puts maximum control and responsibility in the hands of the specifying agency; and

End-Result is e) The contractor is responsible for placing a product, while the agency is responsible for accepting or rejecting the product.

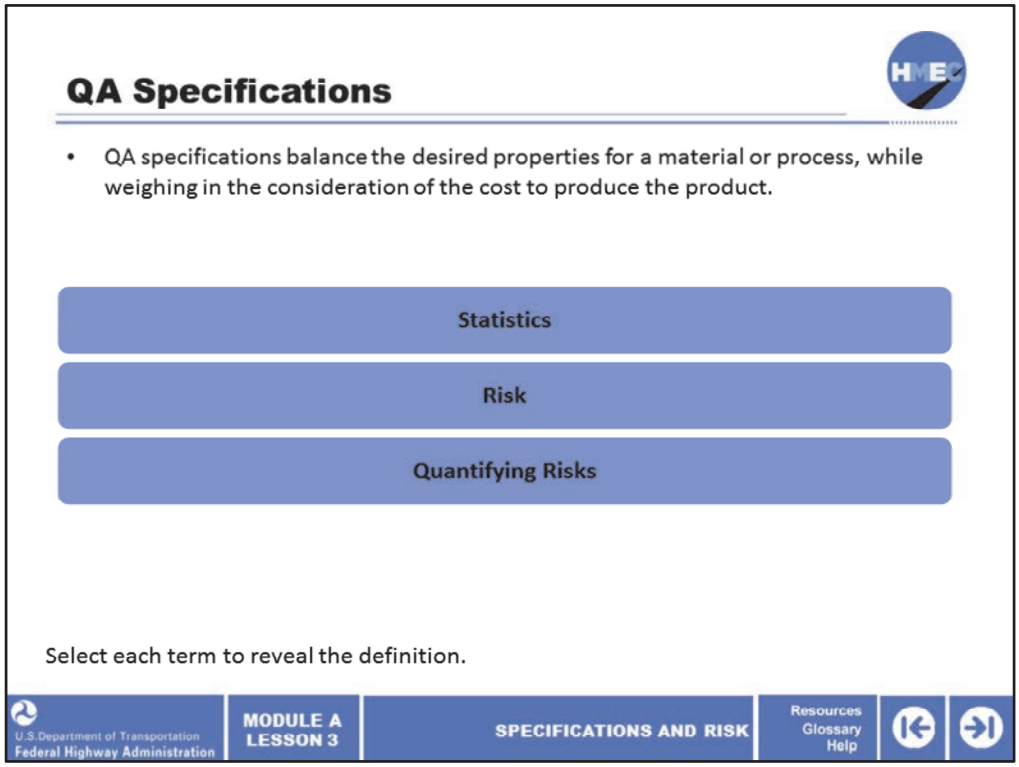


Select the best answer. What is a quality characteristic?

Answer:
a) The characteristic of a product that is measured to determine conformance with a given requirement;
b) The characteristic that indicates the life of a pavement;
c) The characteristic that the contractor has to put in the product; or
d) The characteristic that the agency arbitrarily puts in the specifications.



The correct answer for a quality characteristic is a) The characteristic of a product that is measured to determine conformance with a given requirement.



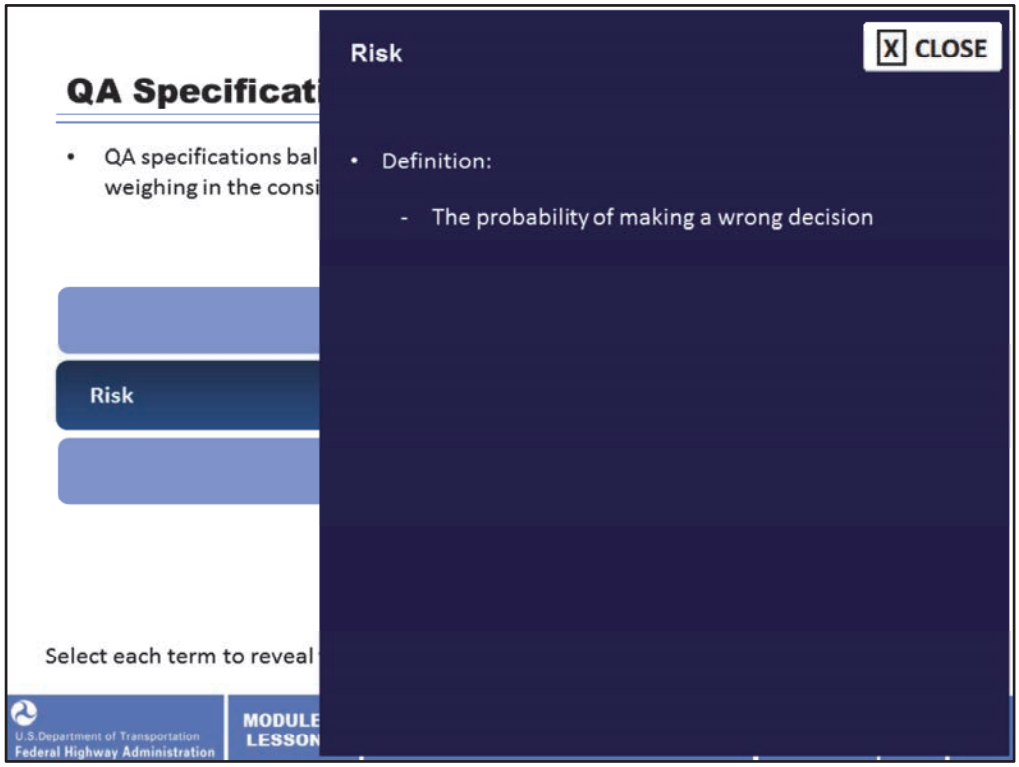
Returning to the discussion of QA specifications, the reason QA specifications are the most common type is because they balance the desired properties for a material or process, while weighing in the consideration of the cost to produce the product. They also separate the functions of QC and acceptance. They place QC as the responsibility of the contractor and acceptance as the responsibility of the agency.

This lesson is intended to provide the ability to understand the analysis of a QA specification. While a thorough understanding of statistical theory is not necessary to use and understand a QA specification, it is necessary to properly develop and determine the risks associated with the specification. To develop a QA specification, the specification writer must know the product desired, how to define it, and determine the risk of accepting nonconforming material and rejecting conforming material. This takes technical training and experience as well as statistical training. There is an old cliché that says, "A little knowledge is a dangerous thing." Analogously, a poorly written QA specification may do more harm than good.

The terms statistics, risks, and quantifying risks are used throughout this module. Their definitions are discussed to make sure that everyone shares a common language when discussing quality assurance.

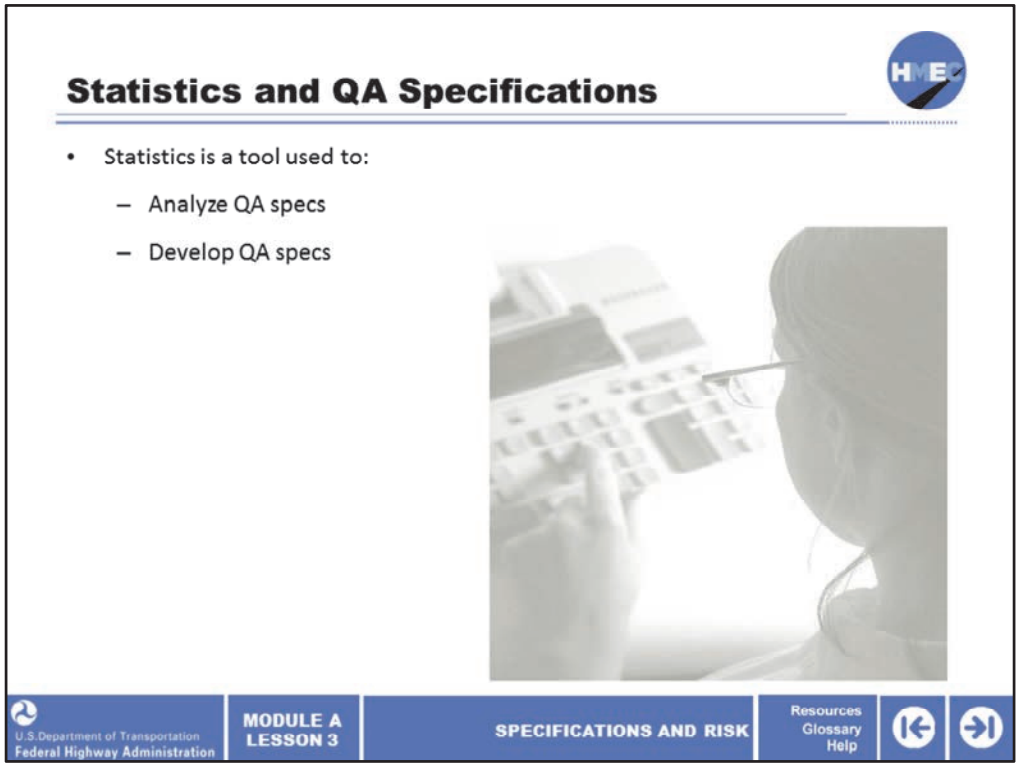
Select each term to reveal the definition.

