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16. Abstract

The materials used within the Texas Department of Transportation (TxDOT) are undergoing a period of change. The purpose of this report is to develop the information necessary to develop (for TxDOT) a method or a database for monitoring the performance of transportation materials. This report builds a foundation based on information obtained from an expert working group meeting, from a state-of-the-art literature review, and from an analysis of TxDOT's current computing and testing programs. Upon this foundation, the researchers have built a scope and methodology for identifying data elements for inclusion in the database. Furthermore, a sample prioritization of data elements is performed. The report also discusses a conceptual framework for the proposed database. Finally, conclusions are summarized and future research directions are explored.

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PLAN FOR DEVELOPING A MATERIALS PERFORMANCE DATABASE FOR THE TEXAS DEPARTMENT OF TRANSPORTATION

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Research Report Number 1785-2

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TEXAS DEPARTMENT OF TRANSPORTATION

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Mr. Mike Koen	Project Director	Construction Division
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Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

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CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

Materials and materials properties/characteristics are essential design elements in construction engineering. Within a given transportation infrastructure, for example, materials properties and characteristics can ultimately control the performance of that infrastructure. Despite pronouncements regarding exotic, new materials and changes in available materials, most of the natural and synthetic materials available for transportation construction within Texas are indigenous. As a consequence, precedents for materials use and performance have historically been based on practical experience with specific material sources.

Now, however, materials sources and observed performance are changing. Changes in the performance and properties of materials have occurred with the development of new asphalt and other material sources within Texas (including importation of Mexican cement). These material property and performance changes often lead to negative changes in infrastructure performance.

Taken in combination, these changes in material properties and in design/ specification procedures make it increasingly important to establish a database record of material properties and material data within the state. With such a database, it will be easier for an agency — particularly the Texas Department of Transportation (TxDOT) — to evaluate the performance of available materials. In order to handle the vast amount of information and data required to monitor the performance of materials used by TxDOT, a *computerized* database will be necessary. Based on current computer and information systems technology, it is clear that a computerized database represents a reasonable solution to this emerging problem. This computerized database and information system, which will generally be referred to as the "proposed database" throughout this report, must be able to store, retrieve, update, modify, analyze, and display the basic information required to monitor the performance of materials.

Many issues must be resolved concerning the specifics of such a database. Since many options exist, the following questions must be answered:

- On what materials should the database focus?
- Should constituent properties of these focus materials be included in the database?
- Should the database focus on pavements as materials or on pavement constituent materials such as concrete, etc.?
- How can the performance of materials be defined or represented in a manageable form?
- How can material properties be for prioritized inclusion in the database?
- What is the conceptual framework of the database?
- Are any data that might be of interest for the proposed database available elsewhere within TxDOT?
- What kinds of standard data formats are available for materials databases?

- Are there other databases that could guide development of this proposed database? What state-of-the-art technologies can be used in developing this database?
- From which current TxDOT databases can data be imported into the proposed database? What types of material data are collected as part of the regular TxDOT testing regimes?
- For which tasks should the proposed database be used?

These questions, among others introduced later in this report, must be addressed before database development can begin.

1.2 PROJECT OBJECTIVE

In September 1997, TxDOT initiated Project 0-1785, *Develop Basic Information to Be Used for Developing a Plan to Monitor Performance of Materials*. The goals of the project were to answer some of the questions introduced above and to develop a plan to monitor the performance of materials. Since a database is considered a necessary part of this plan, the purpose of this project is to develop the information necessary to develop a performance-monitoring database. However, this project seeks neither to produce a database nor to provide precise specifications for one. On the contrary, its goal is to provide most of the information necessary for TxDOT to develop such a database when specific decisions are made regarding database needs. As is suggested throughout the remainder of this report, certain tasks must be accomplished and decisions made before a tangible database can be constructed.

Clearly, then, the findings of this project must precede any further database development. This report details the information and perspective necessary to begin development of the proposed database.

1.3 RESEARCH CONSTRAINTS AND OBJECTIVES

Research of this type is not new to the Center for Transportation Research (CTR). During the past five years, CTR and its researchers have investigated the use of databases and geographical information systems (GIS) for the management of roadways, airports, and urban infrastructures. These research efforts have identified the following constraints involved in developing and implementing computerized database systems:

1. The recommendations must be consistent with the established computation environment and the long-term development plan of TxDOT.
2. The recommended database system must satisfy TxDOT user requirements and must properly interface with the legacy systems that will be retained by TxDOT.
3. The interface between the recommended database system and the existing TxDOT databases should be easy to establish. Additionally, the recommended database system should be able to utilize existing databases either directly or though inexpensive data conversion.

4. The recommended database system should allow operations to be carried out at different levels of sophistication.
5. The recommended database system should be user friendly and have the flexibility to accommodate future modifications.

In addition to these constraints, which the remaining chapters will discuss, four primary objectives will need to be addressed:

1. Identify and prioritize what materials and characteristics should be collected, recorded, and stored in the proposed database.
2. Review the state of the art in the application of database technologies to the principles of monitoring the performance of materials.
3. Review and analyze the needs of potential TxDOT users.
4. Develop a conceptual framework for the proposed database.

These constraints and objectives will determine the focus and recommendations of this report as it addresses the questions posed earlier.

1.4 WORK PLAN/REPORT OUTLINE

This report contains eight chapters. Chapter 2 discusses the literature review and highlights and evaluates the work performed by others in the field of database technology and material science. The information provided in Chapter 2 will be built upon throughout the report and can be built upon during future database development. This chapter also summarizes the database information found in Report 1785-1 and Appendix B.

Chapter 3 summarizes the topics discussed during project meetings, including the expert task group (ETG) meeting that was held for this project. These discussions served as starting points for many of the major issues that are part of this research and that are discussed later. Chapter 4 summarizes information about the testing regimes of TxDOT. This information, coupled with the database information provided in Report 1785-1, may allow the proposed database to act as a search engine that mines data from other sources and may improve its compatibility with the current TxDOT testing and computing environments. Additionally, the information that is provided in this chapter could help future database developers select the material properties that are easiest to obtain for the proposed database.

Chapter 5 defines the scope for the proposed database, describes a methodology for evaluating performance, and presents data organization charts (DOCs) that will aid in prioritizing material properties for inclusion in the proposed database.

Chapter 6 presents a methodology, using the DOCs, for analyzing materials to select the appropriate material properties, at many levels of detail, for inclusion in the database. A sample analysis is given for bituminous mix materials, portland cement concrete, and base materials (stabilized and flexible). Chapter 7 provides future database developers with a conceptual framework. The main computerized features and components of the proposed database, as well as their interrelationships, are described.

Finally, Chapter 8, the concluding chapter, summarizes the previous chapters. It reflects upon future directions for research and development of the proposed database.

CHAPTER 2. SUMMARY OF LITERATURE REVIEW FINDINGS

2.1 INTRODUCTION

To begin researching the information necessary for a database that can monitor the performance of materials, a summary review of related work in the fields of materials performance and materials databases is helpful. Such a review will help summarize and identify research that can be referenced, invoked, consulted, and used in future database development. Currently, there is no work either completed or being performed on the exact topic of this research project, *Develop Basic Information to be Used for Developing a Plan to Monitor Performance of Materials* (TxDOT Project 0-1785). However, there has been a considerable amount of research, which this chapter will seek to summarize, on the use of materials databases in other fields and on pavement and materials performance. This chapter will begin by defining the state of the art for materials databases and pavement/materials performance.

This chapter is best broken down into three main topical sections. The first section reviews literature on the general topic of materials data and material databases. The second section addresses specific database issues and discusses specific examples of materials databases and expert systems. Finally, the third section briefly outlines some of the research being conducted on pavement and materials performance.

This literature review was especially difficult to perform because the subject of this research spans a large number of similarly broad, complex subtopics. Consequently, many divergent topics had to be summarized in less depth than would be possible with a more limited research subject. The subject of this research is a unique topic that has not previously been examined; rather than relying on precisely detailed information, the topic relies on very general principles drawn from materials science, computer science, and other fields.

2.2 GENERAL RESEARCH

Later, this chapter will discuss specific research on expert systems used in a variety of fields, and will highlight traditional databases currently in use. Here, however, it discusses ideas and concepts from the large body of literature on general topics related to materials databases. These topics include the following: how corporate "know-how" may be preserved in a materials database; recommended data formats for concrete and other materials in a database; and some special problems that are unique and inherent to materials databases. While these topics are not directly interconnected, each falls within the category of general materials database research.

2.2.1 General Problems with Materials Property Data

One of the problems in developing materials property databases is that material properties data differ from other kinds of data. McCarthy discusses some of the design considerations for materials property information systems, including the networking of multiple databases (McCarthy 89). He bases his writings on his experience developing an experimental prototype system called Materials Information for Science and Technology (MIST).

McCarthy points out that users of material properties data have a unique problem in that they need "many of the same features in their information systems as other scientists and engineers do, but they also have some unique requirements that have implications for system design" (McCarthy 89). He discusses in depth many of the other problems inherent to material properties data. Many of those problems are summarized here (McCarthy 89).

1. **Complex Data Structures** — Material properties data rely on multivalued fields, footnotes as modifiers, null values, ranges/bounds, and tables/graphs. Such reliance on so many elements makes them much more complex to codify in a computer-readable form.
2. **Diversity of Nomenclature** — Materials properties data use diverse, often nonstandard, nomenclature in names and measurement units. Synonyms must be accounted for in databases.
3. **Different Levels of Abstraction** — Materials designations, property and variable names and even data value domains may contain data pertaining to different levels of abstraction. Many data sets may share identical data elements, yet refer to different levels of specificity (i.e., 304 steel vs. 304 grade B steel).
4. **Incomplete Data Sets —** Older materials often will have incomplete data sets.
5. **Harmony Across Sources —** As materials databases increase in size, with diverse sources, nomenclature must be harmonized across sources.
6. **Distributed Database Issues —** All other problems with material properties data are compounded by multiple databases and a standard host of distributed data management problems, such as heterogeneity of geographic sites, computer hardware operating systems, data management software, communications mechanisms, and interfaces.

Clearly, there are copious problems that may obstruct the development of the proposed materials performance database and that make materials information system design unique. Each of these problems could exist in the current TxDOT computing environment. Consequently, these problems need to be considered carefully during future database development.

While McCarthy describes in detail these problems associated with materials data that inhibit the development of a materials information system, he also suggests some solutions. The following are his recommended solutions for some of these problems (McCarthy 89):

1. **Diversity of Nomenclature** — To solve the problem of synonymous name and measurement units, McCarthy recommends that variable names/units themselves be placed in a general variable name field that "is bound in turn to a set of one or more values (and possibly footnotes) associated with that variable." Additionally, to solve the problem of disagreement among users on data units, he recommends that data be archived in whatever units are used in the original source. However, data values

should be indexed in terms of specified standard units (McCarthy 89). This permits different users to work in the measurement units that they choose.

2. **Different Levels of Abstraction** — To deal with summary and extraction level problems, McCarthy recommends the future use of object-oriented database systems, which are briefly discussed later in this chapter.
3. **Distributed Database Issues** — To solve problems caused by distributed databases, McCarthy stresses that, though costly, a uniform interface must be used among multiple remote systems.
4. **Miscellaneous Materials Data Solutions** — In addition to his aforementioned specific solutions, McCarthy discusses several more concepts, including modular architecture, three-tiered naming, an active thesaurus, class hierarchies, existence table support, and object-oriented representation, that can improve the performance of a materials information system.

2.2.2 Data Formatting Standardization

Common formats for material data and databases can help avoid confusing the scientists and engineers who use them. Accepted standards for presenting materials data will allow computers to replace laboratory notebooks as a more efficient means for "storing and retrieving concrete materials property data" (Oland 97). Furthermore, standardized data formats could prove very influential in the development of the proposed database because they would allow users to compare different sets of standard data without having to worry about verification.

Important formats for data in the proposed database are those contained in documents published by Committee E-49 (ASTM E-49) of the American Society for Testing and Materials, Committee 126 (ACI 126) of the American Concrete Institute, and the National Institute of Standards and Technology (NIST). ASTM E-49 formats are applicable to all materials data. ACI 126 formats are applicable to concrete materials data. Finally, NIST formats are applicable to concrete-constituent materials data.

Kaufman explains the purpose of ASTM Committee E-49 (Kaufman 89):

> ASTM Committee E-49 on the Computerization of Materials Property Data was formed in 1986 in response to an increased recognition of the great resource value of well-documented materials property data and of their importance in high-quality decision making in materials selection and design.

More specifically, the goal of ASTM E-49 is to create database or expert system guidelines that ensure quality, reliability and compatibility with other sources. In addition to the creation of ASTM E-49 to handle the need for easier direct access to "more reliable numeric performance data" (Kaufman 89), the National Materials Property Data Network (MPD Network) was created to provide engineers and scientists with easy, on-line access to high-quality numeric data. Kaufman suggests that while organizations such as ANSI, ISO, IEEE and ASTM E-31 have all also created standards for computerized information systems, E-49 currently is the only committee to deal with factual and numeric materials properties

(Kaufman 89). Consequently, it has special application for this research on a material performance database.

Kaufman outlines some of the standards and formats used to characterize materials property data in general. He lists important categories of information needed to characterize materials and material test results uniquely (Kaufman 89). Once these general data categories are created, data fields or records may be customized to make the categories more appropriate for characterizing a materials' class. Kaufman points out that the fields necessary to characterize a material within a class may not be the same for all classes (i.e., metal, polymer). This leads to the dichotomy between essential and desirable data fields for a given material. This dichotomy will be discussed later.

More specifically relevant to the proposed database are the standard formats for concrete data that have been developed by ACI 126. These data formats include not only formats for composite concrete, but also formats for concrete constituents such as cement and mineral admixtures. Because "the guide being developed by ACI Committee 126 is intended for use in establishing the content of a comprehensive concrete materials property database," it could prove to be an invaluable resource for defining data fields and categories in the proposed database (Oland 97). This will ensure the proposed database's compatibility with other, similar databases.

Oland outlines the procedure for creating the standards that will allow scientists to "efficiently report all of the properties that may be available for a particular concrete." Consequently, the recommendations of ACI 126 will certainly be applicable to the proposed database, no matter upon which particular concrete properties it focuses. According to Oland, "a comprehensive set of guidelines should be followed that establishes unique concrete identification and presents constituent information, processing parameters, mechanical, thermal, physical and other properties, and performance characteristics" (Oland 97).

Concrete materials database development begins with the creation of a list of essential and desirable data elements (as discussed by Kaufman) to be included in the database (Oland 97). These data elements form the data dictionary for the database upon which a database schema, or "way of seeing the information in the database" can be built (Oland 97). An illustration of this development process is shown in Figure 2.1. Chapters 5 and 6 will explain how this list of essential and desirable data elements can be generated, depending on user preferences and goals, for monitoring the performance of numerous sample materials. However, creation of this listing will be the responsibility of future database developers.

While the ACI 126 *Guide to a Recommended Format for Concrete in a Materials Property Database* was in development at the time of the spring 1997 ACI meeting, its general contents are widely known. For instance, all required data elements regarding concrete can be organized into nine main categories, including cement, aggregate, chemical admixtures, mineral admixtures, fibers, water, processing, properties/performance, and identification. Data elements addressing similar topics can be combined to form subcategories or data segments, and "sets of data segments, when combined, create the foundation for a comprehensive data file" (Oland 97). For instance, when referencing concrete A in a data file, one of its data segments may be aggregate, which in turn could be composed of data elements *bulk specific gravity* and *moisture content*.

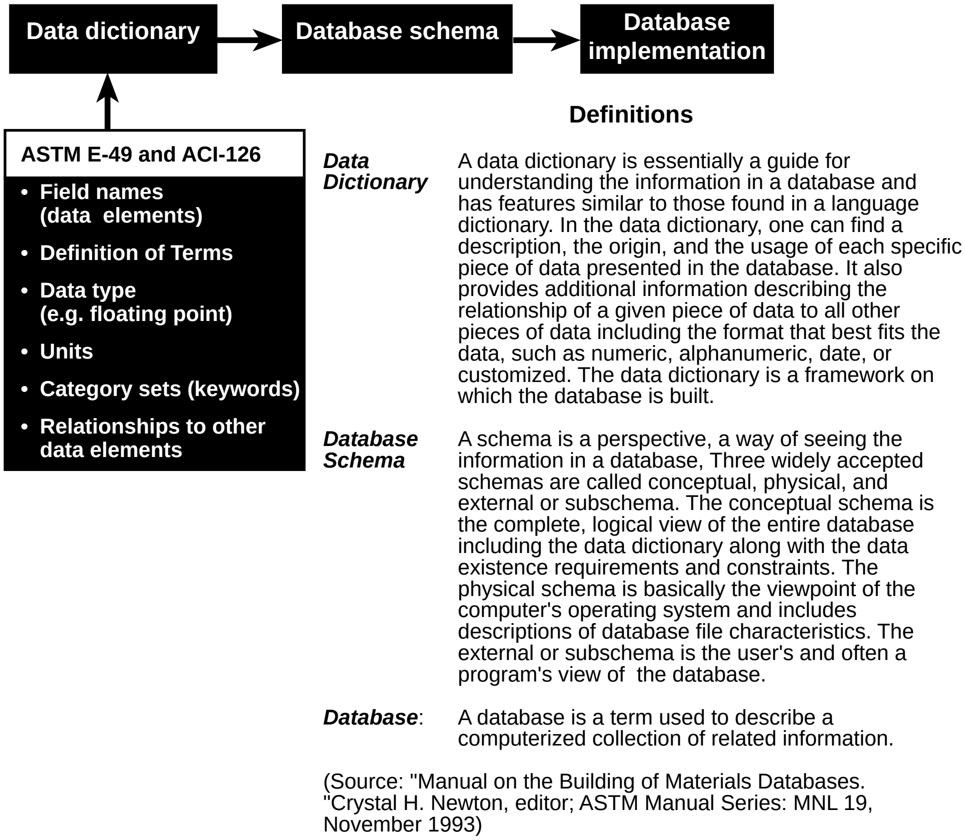

Figure 2.1 Database development process (Kaetzel 97)

Figure 2.2 graphically illustrates this principle. ACI 126 will also recommend formats for reporting constituent data/properties in a database, since this data can be extremely important in evaluating a concrete. These formats will be included for important constituents such as cements, aggregates, chemical admixtures, mineral admixtures, fibers, and water (Oland 97). In Figure 2.3, the data components of a concrete materials database and their interrelationships are shown.

Concrete will not be identified as “X,” for example; it will require a unique identifier. ACI 126 is currently developing such an identifier to make it easier to distinguish the many materials that TxDOT may need to identify.

Clearly, the utility of these data formats will depend on which data elements are required in the proposed database. Consequently, the specific formats should be consulted when those data contents are further formalized.

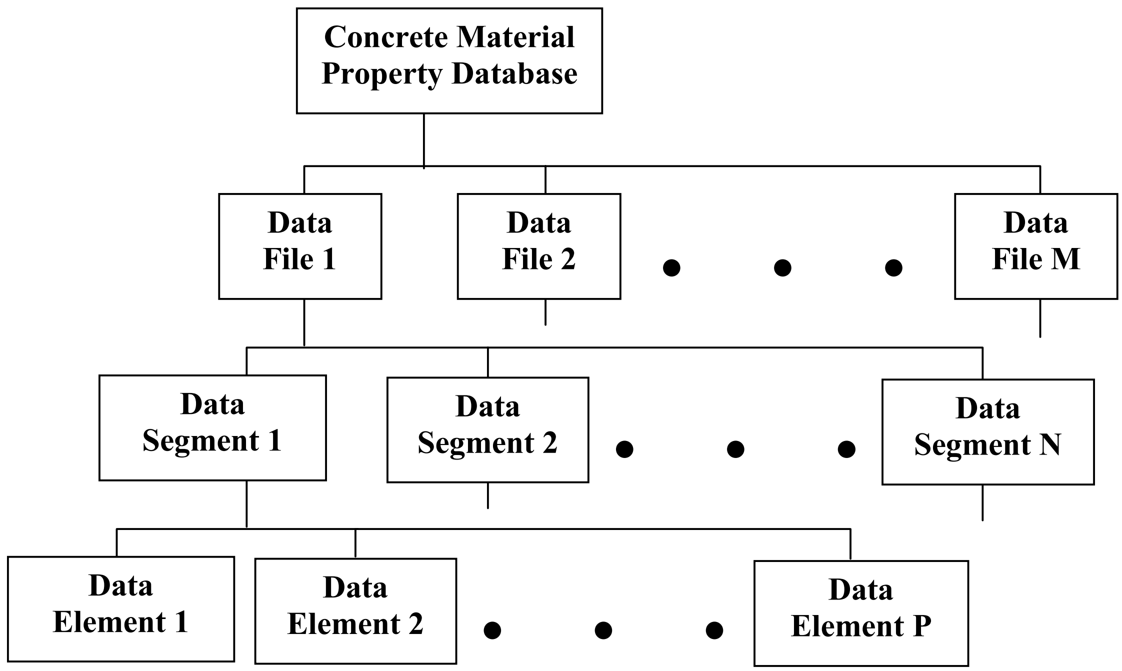

Figure 2.2 Relationships among components of a concrete materials property database (Oland 97)

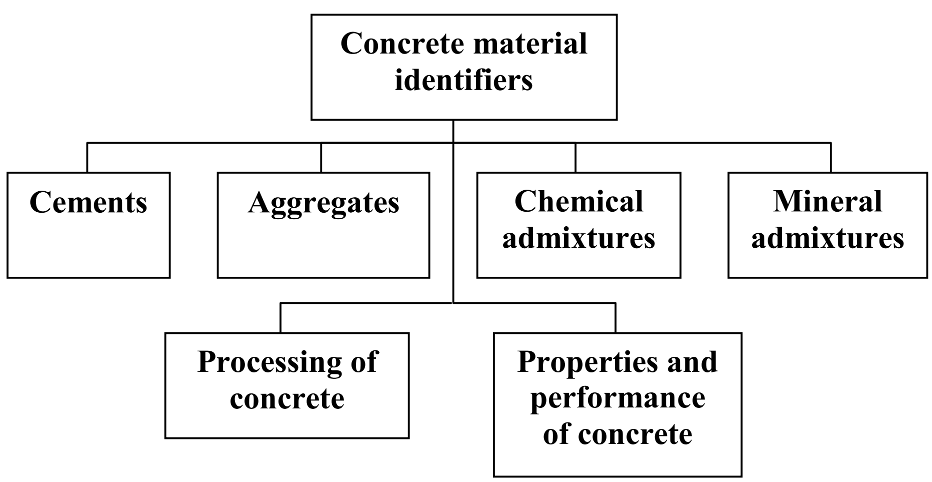

Figure 2.3 Data components of a concrete materials database and their relationships (Kaetzel 97)

ASTM E-49 sets forth very general standards and guidelines for materials property data in general, and ACI 126 sets forth more specific, compatible rules for concrete property data in computerized databases. Even more specifically, NIST proposes a set of guidelines for the data formats for cement and other concrete constituents. Such specific constituent formats could prove instrumental for future development of the proposed material performance database, when, as is discussed in subsequent chapters, it becomes necessary to consider constituent material data 55(of, for instance, concrete). These formats are discussed by Kaetzel and Galler, and are intended to be compatible with those formats already proposed by ACI 126 (Kaetzel 97).

Kaetzel notes that the cement data guidelines will be helpful in exchanging such data for the following areas (Kaetzel 97):

> Communication of property data among cement manufacturers and the concrete industry. Integration of cement and concrete materials property data with computer-based models and expert systems where the properties data are in a regular data format. The creation, exchange and interpretation of cement material property databases that allow the user to obtain understanding of the changes in material properties from different manufacturers in different time periods.

The proposed database certainly conforms to this statement. As previously discussed, the author of this NIST guide explains that the first step in building such a format for materials data is to create a data dictionary, followed by a database schema (Kaetzel 97). Subsequent portions of this report will focus on how to develop this data dictionary at not only the composite, but also, at the constituent level. The NIST methodology is consistent and compatible with both the ASTM and ACI formats.

Most importantly, the author outlines the five data segments that contain all the data elements necessary to define cement uniquely in a way similar to the nine listed data segments that are necessary to characterize a concrete mix. To characterize cement properly, the required segments should include cement constituent identification, chemical characteristics, physical characteristics, properties of the paste or mortar, and raw materials (Kaetzel 97). As was stated previously, NIST has produced similar standards with different data segments in order to format data on chemical admixtures and other concrete constituents. Thus, if the proposed database focuses on concrete constituents rather than the whole of the mix, NIST publications will be quite useful.

It is evident that the NIST, ACI, and ASTM guides will be potent references and guides for the future developers of the proposed database. They will be most useful once a draft data dictionary of the database has been developed (in the manner that is described later in this report) for all materials to be stored in the database.

2.2.3 Preserving Organizational Know-How

Martini-Vvedensky discusses how materials databases can provide a simple framework through which experience reports pertaining to the purchasing, manufacturing, and use of materials may be retrieved to aid in materials selection decisions. This is clearly one of the reasons why the proposed material performance database is being researched.

Retention of “know-how” within TxDOT is one of the user tasks discussed at the Expert Task Group (ETG) Meeting for this research, as is discussed in Chapter 3.

Selecting materials is not just a simple process of matching design requirements to properties. According to Martini-Vvedensky, in addition to depending on design requirements, the optimal material depends on circumstances within the manufacturing company or organization that produces the material (Martini-Vvedensky 92). These circumstances may include the following (Martini-Vvedensky 92):

1. Manufacturing capability and experience
2. Purchasing arrangements with materials suppliers
3. Stocks of materials held and the tonnage and forms of the various materials used by the company for other products
4. Field experience of use of various materials in similar products.

All of the above considerations, in addition to the task of matching properties to design requirements, can make materials selection an overwhelming task to the new engineer, especially in a very large or decentralized corporation where thousands of field service reports for thousands of products are scattered among many highly isolated departments. Martini-Vvedensky notes that (Martini-Vvedensky 92),

> Because the problem is ultimately one of too much information, the engineer needs them (the information) pre-structured so that only the description of the relevant experience is presented to him….materials databases provide the framework for this structure.

Some of these same challenges confront the materials engineer in a department of transportation, where the engineer is responsible for selecting materials. Thus, the use of materials databases to preserve experience seems relevant to the goals of monitoring the performance of transportation materials. Martini-Vvedensky continues (Martini-Vvedensky 92),

> By attaching reports of manufacturing, purchasing and field experiences generated for...material the company uses to the description of those materials in its materials database, the corporation develops a reservoir of corporate know-how.

Clearly, such a system will provide better designs, an improved competitive edge, better knowledge of design experience and better communication within a company (Martini-Vvedensky 92).

Martini-Vvedensky also briefly outlines some principles that govern the creation of such a material information system to capture “know-how.” The creation of such a system should be initiated by a highly placed manager at the vice-president level or higher . This is because it is important for that person to have access to a wide overview of activities in a variety of company departments (Martini-Vvedensky 92). While a ranking executive needs to be in charge of initiation, the staff members whose experience is the target of capture, including lower-level managers and those with access to reports that are already in existence, need to be involved. Martini-Vvedensky further recommends that new experience reports be generated as word processing documents that may be cross-referenced by appropriate keywords and that old reports be captured using optical storage. Clearly, harmonizing and standardizing the language used in reports is a major challenge to the creation of such a system (Martini-Vvedensky 92). Finally, she stresses the need for a network computer system and recommends the use of MATUS software because of its ability to handle purchasing and inventory information.

In a case study that she discusses, Martini-Vvedensky outlines the efforts of BNFL (British Nuclear Fuels), which is involved in the nuclear industry, where law requires the maintenance of vast quantities of records. As she notes, "it is perhaps natural, therefore, that the company has advanced centralized, databases of engineering information." The system run by BNFL has an extensive purchasing data system that captures the occasions of and reasons behind plant maintenance. She notes that while the company has a variety of computerized engineering drawings and experience-based reports, it is trying to "improve the cross-referencing so that the information could also be used for engineering purposes." She notes that BNFL's materials database can be used to provide the framework for cross-referencing their purchasing database. Furthermore, a file in the materials database that lists the order numbers and drawings would indicate to the user where the materials had been used before (Martini-Vvedensky 92). Thus, it appears as though BNFL, similar to TxDOT, stands to profit greatly from a computerized materials database capable of capturing experience and expertise.

Clearly, materials databases can be powerful tools in preserving corporate or agency "know-how," which, in a sense, is the goal of this research. Since experience on the historical performance of materials is often scattered geographically and hierarchically in an organization, a materials database can help to centralize that information to provide the engineer with a reservoir of experience gained by others. Perhaps Martini-Vvedensky renders a conclusion most artfully (Martini-Vvedensky 92):

> Collecting, in an electronic and easily retrievable form, reports of experiences acquiring and using specific grades of materials provides a powerful tool for retaining the know-how generated within a corporation….it ensures that detailed observations made by individuals regarding the use of specific materials are retained for posterity.

Martini-Vvedensky's work provides perhaps the most compelling argument for using a computerized database as the centerpiece of any plan to monitor the performance of materials, thus giving credence to the focus of this report.

2.3 SPECIFIC DATABASES AND DATABASE ISSUES

There has been much research directed toward developing new and more powerful materials property databases. This section attempts to outline some of those endeavors and evaluate each for its relevance to the proposed database. This section first discusses expert systems in general and then describes some actual expert systems in use. Following that, object-oriented programming is discussed. The remainder of the section is devoted to describing specific, non-expert materials databases, in use both in and out of TxDOT, and to commenting on their relevance as data sources for the proposed database. As is discussed in more detail in the subsequent chapters, there is a strong desire on the part of both TxDOT and the Research Team to avoid creating an altogether new database. Instead, both would rather create a search engine that "mines" data from other existing databases. Consequently, some existing and populated databases warrant consideration as possible "mines" for the proposed database.

2.3.1 Expert Systems

Much of the recent research on materials databases has focused on the creation of expert systems to store and manipulate materials data. Munro defines the term "expert system" (Munro 97):

> The phrase "expert system" refers to a computerized means of using knowledge and inference procedures to solve problems. Within this functional definition, expert systems are a natural part of advanced technology and are far more practical than might be suspected from their association with artificial intelligence.

Science and industry are moving beyond rudimentary storage and retrieval of data in traditional computerized databases. They are instead moving on to the use of artificial intelligence to finesse the stored data in the manner of an "expert." Anderson notes the difference between databases and expert systems (Anderson 92):

> Traditional databases provide a ready means for cost-effective storage of large quantities of formatted alphanumeric data with few developer constraints, selective retrieval of data, and, in many cases, data manipulation. Databases can readily incorporate data from a variety of resources, be routinely updated, and, if not too tightly structured, serve a wide range of purposes and interests. However, they often do not solve the user's problem at hand, or in themselves, create knowledge, and all too often, they do not incorporate data relating to all of the contributing factors needed for quantitative interpretations. In contrast, expert systems utilize knowledge bases which are relatively small compared to many databases, are considerably more complex in structure, and are, by necessity, highly focused in specific domains. The systems can be informational or advisory and the output can be precise or ambiguous, depending on the nature of the embedded expertise.

Consequently, expert systems are often labeled "knowledge-based systems" because in addition to storing data, they store knowledge or some means of analysis that allows them to advise or inform the non-expert user. Scientific problem solving involves understanding the interrelations of the scientific principles involved, heuristics derived through experience, and a review of much data (Anderson 92). Anderson writes that (Anderson 92),

> The collective knowledge derived in this manner can also be formulated into rules which, in turn, can be the basis for expert systems which mimic expert consultations and can add important interpretive or advisory interface functions to the informational format of traditional databases.

Clearly, using such knowledge, expert systems can be powerful problem solving tools. Munro discusses some of the intangible characteristics of expert systems. He notes the following (Munro 97):

1. Expert systems perform specific tasks with well-defined problems and solutions.
2. They are available continuously, even as humans sleep.
3. The tasks that they perform are mundane, repetitive, and tedious to a human expert, but necessary.
4. Expert systems are interactive. Information is actively supplied to them using sensors or computers.
5. The systems are interpretive.
6. Expert systems are responsive as actions are taken or recommended to alter or maintain the status of the monitored system.

Moreover, expert systems generally consist of the following components: a computer, a knowledge base, and a set of rules. There are limitless applications for expert systems in industry. Munro outlines numerous, common conditions under which expert systems may be beneficial (Munro 97):

5. There are too many inquiries for too few experts. The experts generally have full command of the required information but do not have sufficient time to respond to all of the requests for service.
6. There are too few experts for too large a field. The full scope of information is rarely commanded by any one expert.
7. Expertise is needed on-site at widely dispersed locations. Too much valuable time is spent in transit between locations.
8. Specialized knowledge that is seldom used is needed on demand. There is no time for review or for the expert to be sick or out of town.
9. The expertise is relatively new and commanded by relatively few people. The training of additional experts is not yet cost effective or cannot be accomplished in a timely manner.
10. Large amounts of data must be searched or manipulated. The effort is tedious, but the expert must remain alert to details.
11. Decision-making criteria must be applied consistently over both short-term and long-term periods of time. The decisions must be impartial and reproducible.

12. There is a risk of losing rate or costly expertise through personnel changes. Knowledge or experience is gained at a significant cost, both monetary and temporal.

Anderson also provides an excellent discussion of some of the applications of expert systems and expert system technology, including data query structuring and data interpretation (Anderson 92).

Obviously, a large number of these conditions and uses apply to a department of transportation (such as TxDOT) and its materials information. This makes a materials-performance expert system a distinct possibility for future improvements in the proposed database, as is discussed in more depth in Chapter 7. For example, an expert system might be helpful for transmitting acquired knowledge about inadequate transportation material combinations throughout Texas. Furthermore, Munro notes that expert systems have much power in analysis because they can combine the knowledge of many isolated experts in one centralized system (Munro 95). Thus, whether they are necessary or not, expert systems can play an essential role in mediating the calamities caused by the above-prescribed conditions.

While expert systems are often applied to complex problem solving situations, perhaps the simplest expert system is the thermostat. With the thermostat, the essential computer component is a single microchip. The knowledge base of the thermostat is the data consisting of the desired and current temperature as well as the tolerance and current state of heat flow. Finally, the rules are programmed as an inference procedure expressed as if-then statements (Munro 97). A more complex example would be the new technologies in "smart houses" wherein the vital systems of the house are operated by an expert system that collects data and corrects house conditions based on if-then statements superimposed on the data.

While many publications focus on the general aspects of expert systems, many articles address specific applications of expert systems. Two of these specific applications may provide insight into similar capabilities that may allow expert systems to augment a materials performance database like that being developed in this research project.

2.3.1.1 Materials Selector Expert System

Munro outlines an example of an expert system in a primitive state of development that is used in conjunction with a materials database to select materials for corrosive environment applications (Munro 95). There has been much literature indicating that one of the main applications of expert systems is for use in mundane, yet complex tasks like selecting materials for a myriad of applications. Munro speaks to this when he states that many of the considerations tied to materials optimization are "related in complex ways and can cause material selection to be a recurrent theme throughout the entire product design process." While corrosion and advanced structural ceramics are the focus of Munro's discussion, these similar complications are no doubt present when a material is selected for a transportation application. Some of the considerations complicating material selection include availability of materials, production capabilities, machining and fabrication requirements, essential timetables, and the physical/chemical properties of materials. Expert systems can make this decision-making process much more efficient and systematic (Munro 95). Furthermore, Munro suggests that rather than a single expert system involved in materials selection, a "material selector expert system" is really a collection of numerous expert systems with diverse functions.

Munro's description of how the aforementioned materials-selection expert system makes its expert decisions could be of some importance in future development of the proposed database (Munro 95). The assessment of whether a material is acceptable for use in a corrosive environment can be made strictly based on its laboratory-determined properties through the search mechanisms allowed in many standard databases. The methodology discussed later in this report is similarly laboratory-based.

Munro discusses rules-based analysis that could be very beneficial in a materials performance database for cases where, for instance, a material and an environment or another material were being combined. A more relevant example, similar to the case with corrosion, examines whether aggregate x performed poorly with cement y in concrete. In that case, an "if-then" rule could be incorporated into an expert system to produce warning if a design involving x and y was submitted to the system. The rules that Munro outlines in his system could have a very similar form for a transportation materials-performance database. Furthermore, the reliance this database has on laboratory-determined properties receives greater attention later in this report as a way to evaluate the performance of a transportation material.

Clearly, then, this type of material-selector expert system could serve as a model or prototype for an expert system that would incorporate TxDOT performance and materials data to warn against poor material selection and aid in proper materials selection. While the goal of the current project is to develop the information necessary to develop a database that can monitor the performance of materials, such increasingly "advanced" applications could be the future of this research.

2.3.1.2 NIST's CIKS

Perhaps one of the most advanced expert systems currently in conceptual design is the CIKS or Computerized Integrated Knowledge Based System. CIKS is a "computerized, intelligent system of integrated knowledge base systems providing the knowledge for solving problems of a wide range of complexities" (Clifton 97). More specifically, CIKS will provide the construction industry with a framework for representing data and information to improve service life and durability of structures and components. What is more, CIKS can be applied to numerous problem-solving applications on a variety of construction materials. Clifton describes four examples of the application of CIKS technology applicable to high-performance concrete (HPC) in an effort to illustrate the diversity of the technology (Clifton 97). Additionally, there is a prototype CIKS that predicts the service life of reinforced concrete.

CIKS generates knowledge from a variety of sources including databases, math/simulation models, artificial intelligence systems, guides, handbooks, standards, and codes (Clifton 97). The powerful features that are required in CIKS ensure that it will be more than an average knowledge base. When completed, CIKS will include the following features (Clifton 97):

1. a fully integrated architecture providing automatic transfer across interfaces of knowledge systems
2. an open system, where execution is independent of computer platform software systems
3. a graphical user interface
4. capabilities for knowledge and data acquisition from distributed knowledge systems
5. easy assimilation of new knowledge
6. assurance that knowledge that is integrated has full integrity

CIKS is relevant to this research because it is so readily applied to problem solving applications for a transportation material such as high-performance concrete. According to Clifton, the CIKS-HPC (high-performance concrete) system will be capable of providing information, guidance and recommendations on the selection, design, processing and quality control testing/inspections of high-performance concrete (Clifton 97). CIKS gets its remarkable capabilities from using state-of-the-art computer technologies such as distributed agents, artificial neural networks and remote database access (Clifton 97). Unfortunately, details of CIKS in the NIST literature tend to be rather vague and conceptual; but with its actual creation, many lessons may indeed be learned that can help future development of the proposed database. Consequently, CIKS represents one of the most fascinating materials data/knowledge bases currently envisioned and can serve as an example of the cutting-edge level of capacity that such an information system can embody.

Thus, it seems clear that one main branch of research in materials databases is in the field of expert systems. These systems through their synthesis not only of data, but also of acquired knowledge, are capable of performing some of the more mundane but expert tasks in a variety of fields. It is clear then that, while expert systems are becoming increasingly standard throughout many industries, they do not appear to have been introduced in the field of transportation materials performance. Thus, the future of databases like that proposed in this report seemingly lies in their ability to adapt to expert systems that can not only store data, but also use expertise to make a variety of decisions ranging from materials selection to process monitoring. This should be considered when the proposed database is actually being developed, and, is briefly mentioned again in Chapter 7.

2.3.2 Object-Oriented Data Organization

One of the common problems associated with materials data is the handling of their complex data sets. Database developers are solving this problem using object-oriented data structuring, and consequently, this topic has found a place in much state-of-the-art literature concerning materials databases. Smith, Krishnamurthy, Tripathy, and Page discuss the advantages of this innovative design method (Smith 95).

Object-oriented data structuring is gaining popularity because it leads to more efficient programming. Additionally, object-oriented data structures “enable us to model, as objects, much more complex representations of the real world than is possible with traditional database systems” (Smith 95).

Object-oriented databases are best understood when viewed in contrast with traditional databases. For instance, in most engineering databases, information is stored in the form of data consisting of numbers and identifiers that can be retrieved easily, but always in the same form as they were entered (Smith 95). For example, in a traditional database, an engineer can retrieve data on the strength of a material that might be used to design a bolt, but cannot obtain a selection of optimum materials for the manufacture of that bolt. For this task, the engineer needs "efficient representation and flexible manipulation of the physical laws that may govern many of the relationships between the data objects and their attributes." This would include, for example, laws on how the strength of a given bolt varies with temperature (Smith 95). On the other hand, object-oriented design can aid in attaining these objectives because it provides a "uniform mechanism for handling the many complex data types and interrelationships that can be stored explicitly in the knowledge base." To this end, an object, often physical, will not only be stored with attributes concerning composition and dimensions, but will also be linked to processes used for calculations and analysis. For instance, an object such as data on a rod will be stored with not only the attributes of radius, length and material, but also with an algorithm, called a method, used to calculate its failure load (Smith 95).

In object-oriented design, data representation is based on hierarchies and inheritance. For instance, similar objects with common attributes and processes/methods are stored only once, in a class of objects. This helps save memory space. Objects may inherit attributes and methods from their general class. In turn, these classes may inherit more-general properties from higher classes. Figure 2.4 clearly demonstrates symbolically how this inheritance works. In Figure 2.4, Smith has shown the inheritance for geometrical classes as opposed to materials classes.

While this type of organization/programming can save memory space, it can also greatly aid the user's ability to make use of the data in the database. Smith et al. show the utility of this design scheme. They discuss an experimental system called Quantitative Problem Solver, or QPS. QPS uses object-oriented organization and programming to perform functions that are normally attributed to an expert system. In fact, the knowledge base in QPS consists of objects that are "related to the quantities, formulas, units of measure and geometry" (Smith 95). QPS is capable of using a knowledge base with object-oriented design to solve problems such as optimal material selection. For instance, if an object is specified that is part of the geometric class "rectangular bar," and that bar consists of a given length, tensile stress and modulus of elasticity and which may only elongate by a given amount, the QPS is capable of cross-referencing the materials class and determining which objects within that class suit a given set of specifications (Smith 95). QPS is capable of this type of analysis because it takes advantage of the methods associated with each class to perform the necessary calculations for elongation under load.

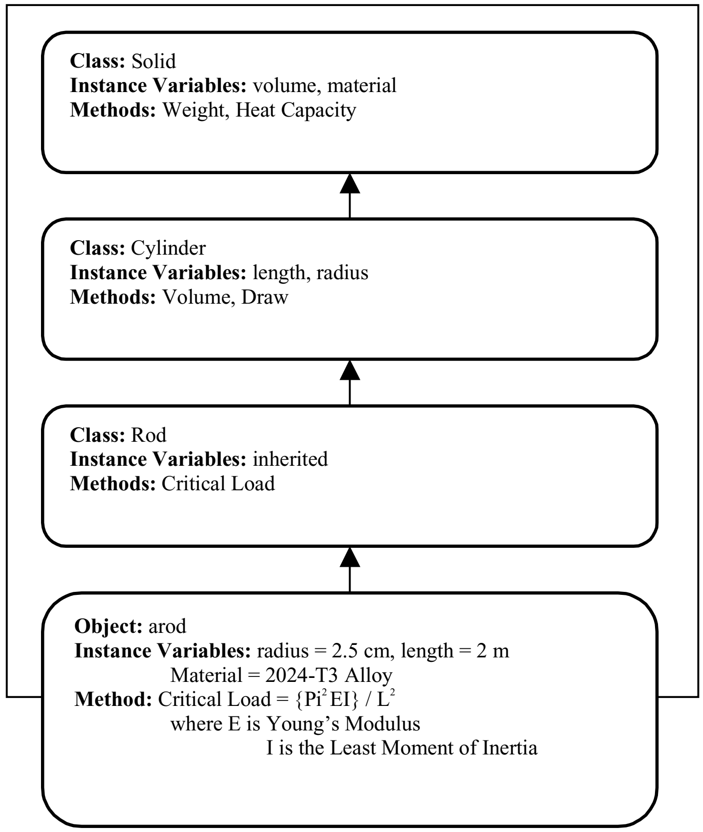

Figure 2.4 Geometrical hierarchy and inheritance (Smith 95)

Based on this simple description of object-oriented organization of materials data, it is clear that it can increase the efficiency of programming and increase the capabilities of expert systems that utilize it. Such an organization/data-structuring may be worth consideration when the proposed material performance database is further developed.

2.3.3 Other Current Materials Databases

While the state of the art in materials databases certainly includes the incorporation of object-oriented design and expert systems, no state-of-the-art discussion would be complete without considering some traditional materials databases that are currently in use. These traditional databases represent the major method of current data storage.

2.3.3.1 Materials Selection Databases

Petrisko outlines one example of a traditional material database that is currently being used. According to Petrisko, the Materials Engineering Center (MEC) database being developed by the Dow Chemical Company is an attempt to attack the problem of too many polymers from which to select for durable goods applications (Petrisko 89). The MEC is designed to supply the end user with engineering data with which to design parts, processes, and for comparison purposes (Petrisko 89). The scope of the activities of MEC includes (Petrisko 89):

1. Thermoplastics and thermosets produced by Dow Chemical Company and its competitors.
2. Physical, thermal, rheological, mechanical, ignition, optical, performance, and electrical end-use properties.
3. The characterization used to evaluate and control end-use properties.
4. Processing parameters, including specifics about the equipment and conditions of operation.
5. The bulk list price in $/lb. and $/cu in.
6. External files containing raw data for further analysis, for example, stress strain curves.

Preventing poor material-selection decisions is one of the main potential tasks in which the proposed database can aid TxDOT users (as is discussed in the subsequent chapter). Interestingly, the MEC database has been quite useful in preventing the inappropriate selection of materials for applications and in evaluating the materials and processes of competitors. Thus, it has given Dow, as the proposed database might give TxDOT, both an economic and strategic windfall (Petrisko 89).

MEC uniquely identifies materials using a combination of product lot numbers, process/product modifications, and data on material preparation (Petrisko 89). Furthermore, MEC subdivides identified materials into groups or families according to their monomeric properties and by using the abbreviations noted in ASTM D1600, *Standard Abbreviations of Terms Relating to Plastics* (Petrisko 89).

Querying the MEC can take two possible forms. In the first form, the user can select a material based on some set of different property combinations. In the second form, the user can address one property at a time and examine the effects of the tested and fabricated conditions on the data while being supplied with measurement statistics (Petrisko 89).

MEC may serve as a very general model for the proposed database. Like the proposed database, one of its main objectives is to prevent the selection of inappropriate materials for applications. It deals with issues in the identification and querying of materials that are similar to those that the performance database may face. According to Petrisko, "Dow's MEC database offers a well-developed capability for selecting, evaluating, and standardizing the data used by researchers and engineers working with structural polymeric materials" (Petrisko 89). These capabilities could be sought in the materials performance database. Finally, MEC may include capabilities for data analysis and integration with computer-aided design programs in the future (Petrisko 89). Consequently, a detailed look at the MEC may be beneficial to future developers of the proposed database.

2.3.3.2 Computerized Pavement Management Systems

In addition to materials databases being used to optimize the selection of materials for applications, they are frequently used to handle infrastructure management. Computerized pavement management systems fit within this group. Computerized pavement management systems are used in many departments of transportation throughout the world for "cost-effective planning of expansion and improvement of the road network, as well as timely maintenance and rehabilitation programs" (Uddin 95). Uddin briefly describes some of these PMSs and their capabilities. Computerized pavement management systems offer a stark example of how materials databases can be used to increase efficiency and reduce wasted resources.

The central data in any computerized pavement management system are related to pavement layer structures and properties at various roadway locations. Such data are important to pavement management functions such as development of performance models and pavement thickness design (Uddin 95).

Computerized pavement management systems exist in a broad range of detail levels, ranging from network-level to project-level applications. The data requirements for these systems are highly reliant upon the level of detail for which the system is designed. The World Bank guidelines on information systems for road management stipulate four information-quality levels, each corresponding to a different degree of resource requirements (Uddin 95).

Uddin outlines many of the steps and issues involved in developing computerized pavement management systems, based on currently operational systems. Such steps include partitioning the road network and identifying the partitioned sections (Uddin 95). Uddin also insists that all computerized PMSs store, at a minimum, construction data, traffic history, and date of last maintenance for each section. Furthermore, all layer material types and property data should be linked to a specific maintenance or construction number that identifies sequential modification to the pavement structure (Uddin 95).

For more detailed explanations, Uddin presents some case studies of PMS databases currently in use. These include a PMS in use by the Strategic Highway Research Program (SHRP) for its long-term pavement performance studies (LTPP), a PMS used by the State of Mississippi, and the aforementioned Dubai PMS (Uddin 95). Each PMS has different requirements and capabilities that represent the range of systems currently in use.

The SHRP Materials Property Database, aptly named the Long-Term Pavement Performance Information Management System (LTPP-IMS), is perhaps the most germane to the proposed database because it focuses on pavement performance. Improving pavement performance through improved material performance is one of the possible objectives that the proposed database could seek to fulfill. The job of LTPP-IMS is to collect and manage a large amount of "good quality inventory and monitoring data" (Uddin 95). The SHRP PMS is a part of the Long-Term Pavement Performance (LTPP) study and is "the largest and most comprehensive pavement performance database ever developed in the United States" (Uddin 95). This database could serve as an indispensable data source for the proposed database.

Clearly, pavement management systems involving materials databases can play a variety of roles in the management of highway infrastructures. In general, they reduce repeated mistakes and streamline the efficiency of road maintenance and construction. More specifically, computerized PMSs could prove influential to this research because of their capacity to store a large amount of data on the condition, structure, and maintenance of roadway structures and, as seen with the SHRP database, because of their ability to tie materials to performance. Selecting materials for use in pavement applications could be one of the possible tasks used to help prioritize data elements in the proposed database, as is discussed later in this report.

2.3.3.3 TxDOT Pavement and Materials Databases

In addition to the PMSs and other "non-expert" databases previously mentioned, the Texas Department of Transportation maintains four particularly relevant pavement and materials databases that are possible data "mines" for the proposed database. This is largely because of the large amounts of materials-related data that they store that might be necessary in a material performance database. To investigate this possibility, each was evaluated carefully based on its background, data elements and structure, uses and applications, updating and maintenance procedures, hardware/software components, and future. The following four databases were the focus of this detailed evaluation: the Pavement Management Information System (PMIS), the Road Life Database (RL), the Maintenance Management Information System (MMIS), and the Texas Reference Marker Database (TRM). From the information gained, it is clear that each can serve alone or synergistically as data "mines" for the proposed database. However, precise definition of the databases' roles will come after the future selection of the actual data elements for the proposed database. As is mentioned later in this report, that selection will have to take place during future database development. Details and findings related to these databases, including interview methods, database maintenance information and updating procedures, are discussed in much more detail in Report 0-1785-1 and will not be repeated here.

2.3.3.4 SiteManager

Another database, SiteManager, which could serve as a data source or "mine" for the proposed materials performance database, is still under development. The American Association of State Highway and Transportation Officials (AASHTO) is currently developing a Construction Management System (CMS), commonly referred to as "SiteManager." The materials management aspect of this database is probably the most relevant to the proposed database. The proposed materials management module would allow daily field inputting of the results from more than thirty different standard field tests (Victorine 98). Such test data, among the other useful data to be stored in CMS, could be quite valuable to short-term performance monitoring schemes that may be implemented in the proposed database.

In contrast to the four aforementioned TxDOT pavement and materials databases, the vast amount of field and laboratory testing data stored in SiteManager could help indicate the short-term performance aptitude of many transportation materials. Consequently, CMS or SiteManager appears to hold great potential as a data source for the proposed database. Unfortunately, since SiteManager is still being developed, it continues to be a moving target for the Research Team.

Information gained about all five of the TxDOT databases during this study, which is discussed in detail in Report 1785-1, is summarized in Table 2.1 and Appendix B so that each can be evaluated as a data source.

Table 2.1 Summary of data aspects of five TxDOT materials and pavements databases

	PMIS	MMIS	TRM	Road Life	SiteManager
Section/ Division Responsible	DES	CMD	TPP	DES	CST
Data Contents (see partial listing in Appendix B)	1, 2, 3, 4, 5, 6, 7, 8, 9	1, 6	1, 2, 8, 10	1, 2, 8, 10, 12	1, 2, 6, 7, 8, 10, 11
Control Section Size	½ Mile	Distance Between TRMs	Continuous	Homog. Sections	Not Applicable
Data Updating Party	District PMIS Coordinator	Maintenance Crew Chief	District TRM Coordinator/ TPP	Ad Lib	Varies
Data Collection Party	District Level	District Level	District Level and TPP	Ad Lib	Varies
Frequency of Data Updating	Annually/Bi-annually	As Needed	As Needed	Ad Lib	Varies
Degree of Population	Complete	Complete	Complete	Sparse	Not Applicable
Material ID Scheme	General Types – Not Specific	Not Applicable	General Types – Not Specific	General Types – Not Specific	Serial Number
Imports from	TRM, RL, MMIS	Not Applicable	Traffic Database	TRM	Unknown
Exports to	Not Applicable	PMIS	PMIS, RL	PMIS	Unknown

Key to Table Data Types	
Number Code	Type of Data
1	Pavement/Material Location Data
2	Pavement Type and Characteristics Data
3	Visual Distress Data
4	Nonvisual Distress Data
5	Pavement Condition Scores
6	Maintenance Data
7	Climatic Data
8	Cross-Section Data
9	Traffic Data
10	Materials Testing Data
11	Construction Administration Data

2.3.3.5 Texas Pavement Research Databases

Databases such as PMIS, MMIS, Road Life, and TRM are TxDOT-operated pavement databases used for pavement management-oriented goals. However, two other databases that focus on Texas pavements for research purposes could also be limited data sources for the proposed database. These are the Texas Rigid Pavement Database and the Texas Flexible Pavement Database.

The Texas Rigid Pavement Database is composed of the Continuously Reinforced Concrete Pavement (CRCP) and Jointed Concrete Pavement (JCP) databases (Victorine 98). The Center for Transportation Research (CTR) at the University of Texas at Austin has maintained this research database since 1974. As a research database, it contains data on sample sections of rigid pavements from across Texas. The Texas Rigid Pavement Database is updated periodically when these sample sections undergo condition surveys. The database contains geometric, environmental, construction, traffic, and inventory data elements (Victorine 98). However, the specific "data elements contained for each pavement type reflect the different distress types and design considerations associated with that type of pavement" (Victorine 97). The historical pavement performance data stored in the Texas Rigid Pavement Database can be used in analysis and design model development as well as in pavement management decisions. It is possible that this database could serve as a critical source of pavement materials performance data for the proposed database. Unfortunately, its data are not likely to be as widely accessible as the data stored in the larger, aforementioned TxDOT databases.

The Texas Flexible Pavement Database is for flexible pavements that the Texas Rigid Pavement Database is for rigid pavements. It has been maintained by the Texas Transportation Institute (TTI) since 1972. It is also a research database, containing detailed data on 350 sections of flexible pavement that were selected as a "random sample of the state's pavements proportional to the total mileage of each class of roadway" (Victorine 97). Currently, the Texas Flexible Pavement Database is a microcomputer database-management system. Like the Rigid Pavement Database, the Flexible Pavement Database focuses on construction and distress data and is updated periodically via condition surveys. The Flexible Pavement Database may be used in performance predictive equation development, design model development, and pavement management decision-making. Consequently, it too could serve as a critical source of pavement materials performance data for the proposed database.

2.3.3.6 The Aggregate Database

One of the more basic types of database that could be used to greatly aid a materials performance database such as that proposed is the simple materials property database. For instance, the proposed database could be more quickly populated if basic materials-property data could be imported from another database. Fowler and Morris from the University of Texas at Austin have created such a database through the International Center for Aggregates Research (ICAR) by working in cooperative agreement with the United States Bureau of Reclamation and the Federal Highway Administration (FHWA). It is called "The Aggregate

Database" (Fowler 97). Figure 2.5 shows a sample printout from that database, illustrating some of the data elements contained within it.

Using a relational database structure, these researchers have managed to create the first national database in the aggregates industry (Fowler 97). This database currently contains data on more than 2,200 reclamation aggregates throughout the western United States, with each record containing general information, location information, physical properties, concrete data (limited cases), and petrography results (Fowler 97). The Aggregate Database identifies aggregates with a unique sample number that is assigned by the Bureau of Reclamation and is analogous to the social security number of an individual. Fowler and Morris note that one weakness with the database is that a user must know the unique sample number of an aggregate in order to view its record, yet the common user may not possess this knowledge (Fowler 97). While a query function eventually allows the user to examine the record, this is a less than ideal method. Once a record is found, it may be easily printed or simply viewed on the computer monitor using Microsoft Access 2.0 or Microsoft Access 97 software.

The Aggregate Database is by no means a complete venture; however, Fowler and Morris believe its future is "very promising" (Fowler 97). Currently, more and more reclamation records are being added to the database, and work is underway to include FWHA records (Fowler 97).

Future developments include optimizing the database by reducing search/run time; providing an Internet interface for on-line queries and data forms to upload aggregate data; providing an Internet-GIS interface; incorporating aggregate quality data from FHWA, COE, state DOTs and other organizations; and distributing aggregate quality data on CD-ROM (Fowler 97). It would thus be of great advantage to adapt the proposed database such that it could import the vast body of aggregate data that is already available in the Aggregate Database. Clearly, any database like the Aggregate Database could greatly aid a performance-monitoring scheme that is based on simple material properties and constituent material properties, as is discussed in the subsequent chapters and sections.

2.4 PAVEMENT AND MATERIALS PERFORMANCE RESEARCH — LTPP

This review of the current state of the art of materials databases and materials data provides a background to aid in developing the "computer" aspects of the proposed database. However, further literature review on material properties and material performance is required to answer questions related to which materials and properties should be included in the proposed database.

It is often tempting to turn this research into an investigation of pavement performance rather than materials performance. This may be because it is so much easier to think of transportation materials performance in terms of the long-term field performance and condition of some roadway to which they were applied. Moreover, pavement performance definitely would be an important field to investigate in developing the proposed database if performance monitoring were to be based on long-term field performance. On the other hand, as other portions of this report clarify, the plan developed by this research to monitor the performance of transportation materials is based, for many reasons, on a short-term, material property-based scheme. One of those reasons is that the effects of materials and material properties on long-term pavement performance is already the subject of some extensive, detailed, ongoing research projects. An understanding of long-term field performance is a task that simply cannot be tackled by this limited research effort. This section is an effort to outline some of those long-term pavement performance research efforts because future development of the proposed database may move in this direction and because pavement performance research could play a role in prioritizing material properties to include in said database.

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US Department of the Interior
Bureau of Reclamation
Aggregate Quality Evaluation

Important Notice: Information contained in this data sheet regarding commercial products may not be used for advertising or promotional purposes and is not to be construed as an endorsement of any product by the Bureau of Reclamation.

Sample Number:	M-6392	**Material:**	Sand and Gravel				
Deposit/Source Name:	Buttes damsite						
Source Owner:							
Location:	Near centerline of Buttes damsite						
State:	AZ	**Region:**	LC	**Latitude:**	33 deg. N	**Longitude:**	111 deg. W
Section:	SE 1/4, Sec. 11						
Township:	4S	**Range:**	11E	**Meridian:**	Gila and Salt River		
Date Received:	5/31/72	**Letter Transmittal Date:**	5/19/72				
Volume:	Cu yd	**Overburden:**					
Comments:	Sample from Hole 1 (depth 0-5 feet)						

Test Procedure	**LA** Abrasion	**Percent Loss** 100 Rev	500 Rev
LA Abrasion, Des 21	A	4.5	21.7

Freezing and Thawing Data **Material:**
W/C Ratio | Slump - inches | % Air, Meter | Water, lbs/yd, | 28-day Strgth | Mass Lss. % | Cycles: | Units:

Notes:

M-6392	**6" to 3"**	**3" to 1-1/2"**	**1-1/2" to 3/4"**	**3/4" to 3/8"**	**3/8" to No. 4**	**Fine Agg**	**Washed FA**	**Course Agg**
								Units: English
Sodium Sulfate Loss, 5 Cycles, WGTD. % (Des 19)							7.5	5.5
Percent Silt, (Des 16)						8		
Organic Impurities, (Des. 14)						No. 4	std	
Absorption, % (Des 9, 10)		1.3	1.1	1.3	1.7		1.4	
Specific Gravity, SSD (Des 9, 10)		2.8	2.86	2.87	2.63		2.64	

Grading (Des 4,5,6) Cum % Ret. **M-6392**

Sieve	6in	3-1/2in	3in	2-1/2in	1-3/4in	1-1/2in	1-1/4in	7/8in	3/4in	5/8in	3/8in	5/16	No.4	No.5	No.8	No.16	No.30	No.50	No.100	No.200	Pan	PM	%Sand
PC Run	0		0			17			48		82		100									747	22
Fine Aggregate													0		30	48	58	70	89		100	294	
Washed Fine Aggregates													0		34	52	63	74	91		100	314	

Petrographic Results

Petro Memo Number 72-76 **Memo Date:** 12/20/72 **Author:** S. Rubenstein

Summary The gravel, essentially subround in shape with about 80 percent subround and 1 percent flat particles, is composed mainly of granitic rock, rhyolites, and intermediate volcanics, amphibolites and other metamorphics, quartzite, and sandstone with lesser amounts of limestone, basalt, glassy rhyolites, and intermediate volcanics, chalcedonic quartz and chert. About 35 percent of the gravel is physically of fair quality because of fractures present and 31 percent alkali-reactive. The sand, subangular to angular in shape, is composed of the same rock types found in the gravel plus increasing amounts of monomineralic grains of feldspar, quartz, homblende, pyroxene, biotite, muscovite, epidote, serpentine, and magnetite. About 1 percent of the sand is physically unsound and about 20 percent alkali-reactive. About 30 percent of the particles were fractured.

Figure 2.5 Sample printout from the Aggregate Database *(Fowler 97)*

Much of the current pavement-performance research discussed in literature is the result of the Long-Term Pavement Performance program (LTPP) of the Strategic Highway Research Program (SHRP). SHRP was begun in the mid-1980s because of recommendations of the FHWA-sponsored Transportation Research Board (TRB) Special Report 202, *America's Highways, Accelerating the Search for Innovation*. That report recommended six important research areas that were combined into the SHRP. One of those research areas is long-term pavement performance or LTPP. The general goal of LTPP is to analyze pavement performance and the factors that affect it. Two sets of experiments were established within the LTPP 20-year research program. The General Pavement Studies (GPS) focus on test sections located on existing pavements, and the Specific Pavement Studies (SPS) involve specially designed and constructed pavement test sections. For both aspects, more than 2,000 sections are located on in-service highways throughout the United States and Canada and are subjected to a variety of loading conditions and climatic environments. According to Rabinow et al., the data collected on pavement sections for the SHRP LTPP research can be divided into five categories (Rabinow 93):

> (a) inventory data describing the location, geometry, and construction history of the test section; (b) monitoring data such as distress, profile, and deflection, which are collected to monitor changes in the pavement over time; (c) traffic data, which describe the loading to which the pavement is subjected; (d) climatic data, describing the environmental conditions to which the pavement is subjected; and (e) maintenance and rehabilitation data, describing and defining any and all maintenance applied to the pavement.

In a previous section of this chapter, the PMS system that stores much of this data mentioned. This vast amount of uniformly collected data has given birth to countless studies ranging from development of future pavement performance studies to modifications of standard pavement design equations. A brief summary of just a handful of those research projects will be outlined to illustrate what some of the state-of-the-art research in pavement and materials performance entails. This research, which often attempts to redefine the issues involved in pavement and materials performance, may someday be relevant to future development of the proposed database.

One main type of materials performance research that is a direct result of LTPP data collection is studies that evaluate the validity of current pavement design equations and that devise other types of pavement performance models. For instance, Owusu-Antwi et al. attempt to evaluate the AASHTO rigid pavement design equation using data collected from some of the concrete pavement sections in the LTPP study. Using statistical analysis techniques, Owusu-Antwi et al. are able to compare the actual number of equivalent single-axle loads that cause a given amount of damage on a given roadway to the AASHTO-predicted number of equivalent single-axle loads (ESALs) that would cause that damage on a given roadway (Owusu-Antwi 93). They are able to determine that modifications made to the AASHTO design equation since its creation had made the equation an increasingly accurate predictor. Owusu-Antwi et al. note that, "Although the results are preliminary, they show to a large extent that the current AASHTO design equation in the 1993 Guide reliably predicts the cumulative ESALs required to cause a given loss in serviceability for concrete pavements" (Owusu-Antwi 93).

In a similar manner, Robinson et al. describe how they created a distress prediction equation for rigid concrete pavements using distress data from the Texas PMIS database (Robinson 96). Their model uses a sigmoidal equation form with unique shape coefficients for each type of distress on each type of rigid pavement (Robinson 96). They noted that, "The number of dependent variables in this equation make it sufficiently flexible to model a wide variety of pavement performance characteristics." However, this is a purely empirical equation, rather than a mechanistic explanation of distress progression, and thus its application is limited to pavements similar to those upon which it was developed (Robinson 96). Finally, Kerali et al. discuss a data analysis procedure by which a pavement performance relationship was derived for rutting using LTPP data (Kerali, 96). Clearly, such studies could prove to be valuable sources for the future research associated with the proposed database. Models and design equations such as these help indicate what variables affect pavement performance and distress for different pavement composites and thus could help the Research Team select the proper data elements for materials performance monitoring in the proposed database.

Another similar body of research, also a direct result of the data collected for SHRP LTPP, has sought to analyze the effects that LTPP would have on future pavement design methods and on the current *AASHTO Guide for Design of Pavement Structures.* Hadley outlines the topical areas in that guide that could undergo a change because of the SHRP LTPP program (Hadley 93). He concludes that the areas of the guide most likely to be affected by these new data analyses include the design equations, serviceability measurements, materials characterization, and rehabilitation (Hadley 93).

> [The] AASHTO serviceability concept will be retained as the basic measure of the 'user rating' of acceptable pavement performance; however, serviceability (or rideability) will be defined through pavement roughness measurements such as International Roughness Index (IRI).

Additionally, Hadley predicts that "distress-specific" rather than distress-generalized relationships will be developed and used as a result of LTPP data.

In a similar paper, Rauhut used the first set of data analyses from the LTPP's National Pavement Data Base (NPDB) to perform sensitivity analyses for rutting, change in roughness, and transverse cracking. In addition, he also used that data to evaluate the AASHTO flexible pavement design equation (Rauhut 93). Rauhut also recommended improvements in AASHTO design procedures, including the use of separate design equations for the several significant distress types instead of the current use of a "composite index" (such as the Present Serviceability Index). These equations could then be used for both pavement management and balanced designs to control distresses individually (Rauhut 93). Clearly, the LTPP research may lead to significant changes in the design procedures that are being analyzed. It will be important for the research staff to monitor any such changes or research recommending them in the near future so that data elements can be reasonably selected for the proposed database.

The preceding paragraphs are brief descriptions of but a few of the numerous research projects that are a direct result of the SHRP LTPP data collection. That program continues to produce research that could be very relevant to the proposed database. While this research and this report are not directed at pavement performance, one task for which the proposed database might be used is selecting materials for use in pavement construction. Consequently, pavement design procedures, as well as long-term pavement performance data, which will be discussed later in this report, could be critical to prioritizing data elements for inclusion in the database.

2.5 CONCLUSION

There has been a great amount of work conducted in the fields of materials data, materials databases, and pavement and materials performance that is relevant to the proposed database. Furthermore, much of this work has been and will continue to be an important guide to current and future research for this project. As previously discussed, it is clear that data formats previously created by standards organizations (NIST, ACI, and ASTM) can be adopted into the proposed database when the data elements required in that database have been selected. Furthermore, the advantages of preserving corporate know-how have been made clear for the purposes of making sound organizational decisions, which lends further credence to the central goal of the research, developing a database to monitor performance of materials.

Other research has made it clear that the future of such databases is development or modification into artificial intelligence as embodied by the expert system. These systems can perform a surfeit of mundane, yet high-level, tasks, and allow experts, such as those at TxDOT, to carry on more challenging work. It is not hard to imagine the proposed database one day being updated into an expert system capable of increasingly high levels of data manipulation. Furthermore, the database could also stand to profit from an object-oriented design that allows for increased efficiency, more streamlined programming, and greater capacity for complex data relationships.

As previously described, there are numerous other databases currently in operation that can serve as models for the proposed database. Moreover, databases like PMS databases, SiteManager, the TxDOT pavement/materials databases, and the Aggregate Database can serve as data sources from which the proposed material performance database can be populated. Finally, performance models that are being created and evaluated as a result of data collected during the SHRP-LTPP study could help identify material properties that will be critical to contain in the proposed database to monitor materials performance. This type of pavement performance research could be helpful in selecting data elements, should the goal of the proposed database be to help select materials for pavement applications. An example of this is shown and described later in this report.

This research has pointed out some of the information that can be assembled to advance this very general research now and during future development of the proposed database. The information summarized in this report can be used to avoid a "reinventing of the wheel," ensuring that this research paves new and unique paths. It should be consulted and used during as many future development phases as possible.

CHAPTER 3. REVIEW OF USER REQUIREMENTS, RECOMMENDATIONS, AND THE EXPERT TASK GROUP MEETING

3.1 INTRODUCTION

There are many options to explore for a database used to monitor the performance of repair and new construction materials. Obviously, much of the content of this report is related to determining the material properties needed to monitor the performance of various materials. However, other more abstract concepts and principles need to be addressed in order to develop a method for properly selecting those properties. The collection of specific user requirements, ideas, and recommendations is the means by which to address the more abstract concepts that will define the scope, purpose, and conceptual focus of the proposed database. For example, how can specific data elements and material properties be selected for monitoring the performance of materials if it is unknown by what method performance is to be monitored? Furthermore, how can material properties be selected if the functional purposes or the focus materials of the database are unknown? These questions could have more than one correct combination of answers and thus define multiple databases capable of monitoring the performance of some materials.

The goal of soliciting user requirements, ideas, and recommendations was to produce brainstormed ideas about how to create a database for monitoring the performance of materials that best meet the needs and demands of TxDOT users. It was a start to answering these larger questions, but not a definitive end. This chapter identifies the user requirements, ideas, and recommendations that have been offered by TxDOT technical staff through the aforementioned channels. It also seeks to summarize some of the discussions that have been shared between the Research Team and TxDOT during the research behind this report. As a start to answering these larger questions, the ideas and recommendations presented in this chapter are often starting points for discussions on a variety of topics later in this report. This chapter in no way seeks to provide definitive specifications regarding the design and construction of a database.

3.2 MEETINGS/DISCUSSIONS WITH TXDOT PERSONNEL

The expert task group (ETG) meetings with the project director and coordinator provided the CTR research team with much user input regarding the proposed material performance database.

On September 23, 1997, a meeting was held between the research team, which included Dr. David W. Fowler, Dr. Zhanmin Zhang, Dr. W. R. Hudson, Dr. Virgil Andersen, Matthew Rechtien, Mark Milton, and members of the project advisory committee (PAC), including Mike Koen (project director) and George Lantz (project coordinator). This meeting was intended to introduce all of the attendees, to reach consensus on the general nature and direction of the project, to discuss future interaction between the attendees, and to discuss some general user requirements and recommendations.

On January 22, 1998, a daylong ETG meeting was held that consisted of discussions and consensus building between members of the CTR research team and a diverse set of

TxDOT technical personnel. The main purpose of this meeting was to solicit opinions from TxDOT regarding the user requirements and structure for the aforementioned material performance database. This included user requirements and recommendations related to topics such as material definition, types of materials in the database, and performance definitions. A complete list of the ETG meeting attendees as well as a detailed summary of the contents of its discussions is available in Appendix A. The central issues discussed at the ETG meeting are summarized later in this chapter.

It is the combination of the ETG meeting, the meeting on September 23,and various other interviews that are the founding discussions for the following topics.

3.2.1 Discussion Topic: General User Requirements and Database Functions

At the heart of developing a database is an understanding of the tasks and functions required of the database and the personnel involved in using it; these comprise, in a sense, the most general of user requirements. This understanding is necessary because while the purpose of the database is to monitor the performance of materials, more specific, task-related, end purposes must be known. As will be discussed throughout this report, it is impossible to have a detailed definition of the data contents of the proposed database without having a clear set of tasks defined.

At the meeting with the members of the PAC, functions, tasks, and intended uses of the proposed database were briefly discussed. For instance, many agreed that the purpose of the proposed database should be to avoid repeated mistakes in material selection. Others felt that the database should help identify which combinations of materials had poor performance records in contrast to isolated materials taken without regard to environment and material interactions. Furthermore, everyone agreed that the database should be flexible, easily modifiable and able to operate when lacking large amounts of data.

Similarly, at the ETG meeting, there seemed to be wide concern among the participants as to who would be using this database and for what specific tasks. Not surprisingly, the task group unanimously agreed that it could not address more specific questions about the database, such as data contents, until it knew the users of and tasks assigned to the proposed database. Consequently, very general discussion of user requirements and basic functions occupied a large part of the ETG meeting.

At times during the ETG meeting, Project Director Koen and Project Coordinator Lantz asserted their vision of the database, which included a very broad range of users from researchers to division-level engineers to district- and area-level engineers. Since the background and job description of members of the ETG were as diverse as the range of users, each member was allowed to identify specific tasks (i.e., user requirements) for which they thought the material performance database could be employed. The user requirements and tasks were as follows:

- capturing and digitally transmitting "word-of-mouth" knowledge within the department; such knowledge is often lost when TxDOT expert engineers retire or change jobs;

- evaluating material aspects of contractor design submittals and improving contractor-submitted designs;
- examining 100 projects throughout the state to gain a perspective on how well a given material has performed in conjunction with a variety of environments and co-constituents; this might allow an engineer to use materials better in design;
- making simple comparisons between two similar materials, such as keeping track of how long each endures similar environments;
- maintaining a "fingerprint" database by storing information on "bad actor" materials that in the past have only been committed to fading, vague memories;
- highlighting and repeating particularly well-performing designs;
- eliminating the repetition of mistakes and poor designs by indicating problem patterns and sharing information;
- creating performance-based specifications by determining which materials properties affect materials performance;
- creating and maintaining mechanistic design models by monitoring newly used materials in the transportation infrastructure;
- quickly verifying statements made by pressuring salesmen;
- eliminating the need for many test road sections;
- determining how various other districts are handling different types of material problems;
- identifying materials sources, querying materials properties and qualities, determining if a material that was used on a project performed similarly on other projects within different districts, and avoiding redundant testing of materials which have never failed a given test;
- evaluating long-term performance of pavements and comparing them to specification requirements;
- identifying historical construction data that could support quality assurance/quality control (QA/QC) specifications;
- assisting in filling out survey responses and answering legislative inquiries; and
- determining which data records and system capabilities were in the highest demand through a monitoring system and allowing for an online feedback system that gave users an interface with system administrators.

Obviously, not all of these user requirements and desired functions can or will be available in the database when it is finally developed. For example, the database scope discussed later in this report will indicate that the proposed material performance database should focus on using short-term, lab-tested performance measures such as material properties, rather than long-term field performance, to predict and define performance. Because of the project constraints, these two methods of measuring and estimating performance are non-compatible. Therefore, while this scope for the database aptly supports functions such as creating performance-based specifications by determining which materials properties affect materials performance, it does not support some of the long-term pavement performance functions mentioned above. These user requirements and suggested functions are not mandatory demands, but rather suggestions as to how a material performance database could be helpful to TxDOT personnel.

The obvious conclusion is that wide ranges of potential users, as represented by the varied background of the expert task group, think that this database could greatly aid many functions and improve the efficiency of TxDOT by monitoring materials performance.

3.2.2 Discussion Topic: Defining a Material by its Whole or by its Constituents

As will be discussed in later in this report, one critical action to be taken during this research is selection of the level of material-property detail that is appropriate for the proposed database. That is, once a material is selected for inclusion in the database, into which appropriate constituents should it be divided? For example, with concrete, should data be included in the database for properties of concrete mix constituents, or should data in the database only consist of composite properties and mix proportions? Predictably, before the CTR Research Team ever answered this question, TxDOT technical personnel at the ETG meeting tackled it.

The ETG expressed great concern over this topic. ETG members recognized the value of storing constituent data. For example, members suggested that extensive constituent property data could help in improving pavement design procedures, enhancing specifications, and identifying patterns of inadequate material usage.

On the other hand, many ETG members felt that the more constituent properties that were included (no matter how relevant to performance they were), the costlier the data collection efforts would be. Additionally, many members of the ETG suggested that much of the data at both the constituent and composite levels simply are not available within the infrastructure of TxDOT. In fact, ETG members were wary that the volume of constituent data required for collection by such bodies as ACI 126 (Chapter 2), too much of a burden. This is especially true when compared to the diminishing returns it provides for identifying patterns of materials performance. Therefore, the best strategy is to start with a relatively small database with the most essential data and let the database grow gradually in practice.

The ETG was obviously circumspect about the proposed material performance database containing too much constituent data. However, it was agreed that the database must contain some constituent data, if only to assure that those constituents meet some minimum level of adequacy. The ETG members generally felt that the level of data to be stored should depend on the material in question. Varying materials have varying sensitivities to various constituent material properties. Consequently, the importance of knowing the value of the constituent properties of a material depends largely on the material's sensitivity to them. Thus, the ETG felt that selection of important material properties for the database would have to be made case by case and involve some cost-benefit analysis for collecting and storing various properties at varying levels of detail. The information presented in the rest of this report should aid in this case-by-case analysis and in selection of materials for the database. The ETG felt that, while it is necessary to store some constituent data, the important decision in developing this database will be how much and for what materials to store this additional data.

3.2.3 Discussion Topic: Defining Performance for a Material

Clearly relevant to the development of any database that focuses on material performance is the meaningful definition of the performance of materials. Before the Research Team could attack this task and come up with the solutions that are presented later in this report, opinions were solicited from TxDOT technical personnel at the ETG meeting about how to define and codify material performance. A plethora of questions surrounds this nebulous task, allowing for a large number of possible solutions. For instance, should performance for a material be based upon laboratory test results or field test results, and within each of these, should performance be judged as long-term or short-term? Each combination of performance criteria composes a new performance "scenario."

The ETG members had a variety of suggestions as to how performance could be defined and evaluated for the proposed database. Two similar suggestions were that, for instance, a pavement failure or material failure could be indicated by the maintenance dollar amounts spent on repairs or the number of repairs to the road section/product. Similarly, performance could be evaluated by learning how long the product or material remains in service or how much loading it has undergone. This would constitute using field performance as the main judge of the quality or performance of a material. However, ETG members were quick to indicate that such dollar or time-in-service evaluation/performance criteria would be seriously hampered by the fact that the different district-level, repair-resource, allocation methods are neither uniform nor scientific. That is, one road section or material in one district could be in a substantially less serviceable state and receive the same maintenance dollars/repairs as a road section in another district. Thus, a number of unquantifiable circumstances could cloud this basis of comparison. Such criteria do not include mitigating circumstances such as abuse to, and varying environmental conditions surrounding, a given material. Chapter 5 discusses these mitigating factors and their clouding of comparison in more detail. Clearly though, trying to evaluate accurately the performance of or quality of a material based on long-term, field-based application performance is very difficult without extensive environmental, construction, and/or loading data.

In contrast to the above-discussed field and long-term performance-based criteria, the ETG members also discussed some laboratory-based, short-term performance evaluation measures. One of the ideas was that numerical, threshold material-property values, would indicate failure for a material or product when not met. While most of the ETG members were thinking of threshold values in terms of pavement distress/condition, such as a minimum Pavement Serviceability Index (PSI) and maximum rut depths, such a threshold-based performance evaluation would also make sense with constituent materials. For example, minimum compressive strengths or densities could be set as the performance criteria for a portland cement concrete. According to one ETG member, different threshold values could be set to indicate a failure in functional, operational and/or structural (in the case of pavement) subcategories. While many ETG members agreed that this would be a strong approach, another faction suggested that it would be impractical to actually define such values and make them compatible between TxDOT districts. This is because each district would have different, individual needs and appropriate threshold values. Furthermore, many thought this performance measure was also problematic since often TxDOT engineers cannot even agree on how to measure threshold values such as PSI and rut depth. For example, some engineers prefer measuring rut depth with lasers while others use straight edges. While it may be difficult to define acceptable thresholds for material or product property values, the general concept of using material property values as measured in the laboratory appears to be sound and is the focus of much discussion throughout this report.

More in tune with the methodologies discussed later in this report, some ETG members suggested that pavement performance is not really the focus of the proposed database and that other materials would require different methods of evaluation. Others suggested that some materials simply elude any definition of performance. One ETG member warned that any performance criteria would have to be as standard as possible. As such, the definition of performance would be greatly simplified if it were based on short-term parameters. Such parameters could include lab testing in a controlled environment rather than in the field, which is beset with many varying boundary conditions. The advantages of this view of material performance are discussed in detail in the scope and methodology portions of this report. Finally, the entire ETG agreed that with any performance evaluation method, accuracy of data should be preserved since they felt that bad data would be worse than no data at all when they made decisions regarding performance.

The ETG reached no definitive agreement on how to measure and evaluate performance. While most members agreed that a field performance-based scheme would be desirable, members agreed that such methods would be extremely difficult to define, especially since long-term performance is the main focus of many other larger research projects across the nation (as mentioned in Chapter 2). On the other hand, many believed that a simpler, short-term, laboratory-based criterion would be more workable, possibly based on threshold levels. This approach is discussed in more detail throughout this report. Deciding on ways to approach performance evaluation became one of the larger tasks and issues associated with this research. However, the ETG meeting helped bring to light some of the alternative solutions for this problem.

3.2.4 Discussion Topic: Prioritizing and Identifying Materials to Include in the Database

It is extremely critical to decide which materials need to be in the database; these are the materials on whose performance the database will focus. Furthermore, there is no simple, objective way to decide which materials should be in the database; this decision is driven by the needs of TxDOT. Consequently, at the ETG meeting and at the meeting with the project director and project coordinator, time was spent discussing the materials to be included in the database.

At the first meeting with members of the PAC, many of the attendees felt that bituminous and portland cement concrete materials would have to be the first priorities for the database. However, with extra budgetary freedom and with a flexible database, more materials, such as joint sealants, could later be added. A great deal of the discussion throughout this report relies on the database being flexible to the point that more materials and material properties could be added as resources for monitoring them become available. This report can serve as a blueprint for adding more materials ad lib.

At the ETG meeting, much of the discussion was focused not only on what specific materials to include but also on methods by which to make rational material prioritizations. For instance, one ETG member recommended that materials be prioritized for inclusion in the database based upon their monetary share in TxDOT's budget, or by what was commonly referred to as "cost indexing." Many ETG members criticized this monetary focus and argued that many materials that are non-large dollar items will be excluded, including some of those whose performance is equally important because of their large impact on safety. Still more ETG members added that prioritizing by dollar expenditures is flawed because it only focuses on initial costs and does not account for maintenance and rehabilitation costs. For example, by this method of prioritization, TxDOT would tend to overlook bituminous concrete mixes because of their relatively low initial cost, despite the fact that bituminous mixes tend to generate more maintenance work, which can generate hidden repair and operational costs. Consequently, while ETG members generally agreed that measuring initial cost is a good way to begin prioritizing, it is flawed and must be used judiciously.

Another important concept raised with regard to prioritizing materials to include in the database is that any such method of selecting materials is and should be completely user/function-based. For instance, while a repair engineer may be more interested in the performance of coating materials and would require the database to focus on them, a pavement engineer would require the same focus on portland cement concrete. Consequently, according to one ETG member, materials cannot be appropriately selected for the database until the users and functions of that database are more clearly chosen. As is discussed throughout the remainder of this report, this step is not taken in this report. It is incumbent upon TxDOT to make that step should the proposed material performance database advance anywhere beyond the conceptual and methodological stage in which it currently is.

While the ETG generally agreed that it is difficult to select materials and material properties for inclusion in the database before users and functions are more clearly outlined, they did continue to discuss other methods of prioritizing. Some of the conclusions and points made during that phase of the meeting are summarized below:

- Safety should be a prime factor in prioritizing materials.
- Frequently failing materials should be the focus of the database.
- QC/QA specification materials should be included in the database because data on these materials are needed to evaluate their performance under that specification.
- Pavements and bridges constitute approximately 60 percent of TxDOT's attention, therefore, the database should focus on them rather than peripheral materials such as signage.
- The database additionally needs to focus on safety improvement as a part of functionality.

- Bridges, due to their uniformity, need not be a prime focus of the database.
- The database must remain broad-based and should be build with a pilot project and then be expanded.

In addition to these other prioritization ideas, many ideas were presented by ETG members regarding specific material properties to be included in the database. They are summarized as follows:

- The database must hold only hard number properties rather than judgment properties, allowing users to evaluate the data rather than being forced to abide by judgments of others that might appear in the database.
- The database would need to include properties relating to traffic and climatic information.
- It could be a source of confusion to include properties such as "ride," which is an important property used to define the performance of a material, because they are composite/structural (in this case pavement), not materials properties; however, the materials database should be able to access ride data when needed.

Some of these points are addressed in the scope and methodology portions of this report. For example, the report will later explain that while traffic and climatic information are important to performance, especially in the long-term, they are not necessarily needed in a database focusing on short-term, lab-based performance.

The remaining chapters focus on developing a methodology for including any material in the proposed database and on demonstrating that methodology for three large-budget items. It is impossible in the scope of this research and this report to develop a comprehensive list of materials and their relevant information. However, when the database is more clearly defined in terms of users and functions, the thoughts on material prioritization expressed here and the relevant work appearing later in this report will be instrumental in developing the database.

3.2.5 Discussion Topic: "As Built" vs. "As Designed" Material Data

Another topic that received some degree of consideration at the ETG meeting was whether the materials data stored in the proposed materials performance database should be of an "as built" or "as designed" nature. The choice between these alternatives becomes particularly forced if performance is defined as short-term and is based on laboratory testing, as was discussed at the ETG meeting. The ETG generally agreed that for the purposes listed above, in which they envision the database being of assistance, "as built" data would be more appropriate and more important to collect than "as designed" data. For instance, in trying to gauge the performance of portland cement concrete, an engineer would more likely be interested in the "as built" compressive strength than in the "as designed" mix compressive strength. The ETG agreed that this is largely because the "as built" data for a given material would provide better insight into the actual behavior and performance of a given material and would serve to highlight any glaring inconsistencies that would make comparison between two such materials meaningless. For example, one ETG member stated that if he or she were investigating a particular portland cement concrete mixture, the "as built" slump would be a much better clue into the performance of concrete than would an "as designed" slump.

While "as built" data are certainly preferred, it was agreed that "as designed" data are not completely useless. One ETG member suggested filling the database with "as designed" data until "as built" data could be obtained and inserted through testing. Another ETG member stated that users would be better able to make historical data comparisons if design values were saved in the database along with "as built" data. Finally, another member stated that "as designed" data could be helpful in determining whether a design or construction problem caused a given material to fail. Ultimately, most ETG members agreed that while "as built" data are definitely a first priority, "as designed" data should also be included whenever reasonable and possible.

3.2.6 Discussion Topic: Relevance of SiteManager as a Data Source for the Materials Database

As is discussed in Report 0-1785-1 and Chapter 4, one of the most important efforts in developing the materials performance database is identifying sources of material data already stored within the TxDOT infrastructure. Such data mines will, among other things, allow the proposed database to serve primarily as a search engine and thereby reduce the data collection effort required to operate that database. The SiteManager database may have the greatest potential to serve as a data mine for the proposed database because of its extensive materials data. Consequently, time at the ETG and PAC meetings was devoted to discussing the possible interaction between the proposed material performance database and SiteManager. At the first meeting with members of the PAC, the consensus was that databases such as SiteManager could serve as excellent sources for the data that would be needed on a materials performance database. Everyone felt that a deep analysis not only of SiteManager, but also of other TxDOT databases, would be an essential phase of this project. Consequently, these analyses were summarized in Chapter 2 and are found in Report 1785-1.

Similar to the attendees at the meeting with members of the PAC, many of the ETG members felt that SiteManager could be a particularly useful data source because TxDOT users will populate its data fields. Moreover, many of the ETG members agreed that much of the materials data sought for the material performance database would be stored in the SiteManager database (Appendix B). On the other hand, some of the ETG members expressed the concern that the limited capacity of SiteManager to support queries could limit its use as a data mine for a search engine such as the proposed material performance database.

Since SiteManager was seen as a "moving target" by many within the ETG, it was agreed that the CTR Research Team should further investigate that database and follow its progress. It was felt that this would allow the Research Team to evaluate the extent to which SiteManager can serve as a source for the proposed database. It would also allow the Research Team to make meaningful recommendations regarding ways in which SiteManager could be modified to improve its relationship with the proposed material performance database. This is the information contained in Report 0-1785-1.

Interestingly, ETG member Paul Krugler, in a later meeting about SiteManager, voiced his opinion that the reliance of the proposed database on SiteManager could be a strong selling point for continued development of SiteManager. He also said that each database could direct and alter the development of the others. For instance, SiteManager could be modified to better support the proposed materials performance database. In turn, the materials database would then have greater capabilities, giving further direction to the development of SiteManager. The future of the proposed material performance database is heavily influenced by the future of SiteManager.

3.3 CONCLUSION

Clearly, the opinions of the users of the proposed material performance database, as represented at the ETG meeting, PAC meeting, and various interviews, represent some of the most important sources of information to guide both current and future research. These recommendations have taken forms ranging from user requirements to suggestions on how to proceed. If nothing else, these discussions have helped identify not only the critical issues to be attacked for this research but also the issues for future database development. Obviously, then, many of the ideas, concepts, and suggestions mentioned above will be or have been examined and discussed in greater detail in other parts of this report. The opinions expressed by TxDOT personnel, especially ETG members, lend credence to the way these critical issues were handled by the Research Team throughout the report.

The ETG meeting served, in part, as a brainstorming session, during which ideas and concerns were discussed not only over the main four topics relating to material levels of detail, material performance, material priorities, and "as built" versus "as designed" data, but also a variety of other topics including major user requirements and integration of SiteManager. It served to give the CTR Research Team a new perspective from which to view the challenges of research.

CHAPTER 4. SUMMARY OF TESTING DATA SOURCES WITHIN TXDOT

4.1 INTRODUCTION

In order to generate the concepts and opinions that would guide the information development of this project, the CTR research team held an Expert Task Group meeting on January 22, 1998. During that meeting, the attendees (listed in Appendix A) unanimously agreed that a critical phase of this project/report would be to determine what data are currently available within TxDOT.

TxDOT currently tests for and collects large volumes of materials data. Consequently, the expert group attendees suggested that, rather than reinventing the wheel with the proposed materials database, the research team should determine what data can be "mined" from sources within TxDOT. In doing so, the team could fulfill the project objectives of taking advantage of the current capabilities of TxDOT and making recommendations that agree with the methods that TxDOT already has in place.

In accordance with this objective, a review of the pavement and materials databases used by TxDOT was made. This review is described in detail in Report 1785-1. Additionally, this review is very briefly discussed in Chapter 2. Furthermore, a summary of the main data elements stored in each database is provided in Appendix B, so that each can be evaluated as a data source.

The purpose of this chapter and the research from which it originates is to avoid developing and recommending data for the proposed database in a total vacuum. Any recommendations regarding important data elements should be promulgated with the testing capabilities of TxDOT in mind. This is demonstrated in the sample prioritization discussed in Chapter 6. Such information can inform TxDOT of the locations of vital sources of materials-related data within its testing and information systems. Furthermore, such information, as supplied in this chapter and in Report 1785-1, can provide TxDOT with some of the means to assess the economic feasibility of collecting and storing data that is important to the proposed database.

This chapter, along with information provided in Report 1785-1, Appendix B, and Chapter 2, describes some of the testing procedures, practices, and protocols used within TxDOT. This information can be valuable for ensuring that recommendations about the data contents of the proposed database are as efficient as possible.

4.2 RESEARCH METHODOLOGY AND IMPORTANT TESTING RESOURCES

This overview of the testing and sampling procedures used by TxDOT was compiled through the examination of four department-published documents and through interviews with expert TxDOT staff.

As a part of this study, one staff member of the Materials and Tests Division who is an expert on the material-testing regimen of TxDOT was interviewed to gain general background on TxDOT material testing practices. At the time of the interview, that TxDOT expert was in charge of the TxDOT Aggregate Quality Monitoring Program and regularly fielded questions from district-level personnel regarding testing procedures, construction procedures, and specifications. Furthermore, this expert had been with TxDOT for 34 years. During the interview, the expect was able to answer very general questions related to very general topics such as discrepancies between the Specifications and the Testing Manual, test protocol, and test data storage.

The first and most general publication examined was the three-volume set *Materials and Tests Division Manual of Testing Procedures* (Testing Manual) (TxDOT (2) 97). This set of manuals lists the TxDOT-standardized tests, in ten numerical series, for the following categories: soils, bituminous, cement, concrete, asphalt, chemical, structural, coatings/traffic materials, calibration, and special procedures. These manuals, containing documents for each test in similar formats to ASTM- or AASHTO-type testing specifications, provide information regarding procedures, apparatus, calculations, and report contents for each test procedure. However, many TxDOT-standardized tests are no longer run in practice; the tests that are still performed can be identified with a thorough examination of the specifications used by TxDOT.

The next document examined was the TxDOT *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges* (Standard Specifications) (TxDOT (2) 95). These specifications were published at irregular intervals — in 1995, 1993, 1982, 1972, 1962, 1951, and 1938/41. The 1993 and 1995 versions are identical but for the fact that they are in metric and English units, respectively. While they provide standard specifications regarding general provisions, as well as an appendix, the most important information related to this project is found in the Construction and Maintenance Details portion. The Construction and Maintenance Details provide specifications for every material upon which TxDOT places such strictures. Consequently, the Divisions of the Details are entitled (TxDOT (2) 95):

1. Earthwork
2. Sub-base and Base Courses
3. Surface Courses and Pavements
4. Structures
5. Incidental Construction
6. Lighting and Signage
7. Maintenance

Each division provides detailed specifications pertaining to relevant materials, products, techniques, and assemblies. For instance, a composite material (e.g., concrete) specification would list testing requirements for that material and either reference another, similar specification for constituent materials or list additional constituent testing requirements. While the tests listed are generally “Tex” series tests (designated with “Tex” followed by a three numbers and a letter, e.g., “Tex” 410A), the specifications occasionally require a test procedure standardized by an alternate organization such as ASTM or AASHTO. According to the interviewee, item 340, relating to hot mix asphalt, is the only specification that is no longer up to date; it is “on hold” while QC/QA specifications (items

3022 and 3116) are developed for hot mix asphalt. The interviewee also remarked that while the Standard Specifications rarely change, special project specifications that alter or amend the Standard Specifications are frequently used. Thus, with few exceptions, the Standard Specifications are particularly valuable because, although they are dense and confusing, they unequivocally list every testing requirement for every material specified by TxDOT.

The third reference that was consulted for this research was the Materials and Tests Division's *Sampling and Inspection Guide Index* (Guide Index) (TxDOT (3) 95). The Guide Index is a compilation of documents that provide information such as the function of the project engineer, the function of the materials and tests division, sampling and testing, and remarks.

The Area Engineers' and Inspectors' Contract Administration Handbook (Engineers' Handbook) (TxDOT 96) was the final reference that was used for the research involved in this chapter. According to the interviewee, the Engineers' Handbook is the most useful source for the progress of this study. The purpose of this handbook is to "unify the management activities for highway construction projects," not including routine maintenance contracts and maintenance activities (TxDOT 96). It provides a concise list of tests that need to be performed for each construction material as well as the frequency with which each test must be performed. This handbook also provides all of the information that a TxDOT staff member would need to perform the bare minimum functions necessary to oversee execution of construction contracts.

While the handbook contains holds information regarding pre-bid and post-bid award activities, the most important information for the purposes of this project are found and is Chapter 4, related to contract administration. One of the important parts of this chapter is Section 6, *Control of Materials.* This section gives background information on the sampling and testing requirements of a job and explains the differences between "project" and "independent assurance" tests. Also important to this chapter is the table *Guide Schedule of Sampling and Testing* (Guide Schedule) (TxDOT 96)*,* which provides the most valuable information. This Guide Schedule applies to all contracts under construction and specifies the minimum tests and test frequencies applicable to the following TxDOT-used materials: embankments, sub-bases, base courses, asphalt-stabilized bases, treated bases and soils, surface treatments, structural and miscellaneous portland cement concrete, portland cement concrete pavements, asphalt concrete pavements, and QC/QA asphalt concrete pavements (TxDOT 96).

The Guide Schedule provides information not only about the purpose of each test and its minimum frequency, but also from where the test sample should be obtained for both monitoring/acceptance tests and independent assurance tests (TxDOT 96). Thus, the Guide Schedule is particularly useful because it makes clear what tests are actually run for what materials, information not provided by the Testing Manual. For example, in the Testing Manual, it is not clear for which materials a test such as Tex 410A is designed and implemented. Tex 410A nebulously lies in the aggregate section of the manual. Many different materials require aggregates as constituents and use various Tex 400-series tests. However, referencing the Guide Schedule, it is clear that Tex 410A is used on coarse aggregates to be used in QC/QA asphalt concrete, but not on coarse aggregate used in granular bases (TxDOT 96). This kind of information is invaluable when one is trying to sort out which constituent properties affecting which materials and material properties are tested for and are available.

Using these four reference materials in isolation yields an incomplete description of the testing regime used by TxDOT. For instance, while the three-volume Testing Manuals provide detailed information about every TxDOT-standardized test that can be run, it is unclear in the manual which tests are actually run in practice. The Standard Specifications clarify which tests are actually run for each material, but they are quite unwieldy to examine and are less clear about testing and sampling frequencies and other details. To complement the Standard Specifications, the Guide Schedule provides summary information about bare minimum sampling and testing requirements for different testing situations as well as the frequencies for testing and sampling. Finally, the Sampling and Inspection Guide Index summarizes the responsibilities of TxDOT staff for various aspects of each material's testing and sampling. The interrelationship of all of these documents is best displayed by Figure 4.1.

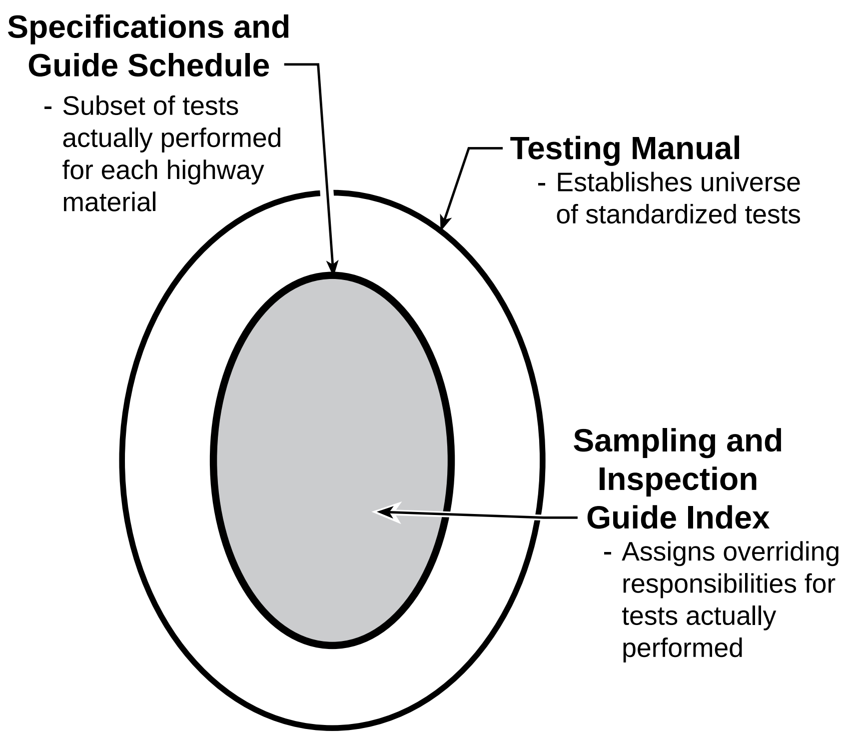

Figure 4.1 The interrelationships among TxDOT testing-related references

Clearly, each reference is part of a larger picture that provides information regarding which tests are applied on which materials, how often, and by whom. A summary of the information provided by the four aforementioned documents relevant to this study is found in Appendix C in the form of two tables. Table 1 lists all TxDOT-standardized test methods that are relevant to the materials that will likely be included as the foci of the proposed database. It lists the Tex series and number and ASTM, AASHTO number if identical, the name and the description of the test when available. Additionally, shading on Table 1 reveals which tests are actually performed as demanded by the Standard Specifications and Guide Schedule, as well as which tests have recently been removed from standardization. Table 2 summarizes the material-by-material testing requirements as mandated by the Standard Specifications and Guide Schedule. It lists testing requirements for composite materials as well as their constituents. These two tables summarize the relevant data in a logical form found in thousands of pages of information related to TxDOT testing procedures.

4.3 BACKGROUND ON TESTING PROTOCOL

According to a TxDOT expert, material-quality tests, such as the LA Abrasion test (Tex 410A), the Magnesium and Sodium Sulfate tests (Tex 411A), and the Aggregate Reactivity Test, are generally performed at the division-level within TxDOT. All other tests are performed at the district or area level. More specifically, the Guide Index outlines responsibilities for testing and sampling at both levels (district and division level) (TxDOT (3) 95). According to the Guide Index, for most materials, the project engineer (at the district level) is responsible for job control and quality tests as required by specifications, etc. for a given material. On the other hand, the division is responsible for administering the Aggregate Quality Monitoring Program and for running quality tests as required (TxDOT (3) 95). However, the Materials and Tests Division functions with regard to material testing are more inclined to vary by material.

Generally, the Engineers' Handbook focuses on those tests applicable at the district level. However, the tests applicable at the district level fall into one of two categories. "Project tests" are performed at area offices, and "independent assurance tests" are carried out at the district laboratory.

Project tests are those used to confirm that a given material conforms to specifications (TxDOT 96). Within project tests, there are acceptance tests and monitoring tests. Acceptance tests "determine if the quality of the materials or the quality of the construction work produced conforms to the plans and specifications" (TxDOT 96). Normally, the area engineer is responsible for these tests, after which he or she can do one of three things: reject and remove the material, rework and retest the material, or accept and adjust the unit price of the material according to the specifications (TxDOT 96). Monitoring tests determine the need for adjustment of the contractor's operations, including material changes or adjustments (TxDOT 96). Normally, the area engineer is also responsible for monitoring tests. If a material fails the monitoring test, the contractor must adjust his or her operation to ensure that the monitoring tests are passed. The failing material is not rejected by the area engineer out of hand, and this only occurs when the engineer "determines that it is clearly unacceptable for the purpose intended" (TxDOT 96). While both acceptance and performance tests are usually performed by the area engineer, they may also be performed in a district lab, an outside lab, and, in the case of acceptance tests, at the Materials and Testing Division lab.

On the other hand, independent assurance tests (previously referred to as Record Tests) are independent checks on the aforementioned project tests (TxDOT 96). One criterion for independent assurance tests is that they must be performed, either through testing or witnessing, by an individual who has no responsibility for the project testing, in order to assure independence. Furthermore, the testing equipment for independent assurance tests should generally be from a different laboratory than that being used for project testing. Data from independent assurance tests are compared to similar project tests by the area engineer in an effort to check the following (TxDOT 96):

1. the procedures and techniques of the actual project sampling and testing
2. the equipment used by the project personnel
3. the project test results

Consequently, while the project tests and independent assurance tests have different protocols and purposes, they are generally based on the same test specifications. For example, an independent assurance and project test for LA Abrasion would be required at different times and might be performed by different personnel and equipment, but the same testing procedure from the Testing Manual would apply to both. On a side note, nearly all the testing on aggregates intended for base materials is performed at the district level, and most division level aggregate testing is on aggregates intended for use on asphalt and portland cement concrete.

4.4 TEST DATA STORAGE

The main interview related to testing provided a brief description of how data from testing are stored within the TxDOT infrastructure. Different protocols exist for division- and district-tested data. Any test that is run at the division level on aggregates is stored on an internally accessible database within the Materials and Tests Division. An outside consulting firm recently developed this database, which stores six years worth of test results catalogued by aggregate source. At the interview, it was revealed that this database might eventually export its data to SiteManager. According to the interviewee, non-aggregate test data obtained at the division level go into paper files and folders organized by laboratory number. These paper files are kept for three years (current year plus two previous years). According to the interviewee, accessing these files can be very impractical. While this person noted that material test results are not available in a computerized database, the person added that some pass/fail-type test results are stored on the TxDOT mainframe for three years. Though the expert deferred any questions about this mainframe system, the expert referred to it as the Construction Information System (CIS). The interviewee suggested that Floyd Inman would be a knowledgeable contact for information regarding CIS.

According to the interviewee, district-level testing data are not widely available at all, but are rather stored at that level, organized by source. These test results are actually stored in two separate copies: one at the district level and one in a project folder that is retained by the area office in charge of inspection and audited by the construction office. Retention time of these test results varies by districts. One interviewee suggested that Bunny Neible would be a good contact for information regarding the storage of material testing data within the district level. According to the interviewee, the entire point of SiteManager is that it could be a reliable, user-friendly, current repository of the aforementioned types of material data.

4.5 CONCLUSION

This chapter has outlined the current TxDOT testing capacities, protocols, and procedures. It is clear that a large number of material properties that may be required in a material performance database are both currently being tested for by TxDOT. This chapter has presented information about testing procedures and practices within TxDOT by outlining not only the existing standardized tests but also those tests that are applicable to specific, relevant materials.

This background in testing sources provides some of the information necessary to determine important data “mines” and to make reasonable decisions about the availability of important data. More specifically, the information provided by this chapter will be built upon and shown to aid the prioritization procedures discussed in Chapter 6. It is important to realize, however, that the precise role of the testing program of TxDOT as a data source for the proposed database cannot yet be accurately defined. This definition can only be completed when the data contents of the proposed database are more accurately defined as per the next two chapters.

CHAPTER 5. SCOPE AND METHODOLOGY FOR IDENTIFYING AND PRIORITIZING MATERIALS AND CRITICAL MATERIAL PROPERTIES TO BE CONSIDERED

5.1 INTRODUCTION

The previous four chapters have described the problems and questions that are the focus of this research and report. Furthermore, they have provided background information relevant to those questions and problems.

The purpose of this chapter is to begin to answer those questions. A specific design for the proposed database cannot be completed until fundamental decisions are made by TxDOT regarding the tasks for which the database will be used and the materials upon which it will focus. With this limitation in mind, this chapter will define the scope of the data for the database and will describe the methodology used to monitor the performance of transportation materials. Such a foundation will give future developers of the proposed database a more specific starting point; that is, those researchers can construct the proposed database on the foundation provided by this chapter.

Because this chapter addresses both the scope of the proposed database and the methodology it will use to monitor the performance of materials, it is divided into two sections. The scope defined in the first section will establish the boundaries for the possible data types that the proposed database may store, allowing for more specific prioritization of that data. The methodology described in the second section is that which the proposed database will use to monitor the performance of materials. The second section will culminate in a description of data organization charts (DOCs), wherein the features and creation process of those charts will be set forth. These DOCs are the recommended tools by which data can be prioritized for the proposed database, as will be seen in Chapter 6.

5.2 DEFINITION OF DATABASE SCOPE

It is easy to take for granted the bounded scope inherent to all databases. That is, all databases for all different uses restrict themselves to data of finite types and levels of detail. Accordingly, defining the scope can be one of the most daunting tasks undertaken in database development.

Concern was expressed by TxDOT and by ETG representatives that the database would be abandoned by its users if it contained too many data elements/fields. Meeting attendees agreed that too intimidating or too large a database would be useless. Consequently, a scheme is required through which the amount and types of data pertaining to materials and material properties can either be included or excluded from consideration in the proposed database. This scope definition is needed to both restrict the types of data that may be stored in the proposed database, and to allow the prioritization and selection of focus materials and material properties. Developing such a scheme cuts to the heart of some of the questions posed in Chapter 1 and discussed in Chapter 3, such as:

- Should constituent properties of the focus materials be included in the database?

- Should the database focus on pavements as materials or on pavement constituent materials, such as concrete?

For example, the first question, about data levels of detail, might be asking, If concrete is one of the materials whose performance this database will monitor, should concrete constituent data also be stored (e.g., cement and aggregate data)? The second question asks whether the database should focus on pavements, on pavement constituents, or on constituents of pavement constituents (e.g., pavements, concrete, or cement). It questions the materials upon which the database should focus. Thus, this portion of the report seeks to outline exactly where, within the different levels of data detail, to draw the line for inclusion in the proposed database. Imposing such limitations, as suggested above and described below, will allow realistic and specific future development of the proposed database and the further development contained within this report. It must be noted that this scope definition is intimately tied to the methodology for monitoring the performance of materials, which is presented later in this chapter. Some discussion is repeated in both sections (though such discussion relates to different subjects).

In order to continue, it is necessary to define some terms that will be used extensively throughout the remainder of this report:

- A "focus material" is a transportation-related material whose performance will be the focus of the proposed database. An example of a "focus material" is portland cement concrete (PCC).
- A "composite property" or "material property" is any property of a "focus material." Examples of this include, in the case of PCC, compressive strength or durability.
- A "focus material constituent" or "constituent" is any material that is a part of, or composes, a focus material. Following the PCC example, a "constituent" would be portland cement or aggregate.
- A "constituent property" is any property of a "constituent" material. For example, aggregate gradation would be a "constituent property" of aggregates.
- A "mix proportion" is a quantity, ratio, percentage, or weight of material per volume related to the amount of "constituents" that composes a given "focus material." With PCC, water-to-cement ratio is an example of a "mix proportion," as is percentage of entrained air.
- "Methods of preparation" and similar such terms represent human controlled construction methods by which materials are created, formed, built or otherwise prepared. For PCC, steam curing would be considered a "method of preparation."
- "Environmental and loading conditions" represent environmentally enforced boundary stresses or conditions placed on a "focus material." That is, traffic loading might be an "environmental and loading condition" on a PCC; so might temperature.

- A “data element” is any piece of data that could be included as a data field in the proposed database. All of the above terms could be embodied in a data element.
- Finally, a “factor” is any type of data element that influences composite property. These include constituent properties, mix proportions, and other composite properties.

These definitions are used for the schemes to be developed. By contrast, the scope definitions that are discussed below are largely arbitrary. Developing an objectively based, analytical method by which to define the scope was not an objective of this research. Furthermore, no adaptable scope definition was found in the literature. Consequently, the scope definition presented below is necessarily based on discretion and practicality.

5.2.1 Materials Considered

Limiting the scope of focus materials in the database is needed to further develop both this report and the proposed database. Unfortunately, the materials on which TxDOT wants the proposed database to focus have not yet been selected. While the clear mandate for the proposed database is to monitor the performance of transportation materials, few specifics about this task have been expressed or outlined. The nearly infinite body of transportation materials range from repair mortars to sealants, from base materials to reinforcing steel. As discussed in Chapter 3 and Appendix A, materials could be prioritized for inclusion in the database based on:

- gross cost to TxDOT.
- importance in safety issues.
- specific tasks with which the database might be expected to assist. For instance, a materials performance database assisting in designing bridge deck railings would not have to focus on base materials the way a database assisting pavement design would.
- the propensity of a material to fail.
- whether the material is included in QC/QA specifications.
- the materials involvement in bridge and pavement structures. These structures represent upwards of 60% of TxDOT’s attention/budget. Consequently, the database should focus on materials used in their construction, rather than on such peripheral materials as signage.

An entire research project could be devoted to developing an analytical method by which to prioritize candidate focus materials. And since a complete prioritization of the materials to be in the proposed database was not possible, the solutions, developed in this report are based on sample focus materials. This approach provides examples based on materials likely to be included in the database, but in no way restricts TxDOT in selecting additional or different materials for inclusion. Thus, the materials selected here — as well as the scope/methodology attached to them — defer this prioritization and decision until either a more rigorous prioritization scheme can be developed, or until TxDOT decides what materials it would like to include.

Since each sample material would require an extensive literature search and substantial development time, each material needed to be judiciously selected; moreover, we needed to ensure that such selections would include those materials that would appear in any list of prioritized transportation materials to be included in the proposed database. On that basis, the CTR research team decided to include bituminous concrete surface mixtures (including those with cutback and emulsified asphalt), portland cement concrete (PCC), and some common base materials in the proposed database. Monitoring the performance of only these three material types, all fundamental to pavement and bridge construction, would represent, in our view, an auspicious start in monitoring the performance of transportation materials, even if no other development (beyond this report) occurred. The reasons for selecting these materials are obvious and mirror the suggestions listed above for prioritization:

- They are complex, composite materials. Consequently, attempts to employ the following methodology on other, less complex materials will likely be a simpler task.
- They represent large budget items for TxDOT.
- All three materials are critical to most tasks in transportation engineering. That is, properties and performance of these three materials could, for example, be very valuable for thickness design, mechanistic design, and QC/QA specifications.
- Each of the three materials is subject to frequent, costly failure, be it within a pavement, a concrete guardrail, or within any other transportation application.
- Finally, because each of the three materials can be used in either bridges, pavements, or both, they represent a large percentage of the items designed and constructed for and by TxDOT. Given their ubiquity, they would be prime materials whose performance would be valuable to monitor and/or improve.

It should also be noted that these materials are those mentioned exclusively in the proposal/agreement for this research. Consequently, the development required to monitor the performance of these three materials may represent the extent of the development required for the proposed database (assuming TxDOT focuses only on these materials).

While it is tempting to include pavement as a focus material in the database, this report and research does not attempt to employ this focus for many reasons. First, the proposed database was never intended to be a pavement performance database. This is clear in the language of the proposal and, generally, in the language used at the ETG meeting (see Appendix A). Second, it would be more reasonable to regard pavement as a structure rather than as a material because, unlike concrete or base-type materials, it is composed of separate, heterogeneous layers. Thus, pavement is not really in the same class as a true material such as concrete. Finally, pavement performance is not generally characterized in the same short-term, material-property-based way as are the other materials that are discussed throughout the rest of the report. The fact that long-term, field performance monitoring is not feasible for this database points to the impracticality of including pavement as a focus material. Clearly, the following methodology would be more difficult to apply to a structure whose quality is long-term and environmentally dependent. Pavement is not the focus of the database — its *components* are. (Note, however, that the methodology described in this and the next section, relying as it does on dynamic levels of detail, *could* be applied to pavement performance, but that task is neither attempted nor described within this report.)

It would be difficult to imagine any transportation materials performance-monitoring database that would not include the three sample focus materials. However, if TxDOT staff want to include additional materials, the proposed database should be flexible enough, as was discussed in Chapter 3, to support these changes. One great advantage of the methodology presented later in this and the next chapter is that it provides for such modifications. However, as will be discussed later, the methodology presented later in this chapter is most readily applicable to other transportation-related composites (i.e., those similar to base materials, aggregate mixes, and concrete-type materials).

5.2.2 Levels of Detail Considered

As mentioned above, the focus materials for the proposed database have been limited so that the forthcoming methodology can be discussed in terms of specific materials. However, this is not the only type of scope definition necessary to continue with the proposed methodology portion of this report. It is also important to predefine the levels of detail from which the data contents in the proposed database can originate; that is the if a given material is the focus of the proposed database, to what level of generality should data be included? Should the data contents extend from the long-term performance of applications using that material down to the subconstituent properties of that material? This facet of scope definition is a prerequisite of the prioritization process that is presented in Chapter 6.

Figure 5.1 illustrates the nature and interrelationships of these different levels of detail for materials within the transportation infrastructure. These dynamic levels of detail are the center of discussion later in this report (when DOCs are introduced), but still deserve explanation here. Figure 5.1 follows one important branch of the transportation infrastructure down through different levels of material property and performance detail. At the top, or most general (low) level of detail, is the transportation infrastructure, which is composed, at the next level of specificity, of such components as the roadways, railroads, bridges, etc. To be increasingly specific, all pavement is subject to various pavement distresses (e.g., raveling, rutting, and cracking), which, over time, determine pavement performance. More importantly, each type of distress is itself caused by numerous factors, including environmental and loading conditions, construction-related factors, and the performance or quality of the constituent pavement materials. These material performances are the focus of the proposed database and of the forthcoming methodology. However, the performance of each of these materials is controlled by a varying number of material properties, which are, in turn, also impacted by constituent material properties, mix proportions, environmental and loading conditions, construction factors, and by other composite material properties. Finally, each constituent property is controlled by many factors at the subconstituent level.