Statistics is the science that deals with the treatment and analysis of numerical data.



Risk is the probability of making a wrong decision.

Quantifying risks is a primary value of QA specifications.



Statistics is a tool that can aid in decision making. The analysis of a QA specification requires a more thorough knowledge of statistical concepts, and the development of QA specifications requires a good working understanding of statistical applications.

QA specs are used by the agency to develop an acceptance plan and carry out specified tests to measure the product against the acceptance criteria. In a well-written QA specification, the risks are balanced between contractor and agency at a reasonably low level. Recall that one of the great advantages of QA specifications is that the risks can be identified and quantified.

Image Description: Photo of a woman entering data on an adding machine.

This is where the statistics come in. To develop and analyze QA specifications, large amounts of data are collected, organized, and analyzed. It sounds pretty complicated, but in reality, we all use data and risk analysis every day.

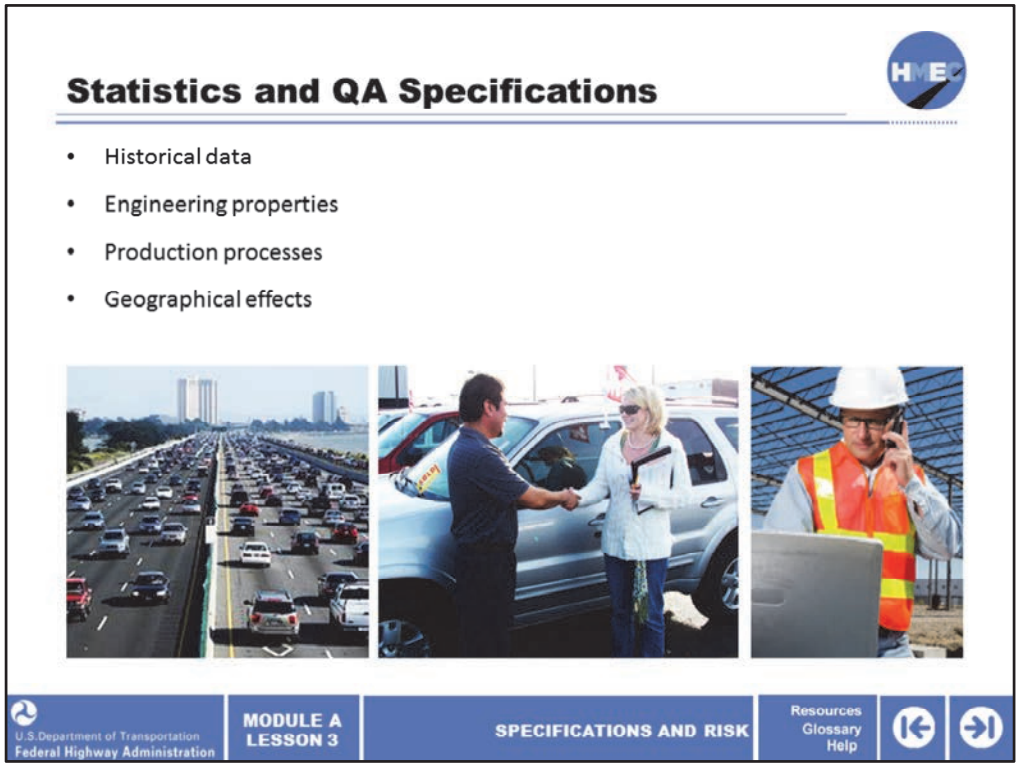
For example, we make decisions such as:

- The route to commute to work;
- Which new car to purchase; and
- Which cell phone plan to use based on the best coverage.

Image 1 Description: Photo of a congested highway.

Image 2 Description: Photo of a man and a woman shopping in a car lot.

Image 3 Description: Photo of a professional looking woman holding her cell phone.



Those elements—historical data, engineering properties, production processes, geographical effects, along with other variables—comprise the same types of data that materials engineers and transportation professionals consider when crafting specifications for materials and processes.

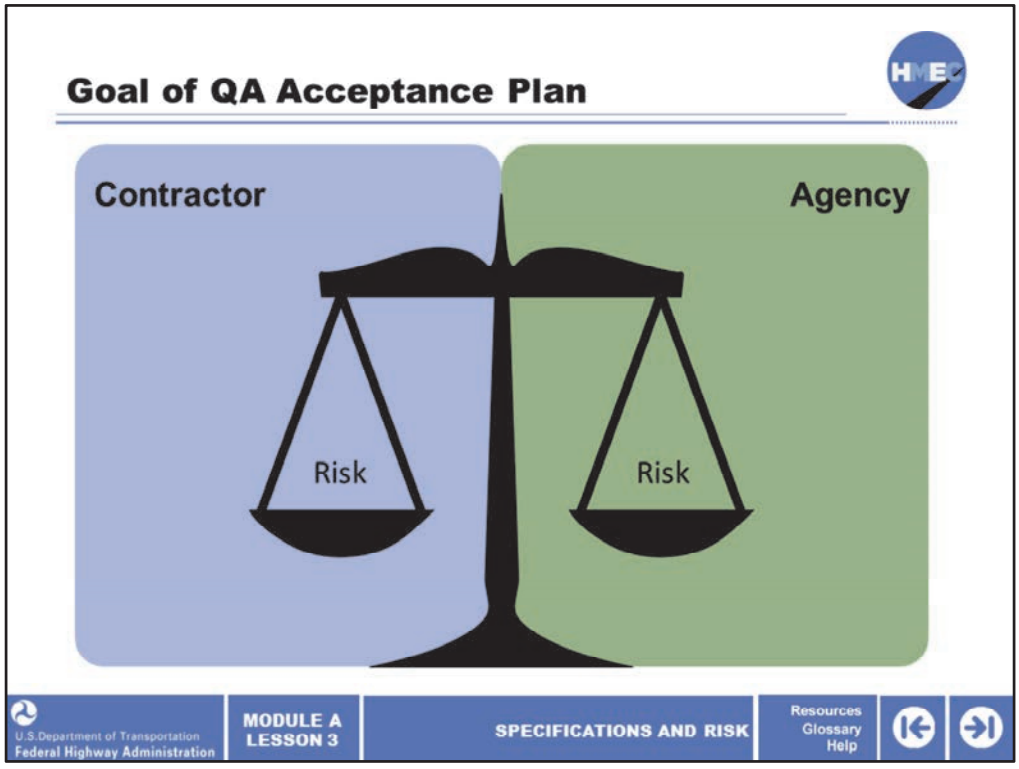
The level of statistical knowledge necessary for using a QA specification is very basic, and certainly no more difficult than calculating most test results.

Although there are almost as many forms of QA specifications as there are agencies using them, they can all be categorized and analyzed. However, this takes some basic level of statistical knowledge.

Image 1 Description: Photo of a busy stretch of highway.

Image 2 Description: Photo of a man shaking a woman's hand in a car lot and a car with a sold sign on the front windshield.