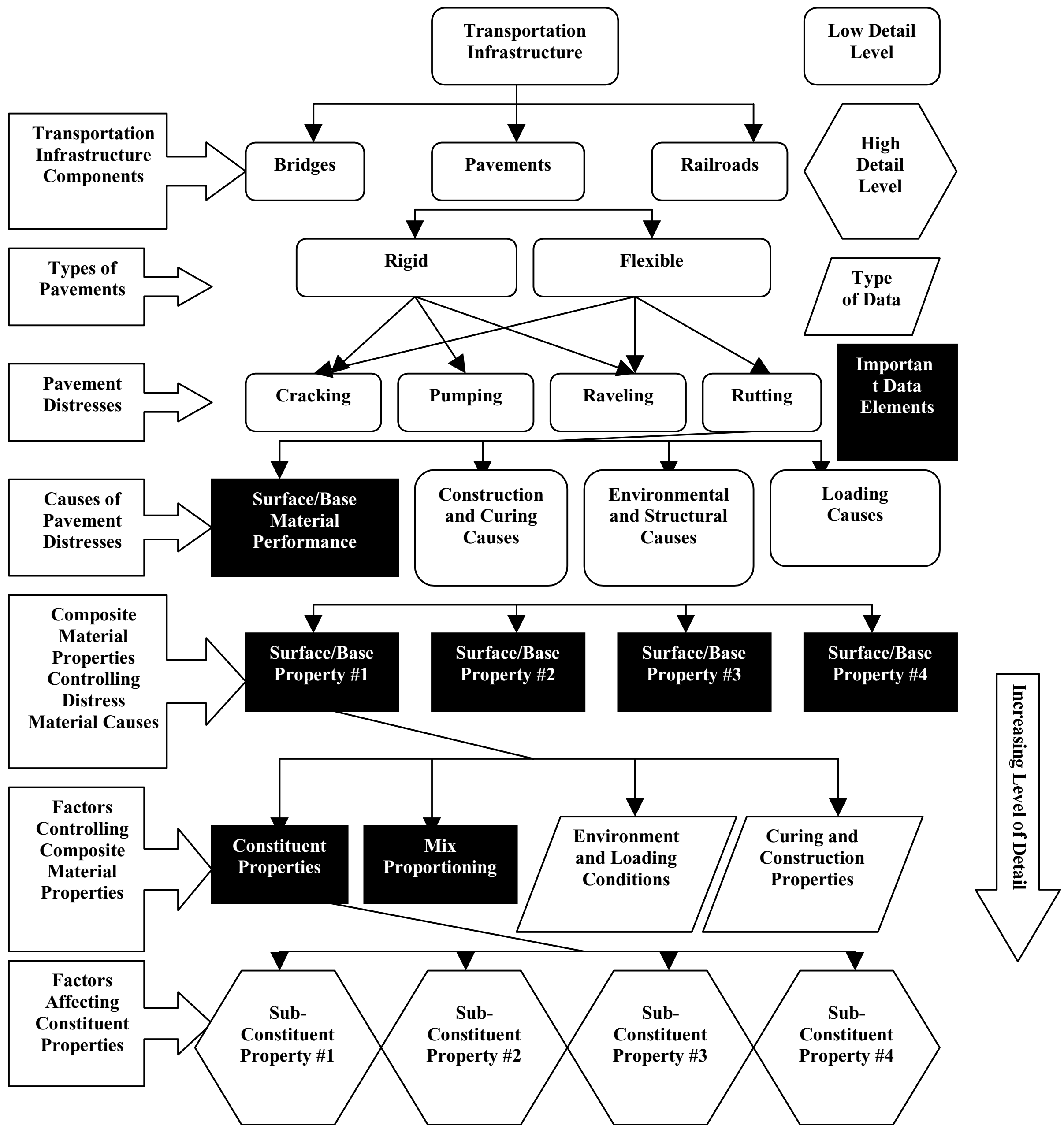

Figure 5.1 The levels of transportation material-properties details

Figure 5.1 represents a necessarily huge spectrum of detail. It would be possible to justify the proposed database carrying data elements from each level of detail in order to monitor the performance of a focus material. For example, at the less-detailed end, the database could carry data related to the performance of the transportation infrastructure and the specific applications (i.e., bridges and pavements) in which the focus materials reside. At the more detailed end, it could carry only the composite properties of the focus materials or constituent data and/or subconstituent data that affect performance.

Figure 5.1 also shows that, in addition to a vast depth of data, there is great breadth. At the level of factors affecting material properties, the database could store only the constituent properties and mix proportions that affect those properties, or it could also store the environmental and loading conditions affecting those properties.

Clearly then, while the proposed database could store data elements at every depth and breadth of detail that affect or indicate the performance of the proposed focus materials, a scope definition must be invoked to keep its data contents manageable. Otherwise, the prioritization and selection of data elements to be stored in the proposed database would be too difficult.

The ways in which scope is limited for each material can best be viewed as three sweeping cuts of the shapes or data types appearing in Figure 5.1, as indicated by the shape of the data types. Like the materials scope limitations, these scope limitations are largely arbitrary in nature. Furthermore, creation of an objective, analytical algorithm for limiting scope would have precluded development of the rest of the topics in the research scope.

Thus, the following three types of scope limitations have been made for the proposed database:

1. **Low-Detail-Level Scope Limitation**. The data that pertain to a level more general than focus material performance will be removed from consideration. Thus, for instance, with concrete as a focus material, pavement and transportation-infrastructure performance data will not be included. This limitation includes removing nonmaterial factors in infrastructure performance such as environmental and loading factors.
2. **High-Detail-Level Scope Limitation**. The data that pertain to levels of detail greater than the material properties of the focus material's constituents will be removed from consideration. For instance, with concrete as a focus material, the chemical properties of a cement constituent will not be stored in the proposed database. However, the materials database should be able to access such "high-detail level" properties through its data search engine.
3. **Type-of-Data Scope Limitation**. The data affecting material properties that pertain to environmental/loading conditions and construction will not be included in the proposed database.

These scope definitions do not limit or demean the significance of this kind of data to the performance or quality of the focus materials. Clearly, environmental and construction variables such as exposure to acidity and curing time, can greatly influence the properties and performance of a material. Likewise, the performance of a pavement in the field over a period of time sometimes can imply many things about the quality or performance of its concrete surfacing. Consequently, it may be important to store such “cut” data in other databases for additional later reference. However, further development of the data contents of the database and requires limiting the scope of the properties considered. Each limitation has its own degree of rationale, as described below.

The low-detail-level scope limitation is tied to the methodology concept, discussed in a later section, which relies on monitoring performance via the measurement and storage of simple material properties. Consequently, the storage of pavement and other application condition/performance data is simply not in accordance with this scope limitation. The reason that this type of data will not be in the proposed database is that long-term pavement performance is the subject of extensive and comprehensive current research. This research makes it clear that evaluating the performance of a constituent material through application performance would require collecting voluminous amounts of data related not only to pavement condition, but also to the environment and to construction practices, etc. Clearly, requiring the collection and storage of such a volume of data would likely overburden the proposed database, jeopardizing its utility. If this volume of data were not stored, collecting long-term pavement and application data would not really aid the evaluation of the performance of a material.

The high-detail-level scope limitation excludes subconstituent data and properties from consideration because, while they do affect composite material performance, they are too far removed and too numerous to be included. For example, the database should monitor concrete performance, of which concrete strength is an important property. If data on concrete strength are unavailable, it could be quite relevant to know what type of cement was used in the concrete or the chemical composition of that cement. Knowing the chemical composition of the cement can indicate the performance characteristics of the cement, which can in turn affect concrete strength. On an even more detailed level, knowing the chemical properties of each of the cement constituents (such as C_3A) can partially reveal information regarding the performance characteristics of the cement. However, it is here that the scope limitation line is drawn. These data elements related to cement constituent chemical properties should not be considered for inclusion in the proposed database. While they do impact concrete performance, they are simply too far removed in detail level from the topic of interest (the performance of a concrete), and thus too numerous to be included. Furthermore, they would rarely be needed, since, in this example, cement chemical composition or cement behavior would nearly always be known, making constituent chemical properties redundant. This simple example with concrete and cement illustrates the general principle behind this type of scope limitation.

The third limitation — type-of-data scope limitation — prevents the proposed database from taking on so many data elements that it becomes unusable. Construction and environmental data are important factors controlling the performance of materials; however, the purpose of the proposed database is to monitor material performance through the storage of innate material properties. Once construction, maintenance, and environmental data are stored, it is difficult to establish a rational limit. However, the materials database should be able to access such data by its data search engine when needed. Furthermore, vast amounts of this type of data are needed in order to relay any significant information regarding material performance. For example, the amount of detailed and elusive data required for reporting concrete curing conditions would be voluminous. Removing construction and environmental data from consideration in the proposed database would be to remove that database from the precipice of the slippery slope that would lead it to collapse under its own weight of data. In a sense, out of necessity, the database will exist under the assumption that, besides varying mix proportions and constituent properties, all other factors, including construction and environmental influences, are approximately equal (unless data regarding these factors are stored in another database or in other important records).

To demonstrate the function of the scope limitations, one of the properties influencing the performance of concrete would be the amount of strain that it undergoes. Whereas a long-term application-based performance criterion would evaluate the concrete performance by measuring cracking or strain, with the performance-monitoring methodology described in a subsequent section the database would need to store data on the propensity of concrete to strain.

The strain of concrete (or any elastic material) is controlled by the following constitutive law:

Strain = Stress/E, where E' is the modulus of elasticity.

It is important to recognize the two types of factors that impact the amount of strain that concrete undergoes. Modulus of elasticity is what is referred to in this report as a "generic property"; that is, it is (within a reasonable temperature range) an innate property of concrete. Stress, on the other hand, is what is referred to in this report as a "boundary condition"; that is, rather than being innate to the material, it is an environmentally imposed demand or effect placed on the material in question. Clearly, then, a generic property, coupled with a boundary condition can be combined to calculate a response. This example can be used to demonstrate why and how two of the proposed scope limitations can be used.

The above example illustrates not only the methodology used for prioritizing material properties (as will be discussed later) but also the low-detail-level scope limitation. Clearly one of the tasks for the database is to aid researchers and engineers in comparing the performance of materials so that the proper material will be selected for the appropriate environment and application. However, the quality or performance of concrete should be measured not by the actual strain that the concrete undergoes, nor by the long-term pavement/application performance data. As the constitutive equation clearly illustrates, the actual strain of concrete is as heavily affected by the stress to which it is subjected as it is to any generic property of the concrete, such as modulus of elasticity. More generally, the large role that boundary conditions play in determining the strain of concretes in applications (such as pavements) clouds the basis for comparing concrete through strain measurement. Thus, lacking knowledge of identical (a virtual certainty) or of different boundary conditions, it is impossible to meaningfully make such comparisons. Since the data collection necessary to identify these boundary conditions is not feasible, collection of long-term pavement/ application performance data would serve no purpose. Such data would not aid in meaningful material performance comparisons without knowledge of the myriad of influential boundary conditions. While it may appear simple to identify, collect, and store the relevant boundary conditions affecting strain in a controlled-laboratory test, it becomes nearly impossible to do so for a large number of more complex properties in more complex environments. Because of the inability to collect all of the environmental and construction data required to assess material performance from long-term application performance, such application performance data (low-detail-level) are outside the scope of the database.

As is discussed in the methodology portion of this chapter, the proposed database should measure the performance of any scope material in terms of the innate or generic properties. These properties define or predict the performance of concrete when coupled with any set of boundary conditions.

The aforementioned example using the constitutive law for concrete can also be used to illustrate the function of the type-of-data scope limitation that has been discussed. Suppose, as was suggested in the methodology part of this chapter as well as in the paragraph above, that concrete or another focus material's performance/quality should be judged by generic properties. Again, suppose that under some artificially created performance evaluation scheme, modulus of elasticity was the only property used to define performance. This would cause the modulus of elasticity of concrete, if it were a focus material, to be a data element stored on the proposed database. Finally, suppose also that though it was important to store modulus data in order to monitor the performance of the concretes, these data simply were not available. Clearly, there would be other ways by which modulus and, therefore, performance could be estimated and evaluated. It is widely accepted that, for concrete, modulus is related to compressive strength. Additionally, there are a number of other factors, such as water-to-cement ratio (generic property) and loading rate (boundary condition), wherein relationships have been developed that suggest they affect compressive strength and, thus, modulus. As pavement performance was eliminated from consideration for inclusion in the proposed database by the low-detail-level scope limitation, so also should boundary conditions that affect material properties by the type-of-data scope limitation be eliminated. In a similar fashion, including such subordinate properties as loading rate or temperature clouds the basis for comparing two materials as much as does the inclusion of long-term field performance of two materials. Consequently, the boundary effects that affect material properties are not included in the proposed database. Instead, since their incomplete inclusion would only cloud the basis for comparison, the database will assume, unless other data exist, that all of these boundary effects are equal.

5.2.3 Scope Definition Conclusions

The previous discussion has served to define the scope of data that will be included in the proposed database. This definition will make prioritization of the remaining material properties feasible through the methodology discussed in the rest of this chapter and the scheme discussed in the next chapter. To summarize, because of their importance to the transportation infrastructure and because they would rank high on any list prioritized according to the schemes suggested at the ETG meetings, portland cement concrete, bituminous concrete mixtures, and bases have been selected as focus materials for the proposed database. This selection constitutes a strong, stand-alone start. The database, when developed, must be flexible so that new materials can easily be included. Additionally, for any focus materials, including the aforementioned three, three different types of data have been excluded from consideration in the proposed database. If the performance of the focus materials is seen as the center of Figure 5.1, then all data elements of lower detail, including application performance, will not be considered. Furthermore, all those data elements from levels higher than the subconstituent level will not be considered. Finally, those data elements concerning boundary conditions that affect focus material properties will not be included in the proposed database.

5.3 METHODOLOGY FOR MONITORING PERFORMANCE AND FACILITATING PRIORITIZATION

Given our definition of scope, it is incumbent that we create a methodology by which the performance of materials may be monitored. With such a methodology "in hand," selection of the data elements to be included in the proposed database will be facilitated, as demonstrated in the next chapter.

Chapter 1, in addition to describing the purpose of this report, listed the following relevant questions:

- How can performance of materials be defined or represented in a manageable form?
- How can material properties be prioritized for inclusion in the database?

In order to answer these questions, one of the tasks of this report is to communicate a logical, repeatable, and suitable methodology by which to select important material properties at a variety of levels of detail for monitoring material performance. The previous sections, through their scope limitations (especially the low-detail-level scope limitation), have already suggested the answer to this question. However, the purpose of this section is to answer those questions and to describe that methodology. The concepts behind the following methodology are demonstrated only for the specific materials mentioned in the scope limitations. However, one of the benefits of the following methodology is that it could conceivably be applied to any material used in the transportation infrastructure.

This discussion of methodology will follow in three separate sections. The first will discuss what data types or categories are necessary to monitor the performance of transportation materials. This section develops the scheme that the soon-to-be-mentioned data organization charts (DOCs) make possible. The second section outlines the features of the materials data organization charts, which represent the actual solution for prioritizing material properties. The third section defines a specific procedure for developing data organization charts. The following chapter, with the DOCs introduced and defined, then describes how the data organization charts may be used to prioritize material properties for any given task related to monitoring the performance for any transportation materials.

5.3.1 A Scheme for Monitoring the Performance of Materials

Unfortunately, it is not clear what the term "performance of materials" means. It is not obvious how performance can be monitored; difficulties and pitfalls accompany every conceivable scheme. Generally, the literature addresses materials performance in two different manners:

1. Performance in terms of long-term performance within some application.
2. Performance in terms of the innate material properties associated with that material.

Clearly, selection of one or the other of these definitions drastically alters the way that the proposed database would be developed and the material properties that it would contain.

Defined either way, performance of materials is impacted by a variety of factors. It is generally accepted that the factors affecting the performance of a transportation material can be grouped into those categories shown in Figure 5.2.

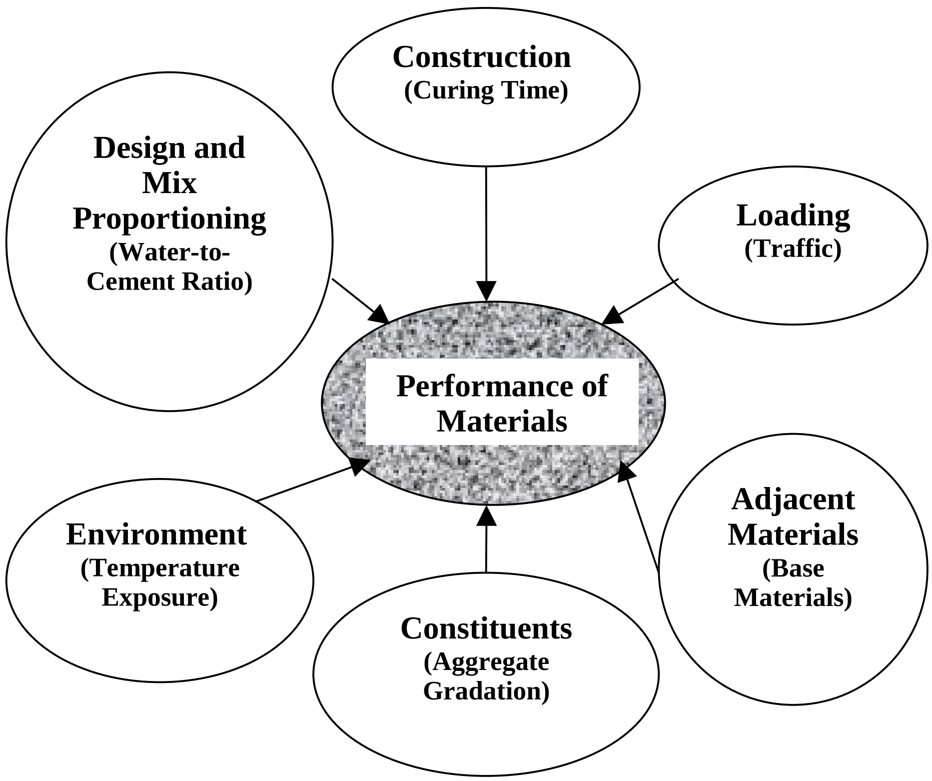

Figure 5.2 Factor categories affecting the performance of materials with examples

Inside each category oval shown in the figure, an example of a factor in that category affecting the performance of concrete is provided. However, any method for monitoring the performance of materials, subject to limited resources (as is the case with this research and database), must limit the number of categories that are taken into account and assume the data in all of the other categories are "equal." The scope limitations suggested in the above sections have done precisely that with the type-of-data limitation.

Clearly, then, the performance of a material may be monitored in different ways. In transportation applications, the different performance-monitoring schemes are best divided into a set of performance scenarios. These performance scenarios represent combinations of the period over which the material is evaluated and the types of data used to monitor that performance. This follows from the two performance definitions listed above. Figure 5.3 shows four possible combinations of field/lab testing and long-term/short-term performance. Each of the combinations requires storage of different types of data elements. However, since performance cannot be measured in the laboratory using long-term performance data, unless some special instrument such as the Texas Mobile Load Simulator (TxMLS) is employed, this combination is removed from consideration. On the other hand, the other three combinations are possible performance-monitoring schemes. Scenarios A and B, including short-term performance using both field- and lab-tested material properties, will be the preferred scheme for monitoring the quality or performance of materials for the proposed database. Finally, though it is possible to monitor the long-term performance of materials through field tests (as in Scenario C), this methodology requires excessive data collection and storage. Accordingly, these types of data and this scheme will not be included in the proposed database.

	SHORT-TERM	LONG-TERM
LAB	Scenario A	
FIELD	Scenario B	Scenario C

Figure 5.3 Matrix showing different performance scenarios

The selection of an entirely short-term-based performance-monitoring scheme requires additional justification. At first glance, monitoring material performance using long-term field performance data is tempting (perhaps because the long-term scheme does not rely on simple material properties to predict performance). It could be argued that the connection between material properties and performance in a field setting is unclear in many cases. If so, the benefits of long-term, field-performance monitoring are clear. Such a scheme actually reveals how well different materials persevere in different environments. Furthermore, long-term application performance monitoring might better utilize the data already available to TxDOT in pavement condition databases (e.g., the PMIS).

However, there are many practical reasons why this method will not be used for the proposed database. Many of those reasons were promulgated in the above discussion on scope and are obvious when the implications of long-term application performance monitoring are considered.

Again, this database is to be used for monitoring the performance of transportation materials. However, as ETG members noted, it should be specifically used for evaluating and comparing materials. Unfortunately, a performance scheme founded on long-term field-based performance is not particularly helpful here. Concrete and other transportation materials do not rest in isolated blocks in the environment. Rather, they are used in such applications as bridges and pavements. Consequently, any long-term performance-monitoring scheme relies on collecting performance data for applications that use these materials. While this is incompatible with the scope and intent for the database, it is also a fallible methodology. There is a large body of research involved with connecting application (e.g., pavement) performance to material performance. Consequently, unrealistically large amounts of additional research would be required for this project to analyze in order to resolve controversial differences. Without such additional research, it may be impossible to draw conclusions about the relative quality of concrete (or other constituent material) in a failed pavement (or other application) versus one in a sound pavement, both of the same age.

Making sense of pavement/application performance data will require more than simple pavement or application condition data. Considering the stress-strain example discussed in the scope section of this chapter, the true measure of the quality or performance of a material is strain resistance, not strain within an application or structure. Comparing the strain resistance of two concretes using field-strain measurements would require not only collecting and analyzing boundary condition data, but also establishing the relationship between strain and strain resistance (modulus). In the case of the example, the most important boundary condition and relationship would be imposed stress and the constitutive law, respectively. While this example seems simple enough, the concept of measuring the quality or performance of a material through application performance falls short when applied to more complex, realistic problems.

Thus, if that example were to be extended to the analogy of monitoring concrete performance through pavement performance/condition, a vast amount of environmental, condition, construction, and design data would be required. This is the kind of low detail-level data, related to pavement performance, that was excluded from consideration in the scope portion of this chapter. Additionally, the derived relationships between field performance and material quality that would be required are much more complex and controversial than the constitutive law for concrete. In fact, they are the subjects of the comprehensive LTPP study mentioned in Chapter 2. Even if these relationships were exact, the amount of extra data required to permit an objective basis of comparison between materials is unacceptable. Without such data, the only conclusions that pavement or other application data would allow are presumptuous generalizations about materials performance.

For example, it may appear that concrete with aggregate A performs better in environment B than does concrete with aggregate C. However, this type of analysis is questionable at best, unless more information is known about environmental and loading conditions. There could be many explanations (or boundary conditions) regarding why a pavement performs poorly or is in a poor condition besides the quality of the materials used. Using long-term condition and performance to monitor material performance — while failing to identify and analyze these boundary conditions — clouds the basis for comparing the proposed database. Therefore, the complexity and difficulty of capturing these factors must be realized when using this indirect, long-term, field application performance-monitoring scheme.

Clearly, a long-term, application-dependent performance-monitoring methodology is beyond the scope of this research and is largely impractical. Consequently, the other major alternative is to monitor the performance of materials using simple, generic material properties. The conception for this short-term, properties-dependant scheme was based on comments expressed at the ETG meeting. Many ETG members felt that while the purpose of the proposed database should be to monitor the performance of transportation materials, the database should practically be employed to aid in specific tasks. Such tasks could include monitoring material properties and comparing the quality of materials. Both of these capabilities would help to make material-selection-type decisions. While ETG members did express a desire for field-based performance information, the underlying reason was a desire to compare the quality of materials. A performance-monitoring scheme based on innate properties allows for just such comparisons, because unlike long-term performance, the basis of comparison is established without the acquisition of such inordinate amounts of boundary condition data.

To better understand this properties-based method of performance monitoring, it helps to consider the performance of a material as being dependent on the totality of its material-properties values. Clearly, those materials that perform well in long-term field applications would be described as high quality, for those circumstances. Furthermore, high quality materials tend to have certain desirable short-term material properties. Consequently, performance of materials can be evaluated through an aggregate of simple short-term material properties. This aggregate, though not a true arithmetic sum, can be represented as follows.

$$P = a_1X_1 + a_2X_2 + a_3X_3 + \ldots + a_nX_n$$

P here is some performance evaluation of a focus material, *X* represents material properties for the focus material, and *a* represents a coefficient. Depending on the purpose of the performance evaluation (i.e., to design pavements vs. to design bridges), the material properties and the coefficients may change. In general, the remainder of this and the next chapter will deal exclusively with how to identify an *X,* i.e., material properties for a given performance evaluation or task. However, it will not focus on the particular coefficients or the relative importance/contribution of each material property to performance. The methodology presented will help determine the appropriate material properties to monitor performance, given a task, such as selecting concrete for pavement, but will not deal with the largely arbitrarily determined coefficients.

Consequently, the proposed database will first use a performance-monitoring scheme founded initially on short-term material properties and then expanded to include long-term performance as data accumulate; that is, in accordance with the aforementioned scope example, it will seek to evaluate the strain resistance of concrete not by measuring field strain, but by measuring and storing modulus of elasticity. This scheme, coupled type-of-data scope limitation, removes from consideration all of the complex environmental and construction data that are normally captured by other databases, such as ForenSys and SiteManager. Furthermore, the ETG members/users would not only be able to use the database to monitor the performance of focus materials such as concretes and bases; they would also be able to compare the quality of different materials.

5.3.2 Data Organization Chart (DOC) Concept

The proposed methodology, based on short-term material properties, requires a system that, for any given task and any given material, selects the appropriate material properties for inclusion in the proposed database. Some of the features that this system *should* include are:

- Flexibility to allow material properties selection at differing detail levels.
- Adaptability to other materials besides PCC, base, and bituminous mixes.
- Capability for selecting different amounts of material properties as limited by data collection resources and capabilities.
- Flexibility to allow different material properties to be selected, depending on different tasks.

The solution that this research provides for identifying important material properties and prioritizing them, along with the factors that affect them, is the use of data organization charts (DOCs). These charts satisfy the above requirements and are constructable for nearly any material through the procedure described in the following section.

These data charts obviously must provide the important material properties, or *X*s, that, when taken together, define the performance or quality of any material. In addition to identifying the basic material properties for each material (in the case of this report, PCC, bituminous mixtures and bases), the data organization charts also must provide what may be called "dynamic levels of detail." This concept corresponds to what was described in Figure 5.1; that is, the performance of a material depends on the aggregate of its properties. Furthermore, those properties depend on mix proportioning, other composite properties, and constituent properties. While the aforementioned scope limitations have, for the purpose of feasibility, cut away many of the levels of detail, the database should be flexible enough for expansion and sophisticated enough to access other related databases.

In a sense, material properties, because of their dependence on these multiple levels of detail, can be measured either directly or indirectly. For example, the compressive strength of concrete can be measured using a cylinder test. However, if the means did not exist to perform a cylinder test, the compressive strength could be estimated through some knowledge of the mix proportioning, particularly the water-to-cement ratio, and constituent materials of that concrete. This type of indirect measurement or estimation is the principle behind the dynamic levels of detail. With knowledge of those levels of detail, multiple means can be employed to estimate material properties. Of course the estimations, when used to compare two materials, have little significance when drastically different construction methods, such as curing procedures, are employed. However, as was mentioned in the scope portion of this chapter, barring additional, helpful information, these things must be assumed equal.

Consequently, one of the salient features of data organization charts is that they provide not only for the material properties, but also for the factors, in accordance with the scope limitations that influence those properties. Given the scope limitations above, these factors can include mix proportioning, constituent material properties, and other composite properties. Figure 5.4 shows an example of these dynamic levels of detail as they are embodied in the data organization charts.

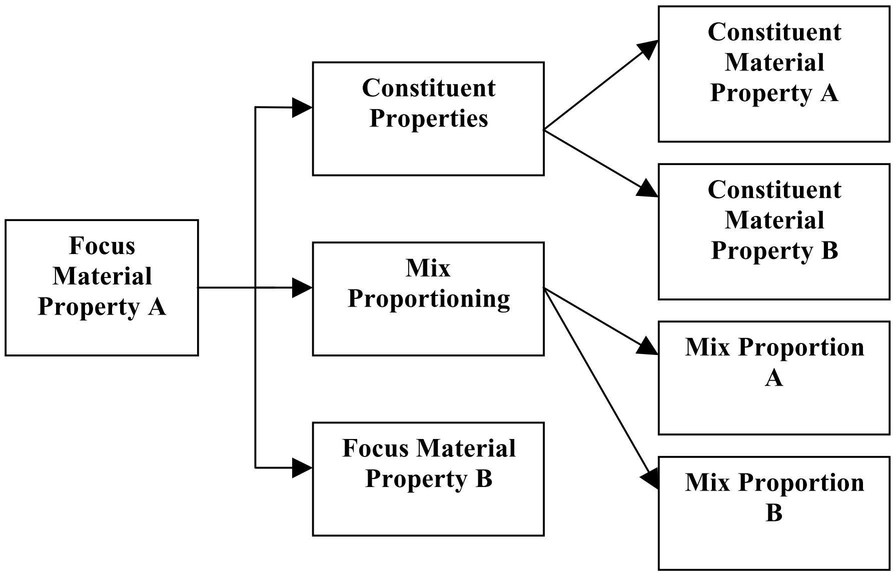

Figure 5.4 Example of dynamic levels of detail

Assuming that the focus material is a PCC, it is clear that material property A, which is likely a factor in some type of performance, depends on property B, the mix proportions, and on constituent properties. These dynamic levels of detail are nearly identical to those that appear in the DOCs in Appendix D and in Figure 5.1. This is the essence of the data organization charts.

Thus, given a performance-monitoring task requiring collection of certain material properties, all the other factors that impact those properties that require storage on the proposed database (within the predefined scope of the proposed database) can be determined. Furthermore, taking advantage of the dynamic levels of detail, the user/engineer can decide, based on data collection capabilities and resources, the level of detail to pursue; that is, TxDOT may only wish the database to carry the bare minimum and elect to carry only the material properties. On the other hand, should its resources increase, TxDOT may elect to go into more depth and include data from greater or fewer levels of detail. The aforementioned methodology provides TxDOT a logical manner in which to include more materials, and these data organization charts provide TxDOT a logical manner by which to include increased amounts of data elements. Furthermore, if TxDOT is unable to capture a certain material property, the data organization charts help to indicate what mix proportions, constituents, etc. could be useful to store in its place. These dynamic levels provide TxDOT abundant flexibility in selecting material properties and their respective factors for the proposed database. Such flexibility is part of the novelty of this approach.

While the numerous data organization charts for the three focus materials are included in Appendix D, certain of their features require clarification. The features discussed below are identified in the legend/key located in the upper left-hand corner of each DOC.

The page continuation markers at the boundaries of each DOC indicate from which and to which pages the DOCs continue. Numerous DOCs require multiple pages. Consequently, these markers indicate other pages to turn to in order to find the additional data elements for a given material property. These markers also connect material properties to the main page for each material.

Some data elements are in the DOCs for their organizational value and are not truly factors that affect material properties. These are called "holding boxes" and are analogous to dummy variables. Examples of holding boxes that frequent the DOCs are those that are labeled "constituent properties," "mix proportioning," etc. Such data elements are used to group many subordinate data elements. For instance, while "constituent properties" have no definable effect on material properties, there are numerous individual constituent properties that do. Holding boxes are identified in the DOCs using a special shading that is shown on the keys appearing in each DOC. Since typical holding boxes could not be tested for and would not be included as data fields in a database, no testing, database, or importance data are associated with them. The idea is that any importance or testing/database information that holding boxes might contain would wholly be "inherited" from the data elements that they serve to organize. Consequently, the testing, database, and importance data that holding boxes would contain are entirely redundant.

Underneath the title or name of each data element (except for holding boxes), information is included regarding whether it is tested for by TxDOT. Moreover, information is included as to whether that element is already stored or planned for storage in another TxDOT database. Clearly, during the prioritization process described later in this report, it will be helpful to know how easily certain data can be obtained. For instance, if two properties provide similar data at a similar detail level, the availability of each could be critical in deciding which, if any, should be included in the proposed database. In the DOCs that appear in Appendix D, whether the data element is tested for or stored in another database is indicated by an outline (as indicated in each DOC's legend).

Each material property, constituent property, and mixture proportion is judged for availability and testing information individually, largely using the information provided in Chapter 2, Chapter 4, Appendices B and C, and Report 1785-1. Data elements, under a specific material, are indicated as "tested for" and/or "available" if a related test specification is required for that specific material (i.e., PCC, etc.) by the *Area Engineers' and Inspectors' Contract Administration Handbook* (TxDOT 96) or the *Standard Specifications for Construction and Maintenance of Highways, Streets and Bridges* (TxDOT (2) 95). These sources list the test procedures actually performed by TxDOT. Consequently, tests appearing in either of these two sources are the best indicators of availability through testing. The contents of those two sources, as well as a listing of the important materials-related testing specifications, are provided in Appendix C.

Data elements for a specific material that are not tested for are still listed as "available" if they are stored in a given database (e.g., PMIS, MMIS, Road Life, TRM, SiteManager) for that material. If stored in such a database, the listing describes not only which database(s) they are stored in but also the organizational location of that data in the database(s). These data contents are summarized from Chapter 2 and Appendix B. As a corollary, then, the testing and database information that appear in the DOCs for a given material apply only for that given material. For example, while abrasion testing may be run on aggregate for concrete, it may not be run for aggregate in base materials. In that case, the same data element, "aggregate abrasion resistance," would have different testing information attached, depending upon which material's DOC it appears in.

Another aid to prioritization that has been represented for all nonholding data elements in the data organization charts is the level of importance. Level of importance is, like database and testing information, indicated by the outline surrounding the data element in question. Importance for a given data element is generally based on the degree to which that element impacts the material property to which it is subordinate. Consequently, importance can be different for data elements of identical names under different material properties. Furthermore, the priorities assigned to material properties are indicative of the influence that those properties have on the performance of their respective material in transportation-type applications. Thus, any importance attached to a data element (e.g., constituent properties and mix proportions) at a level of detail higher than that of the material properties affecting performance refers to the influence of that data element on the given material property. On the other hand, importance for material properties is judged in relation to their impact on the performance (in transportation applications) of the focus material under which they are organized.

Decisions regarding importance level should be (and are, in the case of the DOCs that have been completed for this research) based on the literature that was reviewed for each material and which is identified in a subsequent section. It should be noted that data elements are assigned a more or less important status. That is because, if a data element was mentioned in the literature, it obviously was of some importance; consequently, the level of importance is purely relative. It is important to recognize that these levels of importance are largely arbitrary because any factor, if completely neglected, will heavily influence material properties. Because the line between more and less important is never discussed in the literature, it is regarded as superficial. However, it is reasonable to make a literature-based generalization such as this in order to facilitate the prioritization procedure.

All these features — and the DOC concept in general — are shown in Figure 5.5. This particular chart represents the abrasion resistance of a PCC, a property that may be included in a scheme by which to monitor the performance of concrete. The property of abrasion/wear resistance is dependent on the properties of the concrete constituents and on the compressive strength of the concrete, showing the existence of dynamic levels of detail. The important constituent properties are aggregate properties, and these are held in the constituent properties holding box.

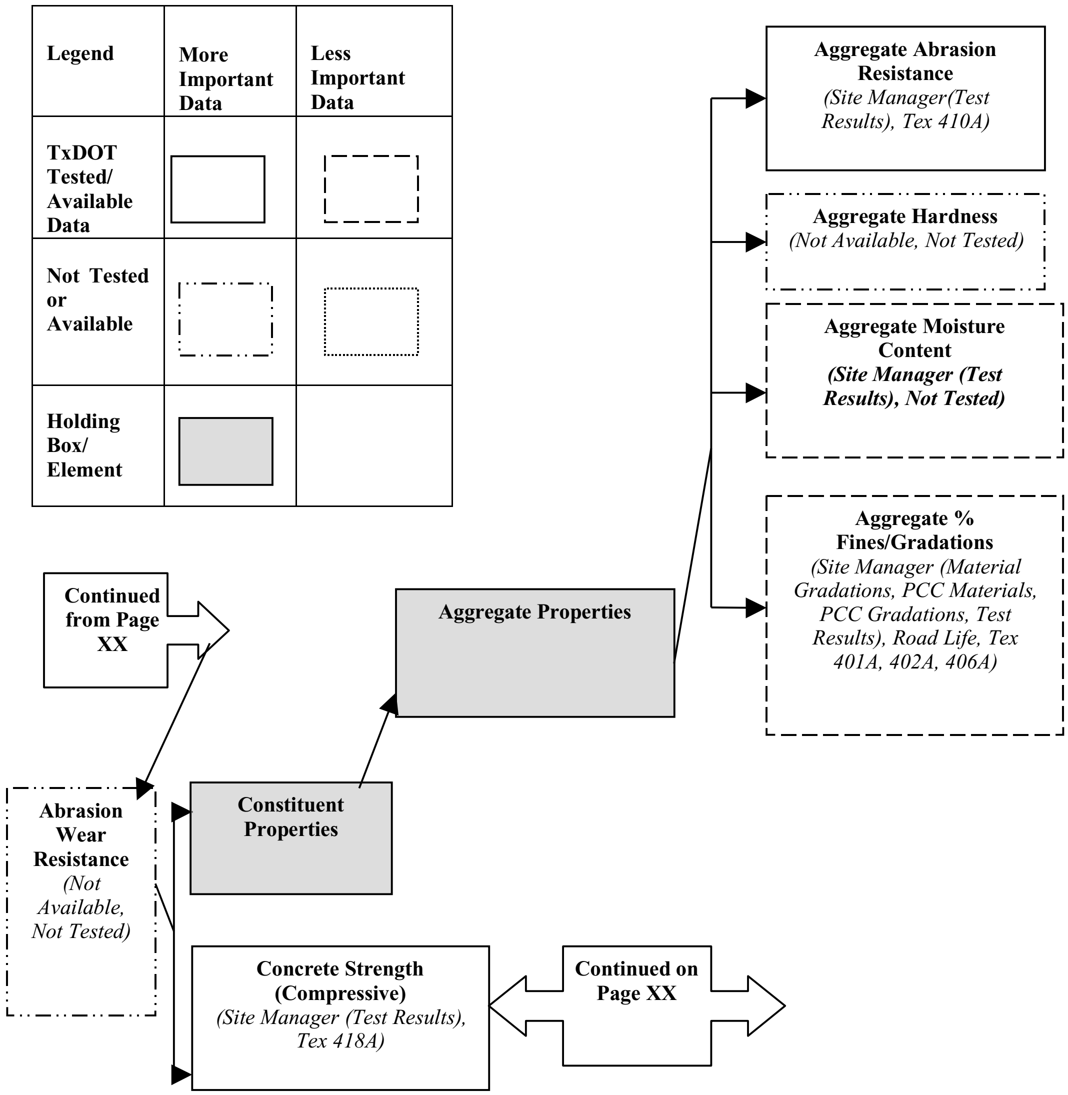

Figure 5.5 Example of a PCC DOC

Finally, down to the level of constituent properties, four different aggregate properties are listed. Page continuations are also indicated and have been generically marked “XX.” Abrasion/wear resistance is obviously continued from a page that holds all durability properties of concrete and, in turn, compressive strength, being a PCC property, continues on page 1. Each data element has different information regarding its testing and database sources as well as its level of importance. For example, aggregate abrasion resistance may be imported from the test results stored in SiteManager and tested for using the Tex 410A test procedure. Furthermore, based on the literature, aggregate abrasion resistance is considered a more important factor controlling PCC abrasion resistance. At the material properties level, abrasion/wear resistance is highlighted as important, given that it greatly impacts the durability of concrete. However, it is marked as neither available nor tested by TxDOT because there is no Tex test procedure by which it is obtained and because it is not stored in any TxDOT database. The legend or key in the upper right hand corner indicates what the outlines on each data element mean. Finally, holding boxes, such as "Aggregate Properties," are herein used. This example chart serves as a model for, and makes clear what features are involved in, all the DOCs.

5.3.3 Procedure for Developing Data Organization Charts

Data organization charts provide the important material properties, at dynamic levels of detail, necessary to define performance. Because these charts will be fundamental to the development of the proposed database for whatever focus materials are selected, we present the steps involved in their creation. The procedure will be discussed in terms of the materials for which DOCs were created, as they appear in Appendix D. However, the purpose of describing this procedure below is to allow similar, future chart development for other materials. After the procedure is presented, some of the more common problems encountered during its employment are presented for the benefit of future DOC developers.

Caution must be exercised when using the attached DOCs. The DOCs that appear in Appendix D should not be overly relied upon by future developers of the proposed database. They should serve only as a guide to how different material properties affect the performance of different materials. Furthermore, they should not be blindly relied upon in the face of new research, without regard for practical experience and other aspects. The performance of materials is almost too complex a subject and the factors controlling it are too interrelated to capture on simple, linear data organization charts.

5.3.3.1 Step 1: Reviewing Literature

The first step in creating data organization charts for any material is to perform a literature search of related publications. Such a literature review should begin with basic texts and other instructional literature on whatever material is in question. These basic publications identify the main material properties associated with a given material, as well as the factors that are commonly believed to impact those properties and the tests used to evaluate both types of data. Additionally, such literature describes the relationships between different levels of data, such as constituent properties, material properties, etc. Following this initial literature review, resources permitting, an additional literature review should focus on increasingly "cutting-edge" research for that material (e.g., journal articles). Such resources allow finer, more precise identification of influencing factors. The literature resources used for the three current focus materials are listed in Table 5.1.

Owing to the conceptual nature of this particular research and report, the literature review for the three focus materials was primarily limited to textbooks and to similar publications. The reasons for this are numerous. First, for identifying the level of depth to which a set of DOCs must go, a basic knowledge of these materials is sufficient. Furthermore, in prioritizing and creating DOCs related to every critical material property for three materials, a full, detailed, state-of-the-art study would be impossible. Moreover, state-of-the-art research often attempts to more accurately develop and quantify relationships that have already been established — a level of accuracy not needed for the data organization charts. These data organization charts, with the exception of their rating factors as more or less important, serve the purpose of qualifying, not quantifying, relationships among material properties.

Additionally, this research was never intended to be a state-of-the-art report on a given material. Overviews of the current research being performed on materials such as the three focus materials could be the entire focus of other research projects. A complete understanding of the intricate behavior of a material such as concrete could hardly be contained in a single bookshelf, much less a single report.

Table 5.1 Summary of materials science sources compiled for literature review for sample data organization charts

Author(s)	Material	Title	Reference
Mindess, Young	PCC	Concrete	(Mindess 81)
Zollinger	PCC	Assessment of Durability Performance of "Early-Opening-to-Traffic" Portland Cement Concrete	(Zollinger 98)
Neville	PCC	Properties of Concrete	(Neville 81)
Mehta	PCC	Concrete: Structure, Properties and Materials	(Mehta 86)
Troxell, Davis, Kelly	PCC	Composition and Properties of Concrete	(Troxell 68)
Shilstone	PCC	The Concrete Mixture: The Key to Pavement Durability	(Shilstone 93)
ACI 201	PCC	Guide to Durable Concrete	(ACI 201 77)
Asphalt Institute	Bituminous	The Asphalt Handbook	(AI 70)
Asphalt Institute	Bituminous	Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types	(AI 95)
Roberts, Kandhal, Brown, Lee, Kennedy	Bituminous	Hot Mix Asphalt Materials, Mixture, Design and Construction	(Kandhal 96)
Martin, Wallace	Bituminous	Design and Construction of Asphalt Pavements	(Martin 58)
Yoder, Witczak	Bituminous	Principles of Pavement Design	(Yoder 75)
Leahy, Monismith, Lundy	Bituminous	Performance-Based Properties of Asphalt Concrete Mixes	(Leahy 95)
Davis	Bituminous	Engineering Properties of Asphalt Mixtures and their Relationship to Performance	(Davis 95)
Chua, Roo	Bituminous	Comprehensive Characterization of Performance-Related Properties of Asphalt Concrete Mixtures Through Dynamic Testing	(Chua 95)
Cabrera, Dixon	Bituminous	Hot Bituminous Mixtures – Design for Performance	(Cabrera 96)
Scholz, Brown	Bituminous	Factors Affecting the Durability of Bituminous Paving Mixtures	(Scholz 96)
Road Research Laboratory	Bituminous	Bituminous Materials in Road Construction	(RRL 62)

Author(s)	Material	Title	Reference
Yoder, Witczak	Base	Principles of Pavement Design	(Yoder 75)
Atkins	Base	Highway Materials, Soils, and Concretes	(Atkins 83)
Krebs, Walker	Base	Highway Materials	(Krebs 71)
Ingles, Metcalf	Base	Soil Stabilization: Principles and Practice	(Ingles 73)

5.3.3.2 Step 2: Organizing References

After the applicable literature has been collected and reviewed, it is important to organize what has been read from a variety of sources; that is, it is helpful to organize the information by outlining relevant chapters and by summarizing those chapters.

Generally, the texts examined for these DOCs were comprised of such similar chapters as: concrete durability, bituminous mix stability, etc. The similar organization found in multiple texts during outlining was helpful in establishing larger grouping for the various material properties. For example, after outlining, it was clear that concrete durability is an aspect of concrete performance and that it is a "parent" category for numerous material properties related to concrete. This conclusion is manifest in the DOCs for concrete.

5.3.3.3 Step 3: Listing of Suggested Material Properties

After outlining and summarizing the literature, the next step is to make a complete listing of the material properties listed within each "parent" category for each material. While not all sources discuss identical material properties, a complete, composite listing can be made by assembling the properties discussed in each source. Often, material properties having nothing to do with transportation applications were summarily removed from the list. After the completion of this task, the data organization charts for any material in question should list all of the material properties subordinate to the performance of the material.

It is worth mentioning that work in this or in any of the remaining steps is not "cut and dry." Rather, it involves making some decisions, where conflicts exist, as to what material properties and what factors should be included. However, this report will discuss neither general nor intricate material issues. Discussions of the materials issues can be found in the aforementioned sources. For the most part, the DOCs rely on conventional materials wisdom, with many of the issues pertaining to different terminology and other trivialities. While a portion of this section does use some very specific examples of materials issues that represent pitfalls in creating DOCs, it does so only to illustrate general concerns.

While Appendix D illustrates the relationships among various factors influencing material properties, Tables 5.2, 5.3, and 5.4 list the composite material properties selected for each of the three main focus materials (as they appear in the DOCs).

Table 5.2 Material properties appearing in DOCs for PCC

Material	Property Group	Property
PCC	**Strength**	*PCC Strength*
	Durability (Physical)	*Freeze-Thaw Weathering Resistance*
		Salt Scaling Weathering Resistance
		Abrasion/Wear Resistance
		Fire Resistance
		Salt Crystallization Resistance
	Durability (Chemical)	*Misc. Chemical Resistances*
		Reactive Aggregate Resistance
		Embedded Metal Corrosion Resistance
		Acid/Base Attack Resistance
		Sulfate Attack Resistance
		Leaching and Efflorescence Resistance
	Volume Changes	*Concrete Extensibility*
		Concrete Modulus of Elasticity
		Poissonś Ratio
		Concrete Thermal Expansions/Contractions
		Concrete Creep Rate and Capacity
		Concrete Shrinkage Rates and Capacities
	Miscellaneous	*Concrete Miscellaneous Thermal Properties*
		Concrete Acoustic Properties
		Concrete Skid Resistance
		Concrete Radiation Shielding
		Concrete Electrical Properties

Table 5.3 Material properties appearing in DOCs for bituminous mixtures

Material	Property Group	Property
Bituminous Surface Mixtures		*Bituminous Mixture Resistance to Permanent Deformation/Fracture (Resilient Modulus)*
		Weathering Resistance of Bituminous Mixtures
		Bituminous Mixture Fatigue Resistance
		Bituminous Mixture Skid Resistance
		Bituminous Mixture Low-Temperature Cracking Resistance
		Bituminous Mixture Miscellaneous Properties
		Bituminous Mixture Stripping Resistance

Table 5.4 Material properties appearing in DOCs for bases

Material	Property Group	Property
Bases (includes Flexible, PC Stabilized, Lime Stabilized, and Bitumen Stabilized)		*Base Stability (includes any type of strength test) and Resilient Modulus of Elast.*
		Base Resistance to Pumping
		Base Resistance to Subgrade Infiltration
		Base Durability
		Base Drainability
		Base Resistance to Frost Action

5.3.3.4 Step 4: Assigning and Organizing Important Factors

Following the creation of a list of important material properties for the given focus materials, it is necessary to re-examine the literature for a discussion of the factors that affect those material properties. These factors can come from a variety of categories, as suggested by Figure 5.2. Using the outline created in Step 3 helps in locating literature chapters/sections that discuss the factors impacting specific material properties. This task can be the most time consuming of the nine, requiring as it does many decisions and judgments on a variety of issues (such as the importance of various factors). Such difficulties are owing to the fact that the scope of the various sources prohibits them from discussing identical factors, from using identical terminology, and from speaking of factors at identical levels of detail (Figure 5.1). These problems are discussed below.

After this step, the data organization charts for the material in question should contain not only all the material properties, but also the subordinate factors from a variety of categories and the relationships between these items. As can be seen in Appendix D, many of the same constituent properties and mix proportions, such as aggregate gradation, appear in many different DOCs.

5.3.3.5 Step 5: Removing/Omitting Data that is Out of Scope

In accordance with the scope limitations, many of the factors that are important to the performance of materials and to material properties should not be included in the proposed database. Consequently, these factors can be removed from the charts. They generally include the factors that fit under holding boxes, such as "Environmental and Loading Conditions," as well as those under "Methods of Preparation" and similar construction-related headings. This removal should yield data organization charts having material properties and their relationships to constituent properties, mix proportions and other focus material properties.

5.3.3.6 Step 6: Matching Test Procedures to Factors

The next step is to use the information in Chapter 4 and Appendix C to determine which of the material properties remaining in the data organization charts are currently tested for by TxDOT. This will help future developers of the proposed database decide which data elements to store in the database. Obviously, all else being equal, a data element that is already being tested and evaluated by TxDOT is preferable to one for which there is no test procedure or protocol. Following this step, each data element should have listed with it the applicable "Tex" testing specifications or the label "not tested." These labels appear under the title of the data element on the DOCs shown in Appendix D.

5.3.3.7 Step 7: Matching Database Locations to Factors and Properties

Step 7 determines which of the remaining factors are currently stored in a TxDOT-operated database. These databases, discussed and analyzed in Chapter 2 and Report 1785-1, include PMIS, MMIS, SiteManager, Road Life, and TRM. Obviously, data already stored, in an importable state, on another TxDOT database would be preferable to data that could not be imported. After the conclusion of this step, each remaining factor or material property should be labeled with a database location from which it can be imported, or as "Not Available" if they are neither tested for nor stored elsewhere.

5.3.3.8 Step 8: Performing Prioritization

After the data elements/factors have been labeled as to their availability in other TxDOT databases and as to whether they are currently tested for, a prioritization — or rather an importance — must be attached to them. This task can be largely arbitrary and might profit from more detailed information found in journal articles. Section 5.3.2 provides a more in-depth discussion of this DOC feature. After the conclusion of this step, each data element should have the proper outline to indicate its importance (and its testing/database availability).

5.3.3.9 Step 9: Adding Aesthetic Refinement

The last step in the process that results in the data organization charts shown in Appendix D includes aesthetic refinements. The main task involves providing some of the visual continuity lost when these charts are set up for printing on standard paper. Because of the space constraints imposed by standard paper sizes, the DOCs must be logically divided for presentation on separate pages. Consequently, in order to provide the continuity that would be provided if the charts could be illustrated on one large page, continuation numbers have been included. These numbers, surrounded by arrows, show from where or to where structures on the charts are continued. For instance, it is not possible to show the data affecting concrete durability properties all the way down to the level of constituent properties. Continuation arrows can make the charts easier to follow. The completion of this step should result in data organization charts similar to those shown in Appendix D, which are ready for use in prioritization of data elements to be included in the proposed database.

5.4 CONCLUSION

This chapter has described the scope of data with which this proposed database would be concerned, as well as the methodology by which it can be used to monitor the performance of materials. Though discussed in two separate sections, the scope and methodology for the proposed database are heavily interconnected. Section 5.2 focused on describing the scope limitations that need to be made in order to develop the proposed database, including limitations on types of materials, levels of detail, and types of data. Section 5.3 then outlined a method by which the performance of materials may be monitored. This methodology requires the collection and storage of short-term material properties in the proposed database. Furthermore, determination of the material properties, constituent properties, mix proportions, etc., that need to be collected for this performance monitoring scheme can be performed using data organization charts. The features, concepts, and development procedures related to these DOCs are also discussed in Section 3. The material presented in this and in the previous chapters is embodied in the DOCs appearing in Appendix D. This material can be used, as will be shown by example in the subsequent chapter, to prioritize data elements to be included in the proposed database.

CHAPTER 6. USING DATA ORGANIZATION CHARTS FOR MATERIAL PROPERTY PRIORITIZATION

6.1 INTRODUCTION

Chapter 5 outlined the scope limitations and methodology for monitoring the performance of transportation materials and introduced the concept of data organization charts (DOCs). These DOCs can be used to develop materials data and to prioritize material properties and factors for inclusion in the proposed database. Chapter 6 illustrates, by generic example, how these charts can be used, for any combination of material and task/objective, to select material properties, mix proportions, and constituent properties for inclusion in the proposed database. Once DOCs have been created by the procedures outlined in Chapter 5, the procedure shown here by example can be used to help select or prioritize material properties for the proposed database.

Of course, one of the precursors to the use of such charts is selection of specific materials for inclusion in the database. While this report has selected some preliminary materials and created the appropriate DOCs, expansion of both materials and DOCs is possible. Possible methods by which to select and prioritize materials for inclusion in the database, such as by cost or by safety importance, were discussed in both Chapter 3 and Chapter 5.

Another precursor is that the tasks in which the database will assist must be more clearly described. It would be ideal, of course, if the DOCs could alone identify what material properties should be contained in the database. However, this is not possible. The proper set of data elements for the proposed database depend in large part upon the tasks for which that database is employed. That is, the database must be given a more conclusive purpose. This will allow the selection of the proper subset of material properties and factors.

Since these decisions have not yet been made, the discussion in this chapter assumes a sample set of materials and tasks; using the DOCs from Appendix D, a partial, sample prioritization is shown as an example for future developers.

With materials and tasks assumed, the prioritization procedure follows in several distinct steps that can best be illustrated by the flow chart in Figure 6.1.

Each of these steps is discussed in detail below. However, this figure can always be used as a guide through the process of prioritization. Steps 3, 4, and 5, seeking to reduce the data requirements of the proposed database, are optional and may be performed in any order.

6.2 SELECTING MATERIAL PROPERTIES

The first step required in any prioritization process involving the DOCs for the three focus materials (PCC, bases, bituminous surface mixtures) is to determine the innate material properties necessary for the performance monitoring. These material properties reside at one level of detail higher than that of the performance of focus materials (Figure 5.1). This step is necessary because the proper material properties required for performance monitoring are not absolute and often vary based on perspective or task. For instance, a bridge design engineer will require properties of a PCC properties (e.g., PCC permeability and compressive strength) that differ from those required by a pavement engineer (e.g., modulus of rupture and coefficient of thermal expansion).

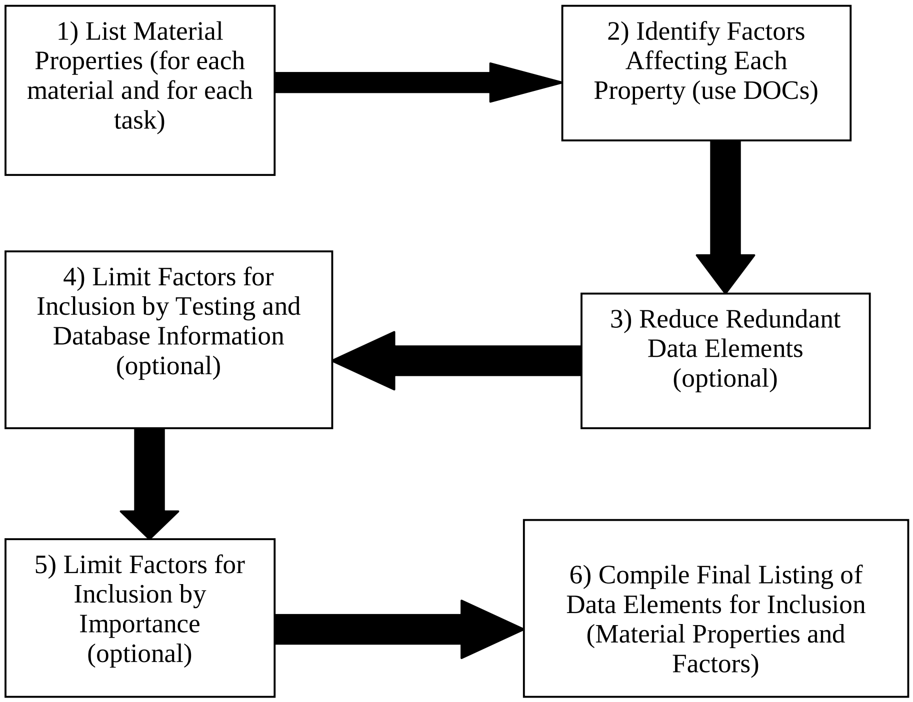

Figure 6.1 Flow chart for the task-oriented prioritization process

6.2.1 Tasks Affecting Material Property Selection

Clearly, there is no point in the database retaining material properties that are not important for the tasks to which it is assigned. Thus, for the sake of efficiency, a decision regarding the set of specific performance-monitoring objectives must be made in order to ensure that the proper set of material properties can be selected for inclusion in the proposed database. From this point on, these specific performance-monitoring objectives will be referred to as "tasks."

While the tasks for which the proposed database will be used have not been definitely identified, it is important to mention a few of the possibilities. The prioritization example that follows focuses on pavement thickness design (i.e., the 1986 AASHTO method) as a task for the proposed database. However, within the field of pavement design, there are many other methods that could be used for prioritizing data elements. For flexible pavements alone, the following methods could be used: Asphalt Institute Design, National Crushed Stone Association Design, and the California Method of Design (Yoder 75). Additionally, mechanistic design procedures could be the focus of the proposed database, as they may require the collection and storage of a different set of material properties and factors.

There are other tasks, besides pavement design, for which prioritization and performance monitoring may be necessary. The database might be required to assist in bridge design or, as suggested at the ETG meeting, to monitor material properties for quality assurance/quality control (QA/QC) specifications. Other tasks suggested at the ETG meeting, such as determining the material properties required for various materials in various TxDOT projects, are summarized in Chapter 3 and will not be repeated here.