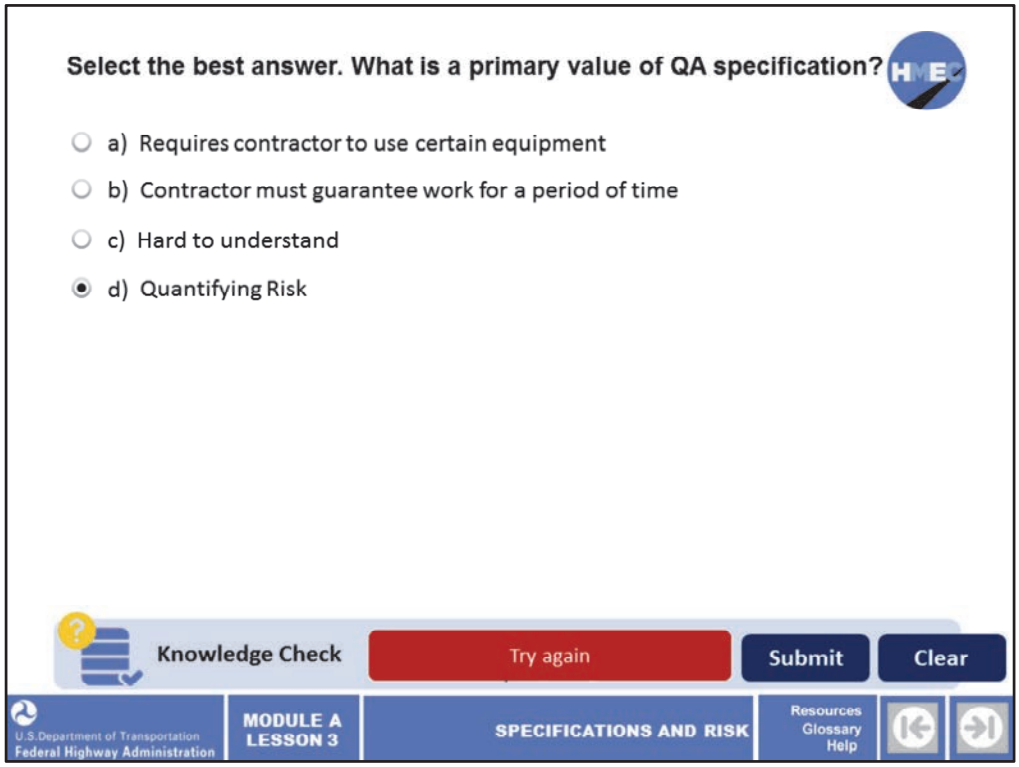
Image 3 Description: A construction worker on a job site standing in front of a laptop and talking on the phone.



The final step in developing a QA specification is to create an acceptance plan, which aims to balance the risks to the contractor and to the specifying agency.

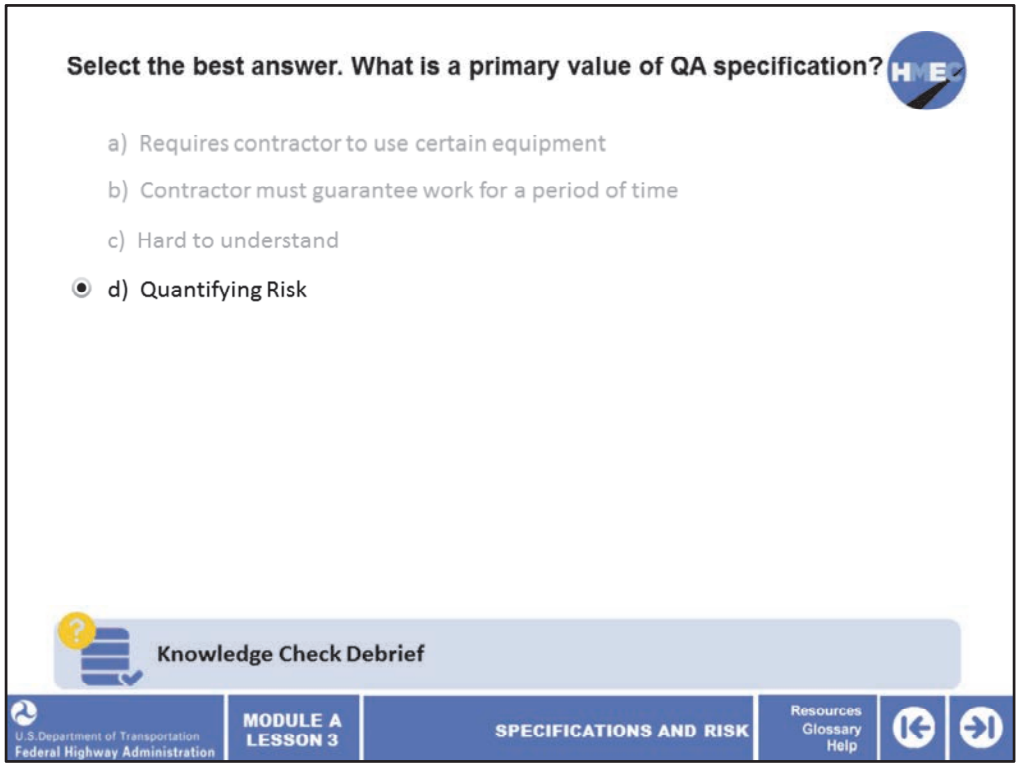
You can see that the idea is to achieve balance between contractor risk and agency risk. This will not happen automatically. As we will see in Lesson 11, basing acceptance on a sample size of one will give the agency a much higher risk of accepting “unacceptable” material than the contractor having “acceptable” material rejected. This risk imbalance can be adjusted by using statistics.

Image Description: A balance scale with the words risk in each of the measure bowls.

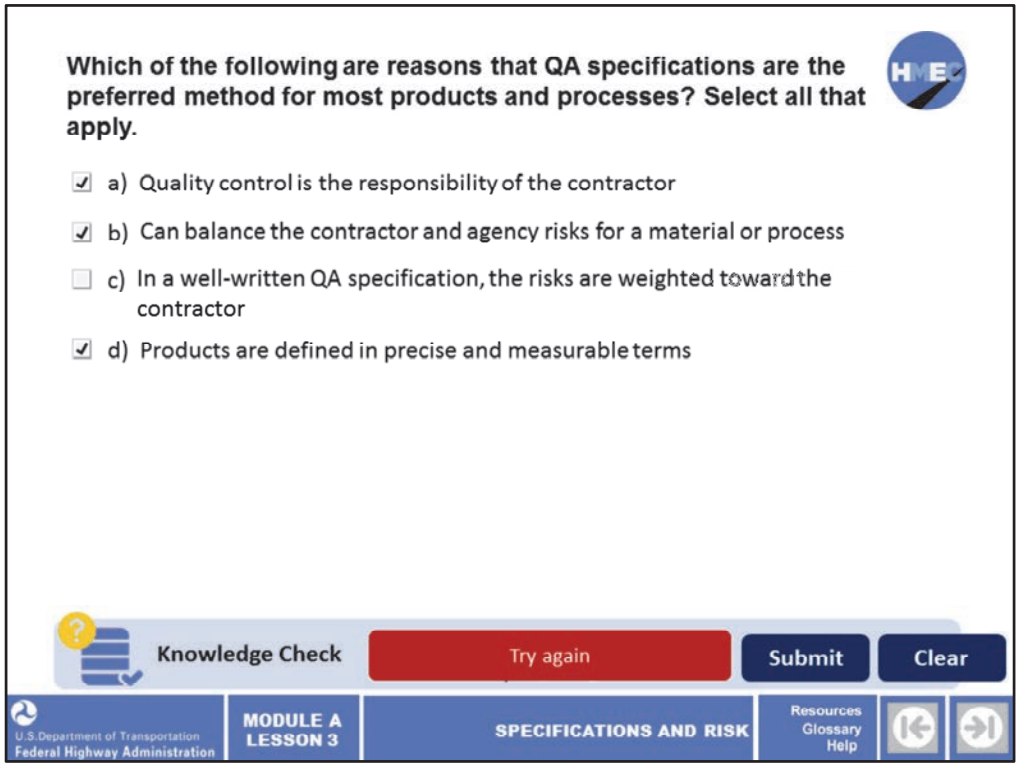


Select the best answer. What is a primary value of QA specification?