Additional tasks, not mentioned at the ETG meeting, could relate to material-mix design procedures; that is, the data elements could be prioritized to support mix design by the Marshall Method, the Hveem Method or even new SuperPave Specifications. Furthermore, the database could be used in conjunction with a geographical information system (GIS) to correlate sources of materials with material properties or qualities (with such usage perhaps requiring its own prioritization). This list is nearly inexhaustible and, clearly, there are as many different ways to choose material properties and factors for the proposed database as there are tasks for which the proposed database can be employed.

6.2.2 DOCs – The Universe of Material Properties

It may be helpful to view the DOCs as universes of material properties that illustrate the relationships among different material properties and factors. As is apparent in Figure 6.2, each task, when outlined by TxDOT, will require a different subset within the universe of material properties (for a given material) shown in the data organization charts. The subsets may even overlap. This research has yielded the universe of material properties for three important materials.

6.2.3 TxDOT Pavement Design Procedures

While the following example is based on the 1986 AASHTO method for designing pavements, it is worth mentioning that TxDOT currently has several design methods for pavements. The Flexible Pavement System (FPS), which was developed in the 1960s and 1970s, is now the primary method by which TxDOT designs flexible pavements and their rehabilitation (Victorine 98).

FPS has seen a number of revisions over the years, but the two main versions currently in use are versions 11 and 19. The following provides a more complete description of the two methods (Victorine 98):

> Stiffness coefficients obtained through deflection testing with the Dynaflect machine characterize the stiffnesses of soil and paving materials for FPS 11. FPS Version 19 is a newer method that uses strength values calculated using a falling weight deflectometer instead of Dyanflect. Thus Version 19 converted the FPS methodology to a linear elastic system using elastic moduli as strength inputs that were representative of pavement layer strengths.

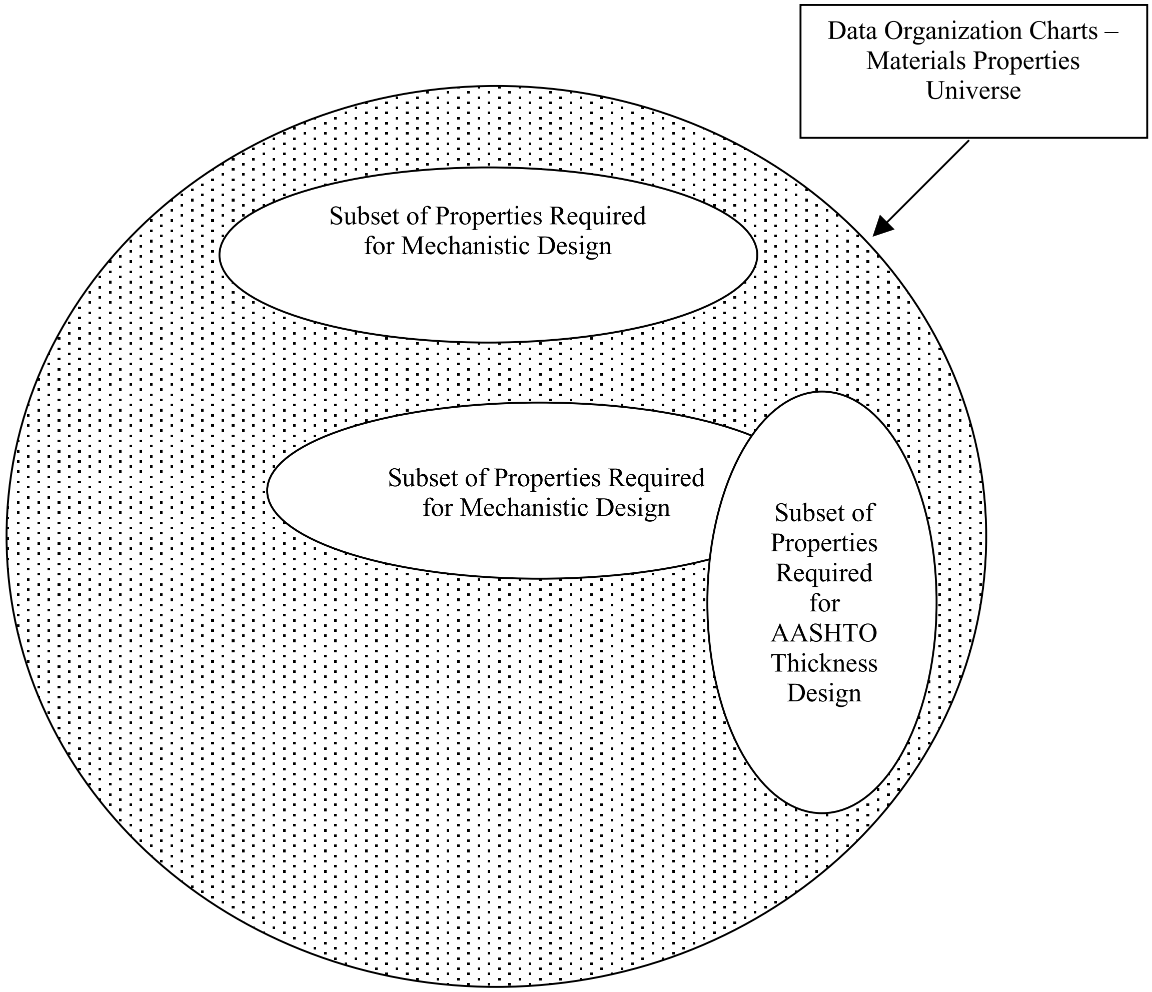

Figure 6.2 The universe concept for material properties and task-based prioritization

Inputs for the FPS versions all include various material properties that would likely have to be included in a database whose goal would be to assist this type of pavement design.

Currently, TxDOT uses the 1993 American Associations of State Highway and Transportation Officials (AASHTO) Rigid Pavement Design Procedure to design new and rehabilitated pavements (Victorine 98). However, TxDOT previously used the 1986 version. Consequently, the following example, using the 1986 version, is relevant to some in-service pavements. The Texas Department of Transportation occasionally issues design specifications related to the AASHTO Rigid Pavement Design Procedure in order to provide additional detail and information (Victorine 98). Wimsatt provides a more complete history of rigid pavement design and construction in Texas, as well as more detail on these specifications for various rigid pavement types (Wimsatt 93).

6.2.4 Example of Selecting Material Properties

These conceptual underpinnings can perhaps be best demonstrated through the example (used throughout this chapter) that incorporates the DOCs for all three current focus materials. For instance, the task for which the proposed database will be used is to select materials for pavement applications. The first step might be a review of literature relating one or more pavement design procedures in order to determine the generally important inputs. As an example, Table 6.1 lists the important PCC, bituminous mixture, and base material properties that the 1986 version of the *AASHTO Guide for Design of Pavement Structures* (AASHTO 86) requires for pavement design.

Table 6.1 Material property inputs required for AASHTO pavement design for three focus materials (AASHTO 86)

Material	Type of Pavement	Required Material Property Inputs
Portland Cement Concrete	Rigid	1. Modulus of Rupture
		2. Tensile Strength
		3. Concrete Shrinkage
		4. Thermal Coefficient
		5. Resilient Modulus of Elasticity
Bituminous Surface Mixture	Flexible	1. Resilient Modulus of Elasticity
Base Materials		
Granular or Flexible Base	Rigid/Flexible	1. Resilient Modulus of Elasticity
	Flexible	2. Stability (i.e., CBR testing)
PC/Lime Stabilized Base	Rigid/Flexible	1. Resilient Modulus of Elasticity
	Flexible	2. Compressive Strength (Stability)
Bitumen Stabilized Bases	Rigid/Flexible	1. Resilient Modulus of Elasticity
	Flexible	2. Stability

Similar listings can be made for nearly any pavement design procedure, other than this example based on AASHTO.

Creation of such a table provides a clear subset of the important material properties considered for and by the AASHTO procedure has been cropped from the universe of material properties. In Chapter 5, Tables 5.2–5.4 provided a listing of all of the material properties appearing in the DOCs for each material. The material properties selected for materials selection in this pavement design procedure represent a dramatic reduction from the original list. Consequently, if the only purpose of the proposed database is selecting material properties for use in pavement applications (as dictated by the 1986 AASHTO procedure), the savings in data and effort would be enormous. It is unlikely that this will be the only task to which the proposed database will be assigned. However, savings in data collection can be made with nearly any set of finite tasks.

Part of the advantage of the DOCs and the universe of material properties that they provide is that the future developers of the proposed database need not rigidly select material properties as per the inputs of the pavement design procedure; that is, if those developers learn that TxDOT considers additional material properties in selecting materials for pavements, those properties may also be included from the whole universe of properties provided by and developed in the DOCs. Clearly, material properties other than those accounted for by current pavement-design procedures do impact pavement performance and may require inclusion. An example is permeability of PCC, which affects pavement performance yet is not included as an input in the above example. Furthermore, should TxDOT later assign additional tasks or require additional material properties, they too can be taken from the provided universe of material properties and be placed in the proposed database.

6.3 SELECTING FACTORS (INCLUDING CONSTITUENT PROPERTIES AND MIX PROPORTIONS)

Once such a list of material properties is created by the previous means, the DOCs can again be used to identify all of the constituent material properties, material properties, and mix proportions that can affect those properties. To do this, simply turn to the DOCs for the appropriate material properties of the material at hand. Those DOCs can then be examined and all of the factors that affect those properties can be carefully tabulated. When this tabulation is performed for the material properties listed in Table 6.1 for each material, the factors shown in Tables 6.2 through 6.7 arise. The terminology in these tables, while not always the same as that used by AASHTO, agrees with the terminology used in Appendix D.

Some of these factors affect only one of the material or composite properties for their given material, while others affect nearly all of them (e.g., water-to-cement ratio). Details about which factors affect which material properties may be found within the DOCs.

This step, relying on the selection of material properties in the previous step, provides all the factors affecting the appropriate material properties. Should TxDOT decide to include every one of these factors for the sake of totality, the prioritization process is completed and the database can be constructed to include all the collected material properties and factors. Furthermore, the database and testing references can be used, in conjunction with the conceptual design presented in Chapter 7, to link the proposed database to the appropriate sources.

However, it is unlikely that every factor will need to be stored in the proposed database. Consequently, additional measures can be taken to limit the amount of factors, such as mix proportions and constituent properties, stored in the database.

6.4 LIMITING FACTORS FOR INCLUSION IN THE DATABASE

If needed, the number of factors to be stored in the proposed database can be limited in a few simple ways. These limitations can be performed using the DOCs provided by this report or the DOCs that are subsequently created. These methods involve identifying and eliminating redundant material properties and factors.

One of the ways to eliminate factors that were “generated” by the previous step is to consider which material properties are actually available for importation from other TxDOT databases, and which are tested for within the department. If a material property is available and can be imported into the proposed database, the factors that impact that material property become less important to the proposed database. For example, if a certain task requires that the compressive strength of concrete be stored in the proposed database, and TxDOT already tests for and stores that data in one of its other databases, then the factors that control compressive strength are redundant and need not be stored in the proposed database.

Table 6.2 Factors affecting AASHTO-required PCC properties as indicated by DOCs for PCC

Material	Category of Data (Holding Box)	Factors
Portland Cement Concrete	**Composite Properties (from Table 6.1)**	*Concrete Modulus of Rupture (Flexural Strength)*
		Concrete Tensile Strength
		Concrete Coefficient of Thermal Expansion
		Concrete 28-day Shrinkage
		Concrete Modulus of Elasticity
	Mix Proportioning	*Water-to-Cement Ratio*
		Aggregate to Cement Ratio
		Cement Content
		Aggregate Content
		% Air/Air Entrainment
		Water Content
	Constituent Properties	*Cement Fineness*
		Cement Chemical Composition
		Admixture Type
		Aggregate Gradation
		Aggregate Max. Size
		Aggregate Shape
		Aggregate Mineralogy
		Aggregate Coefficient of Thermal Expansion
		Aggregate Modulus of Elasticity
		Aggregate Moisture Content
		Water Impurity Content

Table 6.3 Factors affecting AASHTO-required bituminous surface mixture material properties as indicated by DOCs

Material	Category of Data (Holding Box)	Factors
Bituminous Surface Mixture	**Composite Properties (from Table 6.1)**	*Bituminous Mixture Resistance to Permanent Deformation (Resilient Modulus of Elasticity)*
	Mix Proportioning	*Binder Content*
		Coarse Aggregate Content
		Fine Aggregate Content
		% Air Voids
	Constituent Properties	*Binder Viscosity/Penetration*
		Binder Grade/Classification
		Aggregate Gradation
		Aggregate Maximum Size
		Coarse Aggregate Type/Mineralogy
		Fine Aggregate Type/Mineralogy
		Filler Type/Mineralogy
		Aggregate Surface Texture
		Filler Surface Texture
		Aggregate Shape
		Filler Shape

Using the testing and database information given in Chapter 2, Chapter 4, Report 1785-1, and Appendices B and C, further cuts can be made. It may simply be cost ineffective for TxDOT to specify an entirely new set of tests and procedures that are required for collection of a marginally important factor to a given material property. Continuing with the example of PCC strength, if only one of two factors that similarly affect concrete compressive strength can be included in the proposed database, then the one that is already tested for and stored by TxDOT is likely to be the more efficient choice. This choice is even simpler if the two factors being compared provide redundant information.

Finally, the levels of importance built into the DOCs can be used to evaluate the degree to which a given data element influences a given material property. Because the value of factors is that they represent alternative, indirect ways to evaluate the material properties needed to monitor the performance of materials, then a factor that is less important to those material properties has less value in the proposed database. Consequently, when difficult decisions must be made as to which data elements to include in the proposed database, those "less important" data elements make for cuts that are more obvious.

Consequently, the ancillary information provided in the DOCs can be used to limit the number of factors "generated" by the previous step to be included in the proposed database. It should be stated that there is no absolute method by which to limit, or prioritize, the factors to be included. Clearly, the testing and importance data, coupled with knowledge of the redundancy of factors and properties, can greatly aid in this prioritization. However, decisions of this type must still be made case-by-case and may involve cost-benefit-type analysis.

An example of the information that can be provided by the DOCs is provided in Table 6.8. For each of the properties and factors listed in Tables 6.1 and 6.2 for PCC, Table 6.8 shows the relevant testing and database sources. For each factor, it also notes the material properties to which that factor is "more important" and "less" or "not important." "Not important" refers to when a data element is not listed as influential to a given material property. These same data elements may have different sets of information when they appear in DOCs for other materials. These material properties will be limited to the five listed in Table 6.1, as generated through the first step (from the AASHTO design method).

Thus, the DOCs in Appendix D provide a large amount of information that can aid in prioritization. It is evident what data elements are tested for and which appear in other databases. Furthermore, the DOCs, as shown in Table 6.8, provide information about the degree to which data elements influence certain PCC materials properties.

Table 6.4 Factors affecting AASHTO-required flexible base material properties as indicated by DOCs

Material	Category of Data (Holding Box)	Factors
Flexible Base	**Composite Properties (from Table 6.1)**	*Mixture Cohesion*
		Mixture Internal Friction
		Flexible Base Resistance to Subgrade Infiltration
		Flexible Base Resistance to Frost Action
		Flexible Base Stability and Resilient Modulus of Elast.
		Mixture Density
		Flexible Base Permeability
	Mix Proportioning	*Aggregate Content*
		Mixture Moisture Content
		F.A. to C.A. Proportion
		Dust Ratio
		Binder Soil Content/% Fines
	Constituent Properties	*Binder Soil Plasticity/Character*
		Aggregate/Soil Gradation
		Aggregate Crushing Strength
		Aggregate Surface Texture
		Aggregate Shape
		Aggregate Hardness
		Aggregate Durability
		Binder Soil/Fines Mineralogy
		Admixture Type
		Aggregate Maximum Size

To their credit, DOCs simplify the prioritization procedure. That procedure involves the following: listing material properties important to some evaluation of performance; listing influencing constituent properties, material properties, and mix proportions; and then making cuts to limit data based on information contained in the appropriate DOCs. These cuts can be made in view of redundancy and test and database availability and importance.

Table 6.5 Factors affecting AASHTO-required portland cement (PC) stabilized base material properties as indicated by DOCs

Material	Category of Data (Holding Box)	Factors
PC Stabilized Base	**Composite Properties (from Table 6.1)**	*Mixture Cohesion*
		Mixture Internal Friction
		PC Stabilized Base Resistance to Subgrade Infiltration
		PC Stabilized Base Resistance to Frost Action
		PC Stabilized Base Stability and Resilient Modulus of Elast.
		Mixture Density
		PC Stabilized Base Permeability
	Mix Proportioning	*Binder Soil Content/% Fines*
		Cement Content
		Aggregate Content
		Mixture Moisture Content
		F.A. to C.A. Proportion
		Dust Ratio
	Constituent Properties	*Cement Fineness*
		Cement Chemical Composition
		Water Impurity Content
		Admixture Type
		Binder Soil Deleterious Material Content
		Binder Soil Plasticity or Character
		Aggregate/Soil Gradation
		Aggregate Hardness
		Aggregate Shape
		Aggregate Surface Texture
		Aggregate Crushing Strength
		Aggregate Durability
		Aggregate Mineralogy
		Binder Soil/Fines Mineralogy

Table 6.6 Factors affecting AASHTO-required lime stabilized base material properties as indicated by DOCs

Material	Category of Data (Holding Box)	Factors
Lime Stabilized Base	**Composite Properties (from Table 6.1)**	*Mixture Cohesion*
		Mixture Internal Friction
		Lime Stabilized Base Resistance to Subgrade Infiltration
		Lime Stabilized Base Stability and Resilient Modulus of Elast.
		Lime Stabilized Base Resistance to Frost Action
		Lime Stabilized Base Permeability
		Mixture Density
	Mix Proportioning	*Dust Ratio*
		F.A. to C.A. Proportion
		Mixture Moisture Content
		Aggregate Content
		Lime Content
		Binder Soil Content/% Fines
	Constituent Properties	*Water Impurity Concentrations*
		Admixture Type
		Lime Chemical Composition
		Binder Soil Deleterious Material Content
		Binder Soil/Fines Mineralogy
		Binder Soil/Fines Plasticity
		Aggregate Hardness
		Aggregate Soil Gradation
		Aggregate Shape
		Aggregate Crushing Strength
		Aggregate Surface Texture
		Aggregate Mineralogy

Table 6.7 Factors affecting AASHTO-required bitumen stabilized base material properties as indicated by DOCs

Material	Category of Data (Holding Box)	Factors
Bitumen Stabilized Base	**Composite Properties (from Table 6.1)**	*Mixture Cohesion*
		Mixture Internal Friction
		Mixture Density
		Bitumen Stabilized Base Stripping Resistance
		Bitumen Stabilized Base Resistance to Subgrade Infiltration
		Bitumen Stabilized Base Resistance to Frost Action
		Bitumen Stabilized Base Stability and Resilient Modulus of Elast.
		Bitumen Stabilized Base Permeability
	Mix Proportioning	*Dust Ratio*
		F.A. to C.A. Proportion
		Mixture Moisture Content
		Aggregate Content
		Binder Content
		Binder Soil Content/% Fines
	Constituent Properties	*Binder Viscosity/Penetration*
		Binder Grade/Classification
		Mixing Water Impurity Concentrations
		Admixture Type
		Binder Soil Plasticity/Character
		Aggregate Hardness
		Aggregate/Soil Gradation
		Aggregate Shape
		Aggregate Crushing Strength
		Aggregate Durability
		Aggregate Surface Texture
		Aggregate Mineralogy

Table 6.8 Summary of ancillary information from the DOCs for PCC for factors and material properties needed for AASHTO design

Data Element	Type	Database Sources (Database and Location on Database)	Testing Sources	"More Important" Properties	"Less Important" Properties or Not at All
A) Concrete Modulus of Rupture (Flexural Strength)	Material Property	SiteManager (Test Results)	Tex 418A, 448A	N/A	N/A
B) Concrete Tensile Strength	Material Property	SiteManager (Test Results)	Tex 418A, 448A	N/A	N/A
C) Concrete Coefficient of Thermal Expansion	Material Property	Not Available	Not Tested	N/A	N/A
D) Concrete 28-day Shrinkage	Material Property	Not Available	Not Tested	N/A	N/A
E) Concrete Modulus of Elasticity	Material Property	Not Available	Tex 418A, 448A	N/A	N/A
1) Water-to-Cement Ratio	Mix Proportion	SiteManager (PCC Properties)	Not Tested	A, B, C, D, E	None
2) Aggregate to Cement Ratio	Mix Proportion	SiteManager (PCC Materials)	Not Tested	C, D	A, B, E
3) Cement Content	Mix Proportion	SiteManager (PCC Materials, Test Results)	Not Tested	D	A, B, C, E
4) Aggregate Content	M ix Proportion	SiteManager (PCC Materials)	Not Tested	C, D	A, B, E
5) % Air/Air Entrainment	Mix Proportion	SiteManager (PCC Properties, Test Results), Road Life	Tex 414A, 416A	None	A, B, C, D, E
6) Water Content	Mix Proportion	SiteManager (PCC Materials)	Not Tested	A, B, C, E	D
7) Cement Fineness	Constituent Property	SiteManager (PCC Materials, Test Results)	Spec. Item 524 Tests	C, E	A, B, D

Table 6.8 (continued) Summary of ancillary information from the DOCs for PCC for factors and material properties needed for AASHTO design

Data Element	Type	Database Sources (Database and Location on Database)	Testing Sources	"More Important" Properties	"Less Important" Properties or Not at All
8) Cement Chemical Composition	Constituent Property	SiteManager (PCC Materials, Test Results)	Spec. Item 524 Tests	A, B, C, E	D
9) Admixture Type	Constituent Property	SiteManager (PCC Materials)	ASTM C494, C260	A, B, E	C, D
10) Aggregate Gradation	Constituent Property	SiteManager (Material Gradations, PCC Materials, PCC Gradations, Test Results), Road Life	Tex 401A, 402A, 406A	A, B, E	C, D
11) Aggregate Max. Size	Constituent Property	SiteManager (Material Gradations, PCC Materials, PCC Gradations, Test Results), Road Life	Tex 401A, 406A	None	A, B, C, D, E
12) Aggregate Shape	Constituent Property	Not Available	Not Tested	None	A, B, C, D E
13) Aggregate Mineralogy	Constituent Property	Not Available (SiteManager [Name?], Test Results), Road Life	Tex 408A, 413A, 612J	C	A, B, D, E
14) Aggregate Coefficient of Thermal Expansion	Constituent Property	Not Available	Not Tested	C	A, B, D, E
15) Aggregate Modulus of Elasticity	Constituent Property	Not Available	Not Tested	E	A, B, C, D
16) Aggregate Moisture Content	Constituent Property	SiteManager (Test Results)	Not Tested	None	A, B, C, D, E
17) Water Impurity Content	Constituent Property	SiteManager (PCC Materials, Test Results)	AASHTO T26	None	A, B, C, D, E

6.5 CONCLUSION

This chapter has provided future developers of the proposed database a methodology that they can use, assuming tasks and materials have finally been selected, to help determine which material properties and factors to include in the proposed database.

Using a material properties "universe" concept, developers can, for various tasks, select material properties for inclusion in the proposed database. As an example, a list of material properties needed for material selection for the AASHTO pavement design procedures was generated for the three focus materials. Using the DOCs included in Appendix D, the factors, including mix proportions and constituent and material properties, related to the aforementioned material properties can be identified. This was done for the AASHTO pavement design example. Finally, using information that is provided in Chapters 2 and 4 related to database and testing sources of properties and factors, as well as to the level of importance feature in the DOCs, as discussed in Chapter 5, decisions can be made related to how to eliminate certain factors from consideration. Table 6.8 shows this data for PCC from the above example.

The value of this procedure, the methodology presented in the previous chapter, and the DOCs is that they provide much flexibility in this prioritization process; that is, they allow for the selection of a large number of material properties for inclusion at the discretion of TxDOT. Furthermore, with the help of the DOCs, factors can be liberally selected for inclusion in the proposed database. This selection can proceed with the knowledge of their ease of collection and storage, as well as their importance to material properties and their relationship to other factors that might be included. Consequently, the methodologies and tools presented in this and the previous chapter have eased the prioritization that will surely be necessary prior to the subsequent development of the proposed database.

CHAPTER 7. DATABASE CONCEPTUAL FRAMEWORK

7.1 INTRODUCTION

It is not the goal of this research to produce a tangible database. Rather, providing the information needed to advance development of the proposed database is the thrust of this research/report. Part of this information development, as was suggested in Chapter 1, is the creation of a conceptual framework for the proposed database that is flexible, user-friendly, modifiable, and compatible with the existing TxDOT computing environment. A conceptual framework for a database can help provide a computer blueprint for the proposed database. It can describe the various computing components of this database and explain their interrelationships. "The purpose of the conceptual framework is to highlight the major components of the computerized…system and to configure the logical data flow paths among these components" (Victorine 98). It is important to realize that any performance-monitoring database is a system of interrelated functions and components. It is from this system point-of-view that the conceptual framework of the proposed database must be viewed. The conceptual framework can and must help answer that question; yet it must also conform to the above constraints and meet the above objectives.

Considering the nature of the data likely to be stored in the proposed database when prioritized as shown in Chapter 6, a GIS-oriented conceptual design/framework seems a logical choice. This is especially so because it may be important to store information regarding the application and source locations of focus materials. This choice is even more appropriate considering the fact that TxDOT is already in the process of establishing its GIS architecture (Victorine 98); and, accordingly, a research constraint is to ensure compatibility with the TxDOT computing environment. Fortunately, a conceptual design for such a GIS-oriented database has already been developed by Zhang at The University of Texas at Austin (Zhang 96). The conceptual framework presented below relies heavily on the concepts developed by that author and on some of the state-of-the-art concepts presented in Chapter 2.

While in the end, future developers may elect to rely on a simpler conceptual framework not involving GIS, the conceptual design with GIS is described here because it represents the high-end of complexity; that is, the conceptual design can only decrease in complexity if GIS is not included. The advantages of a GIS-based system are as follows (Victorine 98):

1. A GIS-based system can improve reporting by using graphics rather than tabular data. For instance, if materials information were stored with information related to their sources and/or information related to the location of their applications, additional insight into the performance of those materials could be identified. Though the proposed database will not use an application-based, long-term performance-monitoring scheme, such data could be helpful for monitoring trends in the performance of materials used in a certain location or taken from a certain source.
2. A GIS-based system can improve efficiency by acting as a platform for linking several data sources more effectively. Using several sources, information can be

combined in a GIS in order to conduct analyses and create representations of the results that incorporate data from all these sources. This could be valuable, considering the goal of the proposed database to import data from a variety of TxDOT databases.

3. A GIS-based system can make better use of limited human and financial resources available to TxDOT. A materials performance database utilizing GIS could reduce time and resources spent on analysis. Furthermore, GIS may help limit the number of mistakes made with materials selection and other issues, thereby making better use of human and financial resources.

Thus, by making the proposed database GIS-based, TxDOT can reap numerous rewards that mainly center upon improving efficiency and analysis.

7.2 GENERAL CONSIDERATIONS FOR THE PROPOSED DATABASE

As was discussed in Chapter 1, the proposed database is at the heart of any effort to monitor the performance of transportation materials. It serves as a repository of data that can be used for whatever tasks TxDOT assigns to the database. It can assist in material-quality comparisons, performance evaluations, material source evaluations, quality assurance, and quality control. The value of the results of any of these tasks is nearly wholly dependent on the quality of the data stored in the proposed database. Consequently, future developers of the proposed database must make every effort to maintain the following characteristics of the data and the database (Zhang 96):

- **Integrity**: The consistency and correctness of data must be preserved. This can be achieved by coordinated data accessing and updating so that any change of data values can be automatically applied to the dependent or related values.
- **Accuracy**: The data values in the database must represent, as closely as possible, the real-world situation with regard to both the magnitude and the indicated location and time of the values.
- **Validity**: The data values in the database must match the types and formats of corresponding data fields and should pass the logic and limits tests.
- **Security**: Database security is designed to protect any data item from unauthorized intrusion, alteration, and permanent loss, malicious or otherwise.
- **Documentation**: Proper documentation of each data element in the database can help maintain the database's integrity. This includes such basic information as the data element definitions, measuring units, data formats, data sources, and their relationships with other data elements.

Some of these difficulties are similar to those discussed in Chapter 2. For instance, in that chapter, we presented Oland's (Oland 97) discussion of material property formats, and McCarthy's (McCarthy 89) discussion of general problems with materials data. Sources such as these should be consulted during the development of the proposed database in order to ensure that the above characteristics are incorporated.

Zhang suggests specific ways that these five characteristics can be maintained. For instance, to maintain validity, Zhang suggests that specific data-validation procedures should be coded into the data input subroutines of the database so that it rejects data that does not fit. Furthermore, he suggests that one way to improve accuracy is "to use a laptop computer with portable GIS and GPS technologies for field data collection" (Zhang 96). In addition, existing automated forms for material data should also be utilized when designing the materials database. However, specific solutions for maintaining the integrity, accuracy, validity, security, and documentation of the proposed database will be the challenge of future developers of the proposed database.

In addition to maintaining the aforementioned characteristics, there are numerous other capabilities that the system must possess. A materials performance and analysis database/system should "have the capabilities for the users to easily maintain their database, manipulate their data effectively, and present their results visually" (Victorine 98). The following are detailed descriptions of some of those capabilities (Victorine 98):

1. **Database Maintenance**: The system should be maintainable to provide all kinds of database management capabilities, such as modifying the existing database, adding/deleting data elements, and updating data elements.
2. **Multimedia Data Support**: As is discussed below, it would be beneficial for the system to include a multimedia interface and related capabilities to support all kinds of multimedia, especially images, memoranda, test data, graphs, and charts.
3. **Data Query**: Data query implies that data records in a data table can be selected by a defined set of query conditions based on their attribute values and relations. The user should be able to initiate such queries using a well-designed graphical user interface (GUI), rather than complex programming.
4. **Data Manipulation**: The system should allow the user to perform a variety of data manipulation operations on the records of any data type, including number, string, and Boolean. The results from such manipulation can be used to either create a new data field or replace the values in an existing field.
5. **Results Presentation**: The database should allow for the production of presentation-quality reports in the form of tables, maps, spreadsheets, graphic charts, or a combination therein.

Finally, since this proposed database is still in its conceptual beginnings, it is important, as has been intimated throughout this report, that it be flexible to changes in the materials it supports and the material properties/factors that it stores. Furthermore, it should be compatible with the TxDOT computing environment when it is created. The following components and conceptual framework are designed to support these requirements and to fulfill these needs.

7.3 DATABASE INTERFACE

The proposed database should operate under a multiple document interface (MDI). This state-of-the-art interface facilitates easy data analysis, manipulation, and operation, while allowing a variety of data to be handled visually. The MDI is also capable of analyzing data spatially and presenting results graphically (Zhang 96). In essence, MDI gives users more flexibility to navigate among analysis functions.

7.4 MAJOR DATABASE FUNCTIONAL COMPONENTS

Should future developers of the proposed database choose to create a GIS-based database, one capable of storing geographic data, the system will require multiple components. The proposed conceptual design for the proposed database is best represented in Figure 7.1.

Some of the architecture shown in Figure 7.1 requires explanation. The arrows between components represent links through which information is passed. Should geographic data be included, as discussed above, the **Database of Material Properties** would need to be in two general components or databases. The **Geographic Database** would be a database "where a collection of spatial data and related descriptive data are organized for efficient storage and retrieval, using a georelational and topological data model" (Zhang 96). The **Attribute Database** would store tabular materials data, related to the geographic database.

The **Graphical User Interface (GUI)** is the margin across which the user can interact with the database or system. "A well-designed, user-friendly graphical user interface (GUI) not only can greatly decrease the user learning curve; it can also increase the chances of successfully implementing the system" (Zhang 96).

Clearly, the conceptual framework suggests some capacity for the proposed database to store multimedia data. This is represented by the **Multimedia Server**. The purpose of this server is to allow multimedia items to be exported to the proposed database/data system. These items of data often require more disk storage space than a microcomputer can provide. The best solution to limited storage capacity is "to set up a special multimedia server where the same multimedia data can be accessed simultaneously by many users through network connections" (Zhang 96). While this report does not outline or recommend specific types of such data, this conceptual design leaves their inclusion open as an option in the future. At the ETG meeting, some members discussed the need to store diary information or experience-based comments about materials performance in the proposed database. Inclusion of multimedia storage capabilities would lend itself to incorporating this type of data in the proposed database. Other examples of possibly relevant multimedia data items include those documents that report materials properties, mix proportions, and constituent properties; these documents include scanned materials information of lab reports, mill certificates, cement manufacturer tags, etc.

Also shown in the conceptual framework are the five previously discussed TxDOT databases, including **SiteManager, Road Life, MMIS, TRM**, **PMIS, and Automated Forms**. As was suggested in Chapters 2 and 4 and shown in Chapter 6, these databases store large amounts of materials-related data. They will be important sources for the proposed database and could limit the amount of effort spent in data collection for that database. Connection of the proposed database to these data sources is one way of assuring maximum compatibility with the current computing environment in TxDOT.

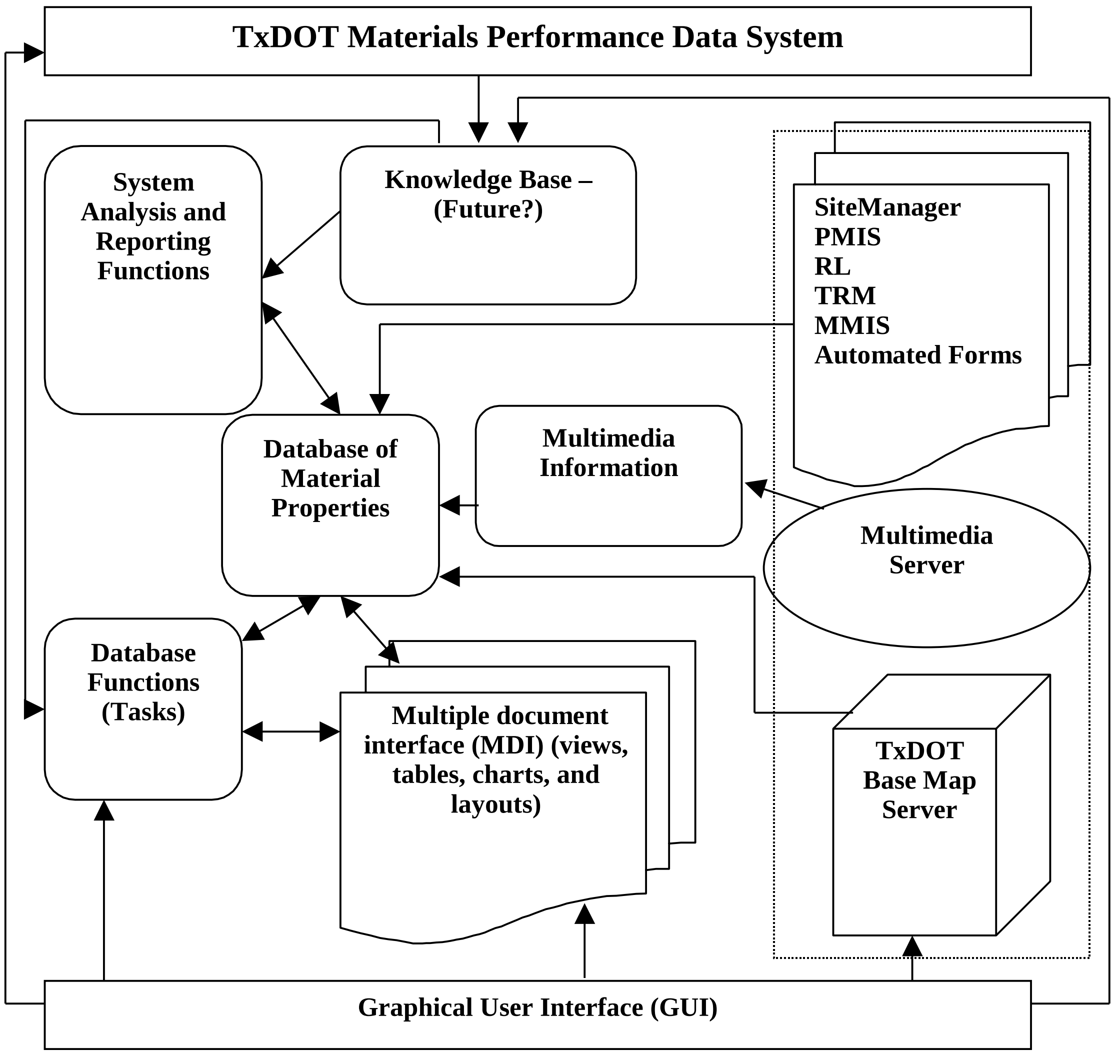

Figure 7.1 Conceptual framework design for TxDOT materials performance database (Zhang 96)

A **Knowledge Base** is also shown as part of Figure 7.1. While the goal of this research was to develop the information necessary to develop a database, it may in the future, be a goal to convert the proposed database into a knowledge base or expert system. Such systems were briefly discussed in Chapter 2. The literature discussed there and elsewhere would be strong sources for developing the proposed database. Clearly, if the proposed database later included some expert-system characteristics, it could perform more powerful analysis functions. The component shown Figure 7.1 for analysis functions represents the group of expert activities that the knowledge base would be required to perform. These activities, which would likely be specified later, could be similar to those expert-system functions discussed in Chapter 2. Consequently, a more thorough review of that and other literature could be helpful should TxDOT decide to implement a knowledge base as part of this performance-monitoring database/system.

The above conceptual framework also mentions database functions. These functions, not outlined here, are the prerogative of TxDOT, but would likely be related to the tasks in which the database would be expected to assist. Possible tasks as well as an example prioritization of data elements for a specific task are discussed in the previous chapter.

7.5 CONCLUSION

This chapter has presented a conceptual framework for the proposed database or data system; it has outlined the major components required as well as the interconnections between those components. Accordingly, this chapter can serve as a crude blueprint for future development of computer issues for the proposed database. While certain components, such as the geographic database and the knowledge base, need not be included in order to store the minimum amount of materials data, they could be useful analytical tools. Furthermore, if they are not included in the initial version of the proposed database, space should be left for their future addition.

The timing of the future development of the proposed database will greatly affect the type of computer technologies implemented. Since the computer industry is advancing at such a rapid pace, it will be important to leave the "ironing out" of further details until such time when the database is actually constructed. In doing so, full advantage can be taken of the state of the art. Some of the discussion in Chapter 2 may be of service as a guide to reviewing these state-of-the-art issues. Whatever the case, the design of the proposed database system needs to maintain flexibility and compatibility with the TxDOT computing environment as was suggested in Chapter 1.

CHAPTER 8. CONCLUSIONS AND FUTURE DIRECTIONS

8.1 OVERVIEW

In addition to summarizing conclusions and discussions from this report, this chapter will also suggest related tasks that remain to be performed to improve and develop a tangible performance-monitoring database, given greater resources and future research efforts.

8.2 SUMMARY OF CONCLUSIONS

The questions, constraints, and objectives presented in Chapter 1 have organized the different topics of this report. Consequently, the contents, recommendations, and conclusions of this report can best be summarized through revisiting these items or, more appropriately, their solutions. The following is a brief summary of the conclusions that have been presented throughout this report.

1. Given the current state of information technology, a database information system is the logical means by which to monitor the performance of materials.
2. No examples of research projects similar to this one were found in the literature. No other databases used to monitor the performance of materials were uncovered in extensive reading.
3. In order to improve and modernize the proposed database, state-of-the-art technologies related to this research that have been, and currently are, the subjects of publications **should be consulted prior to** future database development. Some of the topics reviewed include: TxDOT pavement and materials databases, pavement performance research, data formats for material property databases, object-oriented programming, expert systems, and materials databases.
4. Large quantities of materials-related data are already available within TxDOT in such databases as MMIS, PMIS, TRM, Road Life, and SiteManager. These databases have largely been populated as a result of the TxDOT material testing procedures that are also reviewed in this report.
5. Once tasks and materials are selected for the proposed database, information on testing and existing databases can help prioritize data elements for the proposed database through procedures presented in this report.
6. The proposed database should focus on materials that compose pavement structures and other transportation infrastructure applications. It should not focus on long-term, application-based performance.
7. Data relating to a level of detail lower than performance of focus materials, including data relating to transportation application performance (e.g., bridges and pavements), should be excluded from the proposed database.
8. Data at a detail level higher than focus material properties, constituent material properties, and mix proportions should not be included in the proposed database.

9. Environmental, loading, and construction data influencing material properties should not be included in the proposed database.
10. The performance of materials should be monitored through evaluation of basic material properties. The database should carry these material properties as well as the constituent material properties and mix proportions that affect them.
11. To select/prioritize the material properties, constituent properties and mix proportions to be included in the proposed database, data organization charts (DOCs) (such as those provided for PCC, bituminous surface mixes, and bases) should be consulted through the prioritization procedure presented in Chapter 6. These DOCs, as shown in Appendix D, contain the dynamic levels of detail needed to allow flexibility in selecting data elements for inclusion.
12. The conceptual framework, as presented in Chapter 7, for the proposed database involves integration of GIS-technology, a multiple document interface (MDI), a graphical user interface (GUI), importation of data from other TxDOT databases and a variety of other features. In order to store geographic data, the database will need to be broken down into a geographic database and an attribute database.

8.3 FUTURE DIRECTIONS

This report represents the beginning, not the end, of the process undertaken to develop the proposed database. Consequently, it has been developed with close attention to future work, which is summarized below:

1. It is recommended that an immediate implementation of the research be initiated to develop the database, including specific prioritization of material properties and other factors. Recommendations about possible tasks and materials have been discussed in Chapters 3, 5, and 6 of this report.
2. Additionally, further research and investigation of a number of topics will be important to the proposed database. Further literature monitoring and review may help improve, modernize, and streamline the proposed database. The following topics deserve special attention:

    - **Superpave:** The bituminous mix design methods that are arising out of the SuperPave project may provide additional insight into bituminous mixture properties, etc.
    - **State-of-the-Art Transportation Materials Research:** As explained in Chapter 5, the DOCs rely on generally accepted materials' science facts and on the synthesis of a variety of texts and other sources. On the other hand, more review of additional state-of-the-art materials research could help "fine-tune" the DOCs.
    - **ForenSys:** In addition to the five pavement and materials databases discussed in this report that can be used as data sources for the proposed database, the

implementation of the ForenSys system developed by the Center for Transportation Research for TxDOT could also benefit the proposed database.

- **LTPP Research:** While the performance-monitoring scheme promoted in this report relies on using material properties to estimate performance, future database developers may want to use pavement and other application condition/performance to monitor the performance of materials. Using such research, a definite relationship between pavement performance and materials performance could be better established. This would allow the proposed database to take advantage of the extensive pavement condition data stored in such databases as the PMIS.
- **Changes within TxDOT:** Changes in testing methods, changes to databases, and changes in the computing environment at TxDOT could affect the proposed database. Clearly, this research project and the proposed database must be compatible with the engineering operations within TxDOT.
- **SiteManager Development:** Since SiteManager is closely related to the proposed materials database, its impact on the proposed database should be carefully monitored.

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APPENDIX A: SUMMARY OF ETG MEETING DISCUSSIONS

Appendix A: Detailed Summary of Comments and Discussion at the First Expert Task Group Meeting

Time, Place: January 22, 1998 – 8:00 a.m. – 10th Floor Conference Room, ECJ Hall

Attendee:	Employment at Time of Meeting:
Art Barrow	TxDOT Materials
John Barton	TxDOT Wichita Falls
Randy Cox	TxDOT CMD
Jim Cravens	FWHA Austin
Dr. David Fowler	UT Austin
Ken Fults	TxDOT Design Pavement
Dr. Ronald Hudson	UT Austin
Mike Koen	TxDOT CMD
Paul Krugler	TxDOT Materials
George Lantz	TxDOT CMD
Mike Murphy	TxDOT Design Pavement
John Nichols	FWHA Austin
Mary Lou Ralls	TxDOT Materials
Dale Rand	TxDOT Materials
Matthew Rechtien	UT Austin
Ronnie Van Pelt	TxDOT Beaumont
Tracy Victorine	UT Austin
Richard Williammee	TxDOT Fort Worth
Dr. Zhanmin Zhang	UT Austin

Notes: All comments and observations described below came from various members of the ETG listed above. However, names are given when actions by ETG members are summarized. Generally, comments are grouped under a single number when stated consecutively by a single ETG member. Listed below are the testimonies of the above-listed experts. These testimonies do not necessarily represent facts. In some cases, statements were made in response to immediately prior statements, whereas, in other cases, statements are listed out of chronological order.

8:35 a.m. – Introductions – Mike Koen

1. Mike Koen prompts the attendees to introduce themselves.

2. Agenda is reviewed; however, any topic that an attendee would like to pursue is "fair game."

3. One ETG member remarks that in addition to the four topics on the agenda, topic five should be "miscellaneous and open."

Project Background – Dr. David Fowler

1. Dr. Fowler provides the general background for this project, his remarks supplemented with a short Powerpoint presentation. He stated that the expert working group could greatly help the research team not "reinvent the wheel" by creating a database that does not feed off those already in use by TxDOT.

2. Additionally, Dr. Fowler notes that some northern state representatives attending the Transportation Research Board meeting the previous week were discussing the creation of a national database for concrete materials and noted that this research project could tie into or serve as the forerunner to such a project.

3. Dr. Fowler also gave a brief background of the four main discussion topics at issue for this expert working group meeting. He highlighted a few basic points about each of them. One key issue he stated was that as-

built characteristics are not always identical to design characteristics, and that the database would need to make a selective distinction between the two. Furthermore, he noted that some materials used by TxDOT would be of primary consideration in the database, whereas others would be only secondary. Finally, he gave an overview of some of the issues that will arise when defining a material by its constituent or by its whole and when defining performance.

Topic One: Defining a Material by its Whole or by its Constituents – Discussion led by Mike Koen

1. There is a timeless difficulty with composite materials and with materials databases in general — namely, the more data items that are used, the more detailed the database becomes, but the more difficult it is to populate it adequately.

2. One ETG member related materials definitions to their experiences with the similar forensics database project 0-1731. They brought up the crucial point that on that database, as on this database, not all properties will be actually stored in the database, but, rather, they will be available on other referenced databases. That member also noted that most design procedures do not model themselves on constituent properties, but, rather, on the properties of the whole. They added, though, that knowledge of the individual materials may help define the composite, as with a pavement. Finally, they thought that we needed to define layers as a whole, but not look too closely at individual constituents.

3. Constituent data could be very helpful in improving pavement design procedures, enhancing specifications, and identifying patterns of inadequate materials usage. The database needs to look at both the whole and constituent materials data, but the key will be to make judicious choices about the proper level of detail for each material.

4. Such a database containing constituent information could, in some instances, do away with the need for test sections (on which TxDOT often spends resources).

5. The database should be like a file cabinet; that is, with room for everything. A good analogy is the information needed to file one's income tax report: the information is rarely required and can be voluminous, but when it's needed, it's completely necessary.

6. ACI 126 is attempting to create the necessary formats and standards for a concrete materials database. The research team should take notice of the important material properties that the committee has already outlined. Furthermore, Mr. C. Barry Oland is an excellent source for this information. TxDOT's Mary Lou Ralls has also done extensive work on a high-performance concrete database.

7. It will be very difficult to actually populate the proposed database, given the fact that available man-hours are being reduced within TxDOT. With regards to populating the database, the SiteManager database could be quite a useful source, particularly because TxDOT will be forced to populate it.

8. Using SiteManager to populate this database will be severely hampered by its poor capacity to support querying at this time.

9. SiteManager is a "moving target" that really is still not well defined in the materials aspect. In giving a brief summary of how data is to be entered into SiteManager, this ETG member did state his belief that the proposed materials database will be able to access data entered into SiteManager.

10. All database design is inherently a case of getting the "cart before the horse." This is because one must not focus on what data they can collect, but rather on what data is needed to ensure that the database fulfills its intended purpose. This paradox is also true with the materials database, and, as such, the experts need to focus on the data needed by the database, rather than on data collection difficulties.

11. Ideally, this database would truly not have to be created at all, but that rather, it will import as much data as possible from other TxDOT databases. This project should take as input what the users (experts) feel they

need as far as data in the database. Then, it will be the research team's job to outline a database using that data and to report on where all of that data is stored, if anywhere.

12. The goal of the research team is not to create a whole new database, but, rather, to identify the important materials and properties and then "mine" the appropriate existing databases for that information. However, the first task is clearly to identify the important materials and properties.

13. One ETG member stated that he could grasp what kind of data was needed in the database only if he could identify its end users (divisions or districts).

14. One member of the Project Advisory Committee admitted that they envisioned a broad range of users for the database, anyone from researchers to divisions to districts. They felt that it could be a powerful tool to capture word-of-mouth knowledge familiar to users from each of those categories.

15. This database could be a useful tool for such personnel as district paving engineers. For example, such an engineer could look at 100 projects to get a perspective on how well a given material performed in conjunction with a variety of environments and co-constituents in order to better use a material in design.

16. One ETG member tersely stated that they did not see the real value of such data in the above decision making.

17. One member of the research staff recalled a field trip that they had made to Wichita Falls, where they spoke to a number of engineers with vague memories of "bad actor" materials that had been mentioned only by word of mouth. That member noted that the problem is that this type of word-of-mouth knowledge is for the most part lost as employees who know its specifics either retire or move on. This member noted that he envisioned an engineer being able to query the database in the field to capture such information so that they can resist "pushy" salesmen and so that they can make better materials-usage decisions.

18. This type of database could be extremely useful for making very simple comparisons, such as keeping track of how long two similar products last in similar environments; that is, very simple evaluations of performance could be greatly speeded up through such a database.

19. One key to this project will be weighting the level of effort it takes to record and store a piece of data with the value of its use. This database will be helpful when, in 2002, new mechanized pavement design methods, created by AASHTO, are implemented. When these nonempirical mechanized methods are brought into service, new materials will be used in transportation infrastructure that TxDOT will need to monitor. Frequently, the data that is stored is not intrinsic materials property information, but rather surrogate information. Finally, materials data needs to be kept in databases such as these so that if they are used rarely (such as over a span of 20 years), their performance is electronically documented.

20. The database needs data to make it work — data that is often not currently collected; but too much data cannot be required of it or else it will be too difficult to collect.

21. Many ETG members agreed that before the expert group can begin discussing whether materials should be viewed through their individual constituents or as a whole, the group must first decide what tasks the database will perform, who the users will be, and which materials it will include (and their priority).

22. 9:30 a.m. – There are two broad tasks that the database must address:
    1) Aiding in performance-based specifications. TxDOT is not yet capable of creating these because it does not know which materials properties affect materials performance.
    2) Creating mechanistic design models.

23. TxDOT was at this same point 10 years ago with the Road Life database, but its problems were never resolved, leaving TxDOT in the same position again. This group should really try to get a good start today

at identifying materials and properties and to postpone worrying about where all the desired data will come from.

24. One ETG member complained that they would much rather have the inspectors working for him to actually inspect work rather than spend their time inputting data into a computer database.

25. The proposed database could greatly help reduce time required for other tasks, giving a variety of TxDOT employees more time to be able to populate the database. Furthermore, the database could prove a valuable tool in evaluating pavement design procedures.

26. Eventually there may not even be inspectors, and the data on this database will be helpful in assuring the quality of designs.

27. One ETG member remarked that he saw himself as a user of the database and that he could recall countless situations where this database could allow him to handle pressuring salesmen and to aid in the creation of test roadway sections.

28. Mike Koen, in an effort to summarize the conversation, remarked that it appeared as though people wanted the database to hold data both on composites (wholes) and constituents.

29. Data will be necessary on both composites and constituents.

30. One ETG member reiterated the value of the work performed by ACI 126. However, they tempered their enthusiasm by commenting that the amount of data collection required to develop the level of detail stipulated by ACI 126 would be an enormous task. It might be enough to capture only data on the composite in order to identify patterns of inadequate performance.

31. One research team member noted that ACI 126 data formats would most likely be incorporated into this project to ensure that no work is duplicated.

32. One ETG member remarked that they failed to see the usefulness of a database without information on constituents.

33. The database needs to have some information on constituents. However, it is important that the database not get “bogged down” with the details that are delved into by ACI 126 if all the database is needed to do is identify rudimentary patterns.

34. The panel generally agreed that it might be more important to use the database to identify patterns of good performance rather than patterns of bad performance.

35. While it may not be economical to collect the amount of data required to monitor performance of materials, it will be worthwhile if it will aid in the creation of performance specifications and mechanistic design.

36. Any test that TxDOT currently performs on materials could currently go into the database, though this amount of data may be unwieldy.

37. With the advent of mechanistic design procedures, this seemed like a very auspicious time to be undertaking this database project.

38. It is important that TxDOT first get all of the data that it is currently collecting everywhere on diskettes into a database before the research team begins worrying about what data it will need to collect in addition. That is, the project should first deal with the distributed data.

39. SiteManager will fulfill the role the distributed diskettes in the future. That is, data can be entered into the central SiteManager from remote and even field sites. Its upload capacity will centralize data that is currently being stored on diskettes.

40. One ETG member noted the need to also monitor and store data on the environment and loading conditions of such transportation infrastructure as roadways and pavements.

41. One problem that besets this database is that much of the design at the district level is driven by contractors through submittals. That is, how will this system help design at that level when TxDOT officials are not performing it?

42. The database will help in evaluating contractor design submittals and that in some cases, help contractors improve their designs.

43. Currently, does TxDOT verify as-built data?

44. The districts should have as-built records on hand.

45. Test records on as-built products are usually recorded.

46. Performance-based specifications should drive the database towards a composite, not a constituent, direction, but focus on the composite is based on its constituents meeting basic levels of adequacy. Thus, it follows that the database will need information on those constituents that do not meet basic requirements.

47. One problem with the analysis for which the proposed database is designed is that usually with a failure, there are many causes, and it's hard to single out one cause.

48. One member of the Project Advisory Committee reiterated that the proposed database will need to contain both composite and constituent data elements until the key tasks of the database are better outlined. At that point, it may become clear whether composite or constituent data elements are more critical.

49. This database cannot avoid having to contain some constituent data.

50. 10:00 a.m. – Break

10:15 a.m. – Topic Two: Definition of Performance – Discussion Led by Mike Koen

1. Mike Koen asked Mike Murphy how performance of materials has been specifically defined in the forensics project.

2. Mike Murphy responded by saying that he is not sure exactly how performance will be defined in the forensics project's FORENSYS database.

3. One Project Advisory Committee member noted that for this project, TxDOT wants all types of performance, including long-term and short-term performance.

4. TxDOT databases are moving from a mainframe to a client-server relationship. Thus, the proposed materials database will likely be using a client-server relationship. This type of relationship will work to the advantage of the TxDOT districts because it will allow them to keep their data separate, but will allow them to keep it on a statewide system concurrently.

5. One ETG member expressed concern that the materials database, if overly detailed in its data contents, will overload the TxDOT system.

6. There are combinations of factors that cause failures, and this database could help identify these combinations and prevent them from being used in the future. Conversely, the database could also identify particularly successful combinations so that they could be repeated in future applications.

7. The expert group must decide how to go about logging pavements in as failures. He noted that decisions would have to be made as to what constitutes a failure, versus simple damage and how will one search for these various states.

8. Different parts of the state can handle different degrees of rutting, thus the definition of a failure would seem to depend in part on location and thus not be a simple manner of numbers. Furthermore, there are also functional, operational and structural performance subcategories.

9. One ETG member stated that it seems as though numerical threshold values for failure should be defined, but continued that it would be a very difficult task to make these values compatible among the different states.

10. Failures could be indicated by the amount of dollars spent on a road section for maintenance.

11. It would be inaccurate to use dollars spent on a roadway section to determine failures because districts spend their allocated dollars regardless of how the quality of their roads compare to another district's. Allocation of dollars is less than scientific and do not necessarily reflect the quality of a given road section.

12. Mary Lou Ralls directed the expert group's attention to the February 1996 issue of *Concrete International* that lists high-performance concrete variables that could be adopted by the proposed database.

13. One ETG member summarized discussion on this topic by stating that there are types of distress that need to be controlled, including rutting, fatigue cracking, and thermal cracking. They lamented that, unfortunately, there is wide disagreement among even experts as to what constitutes a failure. They cited the Yoakum project wherein theorists and district pavement engineers legitimately disagreed as to the level of failure on a pavement section. They further noted that it would be difficult to "nail down" thresholds of failure.

14. Because TxDOT engineers cannot even agree on how to measure rutting (i.e., lasers or straightedge), it is difficult to define performance based on rutting. The database may just have to go with an evaluation of performance as simple as how long a product is in service or whether it is still in service.

15. Different states spend dollars differently on repairing roads; Texas, for example, repairs some roads that other states would not even consider repairing. Consequently, dollars spent and repairs made are poor objective indicators of performance.

16. It might be necessary to use simple threshold levels to define performance. For example, FM roads in Texas are limited to no more than 6 mil. Deflection and highways must have no less than a 2.5 psi. Roadway performance could then be gauged based on when those roadways reach the threshold level.

17. Any performance criteria would need to be as standard as possible.

18. A member of the Project Advisory Committee reminded the task group that, while everyone is focusing on evaluating the performance of pavements, there are other materials whose performance will require different methods of evaluation.

19. It is inadequate to use number of repairs or reapplications of a product to judge its performance. For example, consider striping and water-based paint. If one simply focuses on how many times new striping had to be applied to judge performance, they would be misled. This is because striping can decay owing to such activities as snow clearing, potting, and or scraping; that is, a product's performance should not be

marked down just because it is not properly used or abused. Thus, the number of repairs is a poor judge of performance in many cases. There is not a material whose cost represents a clear indicator of performance.

20. There might be some materials wherein performance simply cannot be defined.

21. Because pavements and bridges constitute approximately 60% of TxDOT's attention, the proposed database should focus on those items rather than on peripheral materials (e.g., signage). The RMC shares this opinion.

22. Bridge designs, owing to their uniformity, need to be the focus of the database. If anything, the database should focus on pavements and their constituents.

23. One ETG member suggested the development of a bridge information database that contains data on the performance of bridge spans, including simple, prestressed, etc.