a) Requires contractor to use certain equipment;
b) Contractor must guarantee work for a period of time;
c) Hard to understand; or
d) Quantifying Risk

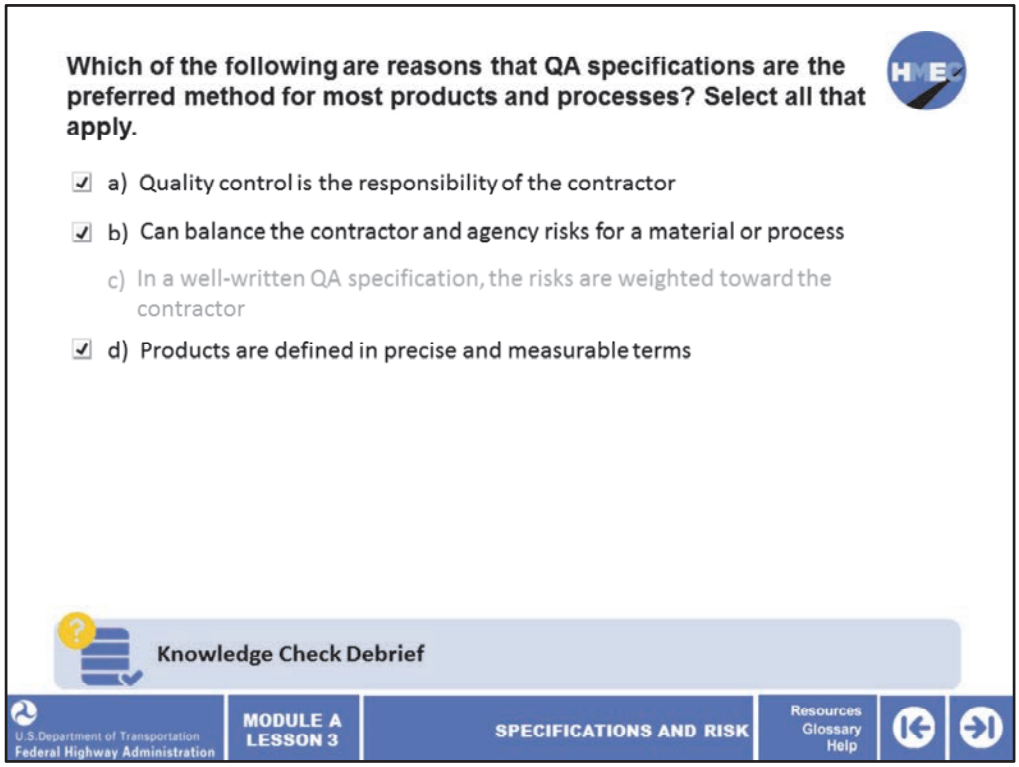


The correct answer for a primary value of QA specification is d) Quantifying Risk



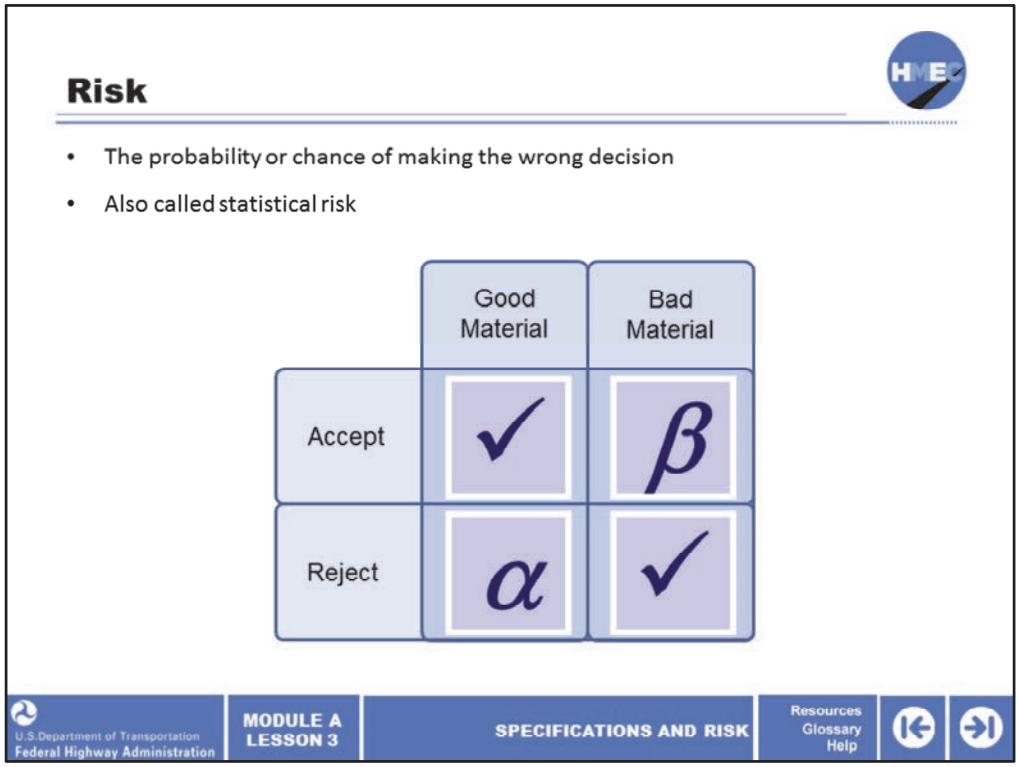
Which of the following are reasons that QA specifications are the preferred method for most products and processes? Select all that apply.

a) Quality control is the responsibility of the contractor;
b) Can balance the contractor and agency risks for a material or process;
c) In a well-written QA specification, the risks are weighted toward the contractor; and
d) Products are defined in precise and measurable terms.



The correct answers for the following reasons that QA specifications are the preferred method for most products and processes are:

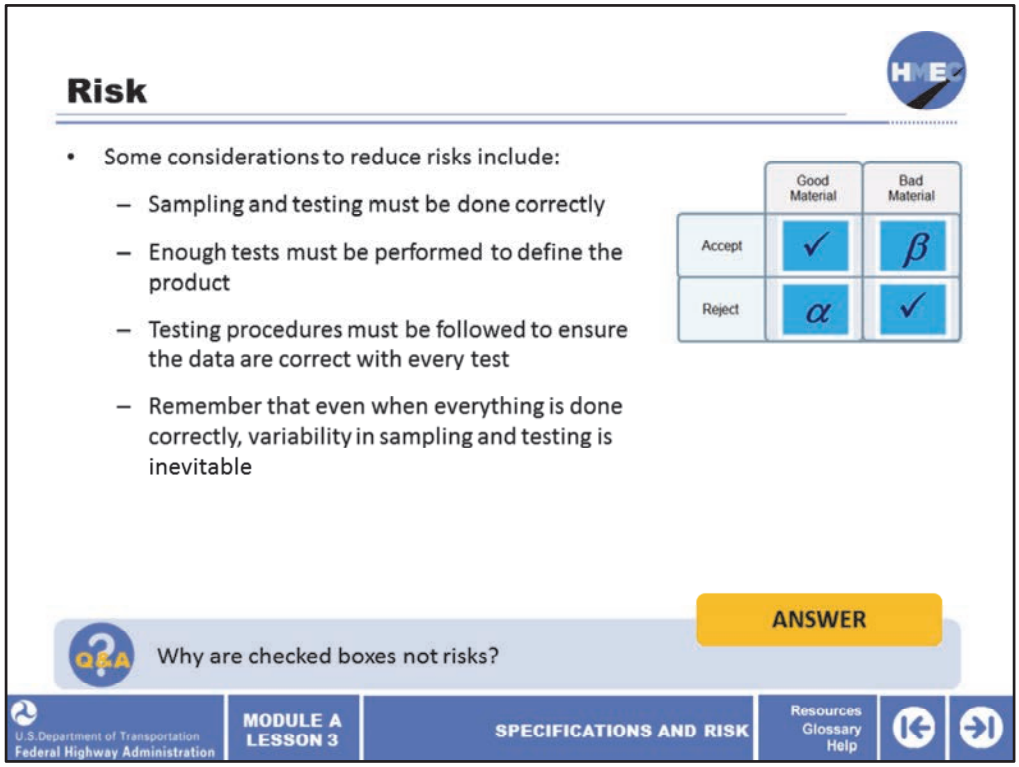
a) Quality control is the responsibility of the contractor;
b) Can balance the contractor and agency risks for a material or process; and
d) Products are defined in precise and measurable terms.



As mentioned in slide 12, the definition of risk is the probability or chance of making the wrong decision. It is also referred to as statistical risk.

In all specification types, a decision must be made regarding compliance with the specifications, which involves risks. There are two types of risk. The seller's (contractor) risk, *α*, is the risk of rejecting "good" material. The buyer's (agency) risk, β, is the risk of accepting "bad" material. One of the greatest advantages of a QA specification is that, when properly developed, the risks can be quantified.

Image description: Boxes showing Good material, accepted with a check mark and rejected with an *α* symbol, and Bad material accepted with a β symbol and rejected with a check mark.

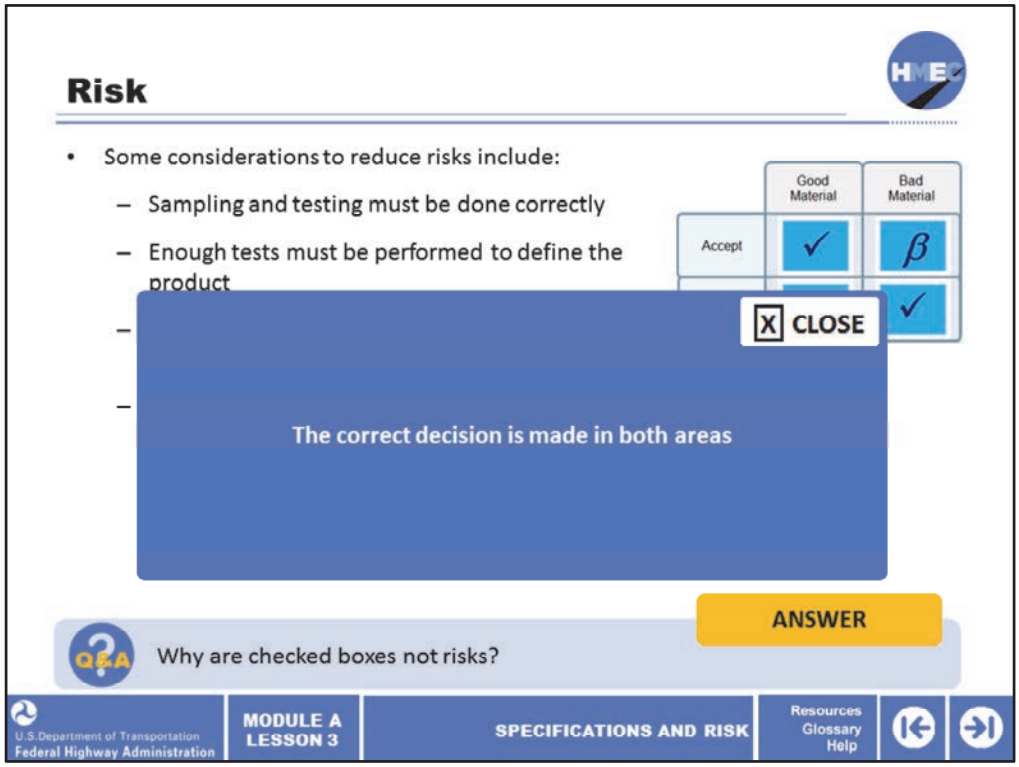


Some considerations to reduce risks include:

• Sampling and testing must be done correctly;
• Enough tests must be performed to define the product;
• Testing procedures must be followed to ensure the data are correct with every test; and
• Remember that even when everything is done correctly, variability in sampling and testing is inevitable.

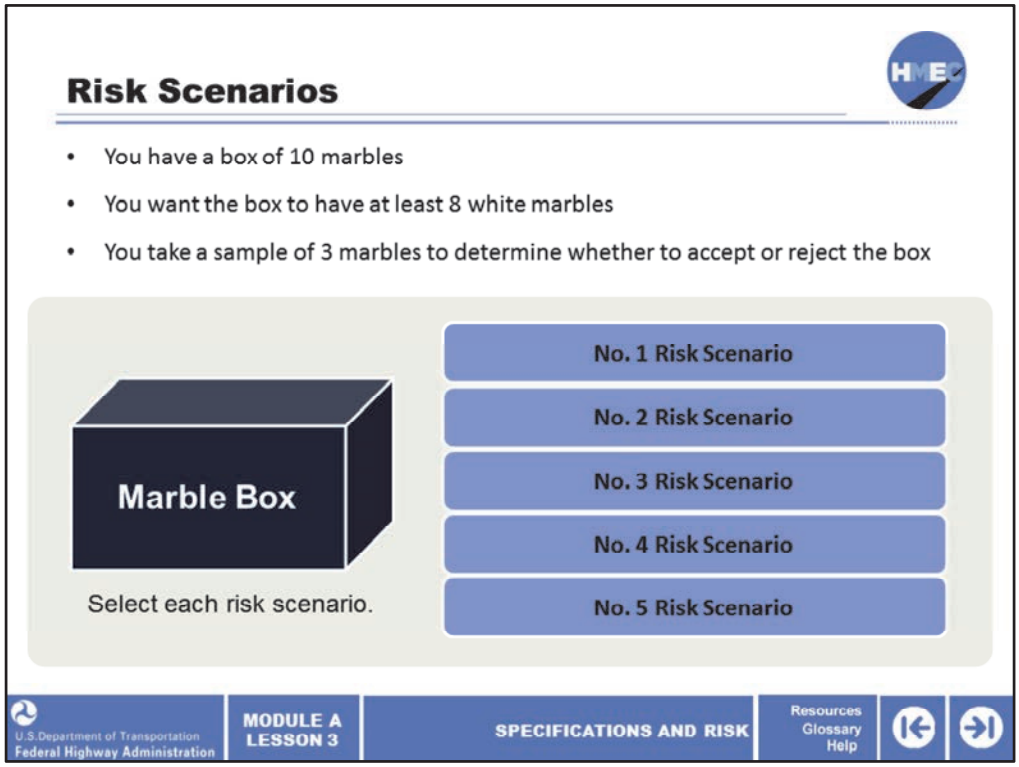
Select the box to answer the question, why are checked boxes not risks?

Image description: Boxes showing Good material, accepted with a check mark and rejected with an *α* symbol, and Bad material accepted with a β symbol and rejected with a check mark.



The checked boxes are not risks because the correct decision is made in both areas.

Image description: Boxes showing Good material, accepted with a check mark and rejected with an *α* symbol, and Bad material accepted with a β symbol and rejected with a check mark.