24. The performance of many discontinued materials could be ignored by the database. For instance, 8" and 9" thick pavement layers are no longer being built, so their performance history holds no value for future decisions. There are many such examples of this.

25. If we no longer are building certain types of bridges, does the materials database need to be capturing or storing performance information on them? The bridge information system is not electronic; it stores data manually.

26. One member of the research staff cited difficulties with the **N**ational **B**ridge **I**nformation **S**ystem, which congress forced transportation officials to populate. Unfortunately, since it did not have wide support, it was poorly maintained and not really checked for accuracy. If desired, records from the bridge information database could be entered into the proposed materials database.

27. Checking for accuracy on a database is of the utmost importance; bad data is worse than no data.

28. 11:00 a.m. — It appears as though the materials database does not really need bridge information but rather information on the performance of a bridge's constituents. Why even create a performance database if TxDOT has no test materials and its maintenance effort means nothing to performance?

29. It might greatly simplify the definition of performance if it were based on short-term parameters such as lab testing in a controlled average environment.

30. It is a legitimate issue as to whether the database properties will be field or design based.

31. There needs to be a transfer function on the database between field performance and laboratory performance.

32. While performance is often vaguely thought of as the inability of a product to fulfill its intended function, there are some objective measures, like chloride content and rutting that can definitely be included.

33. An ETG member suggested that the database and the ETG simply focus on pavements initially so that people are not "turned off" by the scope of the project. The member added that this limited scope of materials would help get a pilot database working that could later be expanded to other materials.

34. Another ETG member lamented that they do not see this project ever really being implemented and they could envision this same group seated around a table discussing a similar topic in ten years.

35. A member of the Project Advisory Committee commented that this is a long-term project and that the group simply needs to decide what data needs to be collected now. They added that the system should be amenable to add on materials and data.

36. What this project really seeks to create is an engine to collect data pertaining to the performance of materials, all of which is probably currently being collected. The essential question is what data is needed; this engine may tackle other tasks later.

37. One ETG member felt that the essential issue is not what data the proposed database will collect and store, but, rather, how will it work and by what mechanisms it will operate.

38. One way to make this database work would be to force the contractors to collect the required data on a disk that would be turned into TxDOT. This form of data collection for the database could be simpler than current data-collection efforts.

39. A Project Advisory Committee member again stated that the goal of the research is not a database or a search engine, but, rather, the generation of a database conceptual design; at the same time the research also seeks to outline the practices going on in TxDOT currently and to ascertain how they can be used to the proposed database's advantage.

40. 11:15 a.m. – TxDOT collects much data that is never used simply because it's easy to collect. This proposed database would help evaluate the value of that data.

41. Much of the data and requirements that the group is discussing would be located on the SiteManager software.

42. One member of the research team noted that this proposed materials database will, as a rule, use all of what is on SiteManager that is pertinent. Unfortunately, the data on SiteManager appears to be stored only for 3 years because SiteManager is a project administration tool, not a long-term monitoring database. They also added that the materials database would have to retrieve data from SiteManager and store it over the long term.

43. SiteManager, like the proposed materials database, will only store data; it will be the responsibility of the engineer to analyze that data. The proposed system could begin to tackle some of these tasks if it were upgraded to an expert system, but that is not the current scope of the project. The information collected on the materials database will be stored for more than 3 years.

44. This database could function like the U.S. fingerprint database, wherein at first only "bad actors" were stored, but where there was never a program to get everyone's fingerprint stored in the database.

45. 11:25 a.m. – FHWA representatives depart meeting

46. It will be important to store information on the source of various materials. This information is already available on SiteManager. Data as simple as brand name, location used, date used, and contract number could be stored as a bare minimum so that TxDOT could keep track of materials usage and later their performance.

47. The above-mentioned kind of data is simply necessary to back up performance-based specifications.

48. Mike Koen mentioned warranties.

49. One ETG member wondered aloud how the FHWA defined performance for warranties and how this database can make use of these definitions.

50. TxDOT currently has fifteen FWDs but still cannot perform structural evaluations of pavement. The proposed database must be first designed and created before TxDOT can worry about analyzing data.

51. It is necessary to look at the state of the art in TxDOT data gathering to see whether this gathering is adequate.

52. This expert group must at least estimate a performance criterion and create a list of things that this database must include.

53. One research team member noted that data might be broken down into three different categories including: data which is collected and which is available, data which is collected and which is not available and data that is neither collected nor available.

54. One ETG member asked aloud whether SiteManager is adaptable such that a state can create formats to collect any data that it so desires. They added that many tests taken are never recorded if they have passing results.

55. SiteManager can be tailored to allow any data to be collected or imported.

56. One research team member remarked that they believe that every sample is stored in SiteManager but that the specific formats can change from state to state.

57. It is the researcher's job to tell TxDOT where data required by the materials database is and also to advise TxDOT which data needs to be collected by the materials database.

58. 11:40 a.m. – One ETG member mentioned the idea of the states working on SiteManager, organizing a new study on a just materials expansion of SiteManager. They indicated that they are not sure if this would be jointly or individually funded. They continued by saying that they are not sure whether more screens should be developed nationally or on a state-by-state basis. This is because, for example, some states need screens relating to Marshall mix design and some need screens relating to CBR method.

59. 11:50 a.m. – Break for Lunch

12:35 p.m. – Topic Three: Materials to Include and Their Priority – Discussion led by Mike Koen

1. Mike Koen asked the group whether materials to include in the materials database should be categorized by dollars spent on them only or by other priorities.

2. The problem with this topic is that priority is completely user-based and that the users of this database have not been adequately limited. For instance, one user may be highly interested in coating whereas a pavement engineer would be interested in asphalt and portland cement concrete.

3. This type of prioritizing used to be performed with a "cost index," but such a system may be here inadequate because there are non-large dollar items that may well be just as critical in the database because of their influence on safety.

4. Prioritizing by dollars spent is flawed owing to the fact that one only ends up following the initial costs. One consequence of that is that TxDOT would give all of its attention to asphalt concrete because it's cheaper initially. The approach focusing on initial costs would miss the fact that asphalt concrete usage generally results in more maintenance and "shut downs," which generate hidden repair and operational costs.

5. Safety definitely should be an issue in deciding what materials to include.

6. One ETG member added that they felt as though the focus should be on those materials that fail the most frequently.

7. Any material under a QC/QA specification must be included, because data on these materials is needed to evaluate their performance under that specification. Furthermore, any pay adjustment materials/properties as well as warrantied items must also be included in the materials database.

8. This project should be first developed as a small-scale pilot, focusing on a small number of materials and properties before it is expanded for general purposes.

9. Confusion could stem from the fact that “ride” is a very important property to a material and its performance, yet it is not a material but a composite property.

10. The database must hold hard number properties rather than judgment properties. The users should be allowed to evaluate the data themselves, rather than be forced to abide by judgments of others placed on the database. If it is decided that some judgment data needed to be added later, it could be.

11. This database would need to include properties relating to traffic and climate information. The traffic data in the PMIS is unfortunately planning oriented, not project oriented.

12. One member of the ETG wondered aloud whether the priority systems discussed above should be applied to a list of all materials or to a list of properties pertaining to one material.

13. A member of the Project Advisory Committee remarked that the research committee was not really intending this project to focus on only one material. Rather, the committee simply wanted to develop a framework to evaluate how much money and time this materials database would require.

14. 1:00 p.m. – A member of the PMC reiterated that this research project needs to remain broad based.

15. The database needs to focus on pavements, bridges, and safety improvements. He noted that safety improvements are a part of functionality. Consequently, the database should include data on how much safer a 6:1 slope is than a 3:1 slope, so that the comparative safety of different processes can be evaluated.

16. QC/QA properties such as “ride” should be included in the database only when they are affected by materials properties. Just because something is in the QC/QA specifications doesn’t mean that the materials database is going to store it.

17. If the database is going to focus on performance, it must look at all of those factors (such as ride or aggregate segregation). Otherwise, it is incomplete.

18. One ETG member disagreed with the above comments by saying that there are not many aspects outside of materials that will be considered, though ride might be one of them. Ride, the member noted, can impact how long a pavement lasts but it is difficult to include in a database since it is not measured in a standard way.

1:10 p.m. – Topic Four: As Built vs. Design Properties — Discussion Led By Mike Koen

1. Mike Koen discussed the advantages in using each kind of property.

2. One ETG member illustrated an example of whether the database should use design slump or as-built slump.

3. The database should begin storing design values and then those values should be replaced or complemented by as-built values when tested.

4. As-built thickness’ may vary quite widely in a pavement, whereas there will be only one design value.

5. Continuing to store design values even if as-built data is collected could be good for historical comparisons.

6. By saving design as well as as-built data, the database's storage requirements could be as much as doubled.

7. Most of the participants seemed to agree that the as-built properties, etc., are more important than the design properties.

8. Storing both kinds of data would aid in determining whether a performance or construction failure had occurred.

Topic Five: Miscellaneous Topics — Discussion Led by Mike Koen

1. A member of the research team reminded the expert group that the goal of the research project was not to produce a database but rather to produce a framework for that database. They illustrated a general thought process for the project by noting that first a database purpose must be defined. Once database purpose and user requirements are decided, the research team can define materials and properties to be included in the database. They continued by noting that once the data required for the materials and properties in the database is determined, the appropriate data sources can be identified throughout TxDOT. With the data required and its sources identified, a conceptual framework will result. Finally, they stated that the research team will outline how to access existing data that will be stored in the database, along with a procedure for collecting data that is not existing.

2. One ETG member stated that they want the database to allow them to perform a very simple and quick success/failure search within the database, rather than a search that confronts the user with a barrage of numbers. They noted that it is often difficult to gauge how a material is performing from many numbers.

3. A new step beyond basic numerical data is success/failure evaluations that capture word of mouth knowledge on a material within the department.

4. Another ETG member agreed that with later adjustments, function (capturing word-of-mouth knowledge) would be available to users.

5. In addition to mechanistic or property factors, engineering judgment is an important design factor.

6. One ETG member stated that they would like the database to hold more materials-specific information, including methods of installation/application, cost, and such other information as the environmental conditions under which it was placed.

7. This ties back to how TxDOT wants to measure performance. That is, is it simple numbers, or is it more? Does it include subjective engineering judgment opinions?

8. The problem with engineering judgment information is that it requires writing a report on every different item used in a project. That is, collecting engineering judgment information could require engineers in his position to write hundreds of reports for every project.

9. The ForenSys database could store, in a GIS format, photos, sounds, and videos to reduce report-writing workloads. He generalized by saying that future technology will minimize all of the workload problems that seem to beset this project.

10. 1:50 p.m. — One ETG member responded to another by stating that they are not saying 100's of reports on every material need to be written, but rather just the "hot items" and new materials. They clarified by saying that they simply want a way to put experience into a simple framework, like a remarks/comments section.

1:55 p.m. – Topic Six: User Purposes — Discussion Led by Mike Koen

1. One ETG member listed the following as his purposes and uses for the proposed material database system:
   a) Identifying materials sources
   b) Querying materials properties and qualities

c) Determining if performance for a material he is using on a project is the same as the performance reported by other projects for that product. This would be used at district offices for comparison purposes.
b) To avoid redundant testing of materials (i.e., if they have never failed a test)

2. One ETG member noted that they would not use this database to make sweeping generalizations, but rather to get a general feel for performance and to reduce hassles at work.

3. An ETG member stated that the proposed materials database could be a great help to them because they would be able to reallocate time away from listening to supplier sales pitches. Furthermore, they stated that they felt it could be a great help in finding out what other districts are doing so that his district will not "reinvent the wheel."

4. Another ETG member commented that this database would help them evaluate long-term performance and compare such performance to specification requirements and properties.

5. An ETG member commented that they did not envision having any use for the proposed materials database.

6. One ETG member noted that this database would help in creating mechanistic design models. Furthermore, they stated that they envision it having a feedback system that allowed users to interface with administrators and that the system would have a user friendly graphical interface. Finally, they want it to have a capability to determine how many on-line "hits" are made on the systems records, etc., to verify which aspects are the most popular.

7. A member of the Project Advisory Committee noted that they believe the database could provide historical construction data that could support QC/QA specifications.

8. One ETG member noted that this database could stop the repetition of mistakes and poor designs by indicating problem patterns. Furthermore, they think it can be a tool to facilitate information sharing.

9. An ETG member stated that they want this database to be able to access other databases outside of TxDOT, such as the LTPP database and the weather databases. They did express concern over terminology and other compatibility problems with these foreign databases.

10. A member of the ETG noted that this database could be helpful in determining whether or not recycled materials are used in a product. Furthermore, they felt it would be helpful for survey responses and legislative inquiries. Finally, they stated that such a database could aid task groups in solving "brush fire" problems.

11. Two ETG members agreed that it would be a wise idea to involve contractors in seeing the data in the database, in an effort to get them to help populate it. They did note that it would be difficult for the districts to collect data because, with the Freedom of Information Act, if the data is available, contractors will have access.

12. 2:25 p.m. — One ETG member stated that they could not imagine contractors would use this database very often. They stated that it is difficult enough getting contractors to use QC/QA information that already exists.

13. One ETG member mentioned that, in the future, the task group might want to look into problems with airport pavements.

14. 2:30 p.m. — Meeting adjourns

APPENDIX B: LISTING OF DATA CONTENTS OF TXDOT MATERIAL AND PAVEMENT DATABASES

Appendix B: Listing of Data Contents of TxDOT Material and Pavement Databases

Following is an abbreviated summary of the main data elements stored in each of the four materials/pavements databases operated by TxDOT. These data were extracted from current data dictionaries received during interviews with TxDOT database experts, information gathered during those interviews, and from past research performed for Project 0-1731. Details on these data elements concerning their exact function, format, etc., are available in the data dictionaries for these various database (Victorine 98), (TxDOT – MMIS), (TxDOT – TRM), (TxDOT – RL), (TxDOT – PMIS), (AASHTO 98). The author has used discretion in selecting the data elements that appear here; that is, many data elements in these databases that are not materials- or testing-related have been left off for the sake of brevity. These omissions include administrative data elements, user verification elements, and approved user elements for examples. Furthermore, in some cases, data elements listed here actually represent multiple data elements in their respective databases, but have been listed as a single unified entry, again for brevity. When applicable, data elements are followed by a parenthetical modifier to indicate the other database from which they import those data elements.

1. PMIS

1.1 Location Data

District (from TRM)
County (from TRM)
Maintenance Section & ID (from TRM)
Highway Designation (from TRM)
PMIS Highway System
Beginning Reference Marker and Displacement (from TRM)
Ending Reference Marker and Displacement (from TRM)
Roadbed ID (from TRM)
Functional System (from TRM)
Urban/Rural Designation Standard (from RL)
Under Construction Flag (from RL)

1.2 Pavement Type and Characteristics Data

Roadbed Pavement Type: CRCP, JCP, ACP
Number of Through Lanes (from TRM)
Left Shoulder Type (from TRM)
Left Shoulder Width (from TRM)
Right Shoulder Type (from TRM)
Right Shoulder Width (from TRM)
Roadway Surface Width (from TRM)

1.3 Visual Distress Data (only for most heavily damaged lane in control section)

1.3.1 For Asphalt Concrete Pavement

Shallow Rutting % (both visual and measured)
Deep Rutting % (both visual and measured)
Patching %
Total Number of Failures
Alligator Cracking %
Block Cracking %
Length of Longitudinal Cracking
Number of Transverse Cracks
Raveling
Flushing

1.3.2 For Continuously Reinforced Concrete Pavement

Number of Spalled Cracks
Number of Punchouts
Number of Asphalt Concrete Pavement Patches
Number of Portland Cement Concrete Patches
Average Crack Spacing

1.3.3 For Jointed Concrete Pavement

Number of Failed Joints and Cracks
Number of Failures
Number of Shattered Slabs
Number of Slabs with Longitudinal Cracks
Number of Portland Cement Concrete Patches
Apparent Joint Spacing

1.4 Other Non-Visual Distress Data

Ride Quality Data
Various Rutting Data

1.5 Condition Scores

Ride Score
Distress Score
SSI Score
Condition Score
Skid Score

1.6 Maintenance Data

Amount Spent (from MMIS)

1.7 Climatic Data

Average Annual Rainfall (constant for all roads within a county)
Average Annual Number of FT Cycles (constant for all roads within a county)

1.8 Traffic Data

Average Daily Traffic (from TRM)
Estimated AADT Achieved @End of Design Year, Growth Rate/Factor %
Cumulative ADT Since Original Surface
Cumulative ADT Since Last Overlay
Truck Traffic (18k ESALs) (from TRM)
Current 18 k Measure, 20 Year Projected 18 kip ESAL (from TRM)
Cumulative 18 k ESAL Since Original Surface Date
Cumulative 18 k ESAL Since Last Overlay Date
% Trucks (from TRM)
Average Ten Heaviest Wheel Loads (from TRM)

1.9 Cross Section Data

1.9.1 Original Surface

Date (from RL)
Type (from RL)
Thickness (from RL)
Width (from RL)

1.9.2 Base

Type (from RL)
Thickness (from RL)
Width (from RL)

1.9.3 Subbase

Type (from RL)
Thickness (from RL)
Width (from RL)
Swelling Potent.(RL)

1.9.4 Subgrade

Type (from RL)
Stabilization Type (from RL)
Stabilization Thickness/Depth (from RL)
Triaxial Class (from RL)

1.9.5 Last Overlay

Type (from RL)
Date of Last Overlay (RL)
Tot. Overlay Thickness (RL)
Width of Last Overlay (RL)

1.9.6 Last Seal Coat

Type
Date of Last Coat (from RL)

2. Road Life

2.1 Location Data

District
County
Highway Designations (hwy syst., #, suffix)
Beginning Reference Marker and Displacement
Ending Reference Marker and Displacement
Roadbed ID
Control – Section – Job #
Urban Rural Designation
Under Construction Flag

2.2 Pavement Type and Characteristics Data

2.2.1 Roadbed Pavement Type

CRCP
JCP
ACP

2.3 Cross Section Data

Location of Layer Information
Layer Number

2.3.1 Original Surface

Date
Type
Thickness
Width
Aggregate Type
Aggregate Grade
Polish Value
Asphalt Binder Type
% Air Content
Date % Air Content Cores Taken
%RAP
% Air Voids
Date % Air Voids Cores Taken
Asphalt Viscosity
Date Asphalt Viscosity Cores Taken
% Passing #200 Sieve
Coarse Aggregate Grade
Cement Type
Fly Ash (0 – 99.9)
Pit I.D. #
Precoated (y or n)

2.3.2 Base

Type
Thickness
Width

2.3.3 Subbase

Type
Thickness
Width

2.3.4 Subgrade

Type
Stabilization Type
Stabil. Thickness/Depth

Stabilization Type
Drainable
Pit I.D. #

Swelling Potential
Stabilization Type
Drainable
Pit I.D. #

Triaxial Class

2.3.5 Last Overlay

Type
Date of Last Overlay
Thickness of Last Overlay
Total Overlay Thickness
Width of Last Overlay
Aggregate Type
Aggregate Grade
Polish Value
Asphalt Binder Type
% Air Content
Date % Air Content Cores Taken
% RAP
% Air Voids
Date % Air Voids Cores Taken
Asphalt Viscosity
Date Asphalt Viscosity Cores Taken
% Passing #200 Sieve
Coarse Aggregate Grade
Cement Type
Fly Ash (0-99.9)
Pit I.D. #
Precoated (y or n)

2.3.6 Last Seal Coat

Type
Date of Last
Aggregate Type
Aggregate Grade
Pit ID #
Precoated (y or n)
Polish Value

3. MMIS

3.1 Location Data

District
County
Responsible Maintenance Section
Highway Designation (hwy system, #, suffix)
Beginning Reference Marker and Displacement
Ending Reference Marker and Displacement
Actual Reference Marker
Contract Number
Fiscal Year

3.2 Maintenance Data

Date Work Performed
Amount Spent
Function Code
Month to Date Amounts
Month to Date Material Area
Type/Kind of Work

4. TRM

4.1 Location Data

District
County
Maintenance Section
Highway Designations (hwy syst., #, suffix)
Beginning Reference Marker and Displacement
Ending Reference Marker and Displacement
Roadbed ID
Elevation Measure
Latitude Measure
Longitude Measure
Functional System
Highway Status Code

4.2 Pavement Type and Characteristics Data

Number of Through Lanes
Left Shoulder Type
Left Shoulder Width
Right Shoulder Type
Right Shoulder Width
Curb Type
Median Type
Roadway Surface Width

4.3 Traffic Data

Average Daily Traffic
Cumulative ADT Since Original Surface
Design Hourly Volume
Current 18 kip Measure, 20 Year Projected 18 kip ESAL
% Trucks
Average Ten Heaviest Wheel Loads

4.4 Cross Section Data

4.4.1 Original Surface

Type

4.4.2 Base

Type

5. SiteManager

5.1 Location Data

County
Contract Number
Prime Contractor

5.2 Material Descriptions

Material Code
Material Short Name
Material Full Name
Material Category
Material Specification Reference
Material Status

5.3 Material Gradations

Gradation Sieve Size
Gradation Minimum Range
Gradation Maximum Range
Gradation Status

5.4 Mix Designs

Contract Mix
Aggregate Blend
Bituminous Concrete Mixes
- *Hveem*
- *SuperPave*
- *Marshall Mix Design*

Portland Cement Concrete Mix Design
Aggregate Mix Design
Pavement Structural Design Data

5.5 Hveem Mix Description

Hveem AC Type
Hveem Mix Type
Hveem Full Name
Hveem Producer/Supplier Name
Hveem Designer Name
Hveem Approved by I.D.

5.6 Hveem Mix Properties

HVEEM VFA %
HVEEM Optimum AC% Tot. Weight
HVEEM Stabilometer Value
HVEEM VMA %

HVEEM Bulk Density
HVEEM Average Film Thickness
HVEEM Bulk Dnsty Optim. AC Units Type
HVEEM Dust Asphalt Ratio
HVEEM Maximum Density
HVEEM Moisture Susceptibility
HVEEM Maximum Density Units Type
HVEEM Maximum Specific Gravity
HVEEM Air Void %
HVEEM Bulk Specific Gravity
HVEEM Mixing Temp. And Units
HVEEM Compaction Temp. Units Type
HVEEM Compaction Temperature

5.7 Marshall Mix Description

Marshall Designer Name
Marshall Mix ID
Marshall Mix Type
Marshall Material Code
Marshall Effective Date
Marshall Full Name
Marshall Termination Date
Marshall Producer/Supplier Code
Marshall Approved Date
Marshall Producer/Supplier Name
Marshall Approved By User ID

5.8 Marshall Mix Props

Marshall Asphalt Content %
Marshall Stability
Marshall Flow
Marshall Air Voids %
Marshall VMA%
Marshall Film Thickness
Marshall Filler/BitumenRatio
Marshall VFA%
Marshall Brick Height
Marshall Recycling Agent %
Marshall Anti-Strip Agent %
Marshall Asphalt Absorp. %
Marshall Weighted BSG
Marshall Max. Spec. Gravity
Marshall Virt. Spec Gravity
Marshall Effective Asphalt
Marshall Density/Unit Wt.
Marshall Number of Blows
Marshall Mixing Temp.
Marshall Compaction Temp.

5.9 SuperPave Mix Description

SuperPave AC Type
SuperPave Mix Type
SuperPave Full Name
SuperPave Producer/Supplier Name
SuperPave Approved By User ID

5.10 SuperPave Mix Props

SuperPave N (Initial)
SuperPave N (Design)
SuperPave N (Maximum)
SuperPave % Gmm @ N (Initial)
SuperPave % Gmm @ N (Maximum)

Superpave Designer Name

SuperPave Opt. AC % by Total Wt
SuperPave Dust Proportion
SuperPave VMA %
SuperPave VFA %
SuperPave Lottman TSR
SuperPave Max. Specific Gravity
SuperPave Bulk Specific Gravity
SuperPave Mixing Temperature
SuperPave Compaction Temp

5.11 Bituminous Materials

Bituminous Material Full Name
Bituminous Material Brand Name
Material %
Bituminous Material Sample ID
Bituminous Material Apparent Specific Gravity
Bituminous Material Producer/Supplier Name
Bituminous Material Bulk Specific Gravity

5.12 Bitum. Gradations

Bit. Gradation Sieve Size
Bit. Gradation Sieve Value Bituminous
Master Grad. Limits Min.
Master Grad. Limits Max.
Production Tolerance Min.
Production Tolerance Max.

5.13 PCC Description

PCC Mix ID
PCC Concrete Class Type
PCC Effective Date
PCC Full Name
PCC Termination Date
PCC Approved Date
PCC Producer/Supplier Name
PCC Approved by User ID
PCC Designer Name

5.14 PCC Properties

PCC Min. Avg. Strength Required
PCC Design Strength Required
PCC Air Content Measure
PCC Water to Cement Ratio
PCC Slump Measured
PCC Theoretical Unit Weight
PCC Unit Weight Measured

5.15 PCC Materials

PCC Materials Specific Gravity
PCC Materials Material Code
PCC Materials Bulk Specific Gravity
PCC Materials Brand Name
PCC Materials SSD Weight
PCC Materials Absorption %
PCC Materials %
PCC Materials Fineness Modulus
PCC Materials Sample ID
PCC Materials Mass

5.16 PCC Gradations

PCC Master Gradation Limits Max.
Grad. Production Tolerance Min.
PCC Gradation Sieve Size
Grad. Production Tolerance Max.
PCC Gradation Sieve Value
PCC Gradation Unit Types
PCC Master Gradation Limits Min.

5.17 Aggregate Mix Description

Aggregate Mix ID
Aggregate Mix Material Code
Aggregate Mix Full Name
Aggregate Mix Producer/Supplier Code
Aggregate Mix Producer/Supplier Name
Aggregate Mix Designer Name
Aggregate Mix Concrete Class Type
Aggregate Mix Effective Date
Aggregate Mix Termination Date
Aggregate Mix Approved Date
Aggregate Mix Approved by User ID
Aggregate Mix Raw Soil Max. Density
Aggregate Mix Units for Raw Soil Max. Density
Aggregate Mix Raw Soil Optimum Moisture %
Aggregate Mix Raw Soil Plus Cement Percent
Aggregate Mix Soil Cement Maximum Density
Aggregate Mix Units of Soil Cement Max. Density
Aggregate Mix Soil Cement Optimum MC%
Aggregate Mix Recommended Cement Content by
Aggregate Mix Recommended Cement Content by
Aggregate Mix Maximum Volume Change %

5.18 Agg. Mix Comp. Str.

Aggregate Mix Age
Aggregate Mix Cement Percent
Aggregate Mix Compressive Str.

5.18 Aggregate Mix Materials

Aggregate Mix Material Code
Aggregate Mix Material Name
Material Producer/Supplier Code
Aggregate Mix Material Blend %
Aggregate Mix Material Sample ID

5.20 Agg. Mix Grad.

Master Grad. Limits Min.
Master Grad. LimitsMax.
Gradation Sieve Size
Production Tolerance Min.
Gradation Sieve Value
Production Tolerance Max.

5.21 Pavement Structural Design Data

Pavement Base
Pavement Subbase
Pavement Shoulder
Pavement Drainage Condition
Pavement Surface Thickness
Pavement Base Thickness
Pavement Subbase Thickness
Pavement Subgrade R-Value
Pavement Structural Capacity
Pavement Composite k-Value
Pavement Beginning Reference Point
Pavement Ending Reference Point
Pavement Milled Depth
Pavement Inside Shoulder
Pavement Lane 1
Pavement Lane 2
Pavement Lane 3
Pavement Lane 4
Pavement Lane 5

5.22 Agg. Blend Data

Aggregate Blend Percent
Aggregate Blend Sample ID
Aggregate Blend Sieve Size
Agg. Blend Material Code
Aggregate Blend % Passing
Aggregate Blend Mat'l Name
Pavement Effective Thickness

5.23 Specifications

SiteManager also stores all the data elements required for the following three specifications:

Steel
Portland Cement
Emulsified Asphalt

Pavement Lane 6
Pavement Lane 7
Pavement Lane 8
Pavement Lane 9
Pavement Lane 10
Pavement Outside Shoulder

5.24 Material Test Results

Sieve Analysis of Fine and Coarse Aggregates
Specific Gravity of Fine and Coarse Aggregates
Materials Finer Than No. 200 Sieve in Mineral Aggregates by Washing
Determining the Liquid Limit of Soils
Determining the Plastic Limit and Plasticity Index of Soils
The Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes

Compressive Strength of Cylindrical Concrete Specimens
Slump of Portland Cement Concrete
Weight Per Cubic Foot, Yield, and Air Content (Gravimetric) of Concrete
Air Content of Freshly Mixed Concrete by Pressure Method
Air Content of Freshly Mixed Concrete by the Volumetric Method
Mechanical Analysis of Extracted Aggregate
Quantitative Extraction of Bitumen from Bituminous Paving Mixtures
Bulk Specific Gravity of Compacted Bituminous Mixtures Using SSD Specimens Maximum
Specific Gravity of Bituminous Paving Mixtures
Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures
Asphaltic Cement Content of Asphalt Concrete Mixtures by the Nuclear Method
Particle Size Analysis of Soils
Specific Gravity of Soils
Resistance to Abrasion of Small Size Coarse Aggregate Using Los Angeles Machine
The Moisture-Density Relations of Soils Using a 5.5 lb. Rammer and a 12 in. Drop
Moisture-Density Relations of Soils Using a 10 lb. Rammer and an 18 in. Drop
Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate
Penetration of Bituminous Materials
Effect of Heat and Air on Asphalt Materials (Thin-Film Oven Test)
Kinematic Viscosity of Asphalts
Viscosity of Asphalts by Vacuum Capillary Viscometer
Specific Gravity of Semi-Solid Bituminous Materials
Plastic Fines in Graded Aggregate and Soils by Use of the Sand Equivalent Test
Total Moisture Content of Aggregate by Drying
Laboratory Determination of Moisture Content of Soils
Unit Weight and Voids in Aggregate
Testing Emulsified Asphalt
Unconfined Compressive Strength of Cohesive Soil
Compressive Strength of Hydraulic Cement Mortar (Using 2 in. or 50 mm. Cube Spec.)

Air Content of Hydraulic Cement Mortar
Fineness of Portland Cement by Air Permeability Apparatus
Clay Lumps and Friable Particles in Aggregate
Water Retention by Concrete Curing Materials
Ductility of Bituminous Materials
Density of Soil and Soil-Aggregate In-Place by Nuclear Methods (Shallow Depth)
pH of Aqueous Solutions with the Glass Electrode
Determination of Organic Content in Soils by Loss on Ignition
Distillation of Cut-Back Asphaltic (Bituminous) Products
Mechanical Testing of Steel Products
Resistance of Concrete to Rapid Freezing and Thawing
Resistance R-Value and Expansion Pressure of Compacted Soils
Autoclave Expansion of Portland Cement
Normal Consistency of Hydraulic Cement
Time of Setting of Hydraulic Cement by Gillmore Needles
Free Form Test

To be Specific, the Following Tests' Results are Provided for on the Current Version of SiteManager (they are represented by the above test names):

AASHTO *T11, T27, T84, T85, T89, T90, M145, T22, T119, T121, T152, T196, T30, T164, T166, T209, T269, T287, T88, T100, T96, T99, T180, T104, T49, T179, T201, T202, T228, T176, T255, T265, T19, T59, T208, T106, T137, T153, T112, T155, T51, T238, T200, T267, T78, T244, T161, T190, T107, T129, T154, Free Form*

ASTM *D2487, D4867*

APPENDIX C: SUMMARY OF TXDOT TESTING REQUIREMENTS AND SPECIFICATIONS

Appendix C, Table 2: Summary of TxDOT Testing of Material Properties

Key:		
	(unshaded)	Indicates tests in the Guide Schedule and possibly in specs as well
	(shaded)	Indicates a test in the specs, but not the guide schedule
	"N/A" indicates that data is not available!	
	"See appropriate specs" indicates that the multiple specifications apply which do not share common names and descriptions	
	"As specified" indicates that a specification exists but not a standard test procedure	

From Guide Schedule and Specifications and Guide Index				From Three-Volume Testing Manual	
Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
Embankment (Item 132)		Compaction	Tex 115E	Field Method for Determination of In-Place Density of Soils and Base Materials	This test determines the density of untreated and treated soil and granular material compacted in the roadway or in the natural state, as exists in a cut section and borrow source prior to excavation. The principle use of the in-place density is to determine the degree of compaction or percentage of the density obtained by the method outlined in Tex 113-E and Tex 114-E. The term "soils" used in this procedure includes as base materials, as well as fine grained soils.
		Liquid Limit	Tex 104E	Determination of Liquid Limit of Soils	This test procedure determines the liquid limit of soils, defined as the water content of a soil at the arbitrarily determined boundary between the liquid and plastic states, expressed as a percentage of the oven-dried mass of the soil.
		Plastic Limit	Tex 105E	Determination of Plastic Limit of Soils	This method determines the plastic limit of soils, defined as the percent water content of a soil at the boundary between the plastic and brittle states.
		Plasticity Index	Tex 106E	Method of Calculating the Plasticity Index of Soils	The plasticity index of a soil is the numerical difference between the liquid limit and the plastic limit. The liquid limit and the plastic limit are both expressed as a percentage of moisture content.
		Shrinkage	Tex 107E	Determination of Bar Linear Shrinkage of Soils	N/A

From Guide Schedule and Specifications				From Three-Volume Testing Manual	
Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
Untreated Subbase and Base Courses (Item 247)		Gradation	Tex 110E	Determination of Particle Size Analysis of Soils	This method determines the distribution of particle sizes in soils. If hydrometer analysis is not required, but a determination of material passing the No. 200 sieve is desired, refere to Tex 401-A or Tex 111-E
		Liquid Limit	Tex 104E	Determination of Liquid Limit of Soils	This test procedure determines the liquid limit of soils, defined as the water content of a soil at the arbitrarily determined boundary between the liquid and plastic states, expressed as a percentage of the oven-dried mass of the soil.
		Plasticity Index	Tex 106E	Method of Calculating the Plasticity Index of Soils	The plasticity index of a soil is the numerical difference between the liquid limit and the plastic limit. The liquid limit and the plastic limit are both expressed as a percentage of moisture content.
		Wet Ball Mill	Tex 116E	Ball Mill Method for Determination of the Disintegration of Flexible Base Material	This test method determines the resistance of aggregate in flexible base material to disintegration in the presence of water. This test provides a measure of the ability of the material to withstand degradation in the road base and detects sof aggregate which is subject to weathering. The result of this test is known as the Wet Ball Mill (WBM) value.
		Triaxial	Tex 117E	Triaxial Compression Tests for Disturbed Soils and Base Materials	This method determines the shearing resistance, water absorption and expansion of soils and or soil-aggregate mixtures.
		Compaction	Tex 115E	Field Method for Determination of In-Place Density of Soils and Base Materials	This test determines the density of untreated and treated soil and granular material compacted in the roadway or in the natural state, as exists in a cut section and borrow source prior to excavation. The principle use of the in-place density is to determine the degree of compaction or percentage of the density obtained by the method outlined in Tex 113-E and Tex 114-E. The term "soils" used in this procedure includes as base materials, as well as fine grained soils.
		Thickness	-	N/A	N/A
		Moisture Content	Tex 103E	Determination of Moisture Content in Soil Materials	This method determines the moisture (water) content of soil, rock, and soil-aggregate mixtures, expressed as a percentage of the mass, by means of either a conventional oven or a microwave oven.
		Bar Linear Shrinkage	Tex 107E	Determination of Bar Linear Shrinkage of Soils	N/A
		Moisture-Density Determination	Tex 113E	Laboratory Compaction Characteristics and Moisture-Density Relationship of Base Materials and Cohesionless Sand	This test method determines the relationship between water content and the dry unit mass (density) of base materials. The base materials are compacted in a mold with a rammer dropped from a set height. The test is performed on prepared materials passing the 1-3/4 in. sieve. Follow Tex 114-E for determination of moisture density relationships of subgrade/embankment soils.
		Particle Count	Tex 460A	Determination of Crushed Face Partilce Count	This method determines the percent of coarse aggregate particles meeting the crushed face requirement and the minimum percent of non-polishing aggregate when handling.

From Guide Schedule and Specifications				From Three-Volume Testing Manual	
Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
Treated Subbase and Base Courses (Items 263, 345, 266, 262, 276)	Untreated Subbase and Base Sourses (Item 247)	Gradation	Tex 110E	Determination of Particle Size Analysis of Soils	This method determines the distribution of particle sizes in soils. If hydrometer analysis is not required, but a determination of material passing the No. 200 sieve is desired, refere to Tex 401-A or Tex 111-E
		Liquid Limit	Tex 104E	Determination of Liquid Limit of Soils	This test procedure determines the liquid limit of soils, defined as the water content of a soil at the arbitrarily determined boundary between the liquid and plastic states, expressed as a percentage of the oven-dried mass of the soil.
		Plasticity Index	Tex 106E	Method of Calculating the Plasticity Index of Soils	The plasticity index of a soil is the numerical difference between the liquid limit and the plastic limit. The liquid limit and the plastic limit are both expressed as a percentage of moisture content.
		Wet Ball Mill	Tex 116E	Ball Mill Method for Determination of the Disintegration of Flexible Base Material	This test method determines the resistance of aggregate in flexible base material to disintegration in the presence of water. This test provides a measure of the ability of the material to withstand degradation in the road base and detects sof aggregate which is subject to weathering. The result of this test is known as the Wet Ball Mill (WBM) value.
		Triaxial	Tex 117E	Triaxial Compression Tests for Disturbed Soils and Base Materials	This method determines the shearing resistance, water absorption and expansion of soils and or soil-aggregate mixtures.
		Compaction	Tex 115E	Field Method for Determination of In-Place Density of Soils and Base Materials	This test determines the density of untreated and treated soil and granular material compacted in the roadway or in the natural state, as exists in a cut section and borrow source prior to excavation. The principle use of the in-place density is to determine the degree of compaction or percentage of the density obtained by the method outlined in Tex 113-E and Tex 114-E. The term "soils" used in this procedure includes as base materials, as well as fine grained soils.
		Thickness	-	N/A	N/A
		Moisture Content	Tex 103E	Determination of Moisture Content in Soil Materials	This method determines the moisture (water) content of soil, rock, and soil-aggregate mixtures, expressed as a percentage of the mass, by means of either a conventional oven or a microwave oven.
		Bar Linear Shrinkage	Tex 107E	Determination of Bar Linear Shrinkage of Soils	N/A
		Moisture-Density Determination	Tex 113E	Laboratory Compaction Characteristics and Moisture-Density Relationship of Base Materials and Cohesionless Sand	This test method determines the relationship between water content and the dry unit mass (density) of base materials. The base materials are compacted in a mold with a rammer dropped from a set height. The test is performed on prepared materials passing the 1-3/4 in. sieve. Follow Tex 114-E for determination of moisture density relationships of subgrade/embankment soils.
		Particle Count	Tex 460A	Determination of Crushed Face Partilce Count	This method determines the percent of coarse aggregate particles meeting the crushed face requirement and the minimum percent of non-polishing aggregate when handling.
	Lime (Item 264)	Compliance with Item 264	Tex 600J	Sampling and Testing of Hydrated Lime, Quicklime, and Commercial Lime Slurry	This tests method, divided into four sections, discusses the sampling and testing of hydrated lime, quicklime and commercial lime slurry.

Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
	Cement (Item 524)	Compliance with Standard Specs and Special Provisions	ASTM C 150, AASHTO M 85, ASTM C 91, ASTM C 595 as appropriate and with exceptions	see appropriate spec.	see appropriate spec.
	Asphalt (Item 300)	Compliance with Item 300	Tex 500C etc.	Item 300 Testing Requirements vary by type of Bituminous Material	Item 300 Testing Requirements vary by type of Bituminous Material
	Fly Ash	Compliance with Dept. Mat'l Spec. D9-8900	Tex 733I	Sampling Fly Ash	This method outlines the procedure for sampling fly ash.
	Complete Mixture (Items 263, 345, 266, 262, 276)	Pulverization	Tex 101E pt. III	Preparation of Soil and Flexible Base Materials for Testing	This test method describes three procedures for the preparation of soil and flexible base samples for soil constants and particle size analysis, compaction and triaxial, and sieve analysis of road-mixed materials.
		Compaction	Tex 115E	Field Method for Determination of In-Place Density of Soils and Base Materials	This test determines the density of untreated and treated soil and granular material compacted in the roadway or in the natural state, as exists in a cut section and borrow source prior to excavation. The principle use of the in-place density is to determine the degree of compaction or percentage of the density obtained by the method outlined in Tex 113-E and Tex 114-E. The term "soils" used in this procedure includes as base materials, as well as fine grained soils.
		Thickness	-	N/A	N/A
		Density	Tex 121E	Soil-Lime Testing	Part I of this method determines the triaxial classification and/or unconfined compressive strength as an index of the effectiveness of hydrated lime treatment in improving desireable properties in flexible base and subgrade materials. Part II applies to lime treated materials sampled from the roadway during construction.

From Guide Schedule and Specifications				From Three-Volume Testing Manual	
Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
Asphalt Stabilized Base (Item 345)	Aggregate (within Item 345)	Gradation	Tex 200F	Sieve Analysis of Fine and Coarse Aggregates	This test method is used to determine the particle size distribution of aggregate samples using sieves with square openings
		Liquid Limit	Tex 104E	Determination of Liquid Limit of Soils	This test procedure determines the liquid limit of soils, defined as the water content of a soil at the arbitrarily determined boundary between the liquid and plastic states, expressed as a percentage of the oven-dried mass of the soil.
		Plasticity Index	Tex 106E	Method of Calculating the Plasticity Index of Soils	The plasticity index of a soil is the numerical difference between the liquid limit and the plastic limit. The liquid limit and the plastic limit are both expressed as a percentage of moisture content.
		LA Abrasion	Tex 410A	Abrasion of Coarse Aggregate Using the Los Angeles Machine	N/A
		Sand Equivalent	Tex 203F	Sand Equivalent Test	This test method determines the relative proportion of detrimental fine dust or clay-like particles in soils or fine aggregates
		Wet Ball Mill	Tex 116E	Ball Mill Method for Determination of the Disintegration of Flexible Base Material	This test method determines the resistance of aggregate in flexible base material to disintegration in the presence of water. This test provides a measure of the ability of the material to withstand degradation in the road base and detects sof aggregate which is subject to weathering. The result of this test is known as the Wet Ball Mill (WBM) value.
	Lime (Item 264)	Compliance with Item 264	Tex 600J	Sampling and Testing of Hydrated Lime, Quicklime, and Commercial Lime Slurry	This tests method, divided into four sections, discusses the sampling and testing of hydrated lime, quicklime and commercial lime slurry.
	Asphalt (Item 300)	Compliance with Item 300	Tex 500C etc.	Testing Requirements vary by type of Bituminous Material	Testing Requirements vary by type of Bituminous Material
	Complete Mixture (Item 345)	Laboratory Density and/or Strength	Tex 126E or 204F	Design of Bituminous Mixtures	Use this procedure to determine the proper proportions of approved aggregates and asphalt which, when combined, will produce a mixture that will satisfy the specification requirements. Typical examples for design by weight and design by volume are provided in Part I and Part II.
		Percent Asphalt	Tex 126E, 210F, 228F, 229F	see 126E, 210F, 228F or 229F	see 126E, 210F, 228F or 229F
		In-Place Density	Tex 207F	Determination of Density of Compacted Bituminous Mixtures	This test method is used to determine the bulk specific gravity of specimens of compacted bituminous mixtures. The bulk specific gravity of the compacted materials is used to calculate the degree of densification or percent compaction of the bituminous mixture.
		Dimensions	-	N/A	N/A

From Guide Schedule and Specifications				From Three-Volume Testing Manual	
Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
PCC: Structural and Miscellaneous (Item 421)	Coarse Aggregate (within Item 421)	Decantation	Tex 406A	Material Finer Than no. 200 Sieve in Mineral Aggregates (Decantation Test for Concrete Aggregates)	N/A
		Sieve Analysis	Tex 401A	Sieve Analysis of Fine and Coarse Aggregate	This test method determines the particle size distribution of mineral fillers, coarse and fine aggregates for portland cement concrete.
		Deleterious Materials	Tex 413A	Determination of Deleterious Materials in Mineral Aggregate	This method determines the percentage, by weight, of deleterious material in mineral aggregates. Deleterious material is defined in various specifications as clay lumps, shale, soft, friable, or laminated materials, vegetable matter, or other objectionable material.
		LA Abrasion	Tex 410A	Abrasion of Coarse Aggregate Using the Los Angeles Machine	N/A
		Soundness	Tex 411A	Soundness of Aggregate by Use of Sodium Sulfate of Magnesium Sulfate	This test measures aggregate resistance to disintegration
	Fine Aggregate (within Item 421)	Sand Equivalent	Tex 203F	Sand Equivalent Test	This test method determines the relative proportion of detrimental fine dust or clay-like particles in soils or fine aggregates
		Organic Impurities	Tex 408A	Organic Impurities in Fine Aggregate for Concrete	This method determines the presence of organic compounds in fine aggregates to be used in cement mortar or concrete. The test provides a quick, relative measure to determine if further tests of the fine aggregate are necessary before approval for use.
		Sieve Analysis	Tex 401A	Sieve Analysis of Fine and Coarse Aggregate	This test method determines the particle size distribution of mineral fillers, coarse and fine aggregates for portland cement concrete.
		Fineness Modulus	Tex 402A	Fineness Modulus of Fine Aggregate	This method determines the fineness modulus of concrete fine aggregate used in evaluation of natural and manufactured sands for Portland Cement Concrete.
		Acid Insoluable Residue	Tex 612J	Acid Insoluable Residue for Fine Aggregate	This test procedure determines the percent by weight of Hydrochloric Acid insoluable residue in a fine aggregate.
	Cement (Item 524)	Compliance with Standard Specs and Special Provisions	ASTM C 150, AASHTO M 85, ASTM C 91, ASTM C 595 as appropriate and with exceptions	see appropriate spec.	see appropriate spec.
	Fly Ash	Compliance with Dept. Mat'l Spec. D9-8900	Tex 733I	Sampling Fly Ash	This method outlines the procedure for sampling fly ash.
	Water	Compliance with the Standard Specifications	AASHTO T 26	see appropriate spec.	see appropriate spec.

Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
	Concrete (Item 421)	Flexural Strength	Tex 448A or 418A	Flexural Strength of Concrete Using Simple Beam Third-Point Loading	This test method covers the determination of flexural strength of concrete by the use of a simple beam with third-point loading, employing bearing blocks to ensure that forces applied to the beam will be perpendicular to the face of the specimen and applied without eccentricity. Excpet for editorial difference, this procedure is identical to ASTM C 78.
		Compressive Strength	Tex 418A	Compressive Strength of Cylindrical Concrete Specimens	Part I of this test method covers determination of compressive strength of cylindrical concrete specimens such as molded cylinders and drilled cores. It is limited to concrete having a unit weight in excess of 50 lb/cubic foot. Except for editorial differences, this method is identical with ASTM C 39/AASHTO T 22. Part II discusses the use of neoprene caps during this testing.
		Slump	Tex 415A	Slump of Portland Cement Concrete	This test method describes the procedure for determining the slump of freshly mixed plastic hydraulic cement concrete in the laboratory and in the field. Except for editorial differences and the inidicated technical differences, this test method is the same as ASTM C 143/AASHTO T 119.
		Entrained Air	Tex 416A or 414A	See 416A or 414A	See 416A or 414A
		Average Texture Depth	Tex 436A	Measurement of Texture Depth by the Sand-Patch Method	This method describes a procedure for determining the average texture depth of a selected portion of the concrete pavement surface.
		Temperature of Slab Concrete	-	N/A	N/A
		Entrained Air	Tex 416A	Air Content of Freshly Mixed Concrete by the Pressure Method	This test method determines the air content of freshly mixed concrete by observation of the change in volume of concrete with a change in pressure. It is not applicable to concretes made with lightweight aggregates, air-cooled blast-furnace slag, or aggregates of high porosity. In these cases use Test Method Tex-414-A. Except for editorial difference and the indicated technical differences, this method is the same as ASTM C 231/AASHTO T 152.

Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
		Making Cylinders	Tex 447A	Making and Curing Concrete Test Specimens	This method covers procedures for making and curing cylindrical and prismatic concrete specimens that can be consolidated by rodding or vibration as described herein. Part I addresses cylindrical specimens and Part II addresses prismatic specimens. Except for provision for 4x8 in. cylinders and provisions for curing at remote sites, this test method conforms to ASTM C 31/AASHTO T 23 and ASTM C 192/AASHTO T 126.
	Admixture (Item 437)	Compliance with the Std. Specifications Item 437	As Specified	As Specified	As Specified
		Chemical Admixture Specifications	ASTM C 494	Chemical Admixture Specifications	N/A
		Air-Entraining Admixture Specifications	ASTM C 260	Air-Entraining Admixture Specifications	N/A
	Joint Material (Item 433)	Compliance with the Standard Specifications and Special Provisions (Dep't Spec D-9-6310)	As Specified	As Specified	As Specified
	Curing Compound	Compliance with the Standard Specifications and Special Provisions	Tex 718I	Sampling of Liquid Membrane-Forming Compounds for Curing Concrete	This method outlines the procedure for sampling liquid membrane-forming compounds for curing concrete.
	Reinforcing Steel (Item 440)	Compliance with the Standard Specifications and Special Provisions	As Specified	As Specified	As Specified
		Depth of Reinforcement	-	N/A	N/A

From Guide Schedule and Specifications				From Three-Volume Testing Manual	
Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
PCC Pavements (Item 421)	Coarse Aggregate (within Item 421)	Decantation	Tex 406A	Material Finer Than no. 200 Sieve in Mineral Aggregates (Decantation Test for Concrete Aggregates)	N/A
		Sieve Analysis	Tex 401A	Sieve Analysis of Fine and Coarse Aggregate	This test method determines the particle size distribution of mineral fillers, coarse and fine aggregates for portland cement concrete.
		Deleterious Materials	Tex 413A	Determination of Deleterious Materials in Mineral Aggregate	This method determines the percentage, by weight, of deleterious material in mineral aggregates. Deleterious material is defined in various specifications as clay lumps, shale, soft, friable, or laminated materials, vegetable matter, or other objectionable material.
		LA Abrasion	Tex 410A	Abrasion of Coarse Aggregate Using the Los Angeles Machine	N/A
		Soundness	Tex 411A	Soundness of Aggregate by Use of Sodium Sulfate of Magnesium Sulfate	This test measures aggregate resistance to disintegration
	Fine Aggregate (within Item 421)	Sand Equivalent	Tex 203F	Sand Equivalent Test	This test method determines the relative proportion of detrimental fine dust or clay-like particles in soils or fine aggregates
		Organic Impurities	Tex 408A	Organic Impurities in Fine Aggregate for Concrete	This method determines the presence of organic compounds in fine aggregates to be used in cement mortar or concrete. The test provides a quick, relative measure to determine if further tests of the fine aggregate are necessary before approval for use.
		Sieve Analysis	Tex 401A	Sieve Analysis of Fine and Coarse Aggregate	This test method determines the particle size distribution of mineral fillers, coarse and fine aggregates for portland cement concrete.
		Acid Insoluable Residue	Tex 612J	Acid Insoluable Residue for Fine Aggregate	This test procedure determines the percent by weight of Hydrochloric Acid insoluable residue in fine aggregate.

Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
	Mineral Filler	Sieve Analysis	Tex 401A	Sieve Analysis of Fine and Coarse Aggregate	This test method determines the particle size distribution of mineral fillers, coarse and fine aggregates for portland cement concrete.
	Cement (Item 524)	Compliance with Standard Specs and Special Provisions	ASTM C 150, AASHTO M 85, ASTM C 91, ASTM C 595 as appropriate and with exceptions	see appropriate spec.	see appropriate spec.
	Fly Ash	Compliance with Dept. Mat'l Spec. D9-8900	Tex 733I	Sampling Fly Ash	This method outlines the procedure for sampling fly ash.
	Water	Compliance with the Standard Specifications	AASHTO T 26	see appropriate spec.	see appropriate spec.
	Concrete (Item 421)	Strength	Tex 448A or 418A	see 448A or 418A	see 448A or 418A
		Slump	Tex 415A	Slump of Portland Cement Concrete	This test method describes the procedure for determining the slump of freshly mixed plastic hydraulic cement concrete in the laboratory and in the field. Except for editorial differences and the inidicated technical differences, this test method is the same as ASTM C 143/AASHTO T 119.
		Entrained Air	Tex 416A or 414A	see 416A or 414A	see 416A or 414A
		Average Texture Depth	Tex 436A	Measurement of Texture Depth by the Sand-Patch Method	This method describes a procedure for determining the average texture depth of a selected portion of the concrete pavement surface.
		Thickness	Tex 424A	Obtaining and Testing Drilled Cores of Concrete	This method covers the proedures for obtaining, preparing and testing cores drilled from concrete for length or compressive or splitting tensile strength determinations, and to determine the length of a core drilled from a concrete structure, particularly pavement. Except for editorial differences the procedures in part I and III are identical with ASTM C 42. The procedures in part II are identical to ASTM C 174.

Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
		Entrained Air	Tex 416A	Air Content of Freshly Mixed Concrete by the Pressure Method	This test method determines the air content of freshly mixed concrete by observation of the change in volume of concrete with a change in pressure. It is not applicable to concretes made with lightweight aggregates, air-cooled blast-furnace slag, or aggregates of high porosity. In these cases use Test Method Tex-414-A. Except for editorial difference and the indicated technical differences, this method is the same as ASTM C 231/AASHTO T 152.
		Making Cylinders	Tex 447A	Making and Curing Concrete Test Specimens	This method covers procedures for making and curing cylindrical and prismatic concrete specimens that can be consolidated by rodding or vibration as described herein. Part I addresses cylindrical specimens and Part II addresses prismatic specimens. Except for provision for 4x8 in. cylinders and provisions for curing at remote sites, this test method conforms to ASTM C 31/AASHTO T 23 and ASTM C 192/AASHTO T 126.
	Admixture (Item 437)	Compliance with the Std. Specifications Item 437	As Specified	As Specified	As Specified
		Chemical Admixture Specifications	ASTM C 494	Chemical Admixture Specifications	N/A
		Air-Entraining Admixture Specifications	ASTM C 260	Air-Entraining Admixture Specifications	N/A
	Joint Material (Item 433)	Compliance with the Standard Specifications and Special Provisions (Dep't Spec D-9-6310)	As Specified	As Specified	As Specified
	Curing Compound	Compliance with the Standard Specifications and Special Provisions	Tex 718I	Sampling of Liquid Membrane-Forming Compounds for Curing Concrete	This method outlines procedures for sampling liquid membrane-forming compounds for curing concrete.
	Reinforcing Steel (Item 440)	Compliance with the Standard Specifications and Special Provisions	As Specified	As Specified	As Specified

From Guide Schedule and Specifications				From Three-Volume Testing Manual	
Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
Asphaltic Concrete Pavements (Items 340, 334, 330, 332)	Coarse Aggregate (within Items 340, 334, 330, 332)	Gradation	Tex 200F	Sieve Analysis of Fine and Coarse Aggregates	This test method is used to determine the particle size distribution of aggregate samples using sieves with square openings
		Deleterious Material and Decantation	Tex 217F	Determination of Deleterious Material and Decantation Test for Coarse Aggregates	This test method provides a procedure for the manual seperation of the deleterious material contained in coarse aggregate (Part I) and the determination of fine dust, clay-like particles and/or silt present as a coating in coarse aggregate (Part II).
		Particle Count	Tex 460A	Determination of Crushed Face Particle Count	This method determines the percent of coarse aggregate particles meeting the crushed face requirement and the minimum percent of non-polishing aggregate when handling.
		Polish Test	Tex 438A	Accelerated Polish Test for Coarse Aggregate	This test method provides an estimate of the polish and relative wear of coarse aggregate.
		Material Finer than No. 200	Tex 406A	Material Finer Than no. 200 Sieve in Mineral Aggregates (Decantation Test for Concrete Aggregates)	N/A
		Plasticity Index	Tex 106E	Method of Calculating the Plasticity Index of Soils	The plasticity index of a soil is the numerical difference between the liquid limit and the plastic limit. The liquid limit and the plastic limit are both expressed as a percentage of moisture content.
		Rock Asphalt Content	Tex 215F	Determination of Asphalt Content of Rock Asphalt by Hot Solvent Extraction	This test method provides a procedure to determine, by hot solvent extraction, the percentage of asphalt in native rock asphalt aggregate. Other methods to determine asphalt content that correlate satisfactorily to the Soxhlet procedure results may be used.
		White Rock Content	Tex 220F	Determination of Percentages of White Rock Contained in Native Rock Asphalt	This test method provides a procedure to determine the percentage, by weight, or white rock (material having a naturally impregnated aspahlt content of less than 1%) in a sample of crushed native rock asphalt.

Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
		LA Abrasion	Tex 410A	Abrasion of Coarse Aggregate Using the Los Angeles Machine	N/A
		Unit Weight	Tex 404A	Determination of Unit Mass (Weight) of Aggregates	This method describes the determination of the loose mass per cubic foot of both fine and coarse aggregates. The unit mass of aggregate in a SSD condition is intended for use in Portland Cement Concrete mix design. The dry rodded condition is intended for use in the American Concrete Institute design procedure.
		Pressure Slaking	Tex 431A	Pressure Slaking Test of Synthetic Coarse Aggregate	This test evaluates the amount of dehydration that has occurred in the production of synthetic aggregates fired in a rotary kiln.
		Freeze-Thaw Loss	Tex 432A	Coarse Aggregate Freeze-Thaw Test	This test method determines synthetic coarse aggregate resistance to disintegration by freezing and thawing, to aid in judging the soundness of aggregate subjected to weathering.
		24-Hour Water Absorption	Tex 433A	Absorption and Dry Bulk Specific Gravity of Lightweight Coarse Aggregate	N/A
	Fine Aggregate (within Items 340, 334)	Gradation	Tex 200F (Dry)	Sieve Analysis of Fine and Coarse Aggregates	This test method is used to determine the particle size distribution of aggregate samples using sieves with square openings
		Plasticity Index	Tex 106E	Method of Calculating the Plasticity Index of Soils	The plasticity index of a soil is the numerical difference between the liquid limit and the plastic limit. The liquid limit and the plastic limit are both expressed as a percentage of moisture content.
		Linear Shrinkage	Tex 107E	Determination of Bar Linear Shrinkage of Soils	N/A
	Mineral Filler (within Items 334, 340)	Gradation	Tex 200F (Dry)	Sieve Analysis of Fine and Coarse Aggregates	This test method is used to determine the particle size distribution of aggregate samples using sieves with square openings
	Combined Aggregates (within Items 334, 340)	Gradation	Tex 200F (Dry)	Sieve Analysis of Fine and Coarse Aggregates	This test method is used to determine the particle size distribution of aggregate samples using sieves with square openings

Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
		Sand Equivalent	Tex 203F	Sand Equivalent Test	This test method determines the relative proportion of detrimental fine dust or clay-like particles in soils or fine aggregates
	Lime (Item 264)	Compliance with Item 264	Tex 600J	Sampling and Testing of Hyrdated Lime, Quicklime, and Commercial Lime Slurry	This test method, divided into four sections, discusses the sampling and testing of hydrated lime, quicklime and commercial lime slurry.
	Asphalts Oils and Emulsions (Item 300)	Compliance with Item 300	Tex 500C etc.	Item 300 Testing Requirements vary by type of Bituminous Material	Item 300 Testing Requirements vary by type of Bituminous Material
	Complete Mixture (Hot Mix ACP and Hot Mix Cold-Laid ACP) (Items 334 and 340)	Laboratory Density	Tex 207F	Determination of Density of Compacted Bituminous Mixtures	This test method is used to determine the bulk specific gravity of specimens of compacted bituminous mixtures. The bulk specific gravity of the compacted materials is used to calculate the degree of densification or percent compaction of the bituminous mixture.
		Stability	Tex 208F	Test for Stabilometer Value of Bituminous Mixtures	This test method, which is a modification of ASTM D 1560, determines the Hveem stability value of an asphaltic concrete mixture.
		Percent Asphalt and/or Gradation	Tex 210F, 228F, 229F	Determination of the Asphalt Content of Bituminous Mixtures by Extraction	This test method is used to determine, by four cold solvent extraction procedures, the percentage of asphalt in a paving mixture, based on the weight of an asphalt aggregate mixture. The aggregate and fines recovered can be used for Test Method Tex 200-F sieve analysis.
		In Place Density	Tex 207F	Determination of Density of Compacted Bituminous Mixtures	This test method is used to determine the bulk specific gravity of specimens of compacted bituminous mixtures. The bulk specific gravity of the compacted materials is used to calculate the degree of densification or percent compaction of the bituminous mixture.
		Moisture Content	Tex 212F	Determination of the Moisture Content of Bituminous Mixtures	Part I of this method, a modification of ASTM D 1461, discusses how to determine by direct measurement the moisture content of any type of bituminous paving mixture. Part II discusses how to determine the moisture (free and absorbed) in aggregates for bituminous mixtures, and in completed bituminous minxtures which have no significant amounts of hydrocarbon volatiles.
		Hydrocarbon Volatile Content	Tex 213F	Determination of Hydrocarbon-Volatile Content of Bituminous Mixtures	This test method, a modification of ASTM D 1461, covers the determination of hydrocarbon volatile content of a bituminous mixture.

Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
		Mix Design	Tex 204F	Design of Bituminous Mixtures	Use this procedure to determine the proper proportions of approved aggregates and asphalt which, when combined, will produce a mixture that will satisfy the specification requirements. Typical examples for design by weight and design by volume are provided in Part I and Part II.
		Theoretical Density	Tex 227F	Theoretical Maximum Specific Gravity of Bituminous Mixtures	Use this test method to measure the theoretical maximum specific gravity (commonly referred to as "Rice" gravity) of a bituminous mixture. The gravity obtained is used to calculate the percent air voids and percent VMA contained in compacted samples as described in Test Method Tex 207-F. The theoretical maximum specific gravity of a bituminous mixture is the bulk specific gravity of that mixture when compacted to the point of zero air voids.
	Limestone Rock Asphalt Pavement (Items 330, 332)	Compliance with Item 330 or 332	As Specified	As Specified	As Specified
		Moisture Content	Tex 212F	Determination of the Moisture Content of Bituminous Mixtures	Part I of this method, a modification of ASTM D 1461, discusses how to determine by direct measurement the moisture content of any type of bituminous paving mixture. Part II discusses how to determine the moisture (free and absorbed) in aggregates for bituminous mixtures, and in completed bituminous minxtures which have no significant amounts of hydrocarbon volatiles.
		Stability	Tex 208F	Test for Stabilometer Value of Bituminous Mixtures	This test method, which is a modification of ASTM D 1560, determines the Hveem stability value of an asphaltic concrete mixture.
		Dimensions		N/A	N/A

From Guide Schedule and Specifications				From Three-Volume Testing Manual	
Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
QC/QA Ashaltic Concrete Pavement (Item 330, 332, 334, 340)	Coarse Aggregate (Item 330, 332, 334, 340)	LA Abrasion	Tex 410A	Abrasion of Coarse Aggregate Using the Los Angeles Machine	N/A
		Magnesium Soundness	Tex 411A	Soundness of Aggregate by Use of Sodium Sulfate of Magnesium Sulfate	This test measures aggregate resistance to disintegration
		Pressure Slake	Tex 431A	Pressure Slaking Test of Synthetic Coarse Aggregate	This test evaluates the amount of dehydration that has occurred in the production of synthetic aggregates fired in a rotary kiln.
		Polish Value	Tex 438A	Accelerated Polish Test for Coarse Aggregate	This test method provides an estimate of the polish and relative wear of coarse aggregate.
		Unit Weight	Tex 404A	Determination of Unit Mass (Weight) of Aggregates	This method describes the determination of the loose mass per cubic foot of both fine and coarse aggregates. The unit mass of aggregate in a SSD condition is intended for use in Portland Cement Concrete mix design. The dry rodded
		Crushed Face Count	Tex 460A	Determination of Crushed Face Particle Count	This method determines the percent of coarse aggregate particles meeting the crushed face requirement and the minimum percent of non-polishing aggregate when handling.
		Linear Shrinkage	Tex 107E	Determination of Bar Linear Shrinkage of Soils	N/A
		Deleterious Material and Decantation	Tex 217F	Determination of Deleterious Material and Decantation Test for Coarse Aggregates	This test method provides a procedure for the manual seperation of the deleterious material contained in coarse aggregate (Part I) and the determination of fine dust, clay-like particles and/or silt present as a coating in coarse aggregate (Part II).

Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
		Material Finer than No. 200	Tex 406A	Material Finer Than no. 200 Sieve in Mineral Aggregates (Decantation Test for Concrete Aggregates)	N/A
		Plasticity Index	Tex 106E	Method of Calculating the Plasticity Index of Soils	The plasticity index of a soil is the numerical difference between the liquid limit and the plastic limit. The liquid limit and the plastic limit are both expressed as a percentage of moisture content.
		Rock Asphalt Content	Tex 215F	Determination of Asphalt Content of Rock Asphalt by Hot Solvent Extraction	This test method provides a procedure to determine, by hot solvent extraction, the percentage of asphalt in native rock asphalt aggregate. Other methods to determine asphalt content that correlate satisfactorily to the Soxhlet procedure
		White Rock Content	Tex 220F	Determination of Percentages of White Rock Contained in Native Rock Asphalt	This test method provides a procedure to determine the percentage, by weight, or white rock (material having a naturally impregnated aspahlt content of less than 1%) in a sample of crushed native rock asphalt.
		Freeze-Thaw Loss	Tex 432A	Coarse Aggregate Freeze-Thaw Test	This test method determines synthetic coarse aggregate resistance to disintegration by freezing and thawing, to aid in judging the soundness of aggregate subjected to weathering.
		24-Hour Water Absorption	Tex 433A	Absorption and Dry Bulk Specific Gravity of Lightweight Coarse Aggregate	N/A
	Fine Aggregate (within Items 340, 334)	Linear Shrinkage	Tex 107E	Determination of Bar Linear Shrinkage of Soils	N/A
		Gradation	Tex 200F	Sieve Analysis of Fine and Coarse Aggregates	This test method is used to determine the particle size distribution of aggregate samples using sieves with square openings
	Combined Aggregates (within Items 340, 334)	Sand Equivalent	Tex 203F	Sand Equivalent Test	This test method determines the relative proportion of detrimental fine dust or clay-like particles in soils or fine aggregates
		Gradation	Tex 229F	Combined HMAC Cold-Belt Sampling and Testing Procedure	This test method discusses how to sample and test combined aggregates from the hot mix asphaltic concrete plant cold feed belt, plus how to verify the accuracy of cold-belt analysis as compared to solvent extraction analysis. Use this procedure in conjunction with Test Method Tex 228-F.

Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
	Complete Mixture (Items 330, 332, 334, 340)	Percent Asphalt	Tex 228F	Determination of Asphalt Content of Bituminous Mxitures by the Nuclear Method	Use this test method to determine the quantitative aspahlt cement content of bituminous mixtures by testing a sample with a device that utilizes neutron thermalization techniques. It can be used for rapid determination of the asphalt cement content of bituminous mixtures and adjustments, if necessary, can be made in the asphalt cement metering system with a limited amount of mix production. This procedure is useful in the determination of asphalt cement content only, as it does not provide extracted aggregate for gradation analysis.
		Voids in Mineral Aggregates	Tex 207F	Determination of Density of Compacted Bituminous Mixtures	This test method is used to determine the bulk specific gravity of specimens of compacted bituminous mixtures. The bulk specific gravity of the compacted materials is used to calculate the degree of densification or percent compaction of the bituminous mixture.
		Moisture Susceptibility	Tex 530C or 531C	Prediction of Moisture-Induced Damage to Bituminous Paving Materials Using Molded Specimens	This procedure describes a stripping test utilizing molded specimens of mix. Some of these molded specimens are subjected to moisture conditioning and compared by indirect tensile strength to unconditioned specimens. The tensile strength ratio (TSR) of a mix is calculated as the indirect tensile strength of the moisture-conditioned specimens divided by the indirect tensile strength of the unconditioned specimens. The TSR is therefore an indication of loss of strength caused by the moisture conditioning (stripping). This procedures may be used to evaluate untreated mixes or evaluate the effectiveness of anti-strip additives.
		Gradation	Tex 210F Extraction	Determination of the Asphalt Content of Bituminous Mixtures by Extraction	This test method is used to determine, by four cold solvent extraction procedures, the percentage of asphalt in a paving mixture, based on the weight of an asphalt aggregate mixture. The aggregate and fines recovered can be used for Test Method Tex 200-F sieve analysis.

Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description
		Maximum Theoretical Gravity	Tex 227F	Theoretical Maximum Specific Gravity of Bituminous Mixtures	Use this test method to measure the theoretical maximum specific gravity (commonly referred to as "Rice" gravity) of a bituminous mixture. The gravity obtained is used to calculate the percent air voids and percent VMA contained in compacted samples as described in Test Method Tex 207-F. The theoretical maximum specific gravity of a bituminous mixture is the bulk specific gravity of that mixture when compacted to the point of zero air voids.
		Lab Molded Density	Tex 207F	Determination of Density of Compacted Bituminous Mixtures	This test method is used to determine the bulk specific gravity of specimens of compacted bituminous mixtures. The bulk specific gravity of the compacted materials is used to calculate the degree of densification or percent compaction of the bituminous mixture.
		Hveem Stability	Tex 208F	Test for Stabilometer Value of Bituminous Mixtures	This test method, which is a modification of ASTM D 1560, determines the Hveem stability value of an asphaltic concrete mixture.
		Moisture Content	Tex 212F	Determination of the Moisture Content of Bituminous Mixtures	Part I of this method, a modification of ASTM D 1461, discusses how to determine by direct measurement the moisture content of any type of bituminous paving mixture. Part II discusses how to determine the moisture (free and absorbed) in aggregates for bituminous mixtures, and in completed bituminous minxtures which have no significant amounts of hydrocarbon volatiles.
		Mix Design	Tex 204F	Design of Bituminous Mixtures	Use this procedure to determine the proper proportions of approved aggregates and asphalt which, when combined, will produce a mixture that will satisfy the specification requirements. Typical examples for design by weight and design by volume are provided in Part I and Part II.
	Roadway	Air Voids	Tex 207F	Determination of Density of Compacted Bituminous Mixtures	This test method is used to determine the bulk specific gravity of specimens of compacted bituminous mixtures. The bulk specific gravity of the compacted materials is used to calculate the degree of densification or percent compaction of the bituminous mixture.
		Profile Index	Tex 1000S	Operation of Pavement Profilograph and Evaluation of Profiles	This test method covers the procedures to operate, calibrate, and maintain a California-type profilograph.

Material or Product (with Spec)	Sub - Classification (with Spec)	Test For	Test Number	Test Name	Test Description

APPENDIX D: DATA ORGANIZATION CHARTS (DOCS) FOR PCC, BITUMINOUS SURFACE MIXTURES AND BASE MATERIALS

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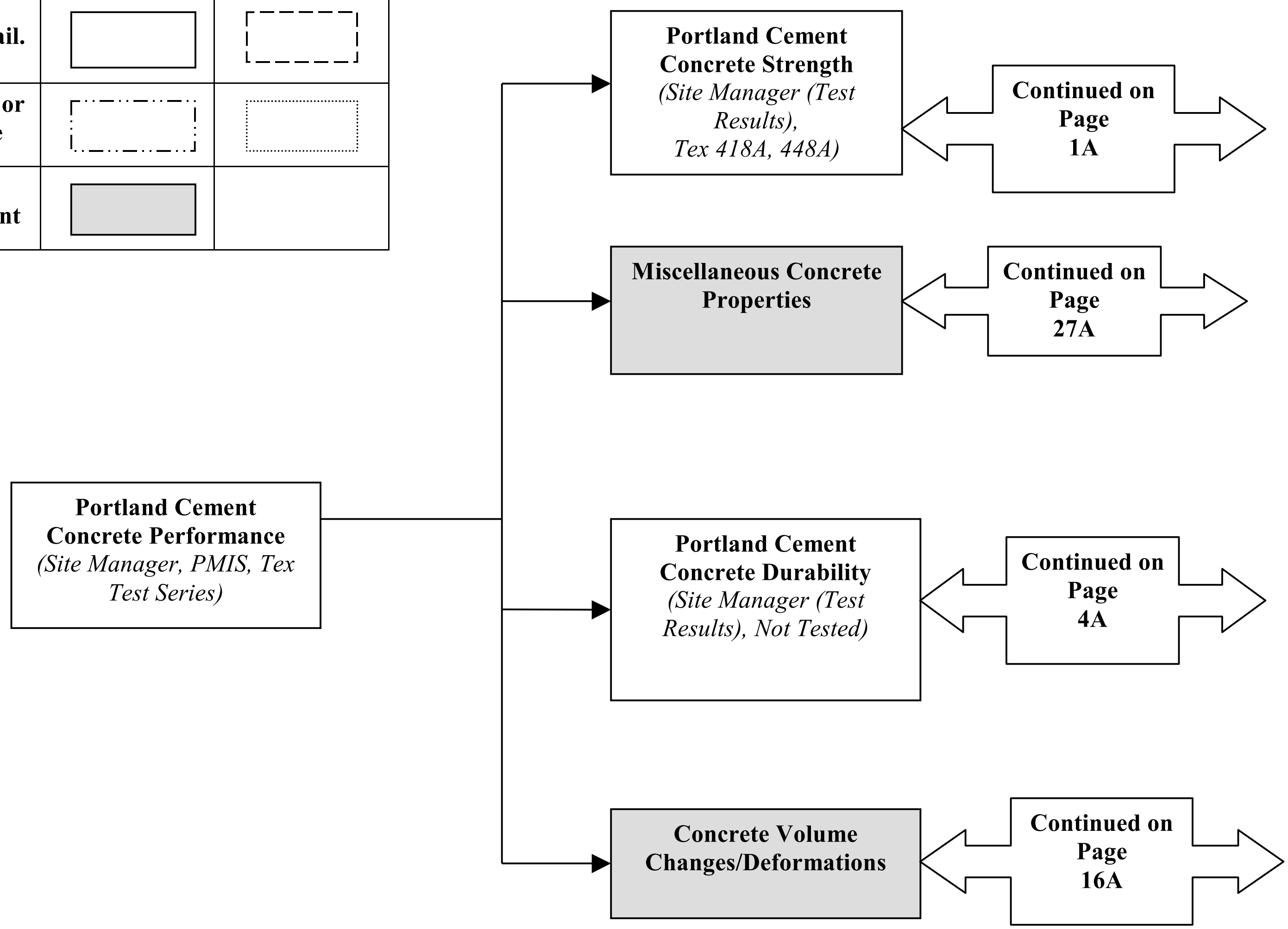
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



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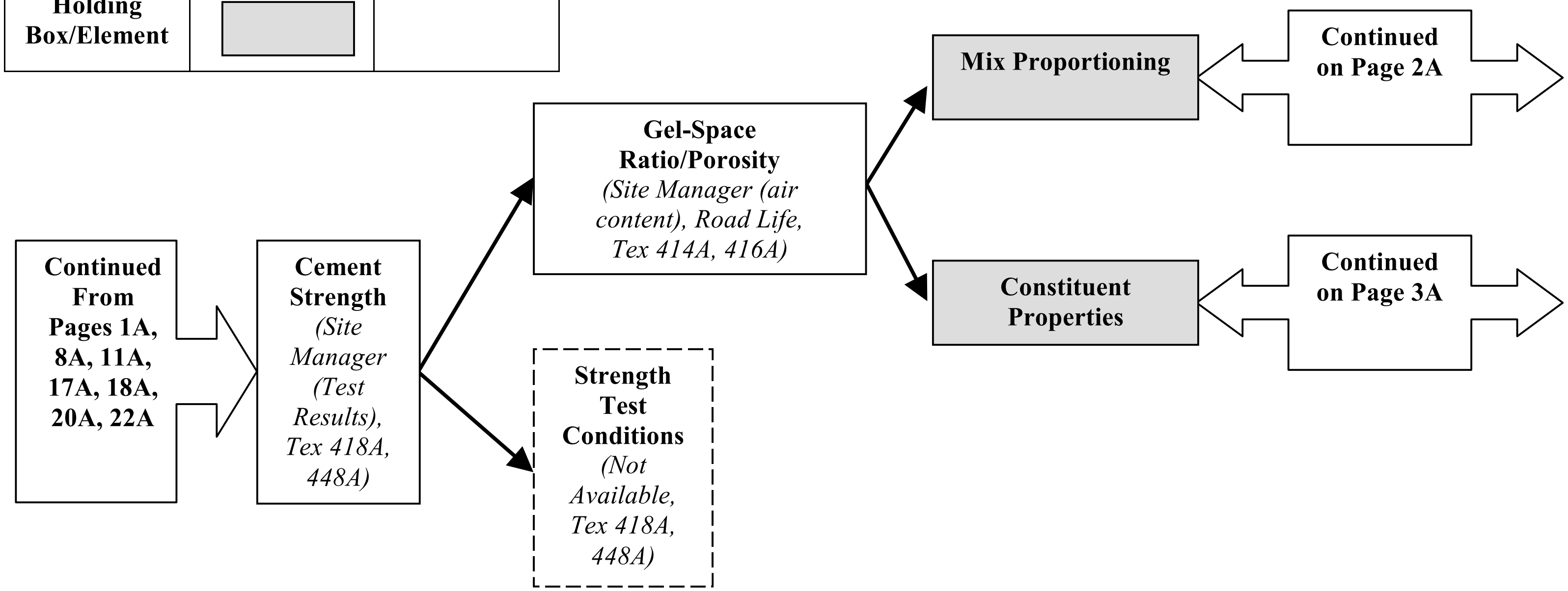
Holding Box/Element		



Legend	More Important Data	Less Important Data
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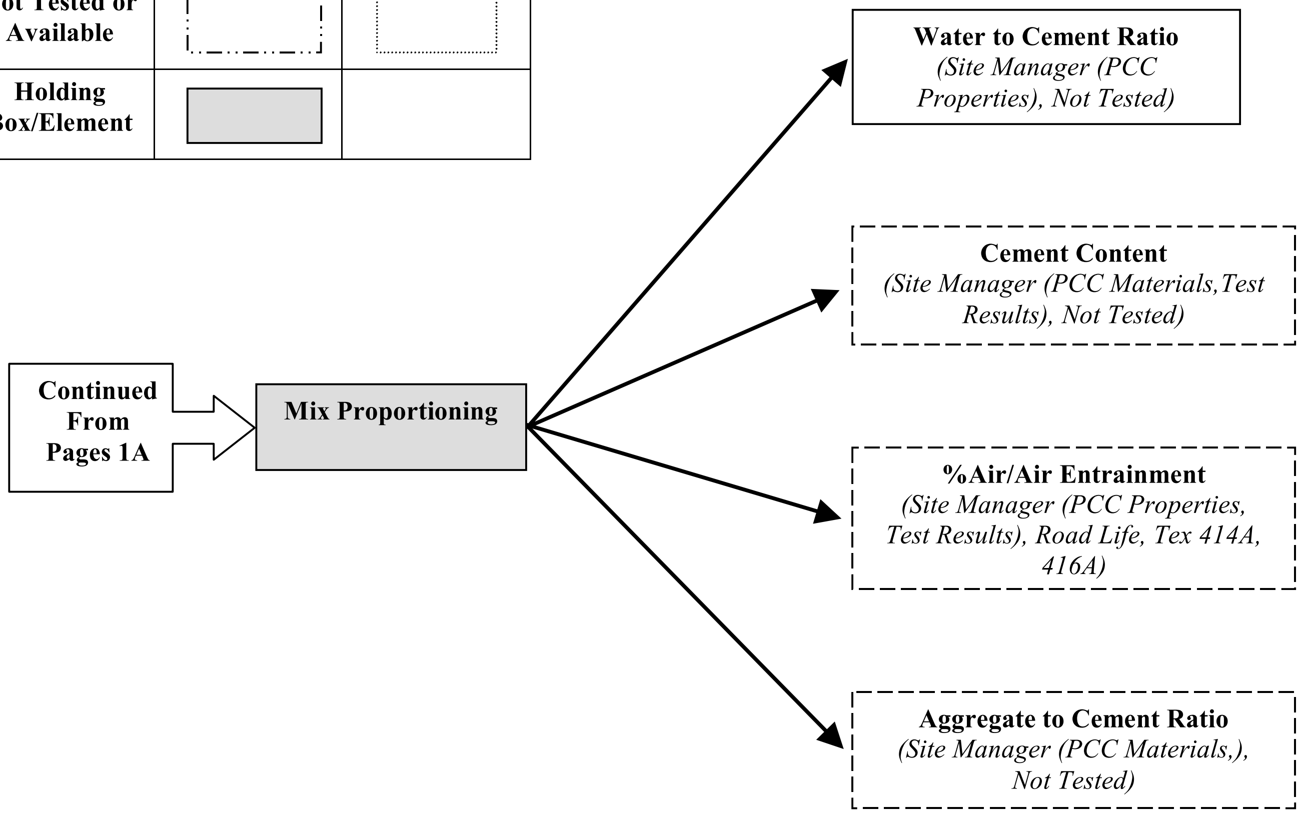
Not Tested or Available		
Holding Box/Element		



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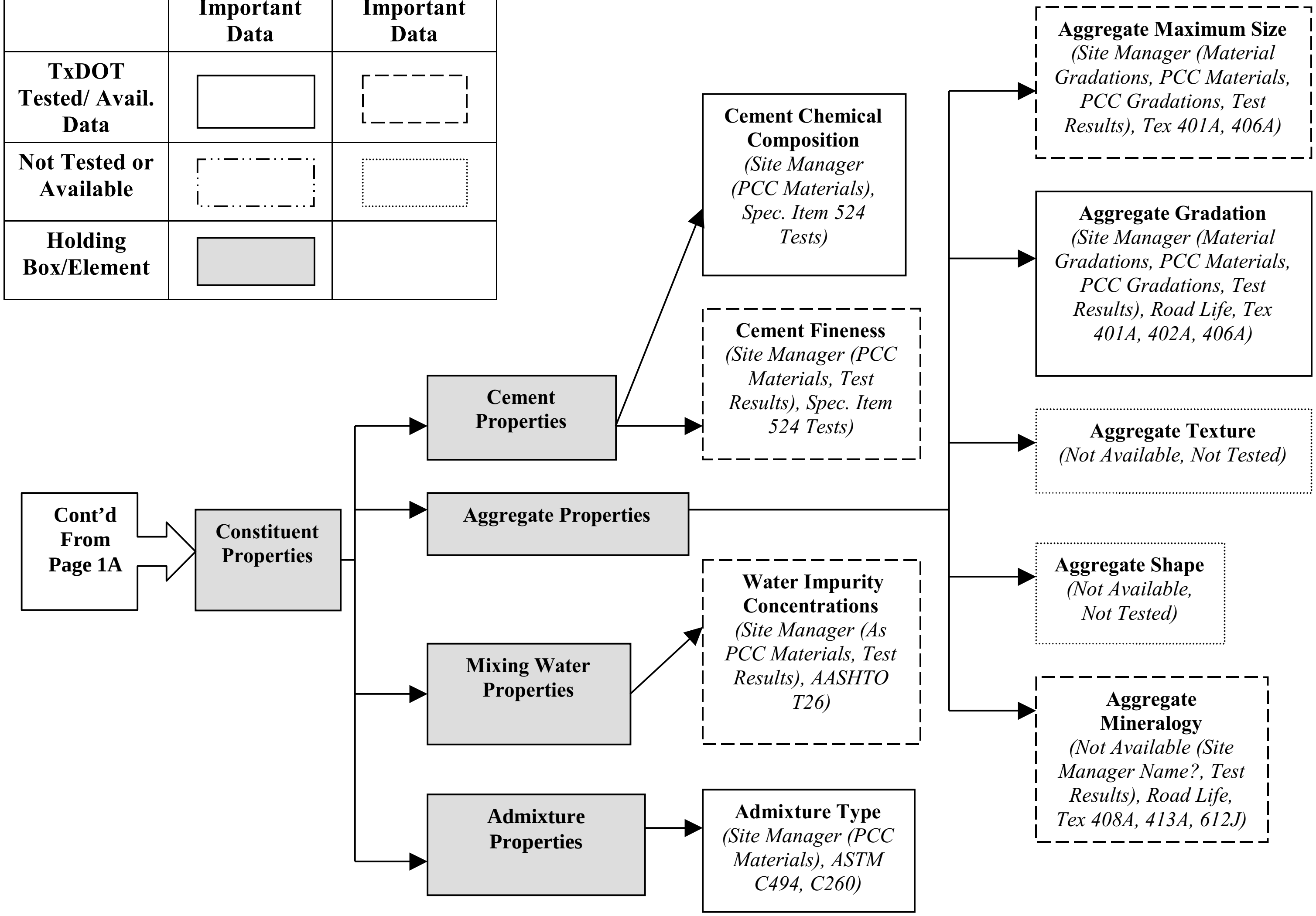
Holding Box/Element		



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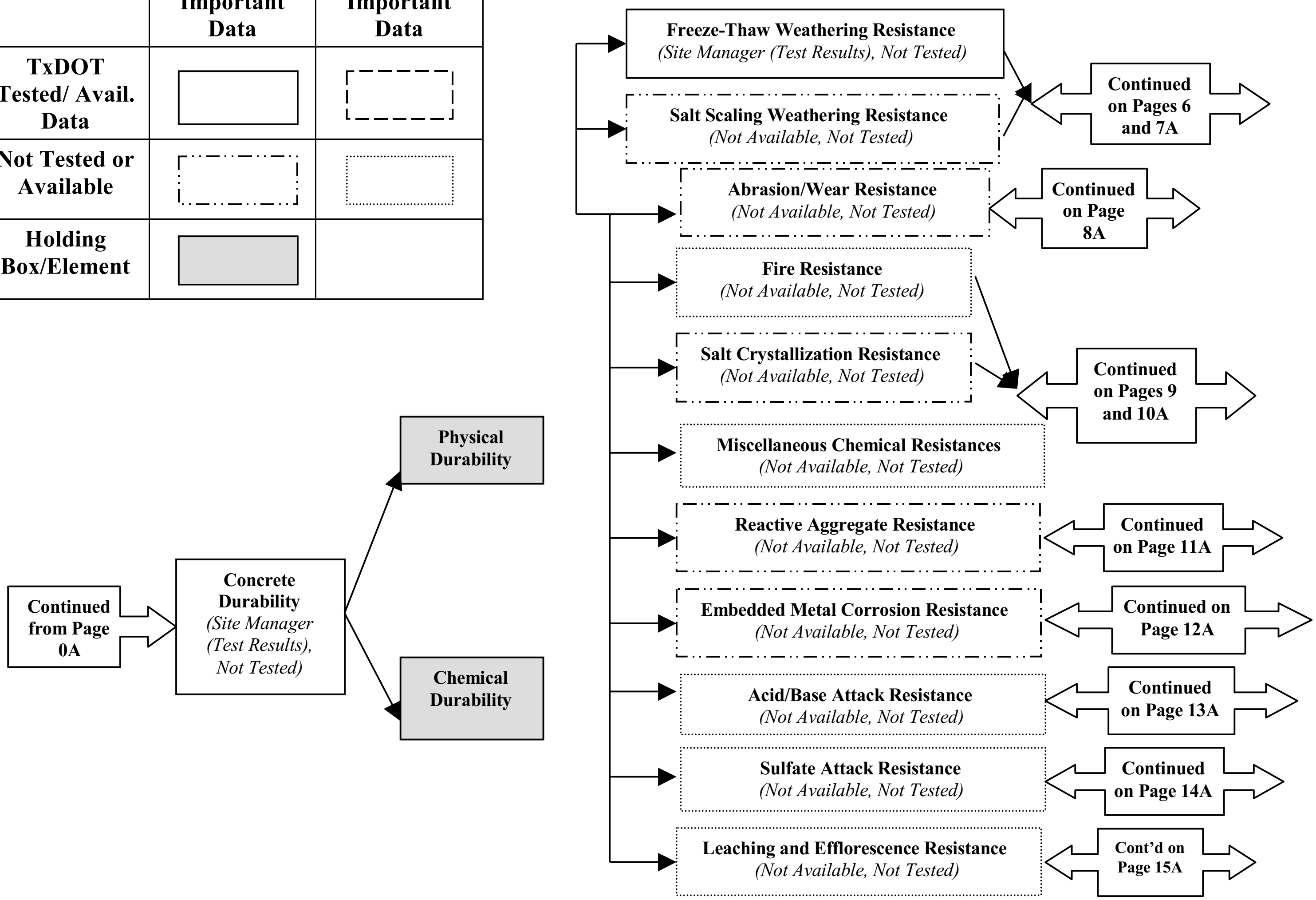
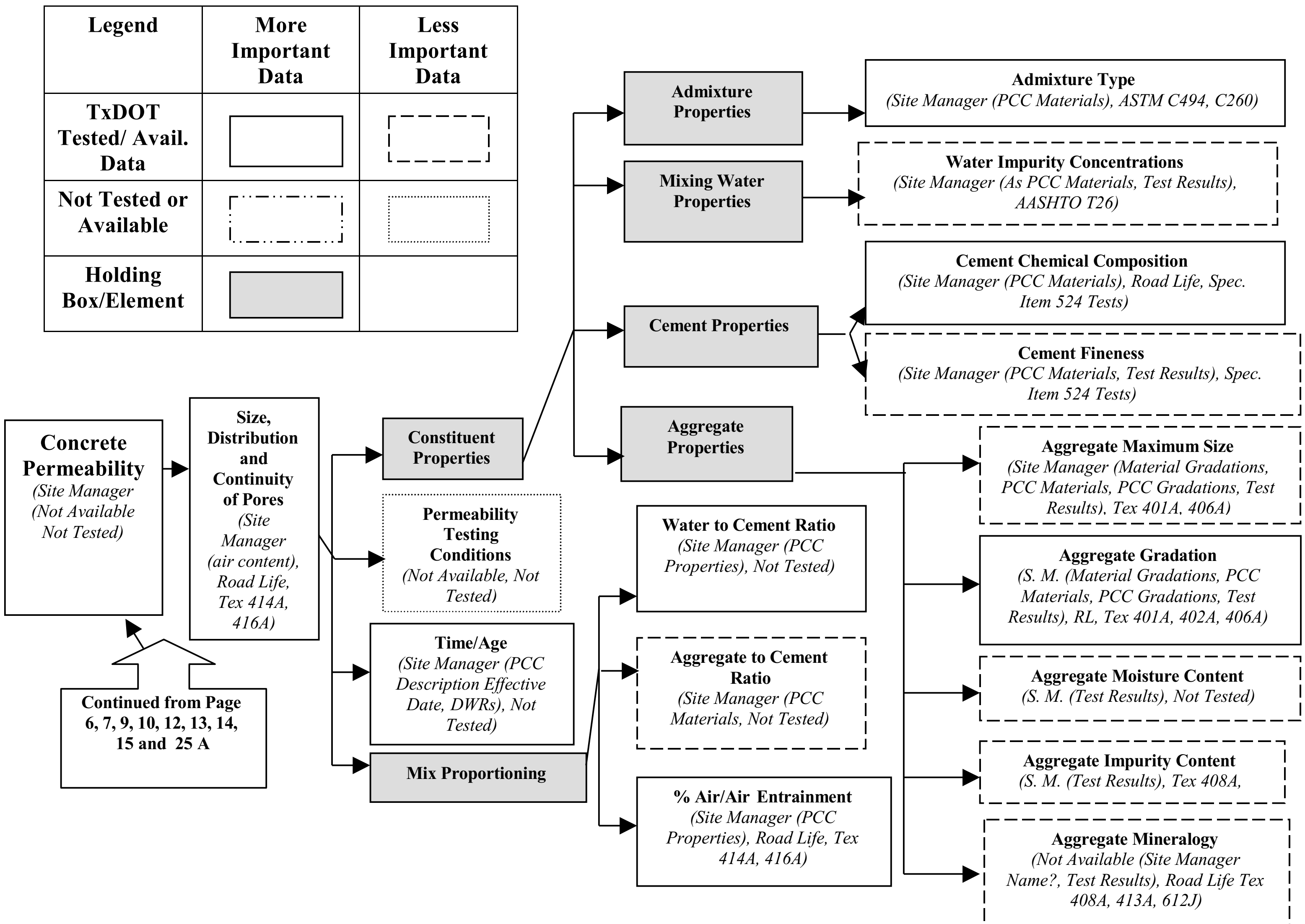
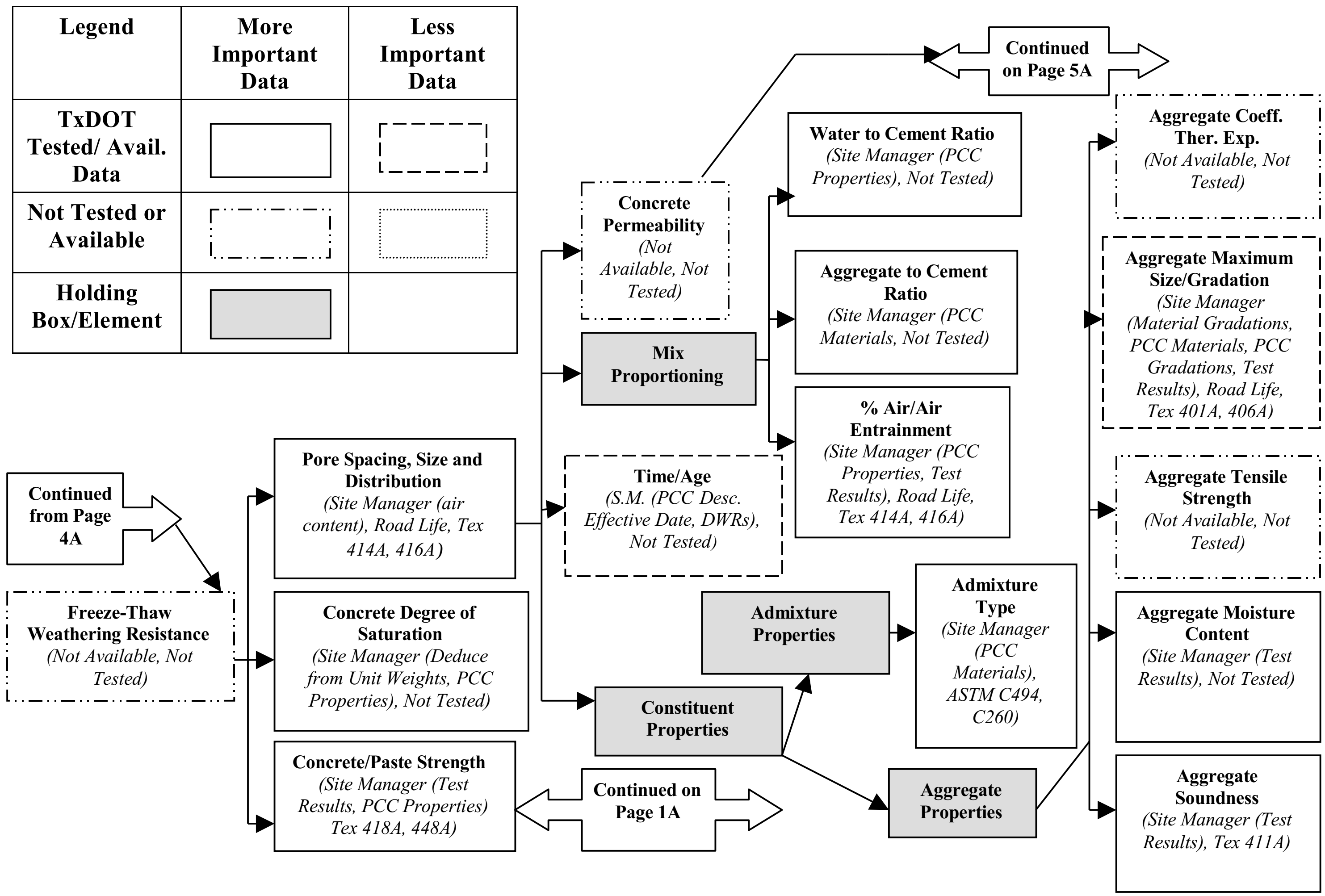
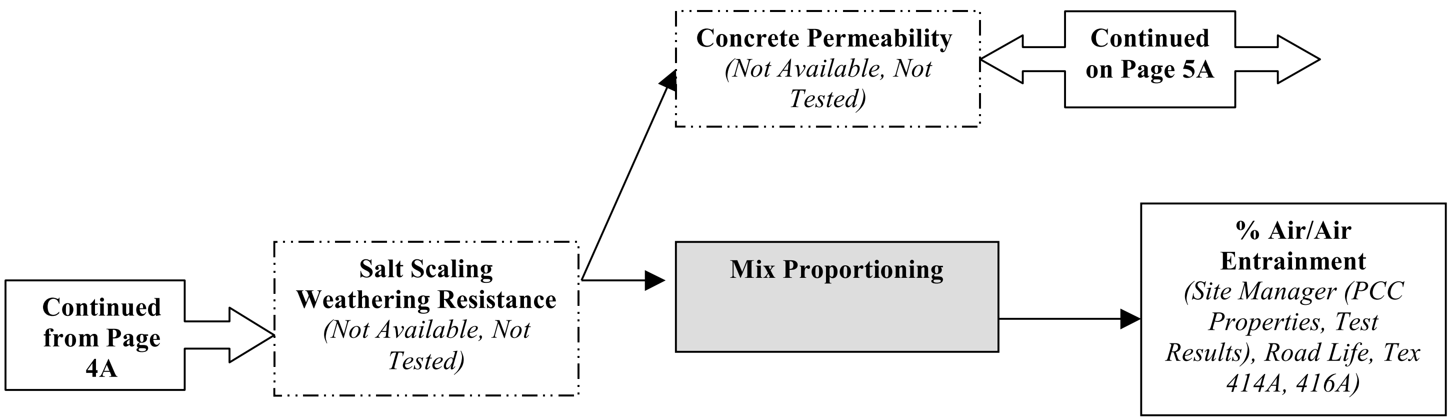
Holding Box/Element		




Legend
More Important Data
Less Important Data
TxDOT Tested/ Avail. Data
Not Tested or Available
Holding Box/Element
Concrete Permeability
(Site Manager (Not Available Not Tested)
Size, Distribution and Continuity of Pores
(Site Manager (air content), Road Life, Tex 414A, 416A)
Continued from Page 6, 7, 9, 10, 12, 13, 14, 15 and 25 A
Constituent Properties
Permeability Testing Conditions
(Not Available, Not Tested)
Time/Age
(Site Manager (PCC Description Effective Date, DWRs), Not Tested)
Mix Proportioning
Admixture Properties
Mixing Water Properties
Cement Properties
Aggregate Properties
Water to Cement Ratio
(Site Manager (PCC Properties), Not Tested)
Aggregate to Cement Ratio
(Site Manager (PCC Materials, Not Tested)
% Air/Air Entrainment
(Site Manager (PCC Properties), Road Life, Tex 414A, 416A)
Admixture Type
(Site Manager (PCC Materials), ASTM C494, C260)
Water Impurity Concentrations
(Site Manager (As PCC Materials, Test Results), AASHTO T26)
Cement Chemical Composition
(Site Manager (PCC Materials), Road Life, Spec. Item 524 Tests)
Cement Fineness
(Site Manager (PCC Materials, Test Results), Spec. Item 524 Tests)
Aggregate Maximum Size
(Site Manager (Material Gradations, PCC Materials, PCC Gradations, Test Results), Tex 401A, 406A)
Aggregate Gradation
(S. M. (Material Gradations, PCC Materials, PCC Gradations, Test Results), RL, Tex 401A, 402A, 406A)
Aggregate Moisture Content
(S. M. (Test Results), Not Tested)
Aggregate Impurity Content
(S. M. (Test Results), Tex 408A,
Aggregate Mineralogy
(Not Available (Site Manager Name?, Test Results), Road Life Tex 408A, 413A, 612J)


Legend
More Important Data
Less Important Data
TxDOT Tested/ Avail. Data
Not Tested or Available
Holding Box/Element
Continued on Page 5A
Water to Cement Ratio (Site Manager (PCC Properties), Not Tested)
Aggregate Coeff. Ther. Exp. (Not Available, Not Tested)
Concrete Permeability (Not Available, Not Tested)
Aggregate to Cement Ratio (Site Manager (PCC Materials, Not Tested)
Aggregate Maximum Size/Gradation (Site Manager (Material Gradations, PCC Materials, PCC Gradations, Test Results), Road Life, Tex 401A, 406A)
Mix Proportioning
% Air/Air Entrainment (Site Manager (PCC Properties, Test Results), Road Life, Tex 414A, 416A)
Pore Spacing, Size and Distribution (Site Manager (air content), Road Life, Tex 414A, 416A)
Time/Age (S.M. (PCC Desc. Effective Date, DWRs), Not Tested)
Aggregate Tensile Strength (Not Available, Not Tested)
Continued from Page 4A
Freeze-Thaw Weathering Resistance (Not Available, Not Tested)
Concrete Degree of Saturation (Site Manager (Deduce from Unit Weights, PCC Properties), Not Tested)
Admixture Properties
Admixture Type (Site Manager (PCC Materials), ASTM C494, C260)
Aggregate Moisture Content (Site Manager (Test Results), Not Tested)
Constituent Properties
Concrete/Paste Strength (Site Manager (Test Results, PCC Properties) Tex 418A, 448A)
Continued on Page 1A
Aggregate Properties
Aggregate Soundness (Site Manager (Test Results), Tex 411A)

Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



Legend	More Important Data	Less Important Data
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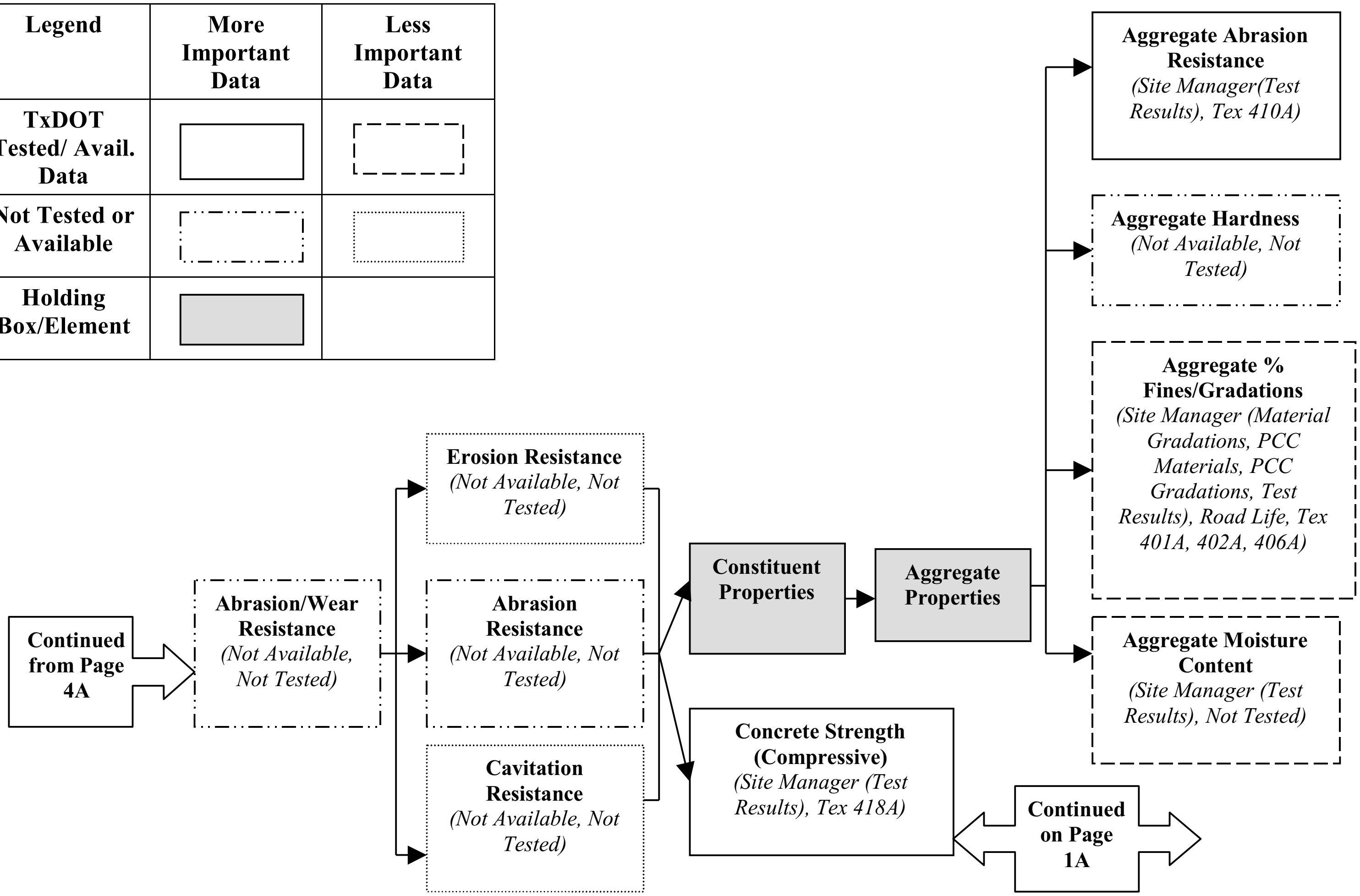

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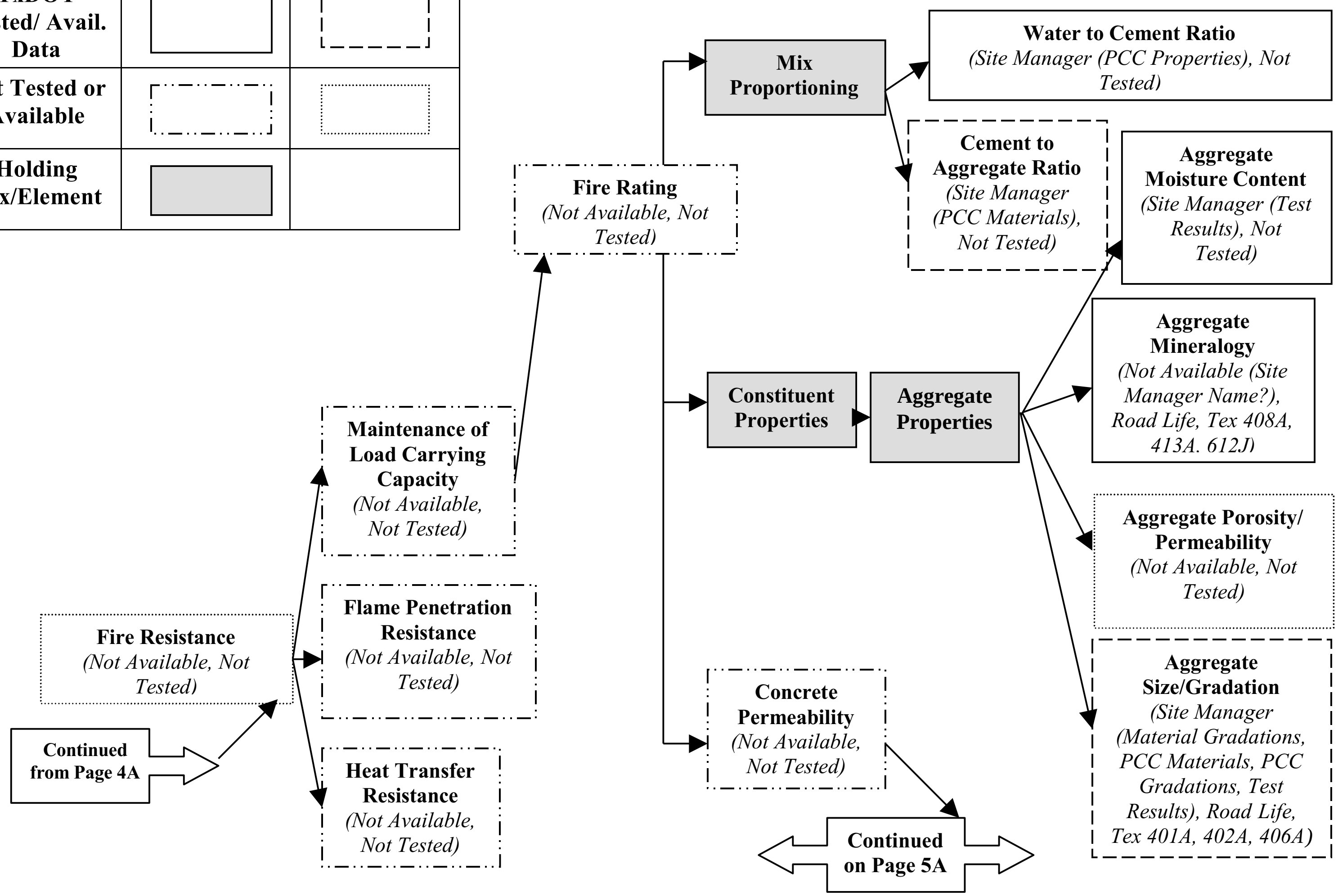

Legend	More Important Data	Less Important Data
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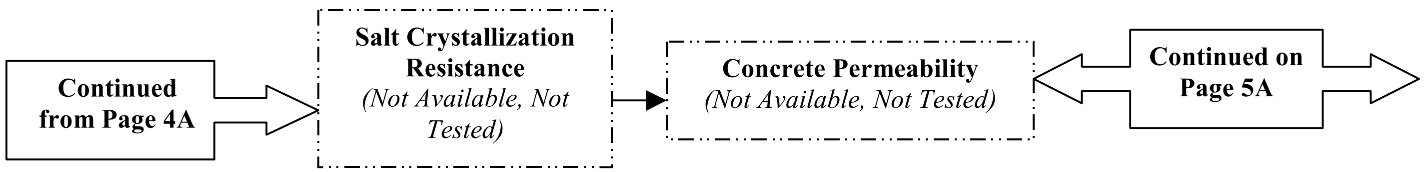
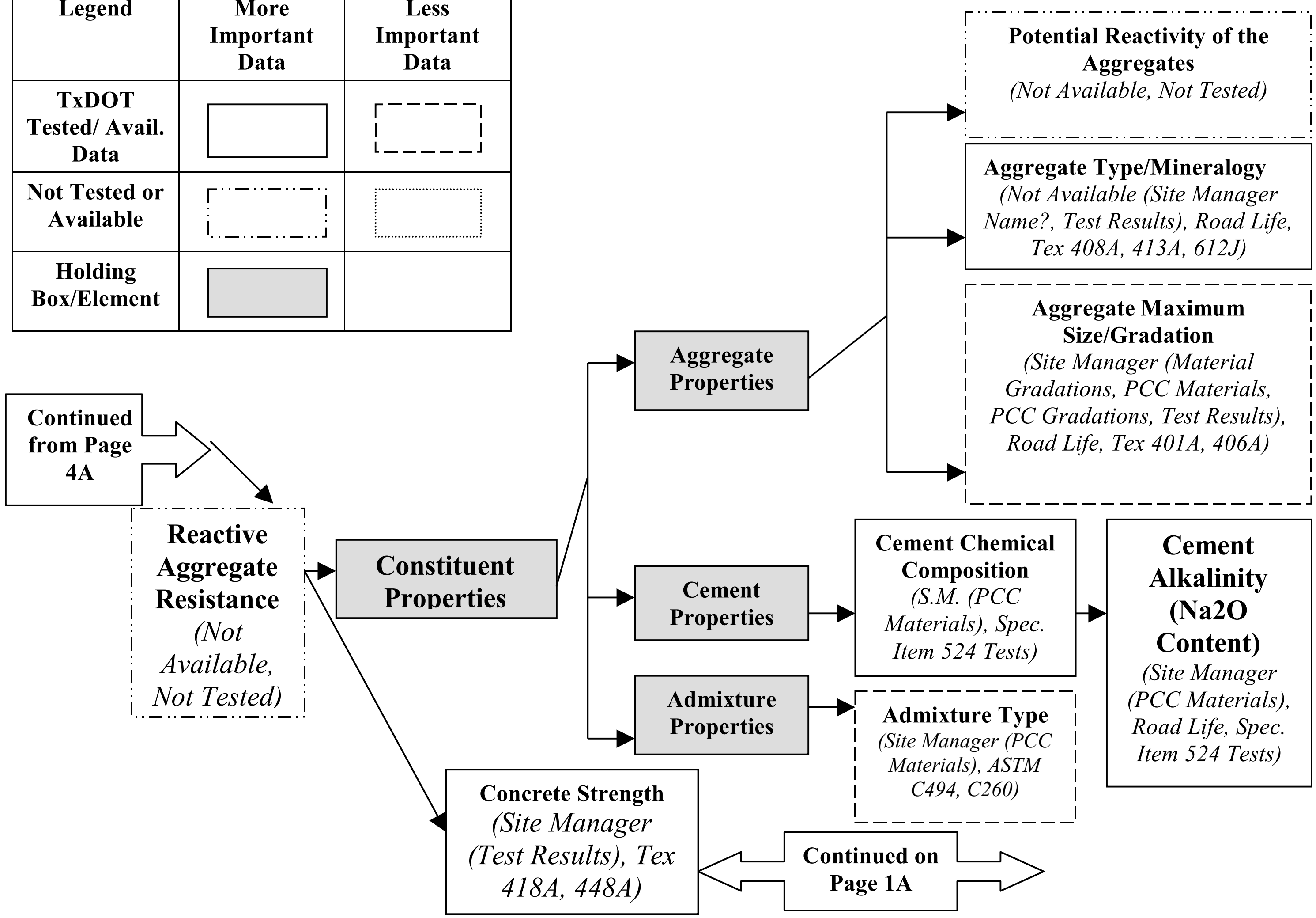
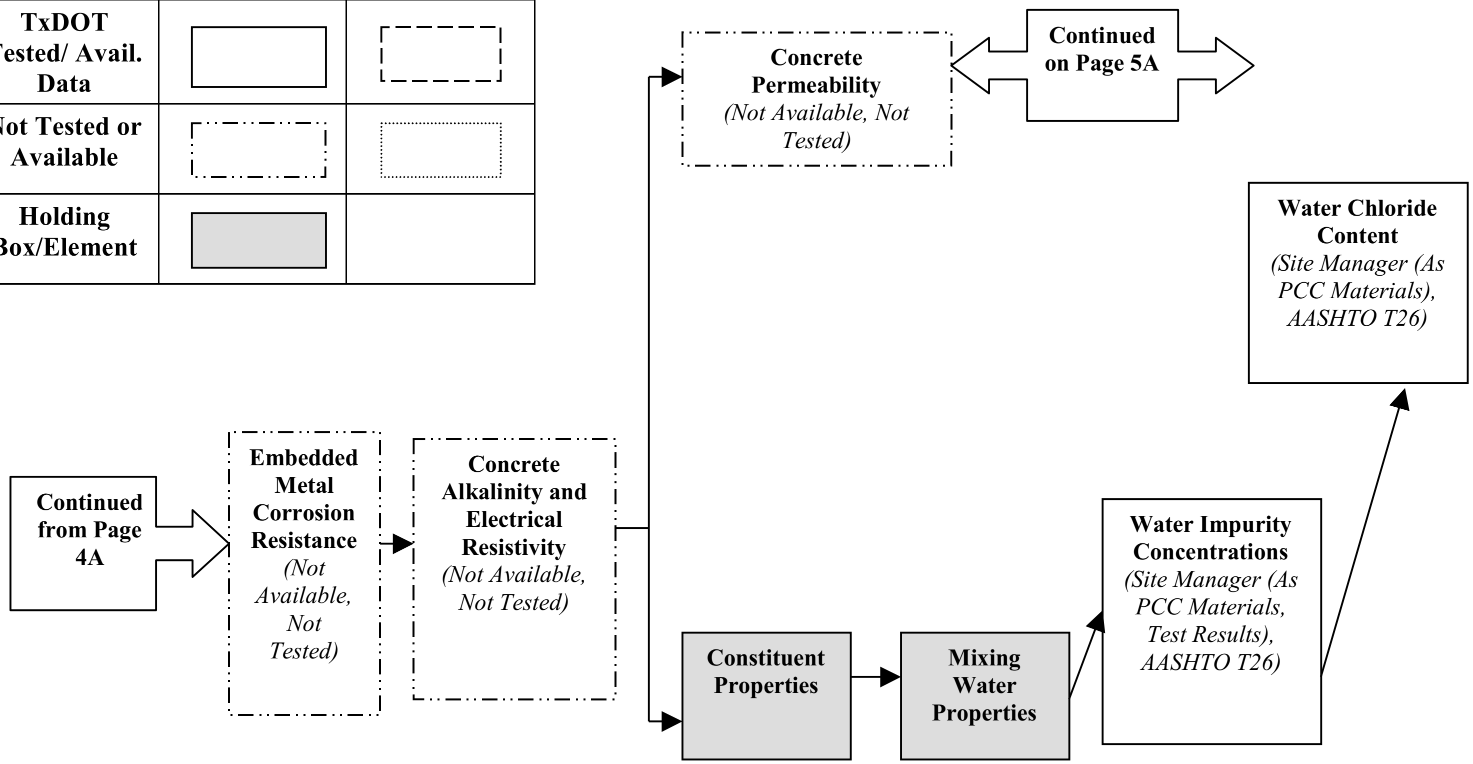
Not Tested or Available		
Holding Box/Element		



Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



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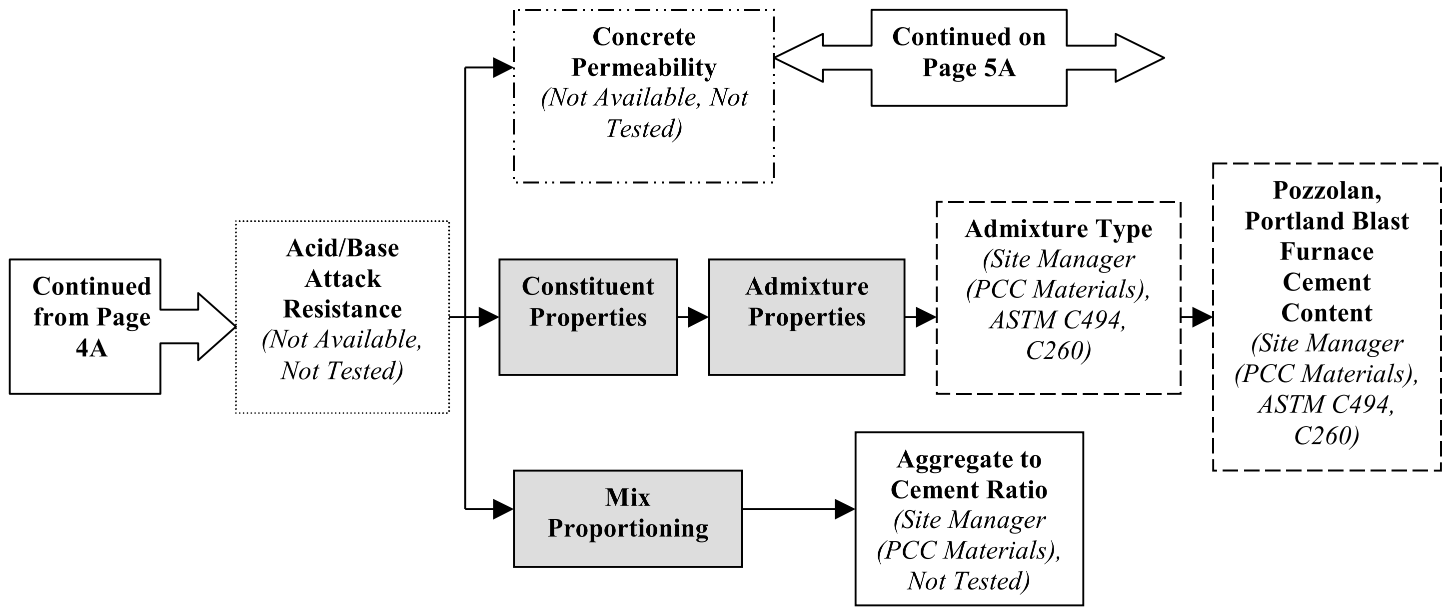
Holding Box/Element		



Legend	More Important Data	Less Important Data
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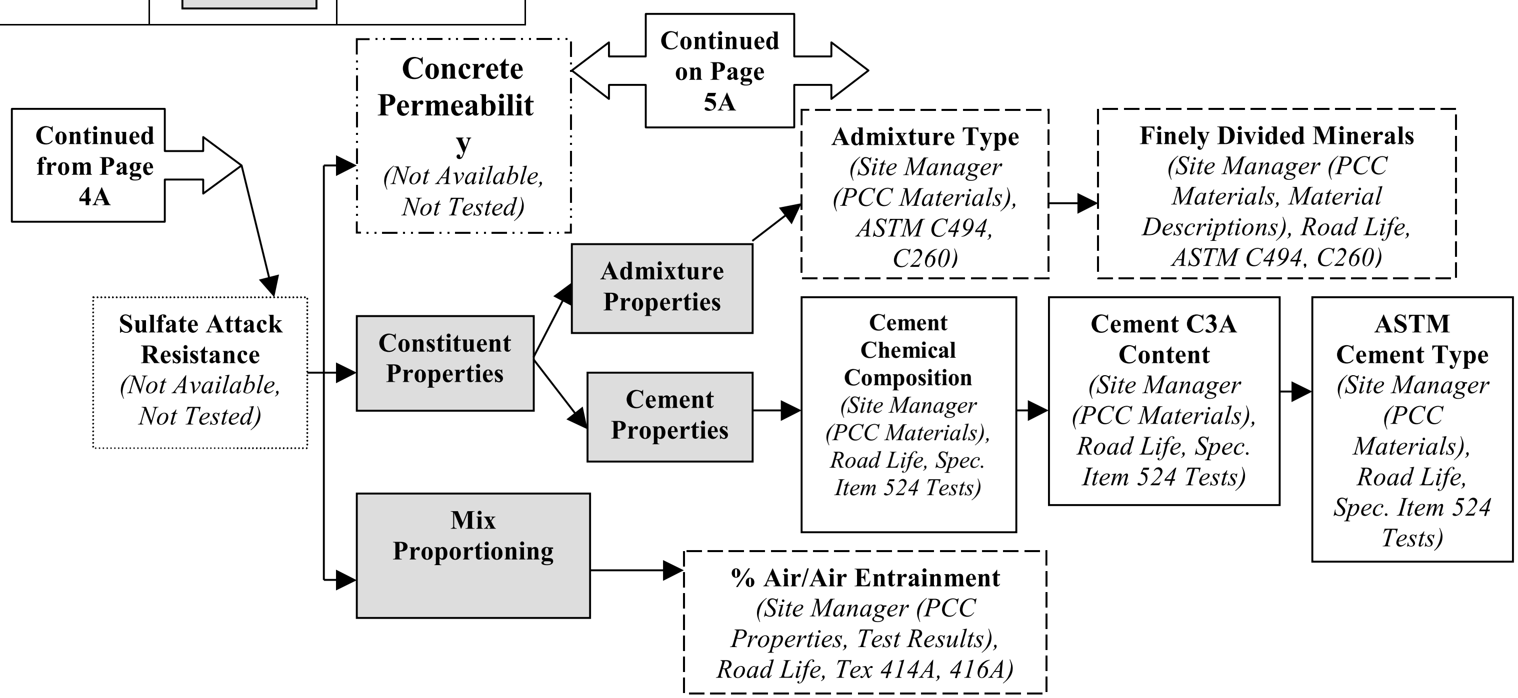
Not Tested or Available		
Holding Box/Element		



Legend	More Important Data	Less Important Data
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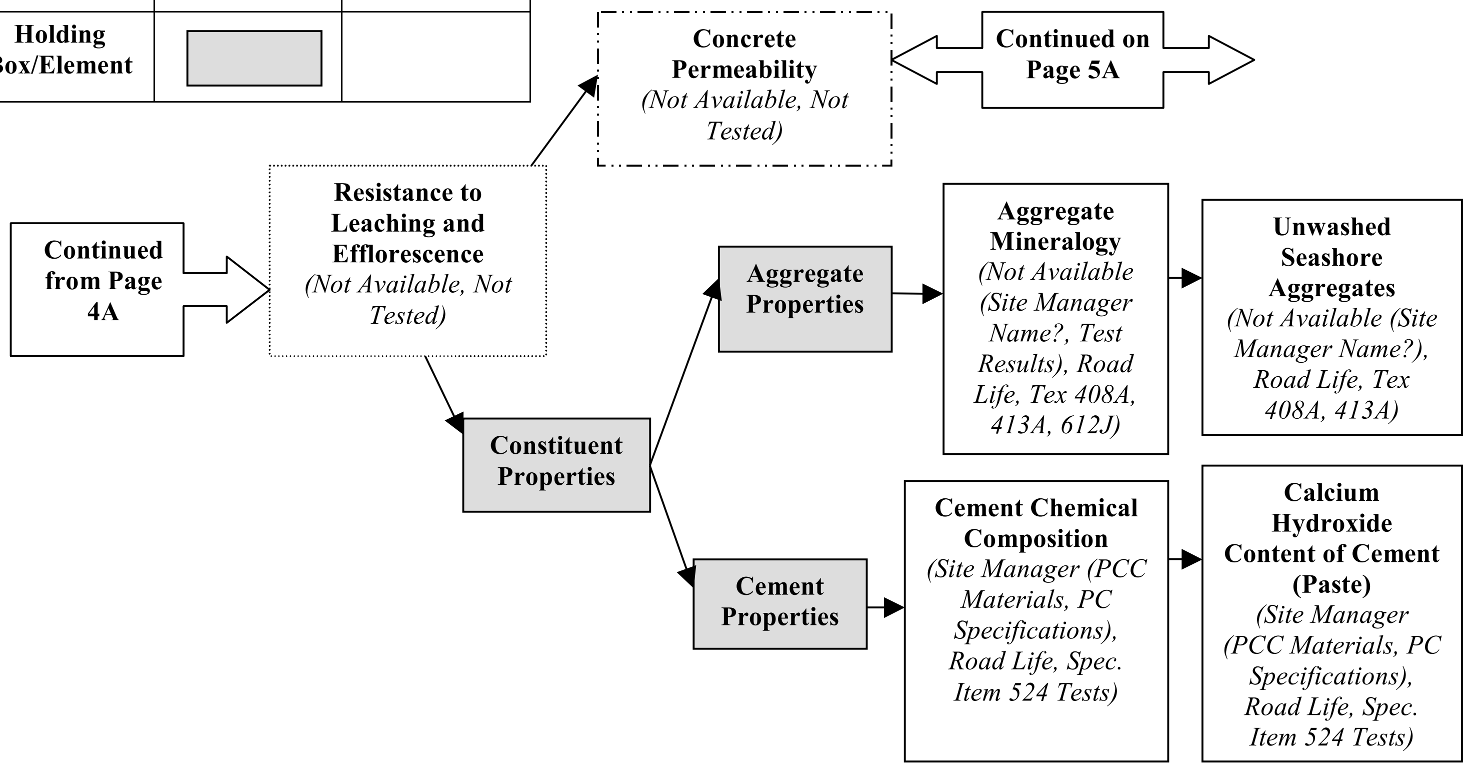
Not Tested or Available		
Holding Box/Element		



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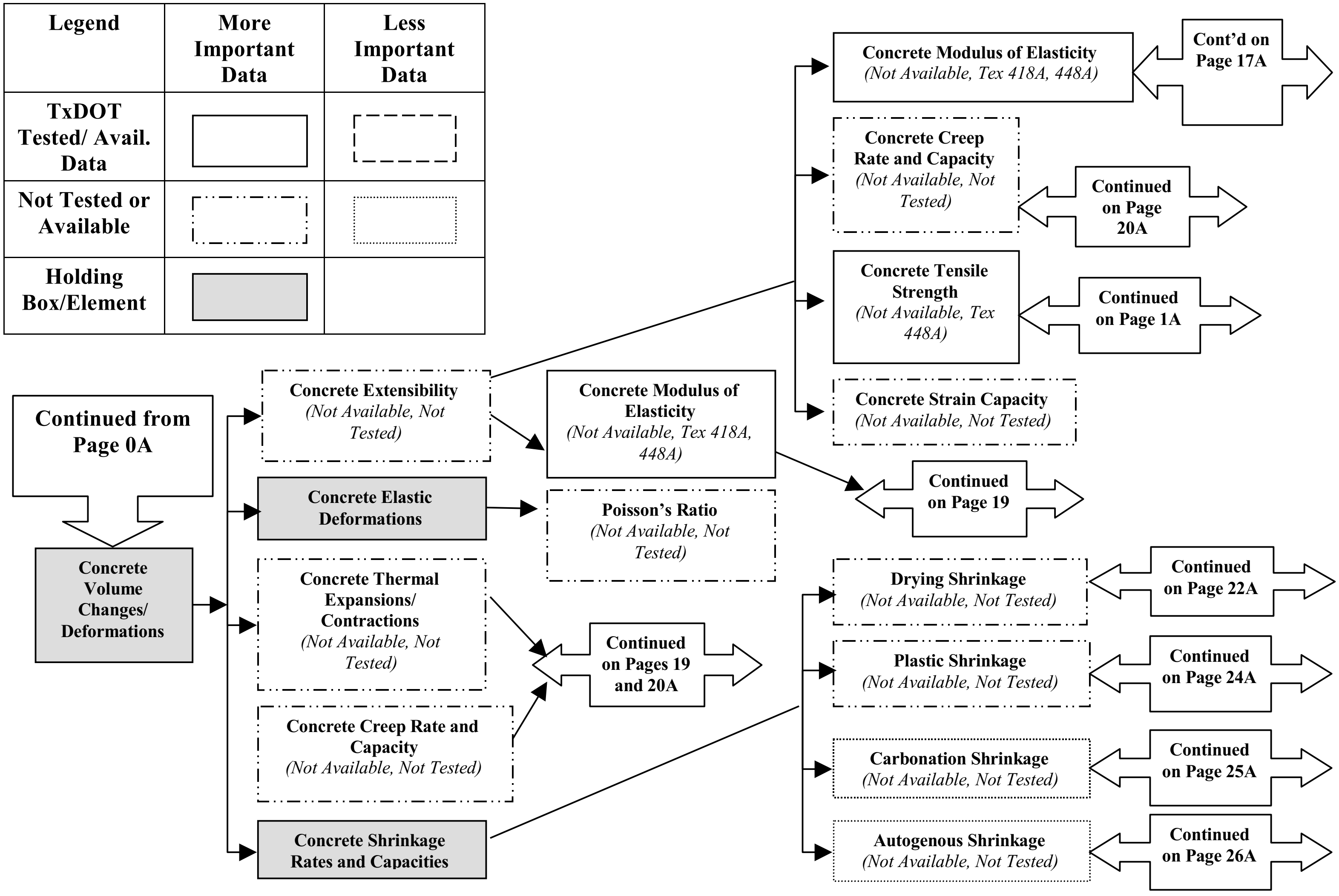
Holding Box/Element		



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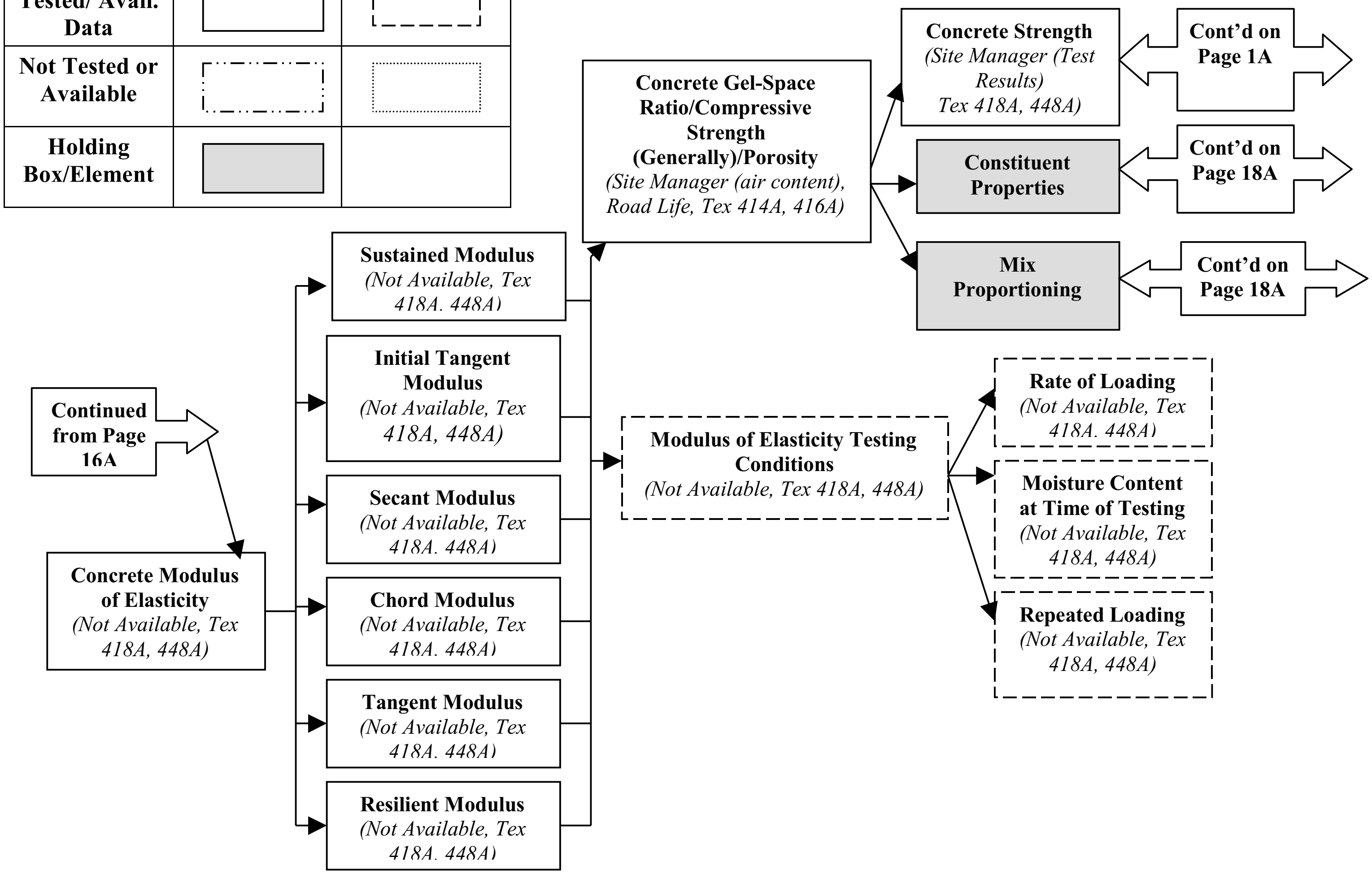
Holding Box/Element		



Legend	More Important Data	Less Important Data
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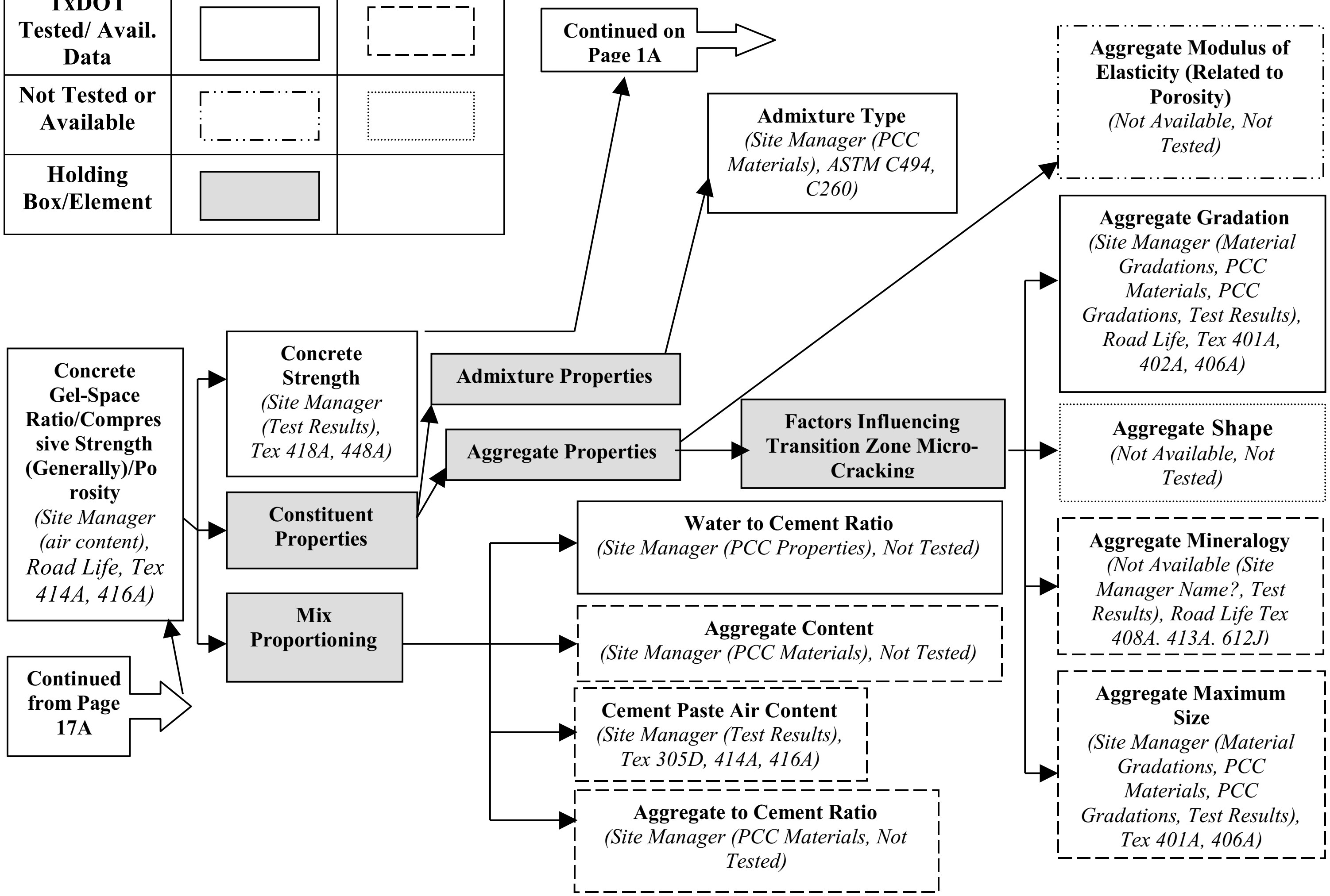
Not Tested or Available		
Holding Box/Element		



Legend	More Important Data	Less Important Data
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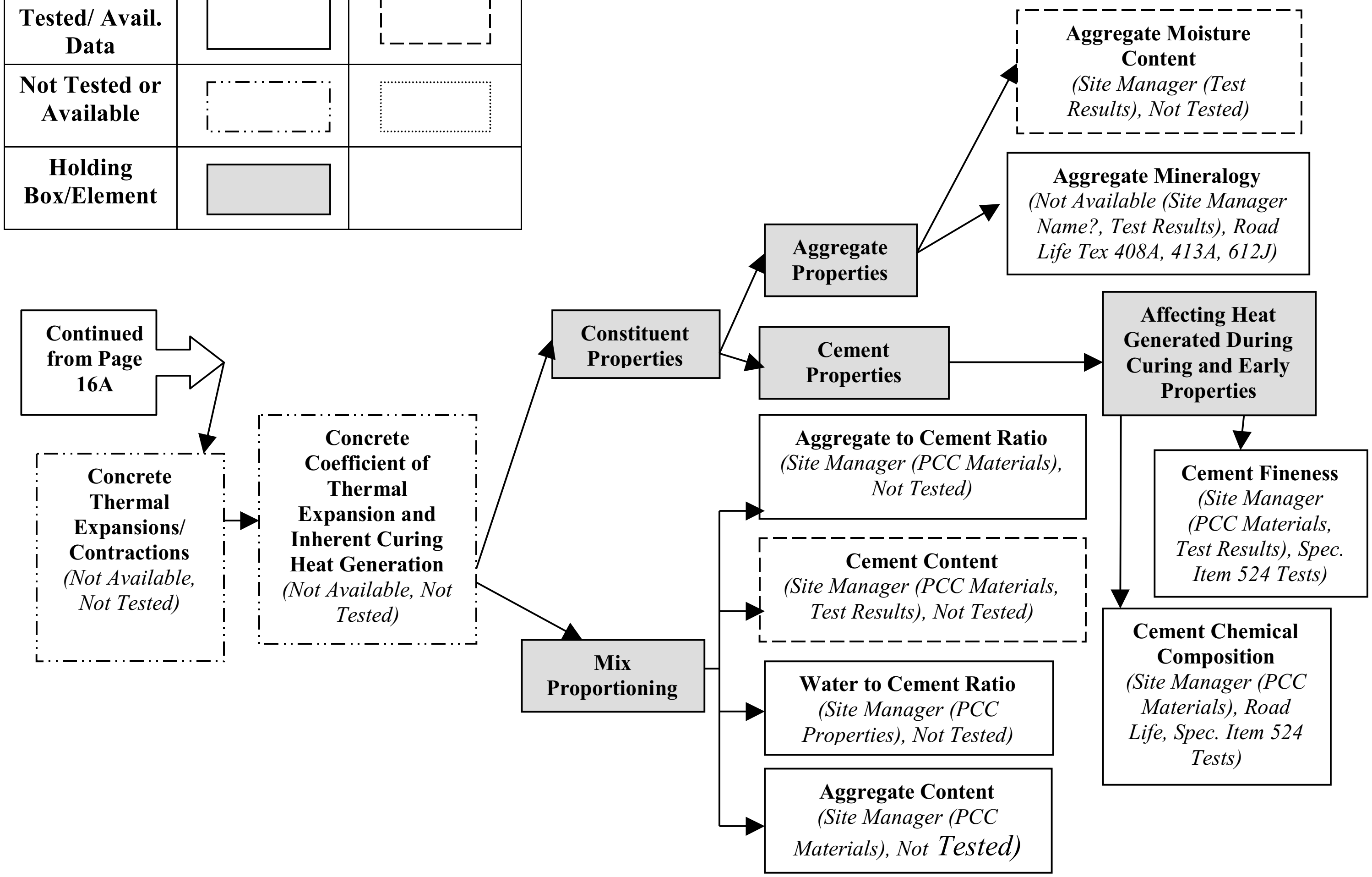
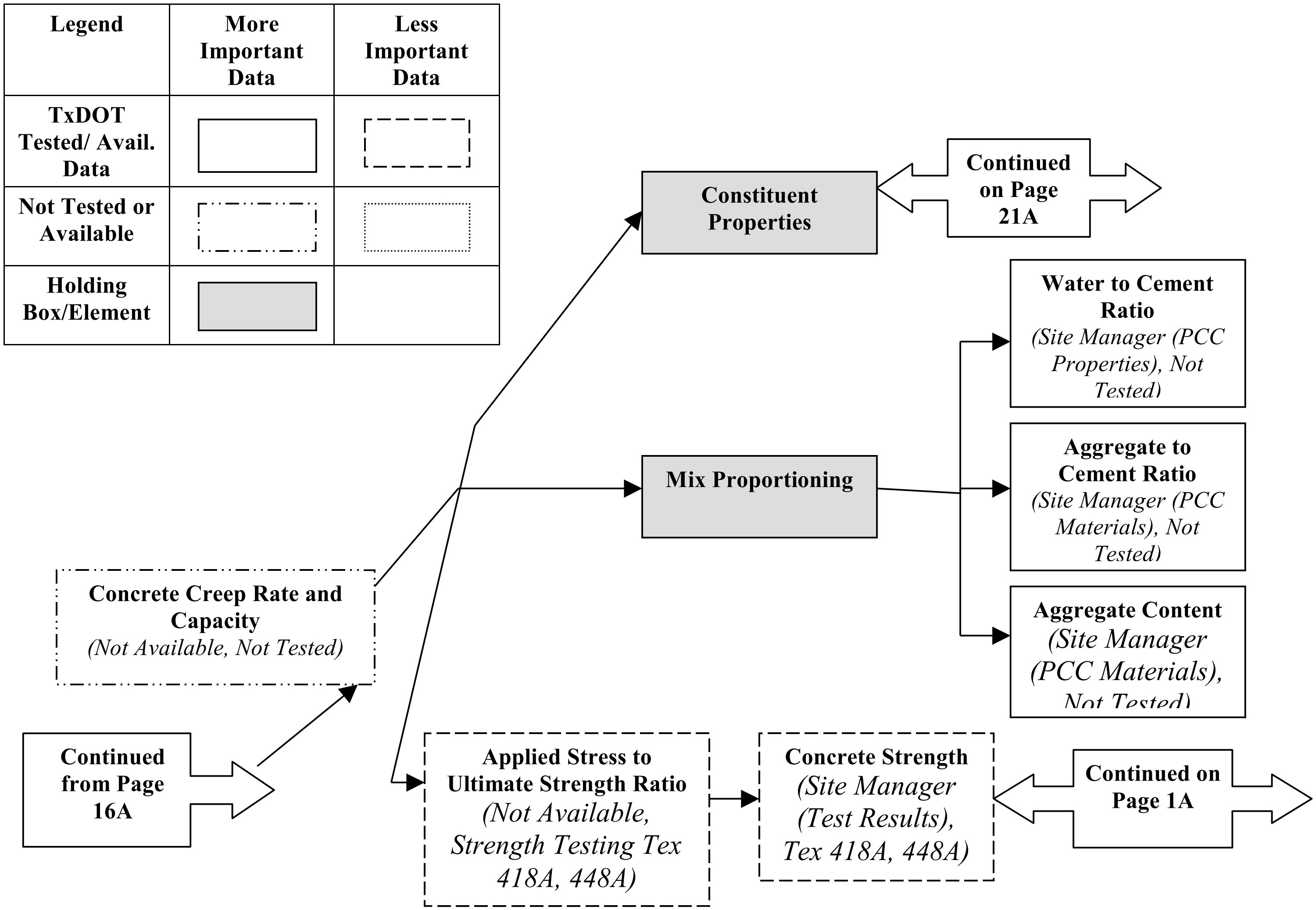
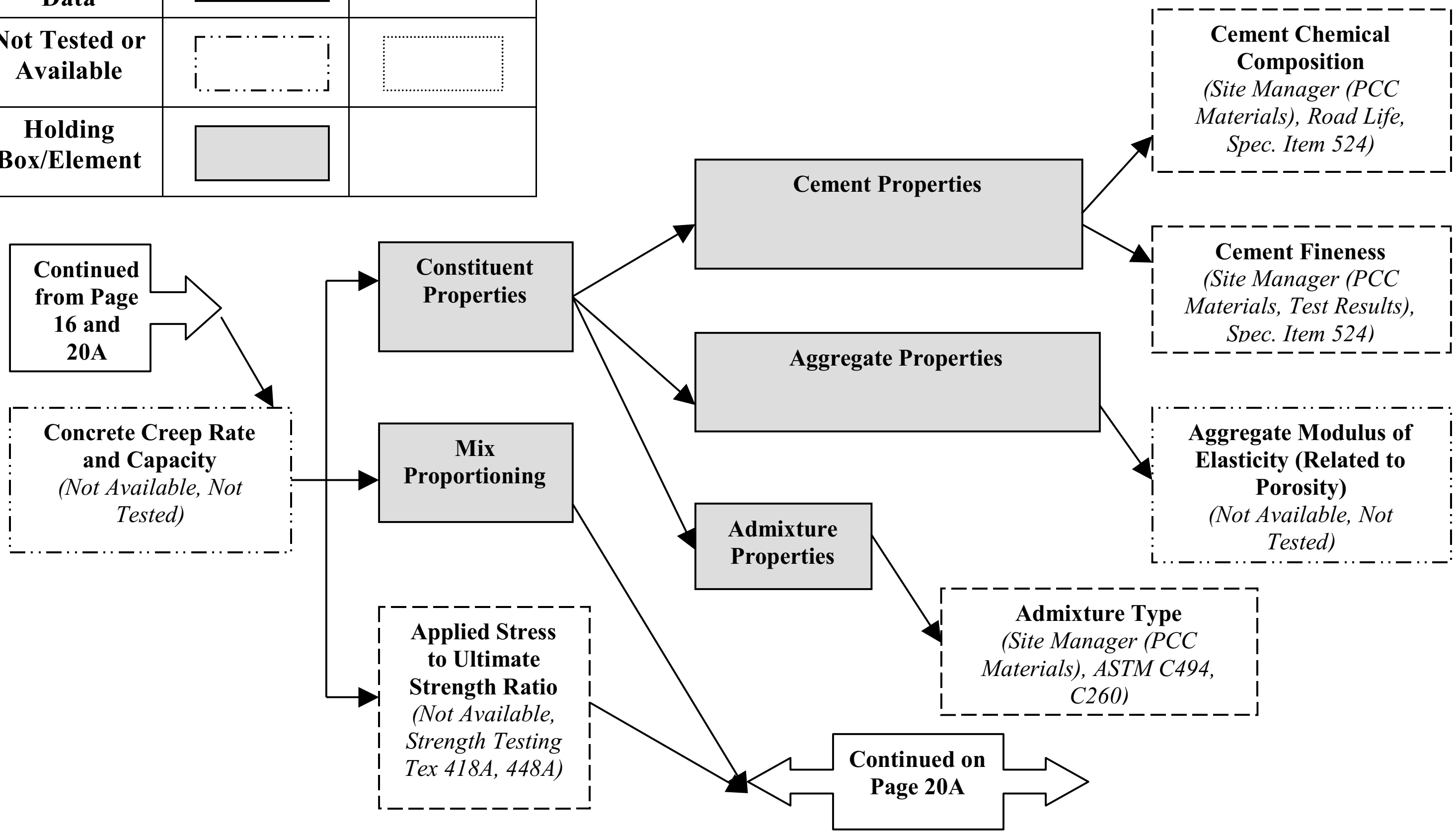
Holding Box/Element		




Legend
More Important Data
Less Important Data
TxDOT Tested/ Avail. Data
Not Tested or Available
Holding Box/Element
Constituent Properties
Continued on Page 21A
Water to Cement Ratio
(Site Manager (PCC Properties), Not Tested)
Mix Proportioning
Aggregate to Cement Ratio
(Site Manager (PCC Materials), Not Tested)
Concrete Creep Rate and Capacity
(Not Available, Not Tested)
Aggregate Content
(Site Manager (PCC Materials), Not Tested)
Continued from Page 16A
Applied Stress to Ultimate Strength Ratio
(Not Available, Strength Testing Tex 418A, 448A)
Concrete Strength
(Site Manager (Test Results), Tex 418A, 448A)
Continued on Page 1A

Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



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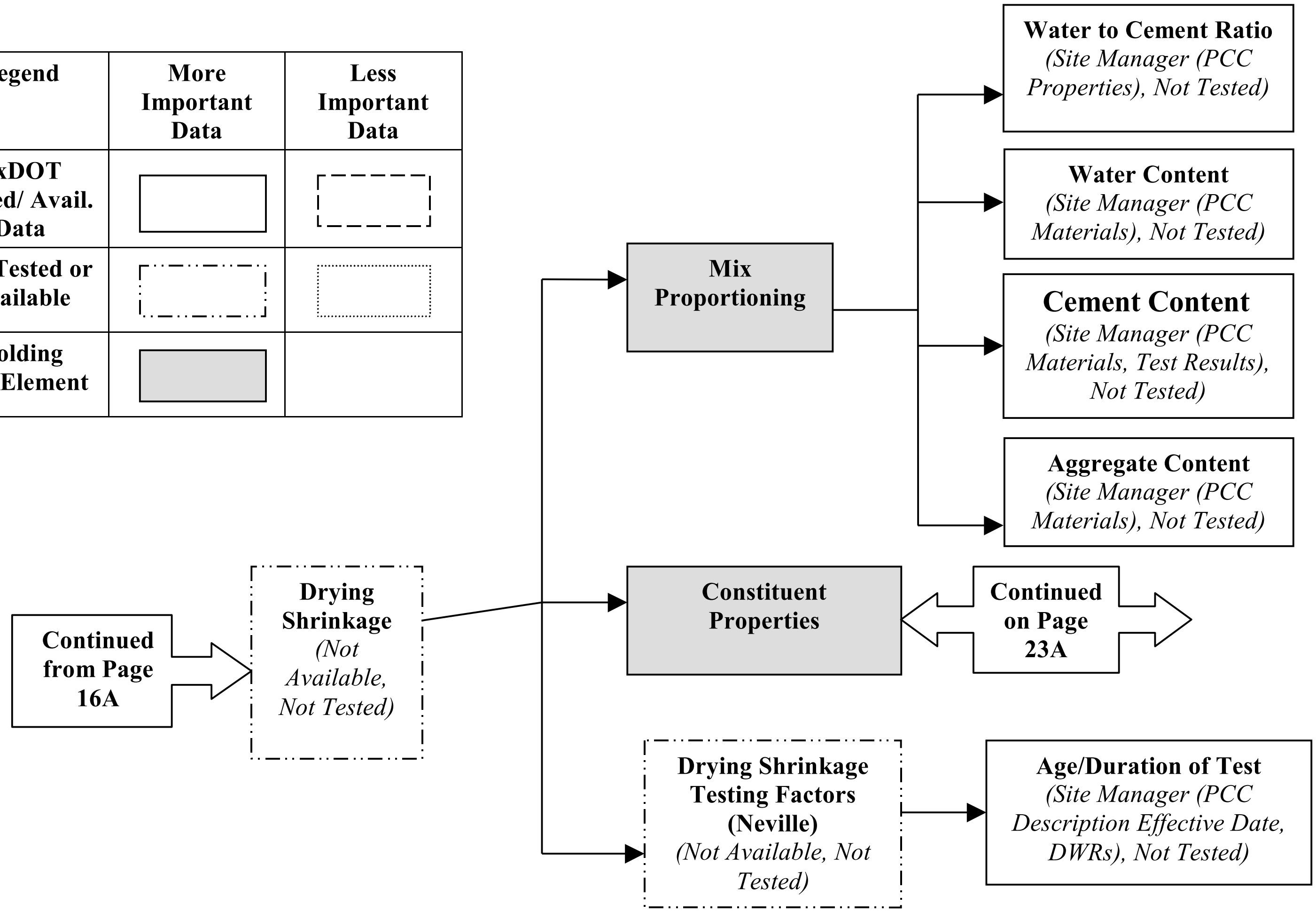
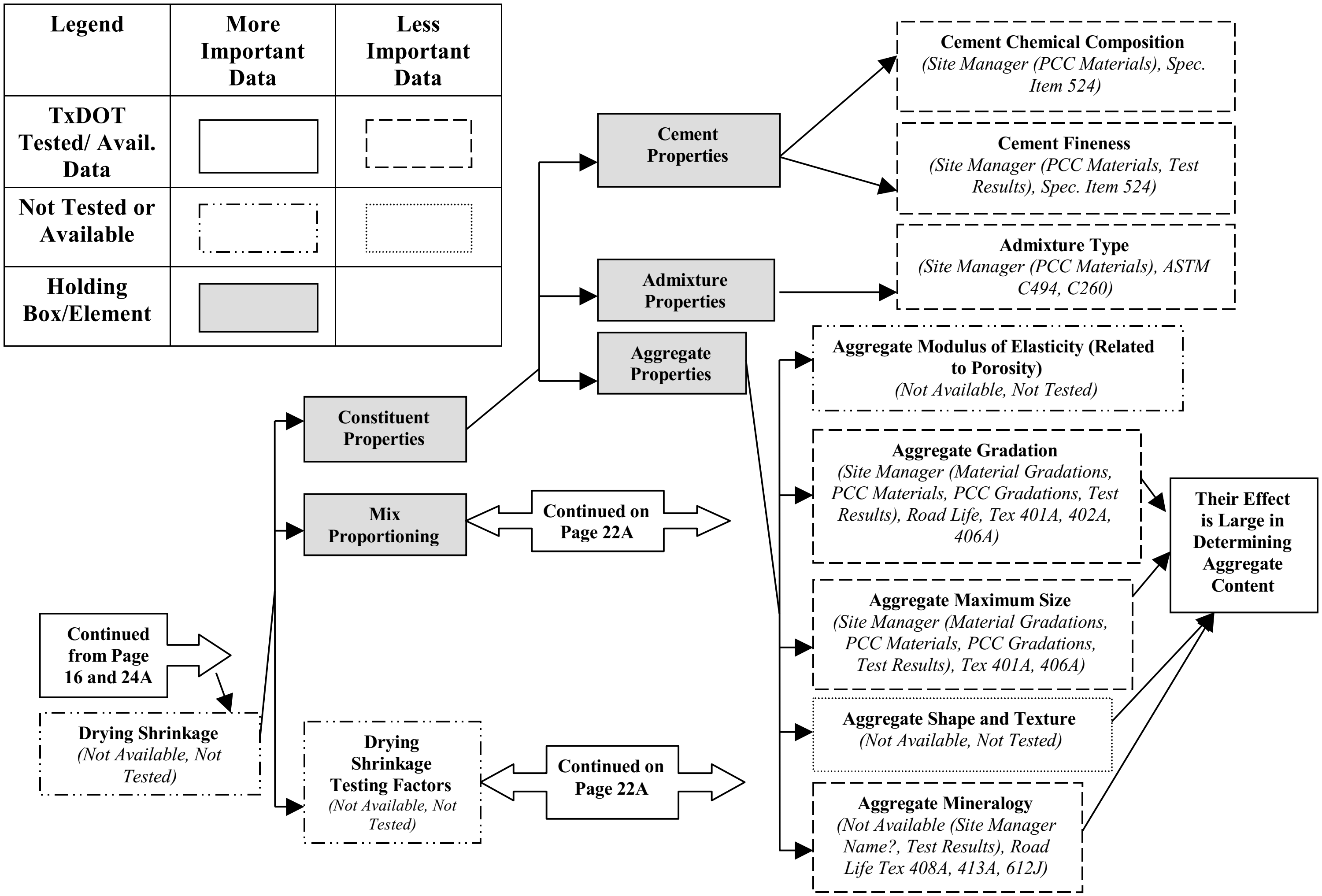
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		




Legend
More Important Data
Less Important Data
TxDOT Tested/ Avail. Data
Not Tested or Available
Holding Box/Element
Cement Chemical Composition
(Site Manager (PCC Materials), Spec. Item 524)
Cement Fineness
(Site Manager (PCC Materials, Test Results), Spec. Item 524)
Cement Properties
Admixture Type
(Site Manager (PCC Materials), ASTM C494, C260)
Admixture Properties
Aggregate Properties
Aggregate Modulus of Elasticity (Related to Porosity)
(Not Available, Not Tested)
Constituent Properties
Aggregate Gradation
(Site Manager (Material Gradations, PCC Materials, PCC Gradations, Test Results), Road Life, Tex 401A, 402A, 406A)
Mix Proportioning
Continued on Page 22A
Their Effect is Large in Determining Aggregate Content
Aggregate Maximum Size
(Site Manager (Material Gradations, PCC Materials, PCC Gradations, Test Results), Tex 401A, 406A)
Continued from Page 16 and 24A
Aggregate Shape and Texture
(Not Available, Not Tested)
Drying Shrinkage
(Not Available, Not Tested)
Drying Shrinkage Testing Factors
(Not Available, Not Tested)
Continued on Page 22A
Aggregate Mineralogy
(Not Available (Site Manager Name?, Test Results), Road Life Tex 408A, 413A, 612J)

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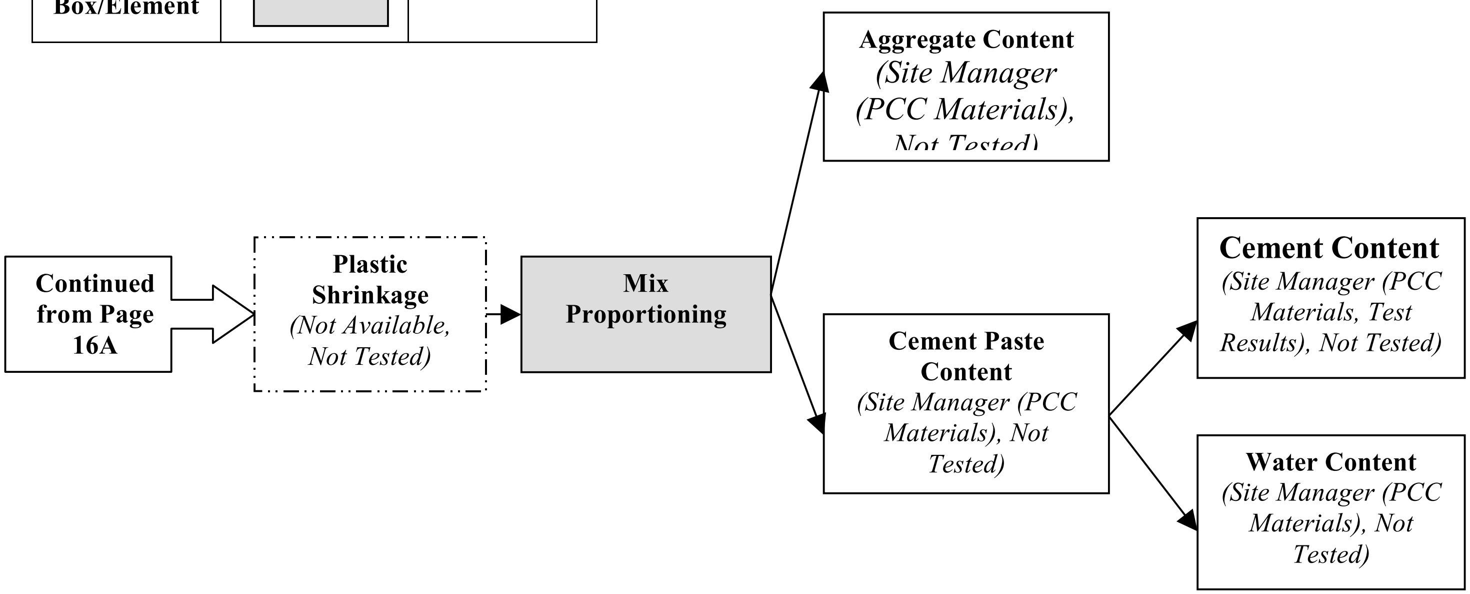
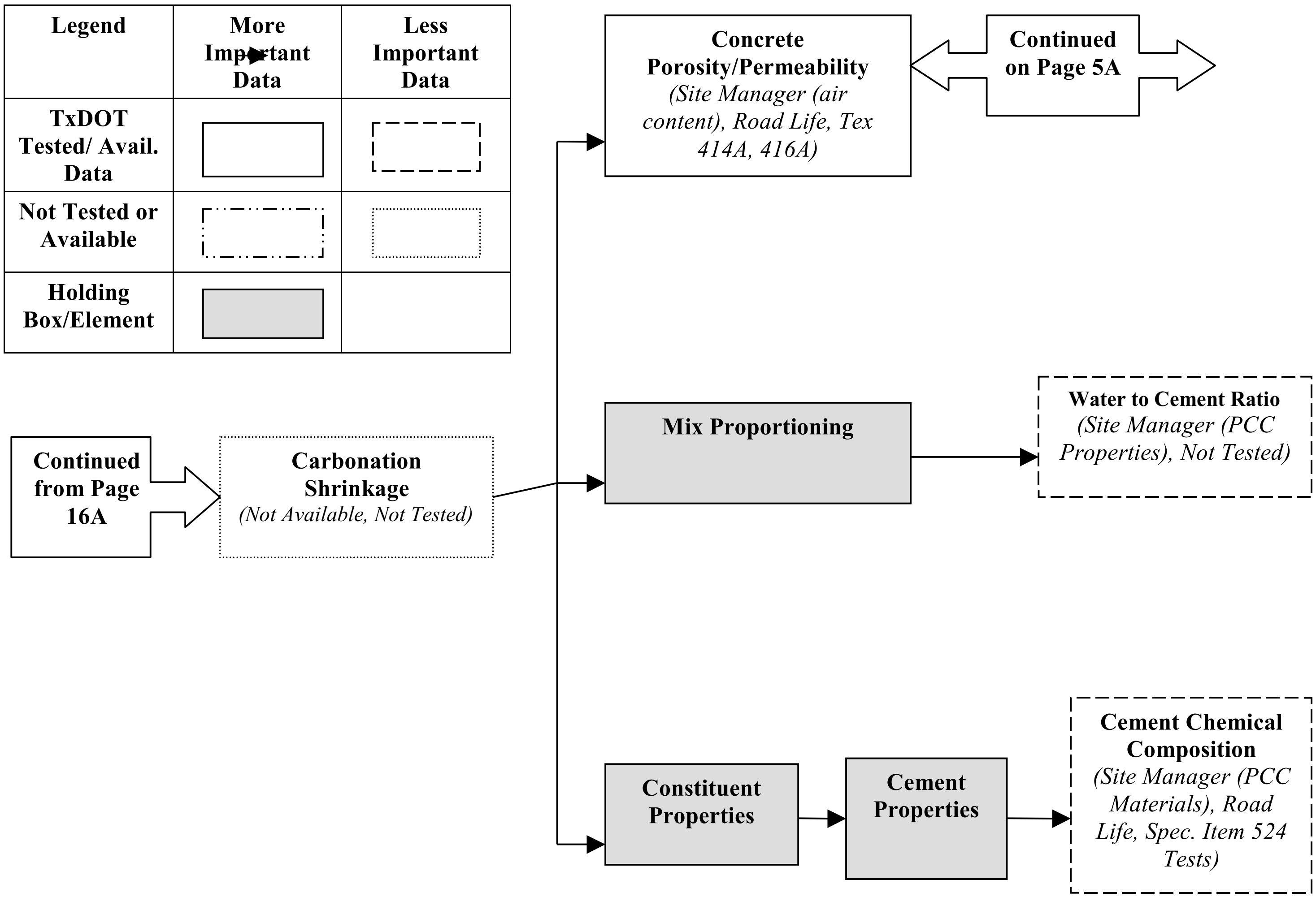
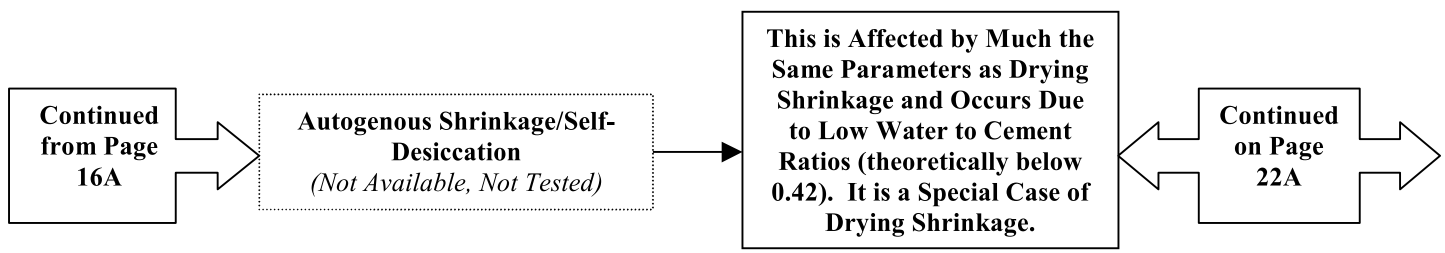
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		

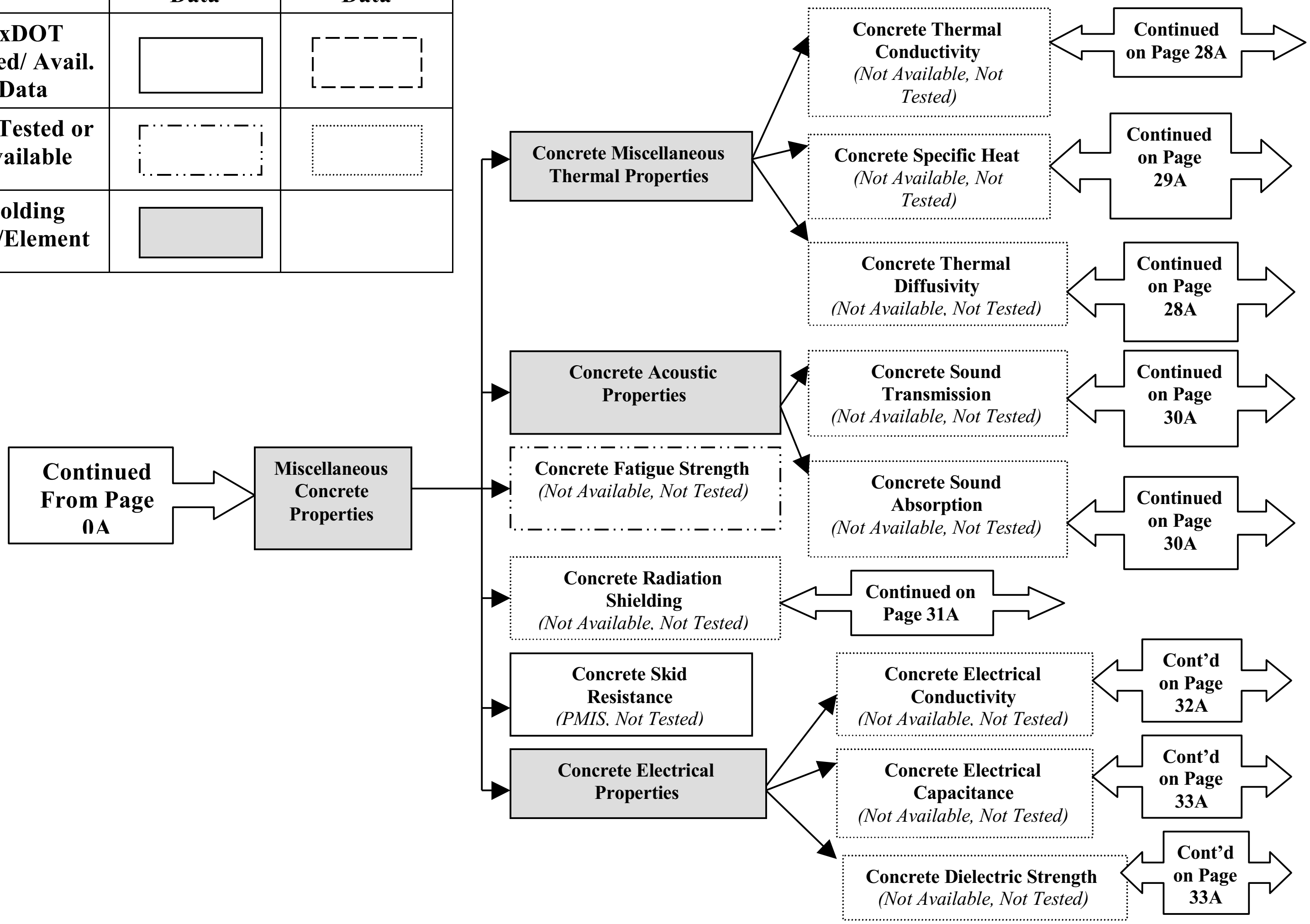



Legend
More Important Data
Less Important Data
TxDOT Tested/ Avail. Data
Not Tested or Available
Holding Box/Element
Concrete Porosity/Permeability
(Site Manager (air content), Road Life, Tex 414A, 416A)
Continued on Page 5A
Continued from Page 16A
Carbonation Shrinkage
(Not Available, Not Tested)
Mix Proportioning
Water to Cement Ratio
(Site Manager (PCC Properties), Not Tested)
Constituent Properties
Cement Properties
Cement Chemical Composition
(Site Manager (PCC Materials), Road Life, Spec. Item 524 Tests)

Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



Legend	More Important Data	Less Important Data
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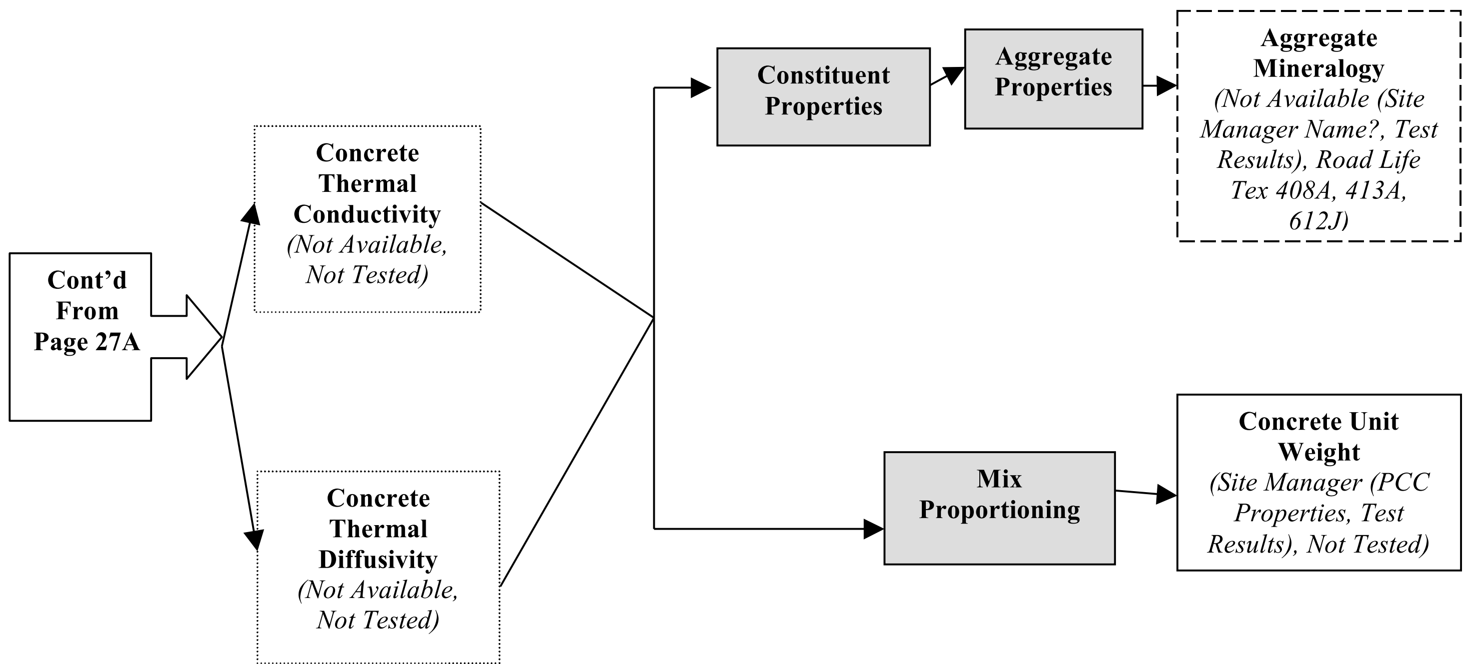
Not Tested or Available		
Holding Box/Element		