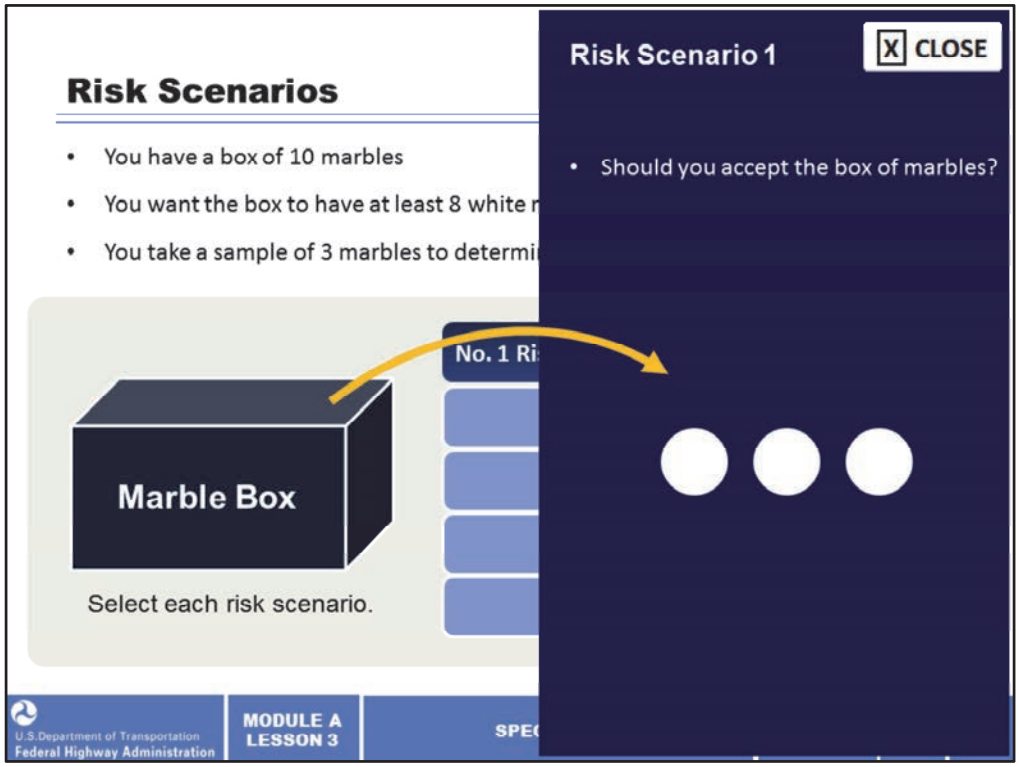
The following example of sampling a population illustrates how risks are involved in an acceptance decision.

Suppose that you wish to purchase a box of 10 marbles, and that you want *at least* eight of the marbles in the box to be white. You then decide to take a sample size of three marbles from the box to determine whether or not to purchase the box of marbles.

The specification is clear: it states that at least eight white marbles must be in the bag; it does not state that the bag must contain “mostly” white marbles. It also clearly states the sample size is three; it does not state “take a few samples.”

Select each risk scenario to learn more.

Image description: A marble box.

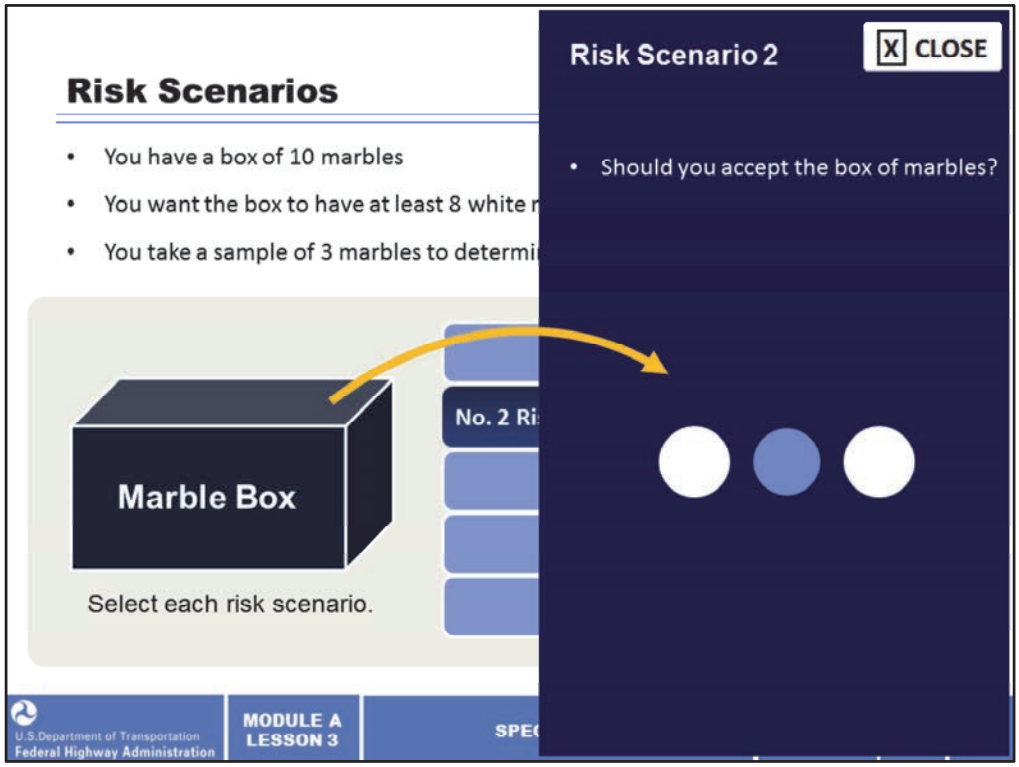


In the first scenario, the three marbles you draw are white. Should you be willing to purchase the box of white marbles? The specification states that the box must have eight white marbles and your sample does not disprove that. So you have to accept the box. Does this mean that there are eight white marbles (your specification desire) in the box? No, why? Because they may be the only white marbles in the box and the other seven are blue.

A sample size of three may not be enough to determine if 8 of the 10 marbles in the box are white. You cannot be certain one way or the other regarding whether or not the box has at least eight white marbles. You have not proven that it has at least eight white marbles, but you have no reason to doubt that it has the required eight white marbles.

So the question arises, did you make the right decision, which is not a risk? Or did you make the wrong decision, which is a risk?

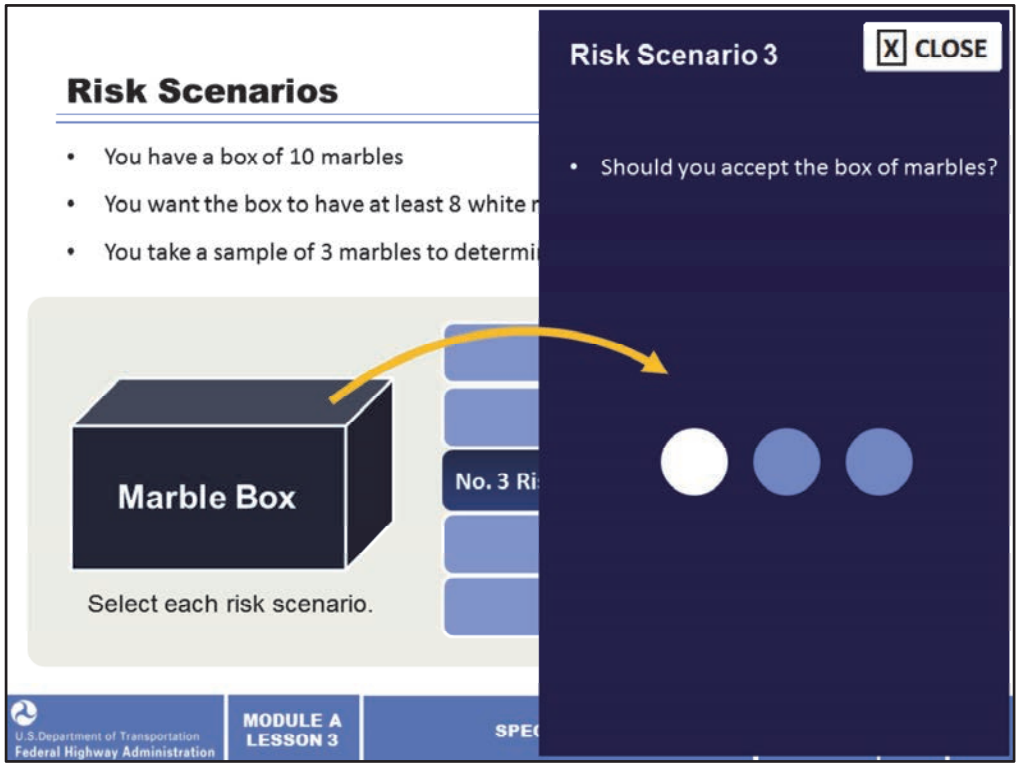
Image description: A marble box with an arrow pointing to three marbles sitting outside of the box.



In the second scenario, of the three marbles you draw, two are white and one is blue. Should you be willing to purchase the box of white marbles? The specification states that the box must have eight white marbles and your sample does not disprove this. But you are much less certain that the specification has been met. Can you reject the box; that is prove that there are not eight white marbles? No, because you may have sampled the only blue marble in the box and the other nine are white marbles (exceeding your specification desire). So a sample size of three provides even less assurance when one of the marbles is not white.

It is not certain whether or not the box has eight white marbles. But you are probably less confident that it has eight white marbles than you were in the last case where all three marbles were white. What does this do to the risks? Answer: It makes the risk to the buyer higher than before.

Image description: A marble box with an arrow pointing to three marbles sitting outside of the box and the middle marble highlighted.



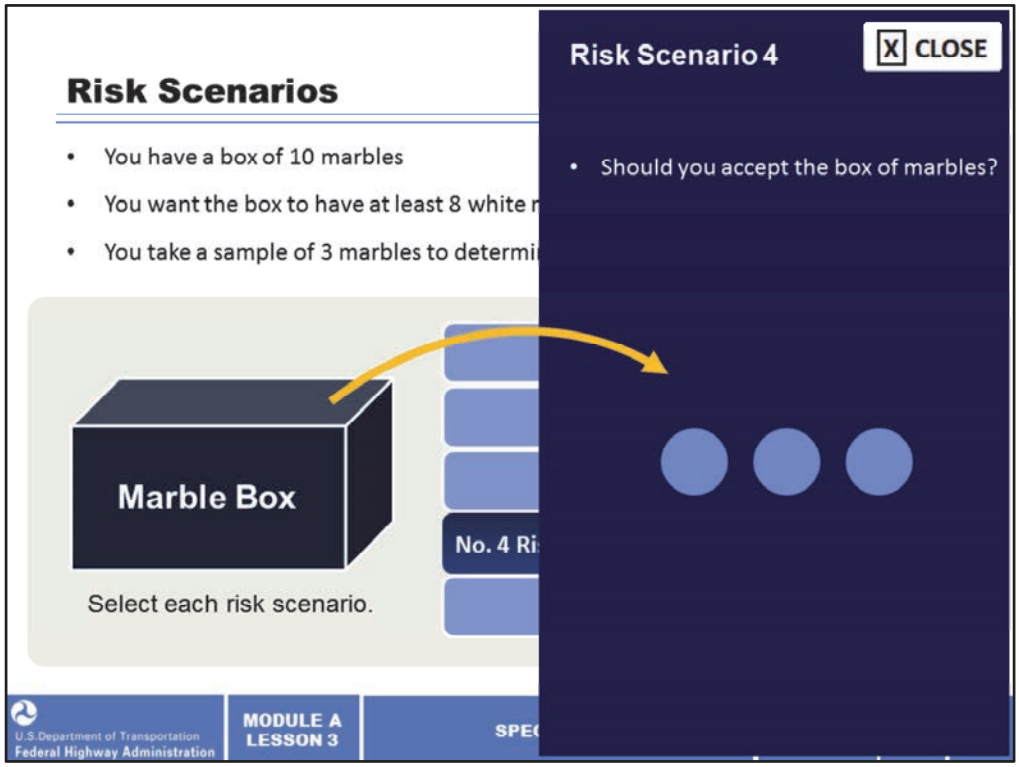
In the next scenario, of the three marbles you draw, two are blue and one is white. Should you be willing to purchase the box of white marbles? The specification states that the box must have eight white marbles. Did you pick the only two blue marbles in the box? There is that possibility. So you are even less certain that the specification has been met than before. But can you reject the box; that is, prove that there are not eight white marbles? No, because you may have sampled the only two blue marbles in the box and the other eight are white marbles (your specification desire)? So a sample size of 3 becomes even less certain when two of the marbles are not white.

While it is still possible that there are eight white marbles in the box, you probably feel that it is unlikely that the box contains the necessary eight white marbles. However, if you reject the box, there is still a chance that you rejected a box that contained eight white marbles since you did not prove that the box could not have eight white marbles.

Question: What happened to the risk to the buyer?
Answer: The risk is even higher than before.

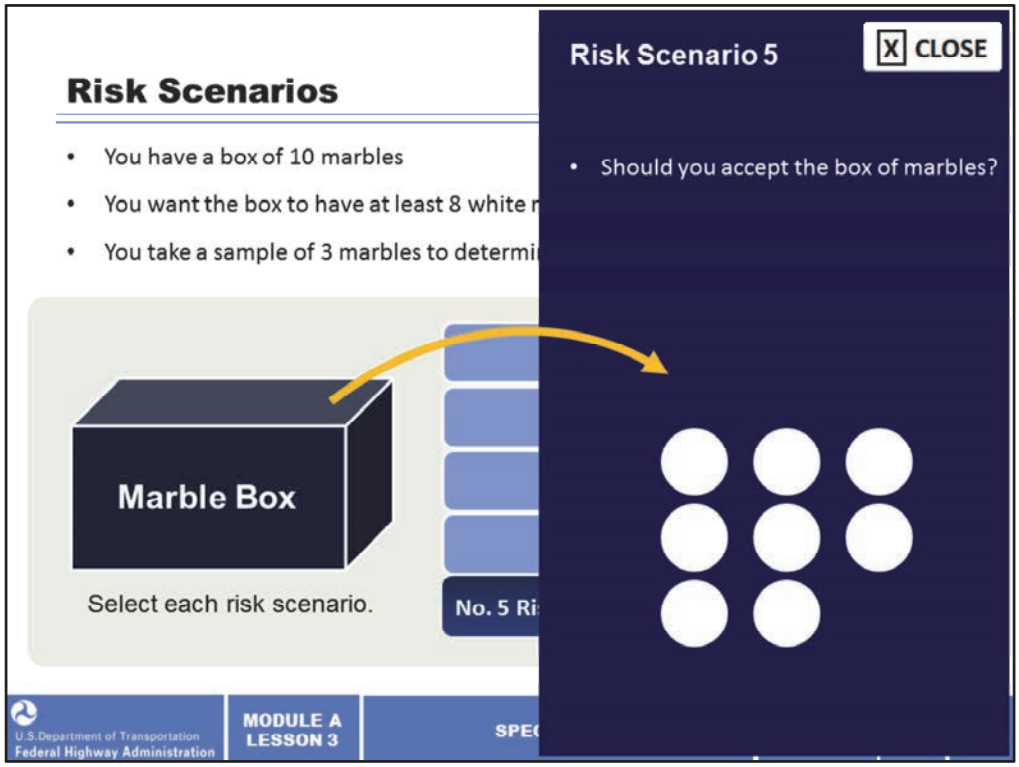
Keep in mind we have only discussed the risk to the buyer. The only risk to the seller would occur if the box were rejected incorrectly. That requires more knowledge than is provided in this simple example.

Image description: A marble box with an arrow pointing to three marbles sitting outside of the box and the two right marbles highlighted.



In this scenario, the three marbles you draw are all blue. Should you be willing to purchase the box of white marbles? No, there is no chance that there are eight white marbles in the box. If the box has 10 marbles, then you know with certainty that it cannot contain eight white marbles. It is therefore possible to show that the box did not meet your requirement of eight white marbles. So you can reject the box and since this has to be the correct decision, there is no risk to the buyer.

Image description: A marble box with an arrow pointing to three marbles sitting outside of the box with all three marbles highlighted.

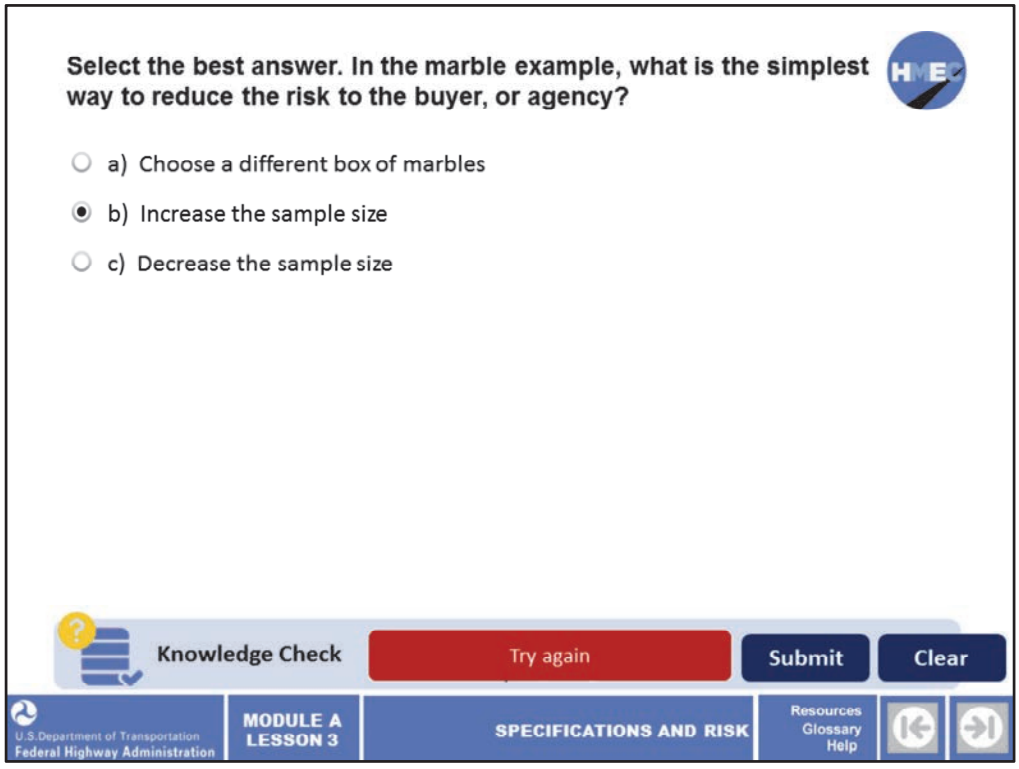


The sample size should be based on the probability that the number of samples collected represents the quality of the material required. The higher the probability, the less risk there is for the agency.

To be able to prove that the box has at least eight white marbles would require that you sample at least eight of the marbles in the box. If all eight were white, then you have proven that the box meets your requirements. If there were one or two non-white marbles in the box, then you might have to draw nine or 10 marbles to prove that the box should be purchased.

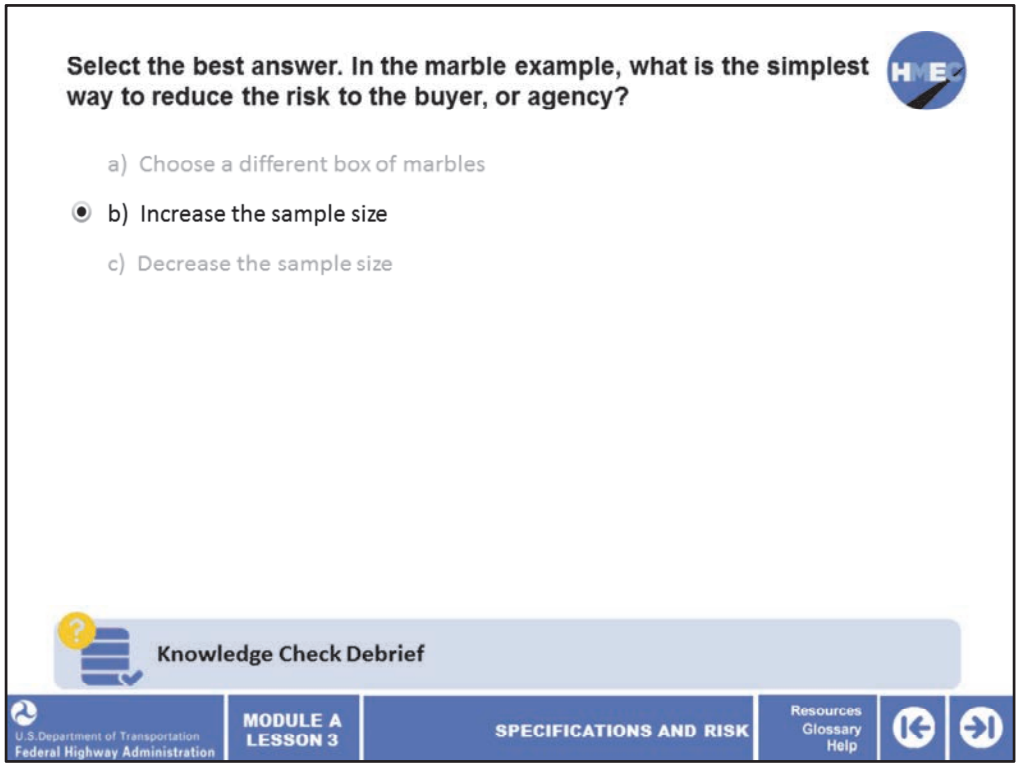
How does this relate to material and construction testing? The specification required 30% of the population be tested (3 out of 10). How often is this done? Answer: Almost never. To get 100% assurance of the specification being met would require you to sample 80% of the product. How practical is this? Answer: Not at all.

Image description: A marble box with an arrow pointing to eight marbles sitting outside of the box.

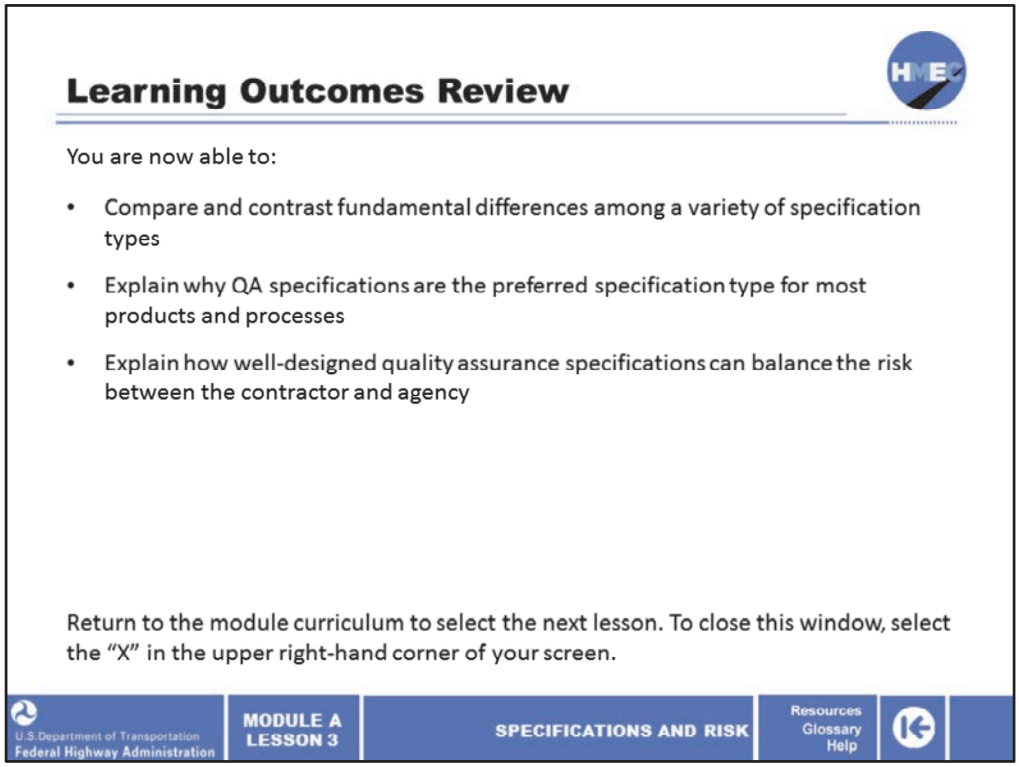


Select the best answer. In the marble example, what is the simplest way to reduce the risk to the buyer, or agency?

a) Choose a different box of marbles;
b) Increase the sample size; or
c) Decrease the sample size.



The correct answer for the simplest way to reduce the risk to the buyer, or agency is b) Increase the sample size.



You have completed Module A, Lesson 3: Specifications and Risk. You are now able to:

• Compare and contrast fundamental differences among a variety of specification types;
• Explain why QA specifications are the preferred specification type for most products and processes; and
• Explain how well-designed quality assurance specifications can balance the risk between the contractor and agency.

Close this lesson, and return to the module curriculum to select the next lesson. To close this window, select the "X" in the upper right-hand corner of your screen.