Legend	More Important Data	Less Important Data
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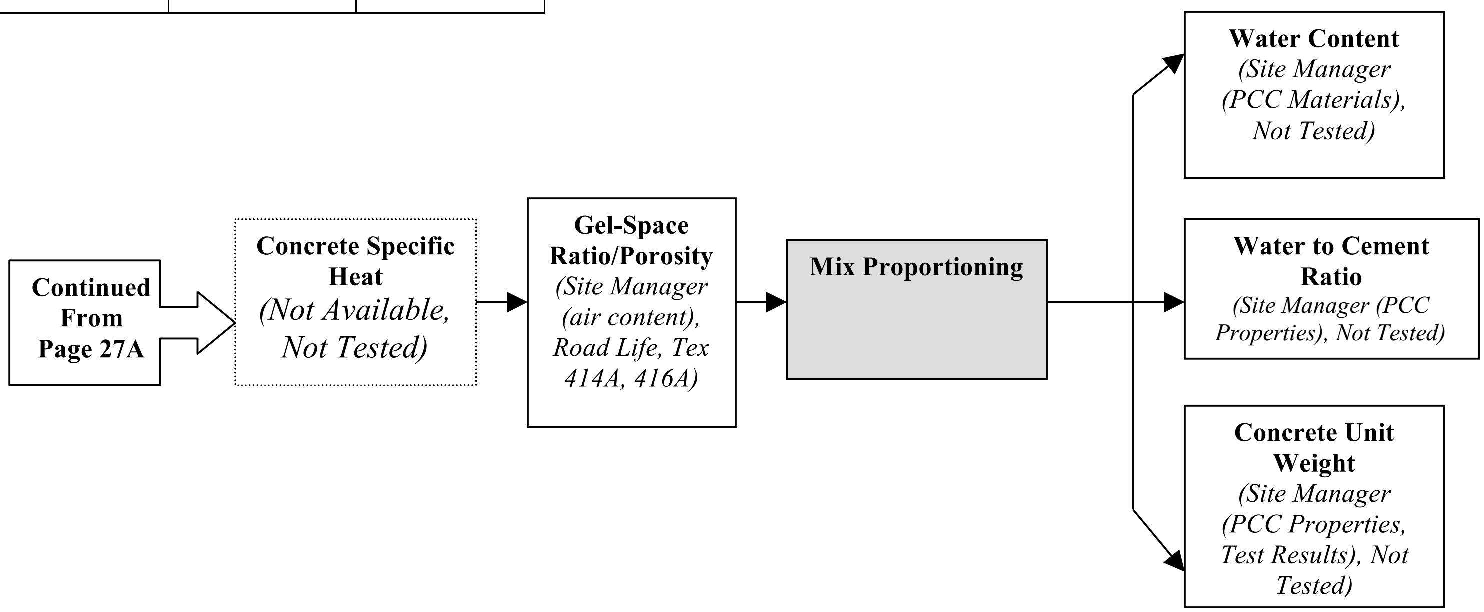
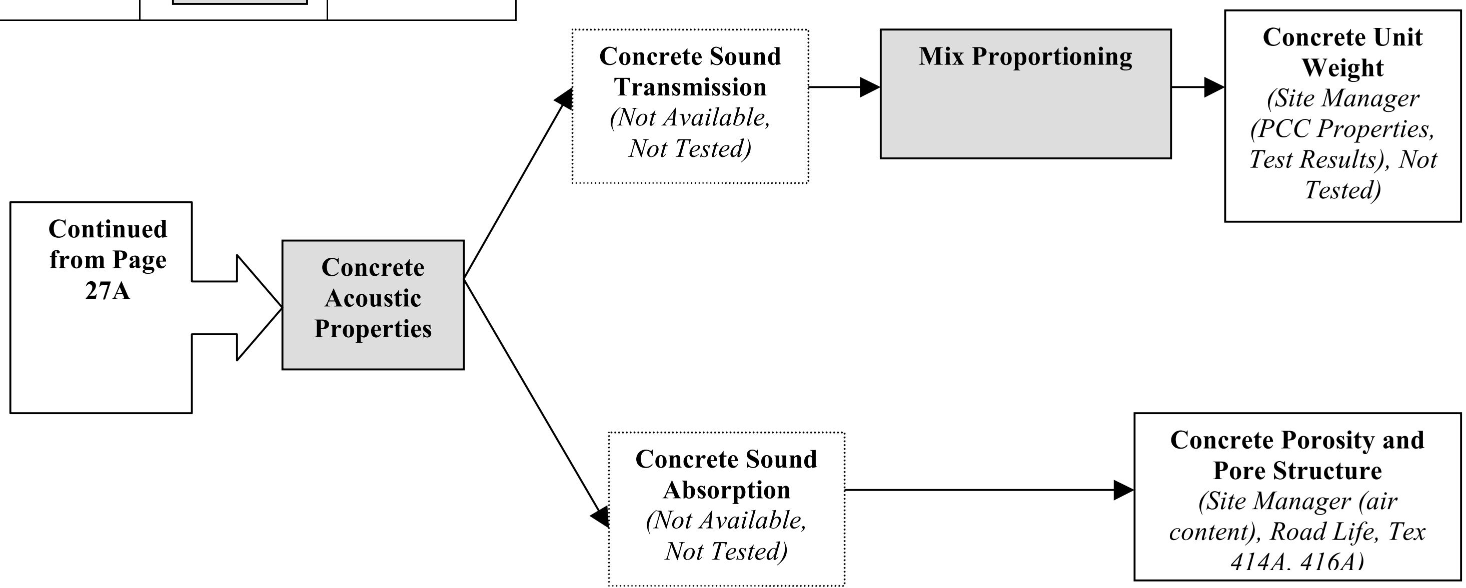
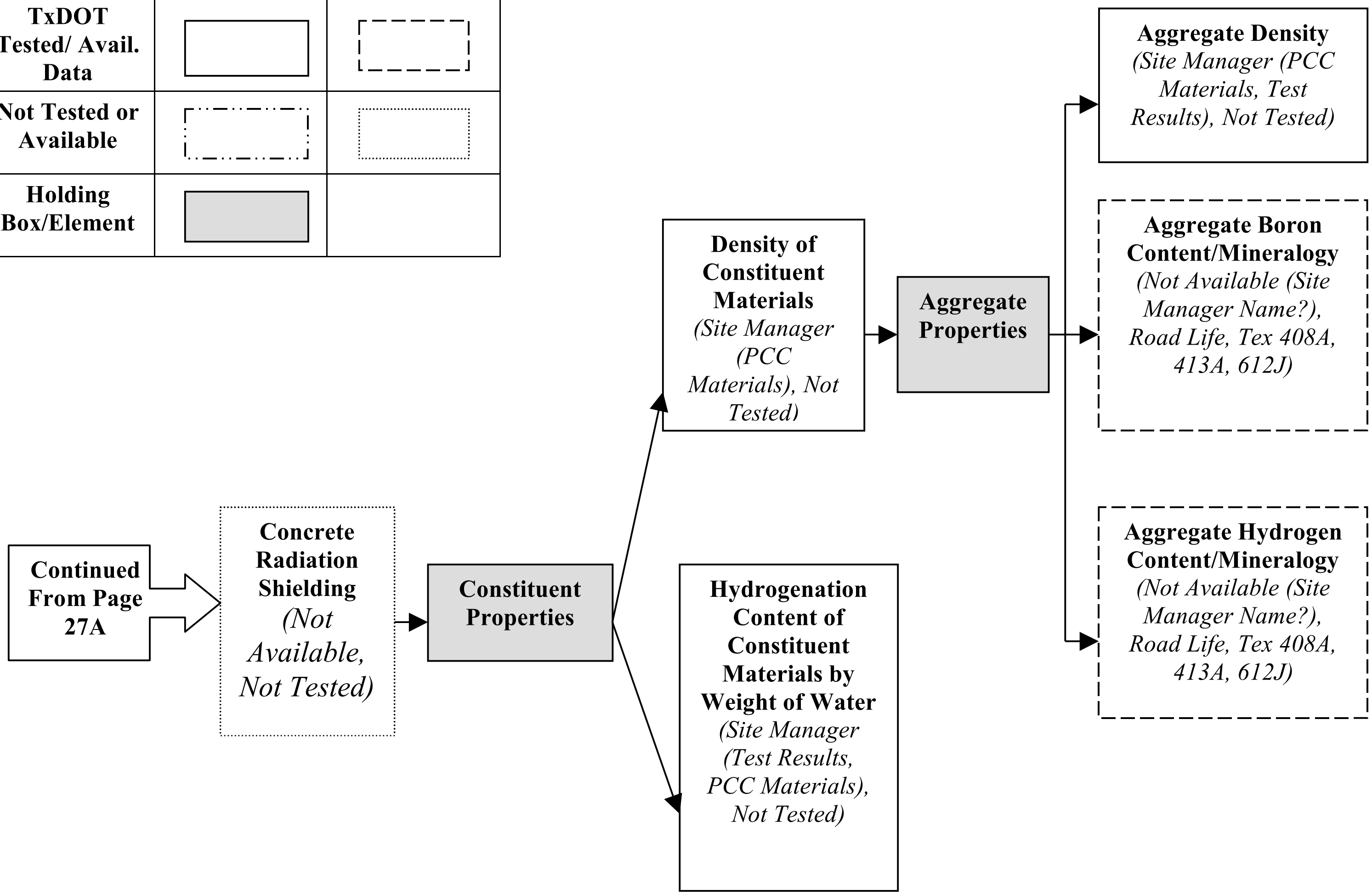
Not Tested or Available		
Holding Box/Element		



Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



Legend	More Important Data	Less Important Data
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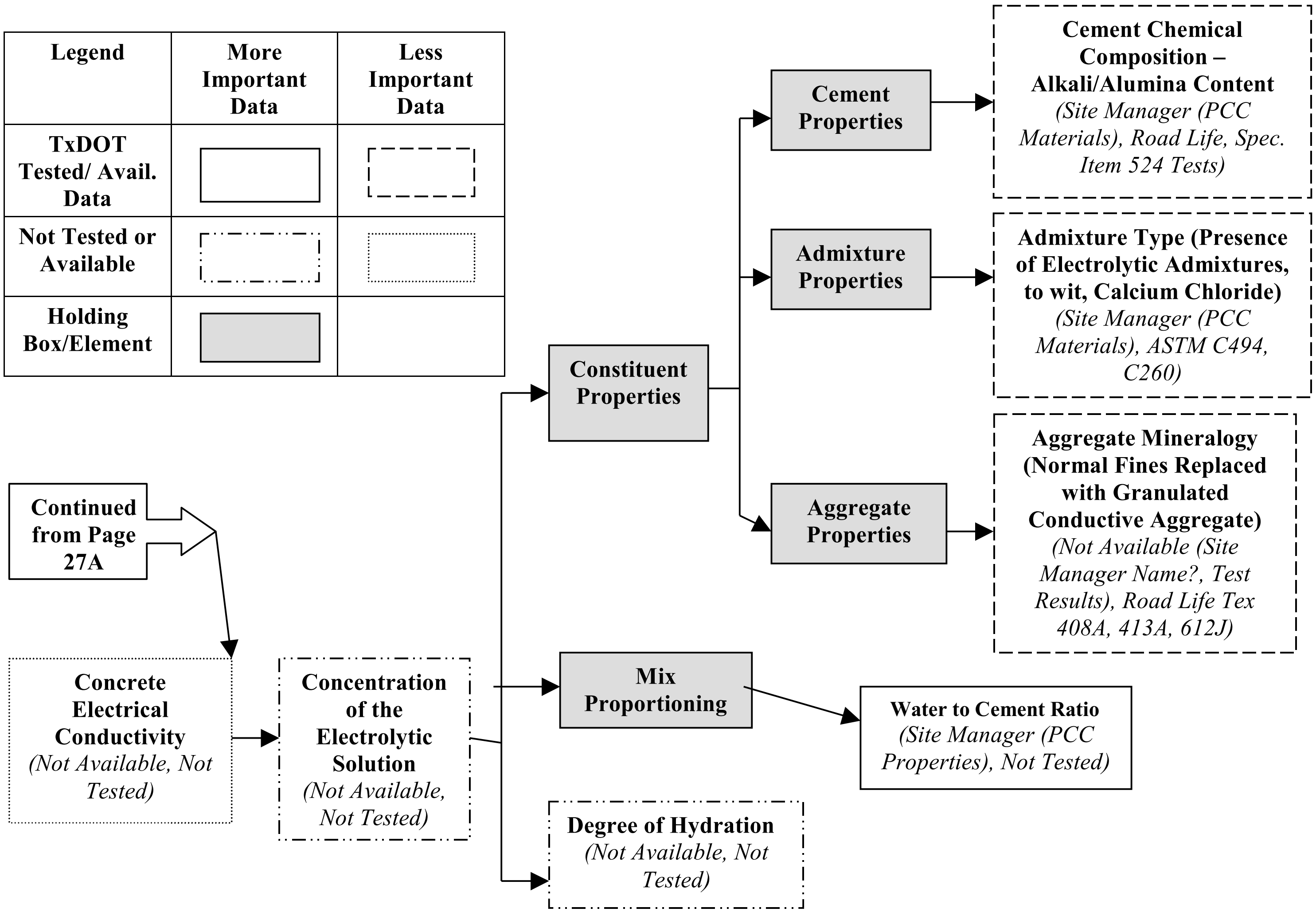
Not Tested or Available	(dash-dot box)	(dotted box)
Holding Box/Element	(shaded box)	



Legend	More Important Data	Less Important Data
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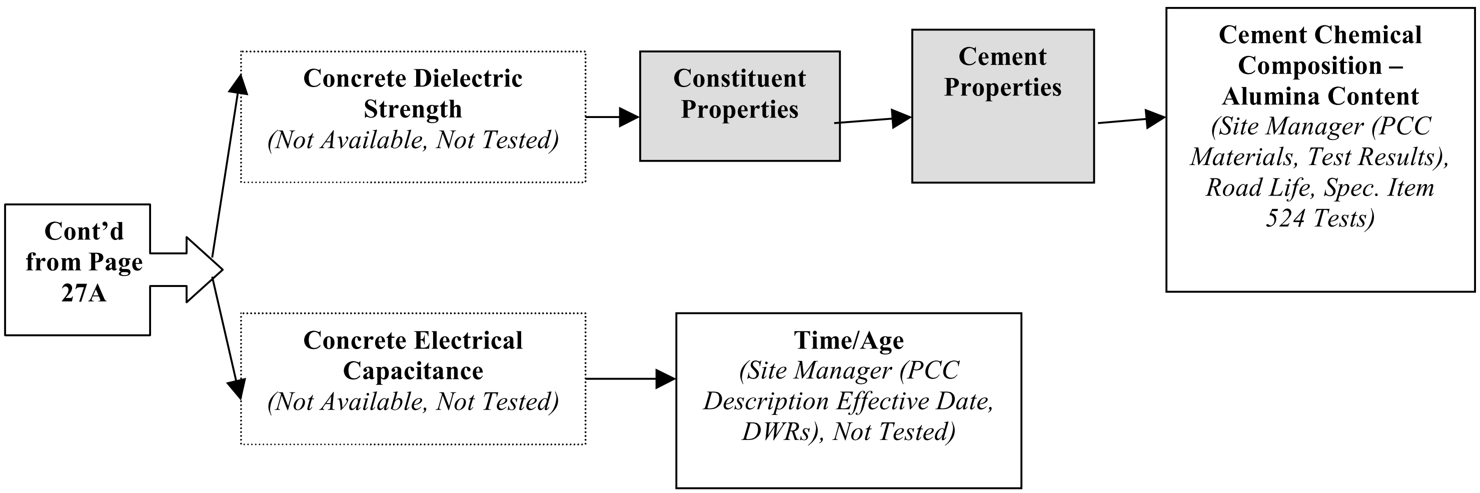
Not Tested or Available	(dash-dot box)	(dotted box)
Holding Box/Element	(shaded box)	



Legend	More Important Data	Less Important Data
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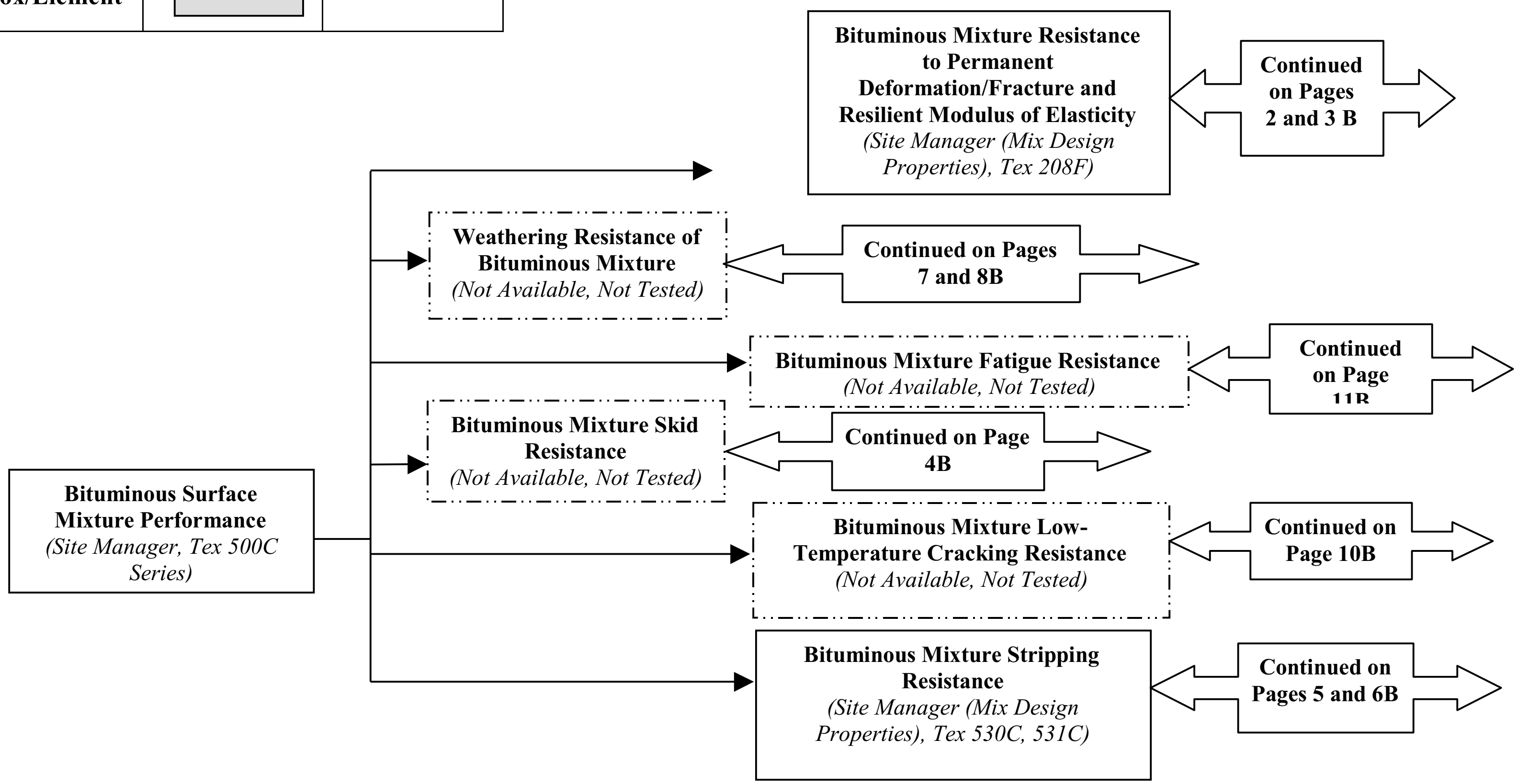
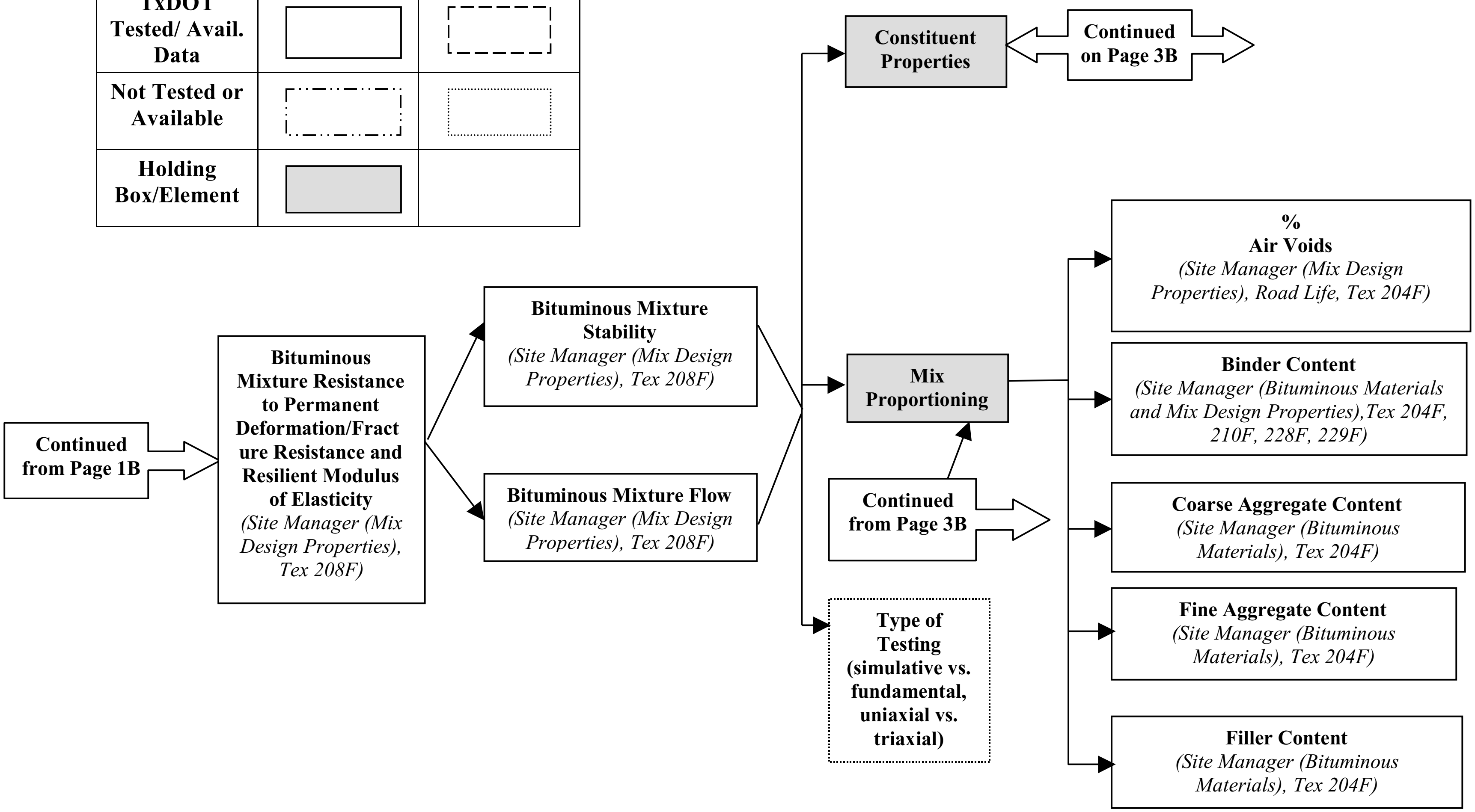
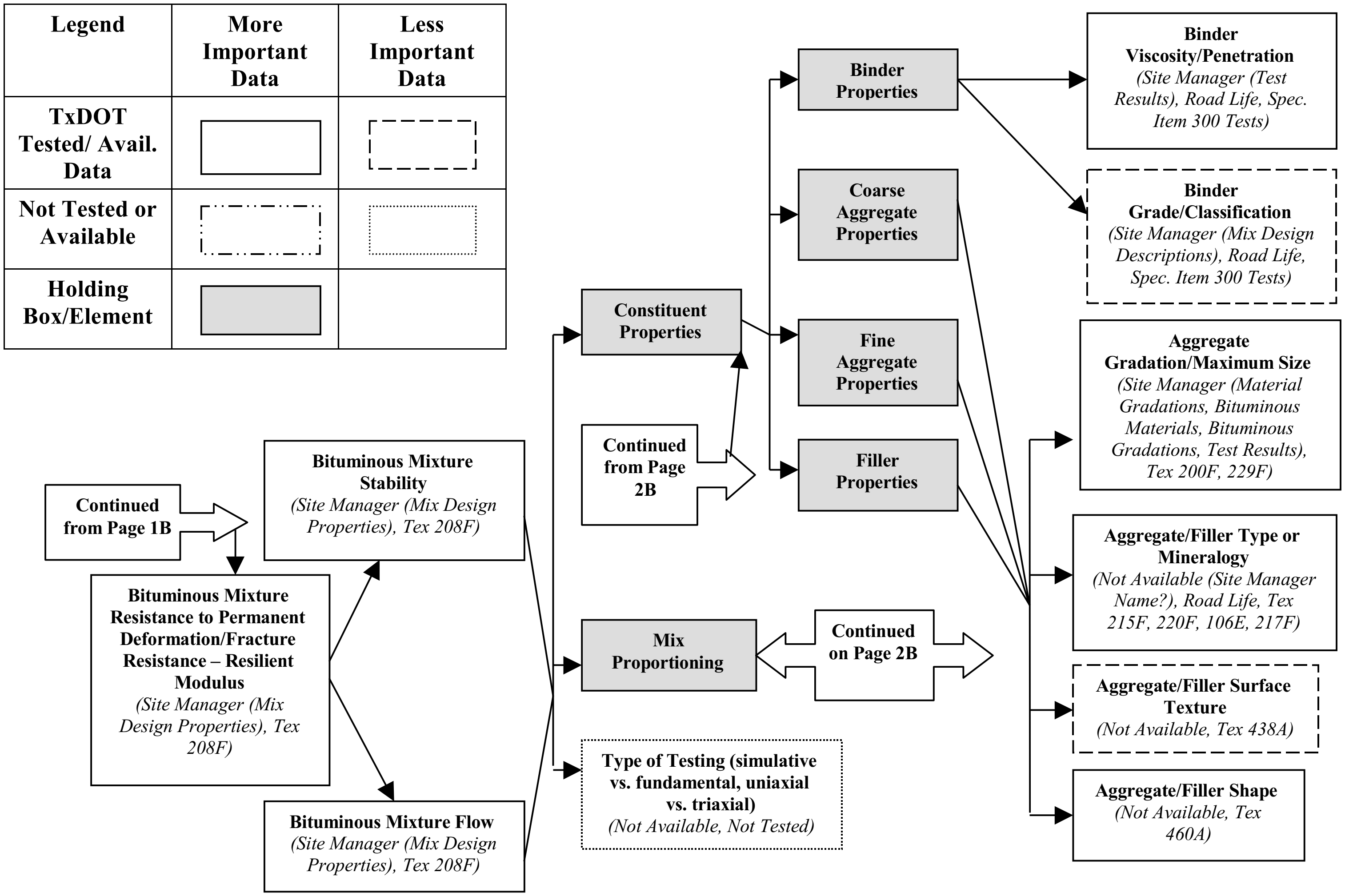
Not Tested or Available		
Holding Box/Element		

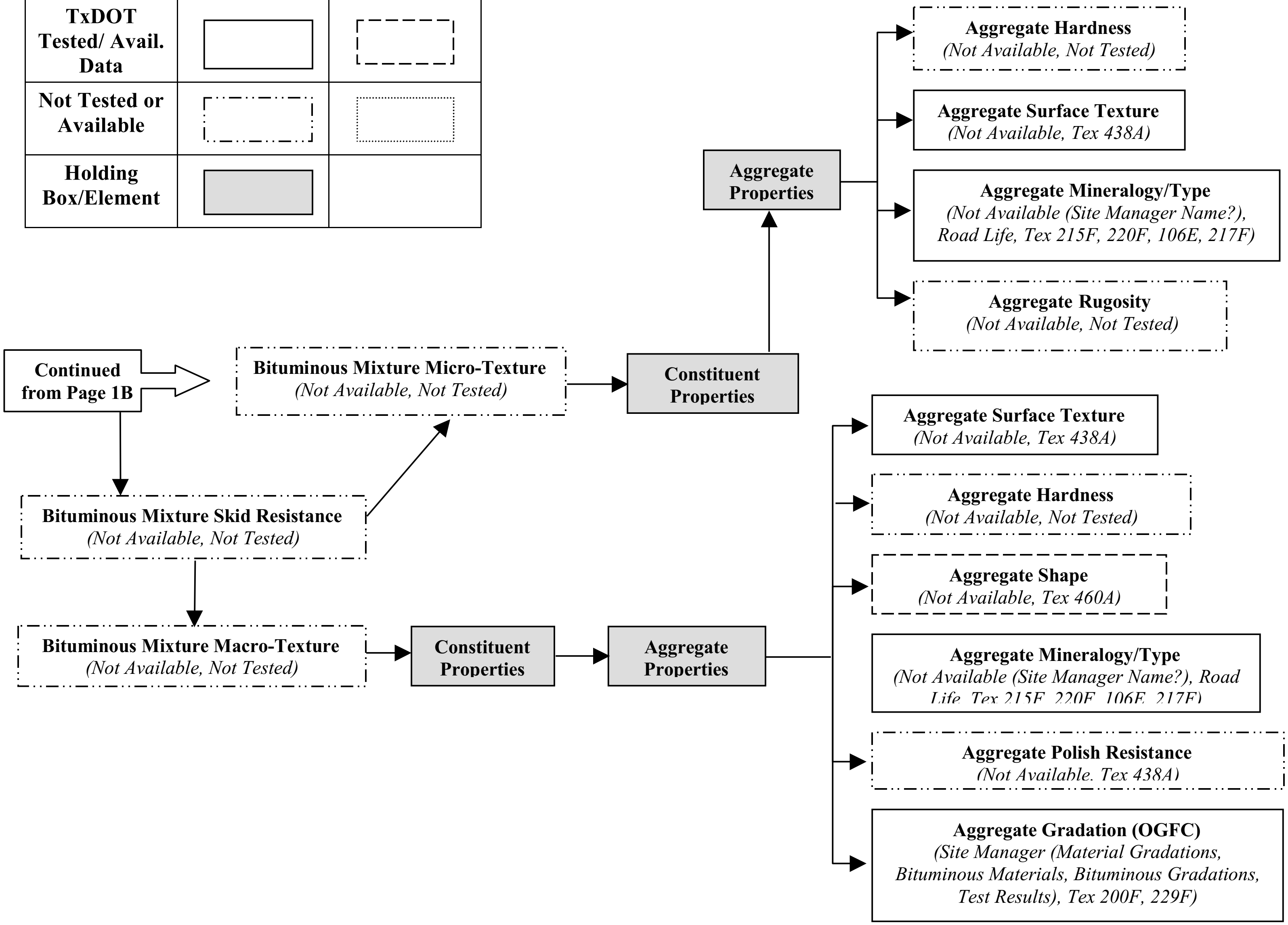


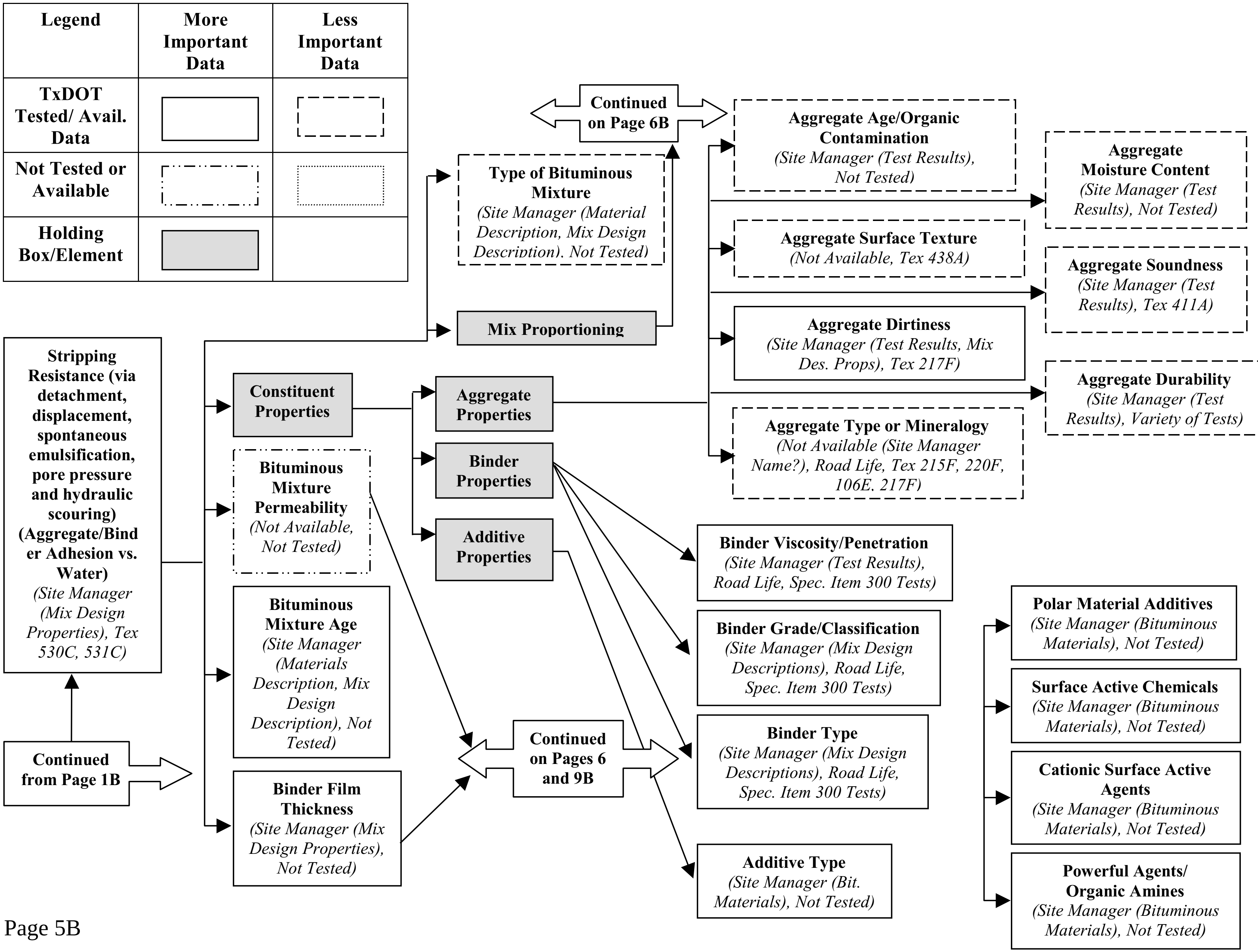
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



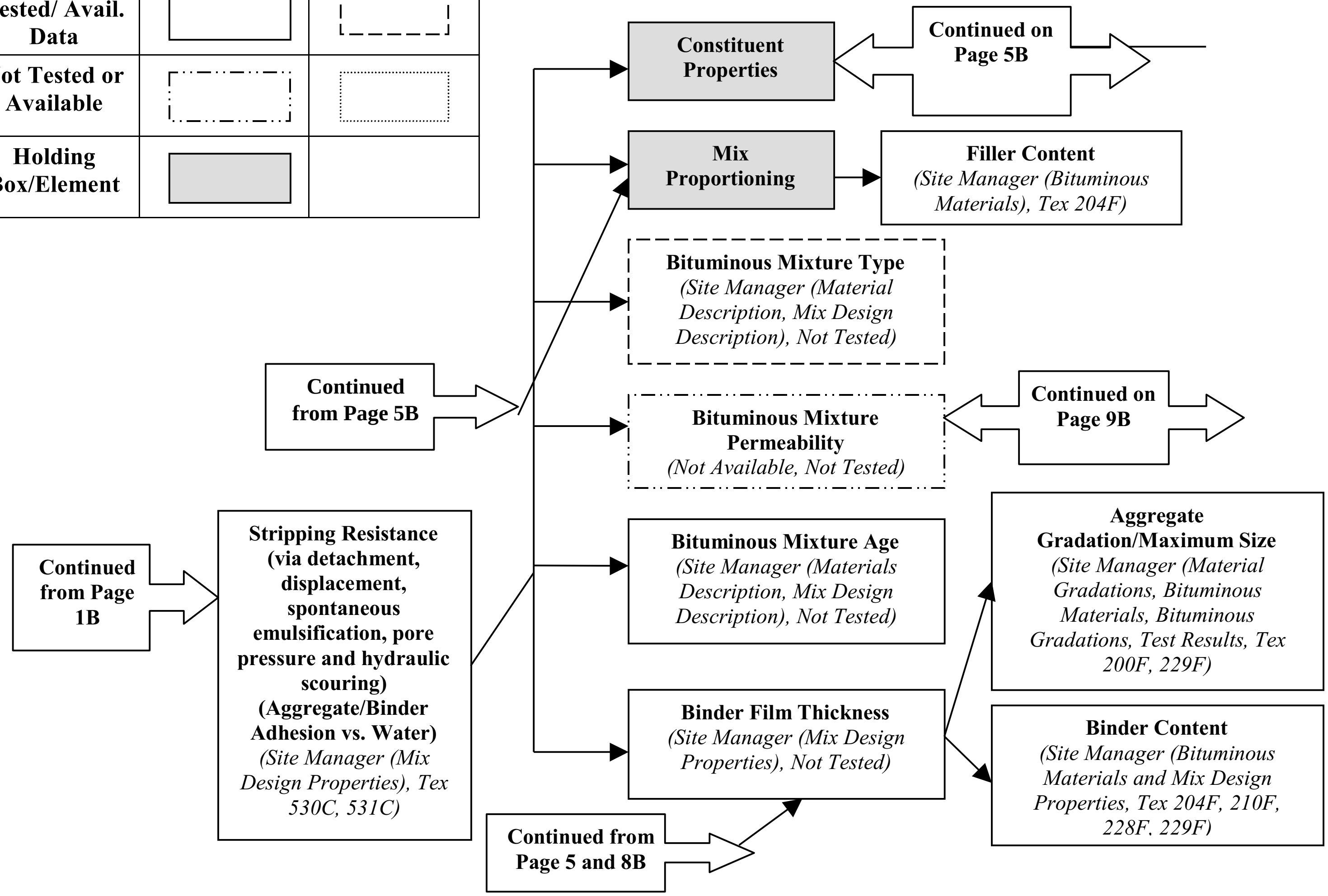

Legend
More Important Data
Less Important Data
TxDOT Tested/ Avail. Data
Not Tested or Available
Holding Box/Element
Continued from Page 1B
Bituminous Mixture Stability
(Site Manager (Mix Design Properties), Tex 208F)
Bituminous Mixture Resistance to Permanent Deformation/Fracture Resistance – Resilient Modulus
(Site Manager (Mix Design Properties), Tex 208F)
Bituminous Mixture Flow
(Site Manager (Mix Design Properties), Tex 208F)
Constituent Properties
Continued from Page 2B
Mix Proportioning
Continued on Page 2B
Type of Testing (simulative vs. fundamental, uniaxial vs. triaxial)
(Not Available, Not Tested)
Binder Properties
Coarse Aggregate Properties
Fine Aggregate Properties
Filler Properties
Binder Viscosity/Penetration
(Site Manager (Test Results), Road Life, Spec. Item 300 Tests)
Binder Grade/Classification
(Site Manager (Mix Design Descriptions), Road Life, Spec. Item 300 Tests)
Aggregate Gradation/Maximum Size
(Site Manager (Material Gradations, Bituminous Materials, Bituminous Gradations, Test Results), Tex 200F, 229F)
Aggregate/Filler Type or Mineralogy
(Not Available (Site Manager Name?), Road Life, Tex 215F, 220F, 106E, 217F)
Aggregate/Filler Surface Texture
(Not Available, Tex 438A)
Aggregate/Filler Shape
(Not Available, Tex 460A)

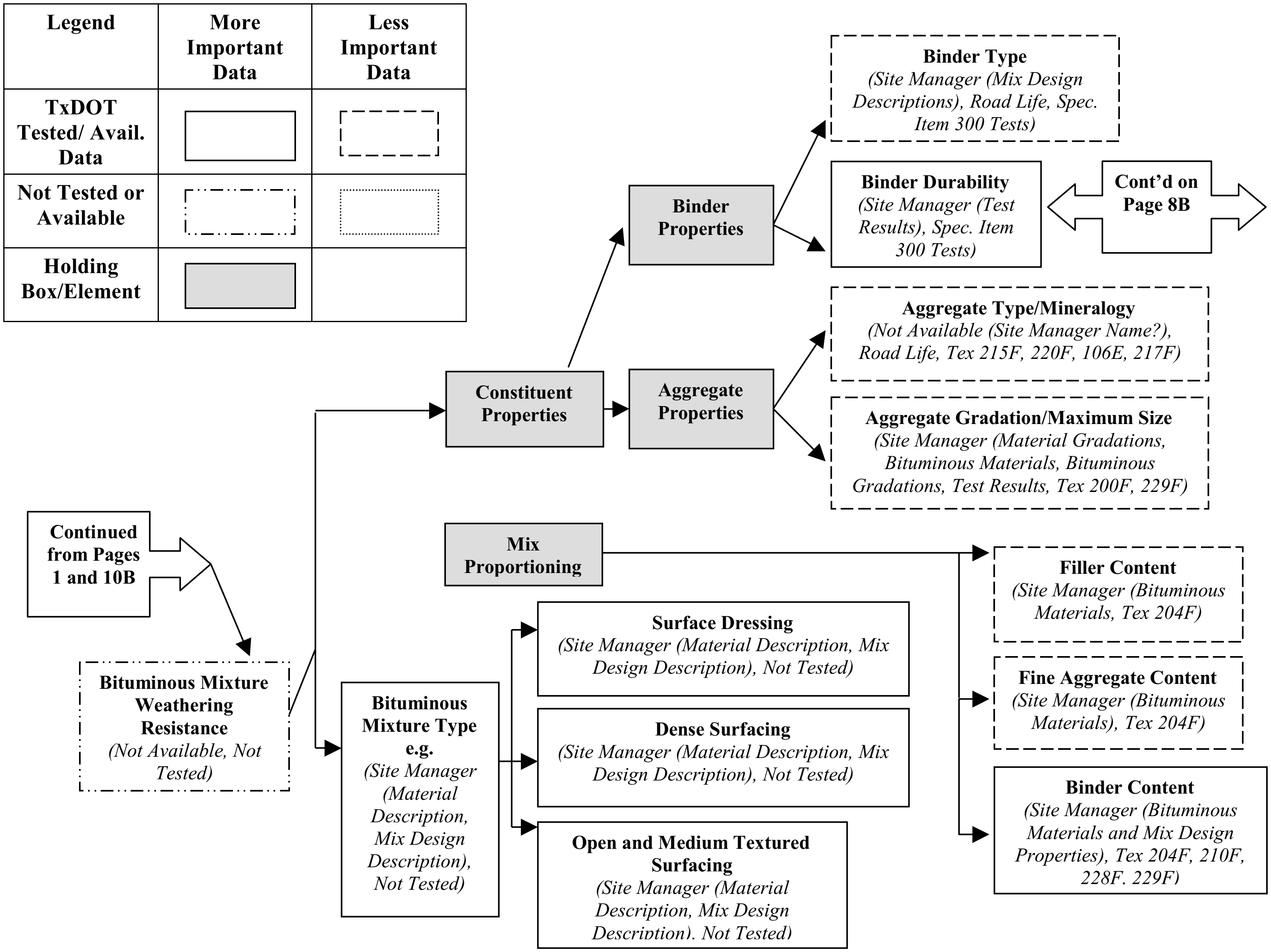
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		

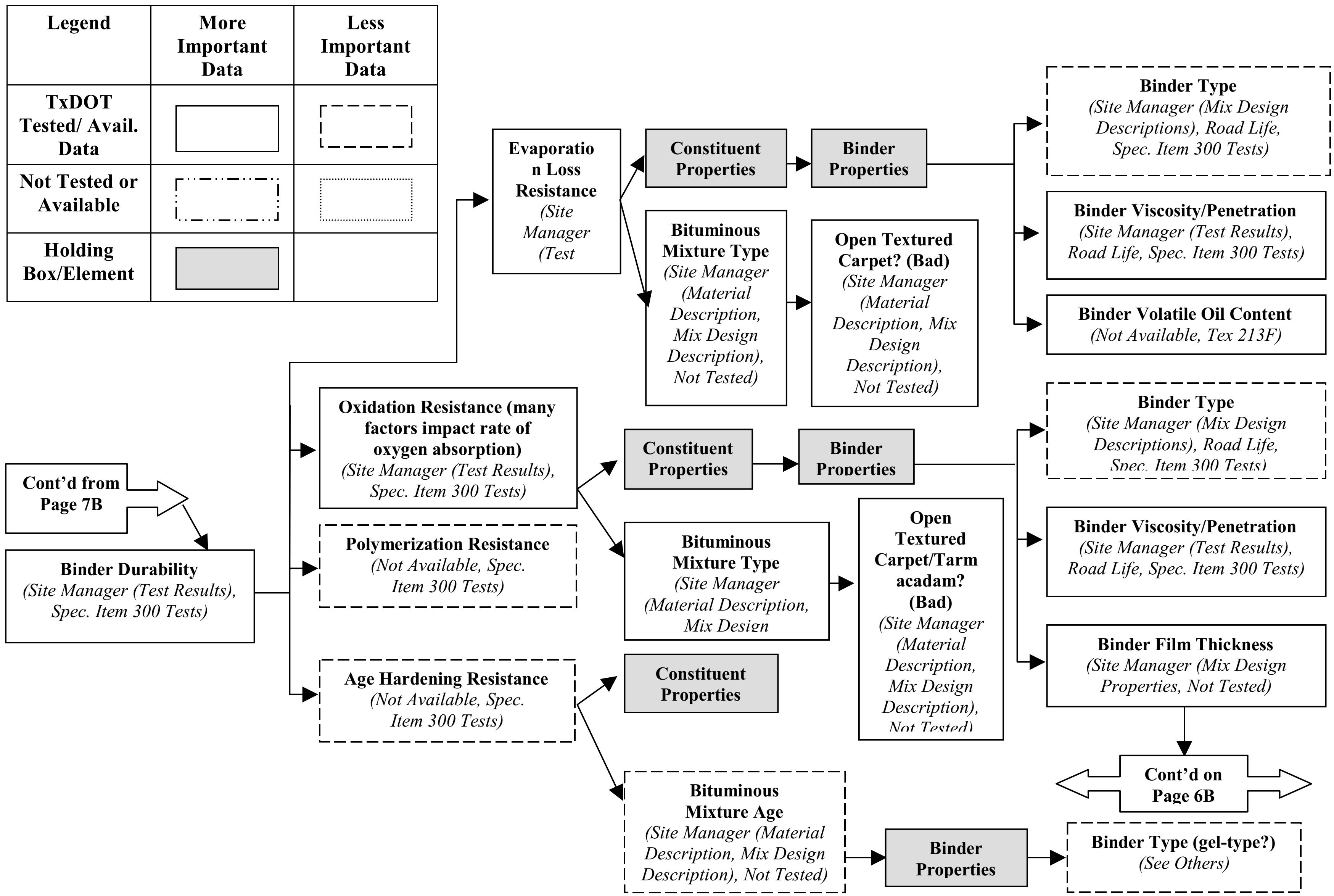



Legend
More Important Data
Less Important Data
TxDOT Tested/ Avail. Data
Not Tested or Available
Holding Box/Element
Continued on Page 6B
Aggregate Age/Organic Contamination (Site Manager (Test Results), Not Tested)
Aggregate Moisture Content (Site Manager (Test Results), Not Tested)
Type of Bituminous Mixture (Site Manager (Material Description, Mix Design Description), Not Tested)
Aggregate Surface Texture (Not Available, Tex 438A)
Aggregate Soundness (Site Manager (Test Results), Tex 411A)
Mix Proportioning
Aggregate Dirtiness (Site Manager (Test Results, Mix Des. Props), Tex 217F)
Stripping Resistance (via detachment, displacement, spontaneous emulsification, pore pressure and hydraulic scouring) (Aggregate/Binder Adhesion vs. Water) (Site Manager (Mix Design Properties), Tex 530C, 531C)
Constituent Properties
Aggregate Properties
Aggregate Durability (Site Manager (Test Results), Variety of Tests)
Aggregate Type or Mineralogy (Not Available (Site Manager Name?), Road Life, Tex 215F, 220F, 106E. 217F)
Binder Properties
Bituminous Mixture Permeability (Not Available, Not Tested)
Additive Properties
Binder Viscosity/Penetration (Site Manager (Test Results), Road Life, Spec. Item 300 Tests)
Polar Material Additives (Site Manager (Bituminous Materials), Not Tested)
Bituminous Mixture Age (Site Manager (Materials Description, Mix Design Description), Not Tested)
Binder Grade/Classification (Site Manager (Mix Design Descriptions), Road Life, Spec. Item 300 Tests)
Surface Active Chemicals (Site Manager (Bituminous Materials), Not Tested)
Continued on Pages 6 and 9B
Binder Type (Site Manager (Mix Design Descriptions), Road Life, Spec. Item 300 Tests)
Continued from Page 1B
Cationic Surface Active Agents (Site Manager (Bituminous Materials), Not Tested)
Binder Film Thickness (Site Manager (Mix Design Properties), Not Tested)
Additive Type (Site Manager (Bit. Materials), Not Tested)
Powerful Agents/ Organic Amines (Site Manager (Bituminous Materials), Not Tested)

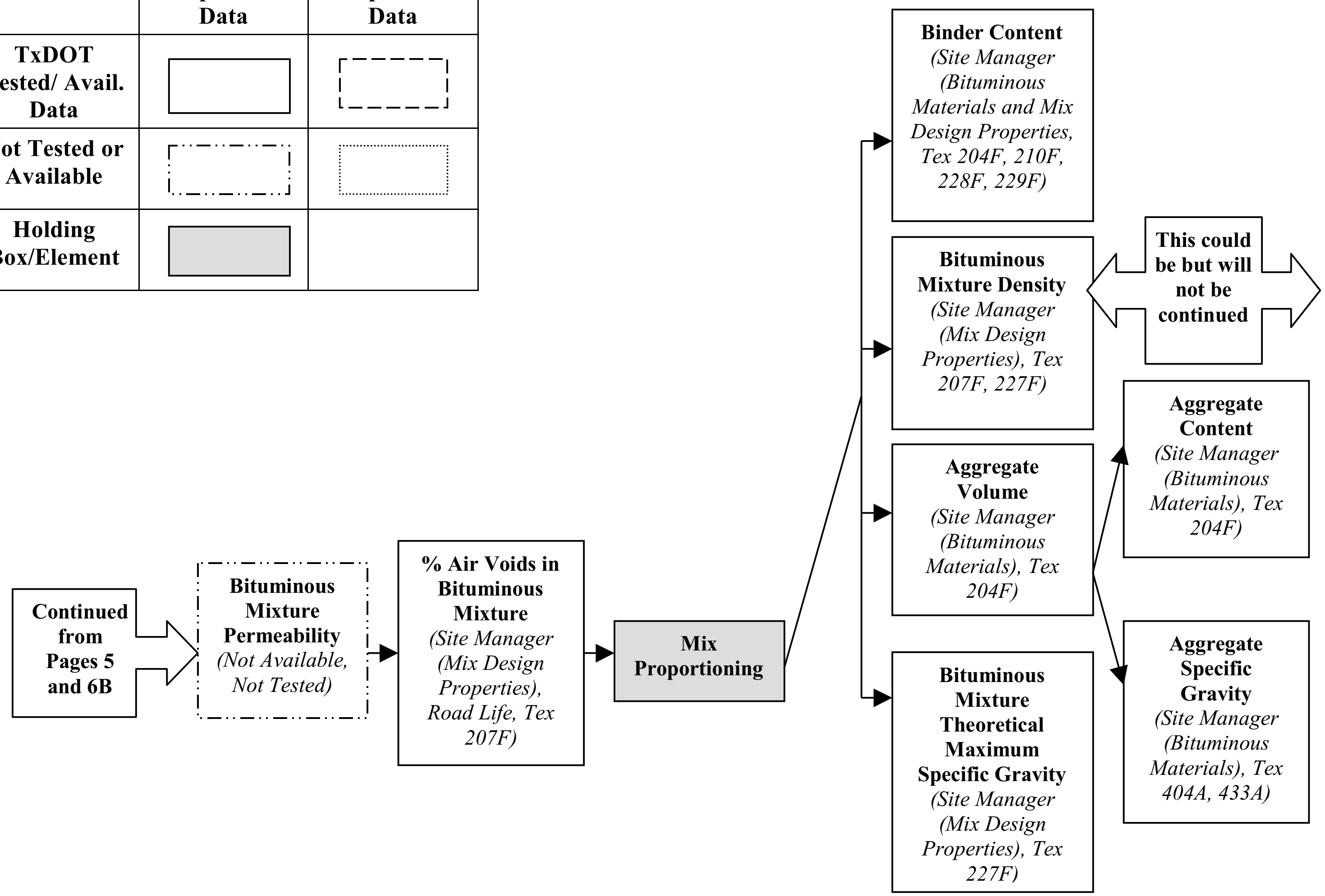
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



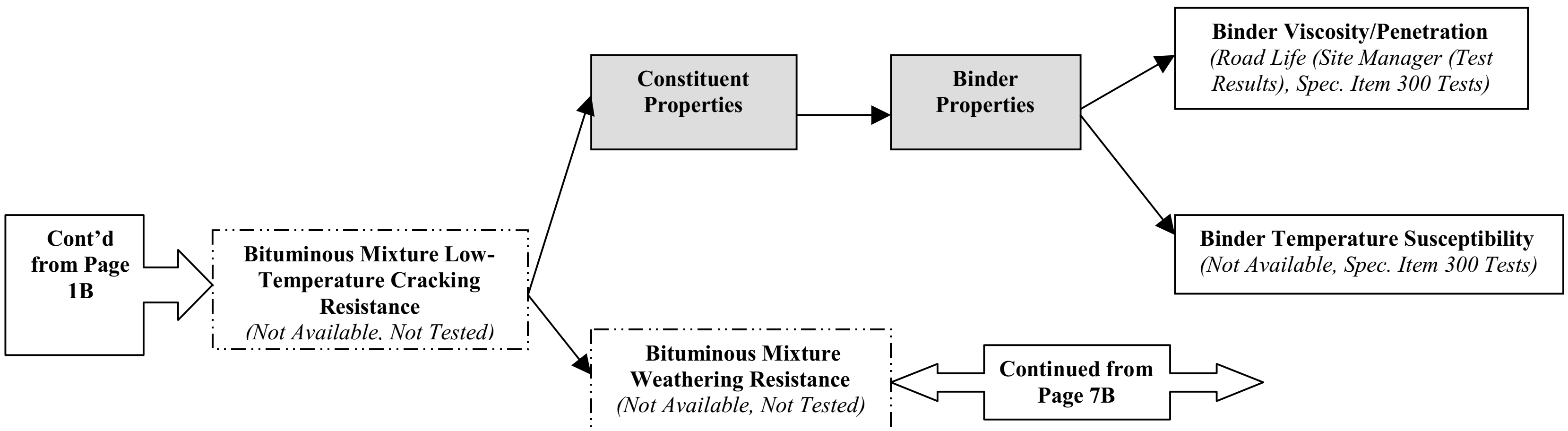

Legend
More Important Data
Less Important Data
TxDOT Tested/ Avail. Data
Not Tested or Available
Holding Box/Element
Binder Type
(Site Manager (Mix Design Descriptions), Road Life, Spec. Item 300 Tests)
Binder Durability
(Site Manager (Test Results), Spec. Item 300 Tests)
Cont'd on Page 8B
Binder Properties
Aggregate Type/Mineralogy
(Not Available (Site Manager Name?), Road Life, Tex 215F, 220F, 106E, 217F)
Constituent Properties
Aggregate Properties
Aggregate Gradation/Maximum Size
(Site Manager (Material Gradations, Bituminous Materials, Bituminous Gradations, Test Results, Tex 200F, 229F)
Continued from Pages 1 and 10B
Mix Proportioning
Filler Content
(Site Manager (Bituminous Materials, Tex 204F)
Surface Dressing
(Site Manager (Material Description, Mix Design Description), Not Tested)
Bituminous Mixture Weathering Resistance
(Not Available, Not Tested)
Fine Aggregate Content
(Site Manager (Bituminous Materials), Tex 204F)
Bituminous Mixture Type e.g.
(Site Manager (Material Description, Mix Design Description), Not Tested)
Dense Surfacing
(Site Manager (Material Description, Mix Design Description), Not Tested)
Binder Content
(Site Manager (Bituminous Materials and Mix Design Properties), Tex 204F, 210F, 228F, 229F)
Open and Medium Textured Surfacing
(Site Manager (Material Description, Mix Design Description), Not Tested)


Legend
More Important Data
Less Important Data
TxDOT Tested/ Avail. Data
Not Tested or Available
Holding Box/Element
Cont'd from Page 7B
Binder Durability (Site Manager (Test Results), Spec. Item 300 Tests)
Evaporation Loss Resistance (Site Manager (Test
Constituent Properties
Binder Properties
Binder Type (Site Manager (Mix Design Descriptions), Road Life, Spec. Item 300 Tests)
Binder Viscosity/Penetration (Site Manager (Test Results), Road Life, Spec. Item 300 Tests)
Binder Volatile Oil Content (Not Available, Tex 213F)
Bituminous Mixture Type (Site Manager (Material Description, Mix Design Description), Not Tested)
Open Textured Carpet? (Bad) (Site Manager (Material Description, Mix Design Description), Not Tested)
Oxidation Resistance (many factors impact rate of oxygen absorption) (Site Manager (Test Results), Spec. Item 300 Tests)
Constituent Properties
Binder Properties
Binder Type (Site Manager (Mix Design Descriptions), Road Life, Spec. Item 300 Tests)
Binder Viscosity/Penetration (Site Manager (Test Results), Road Life, Spec. Item 300 Tests)
Binder Film Thickness (Site Manager (Mix Design Properties, Not Tested)
Bituminous Mixture Type (Site Manager (Material Description, Mix Design
Open Textured Carpet/Tarmacadam? (Bad) (Site Manager (Material Description, Mix Design Description), Not Tested)
Polymerization Resistance (Not Available, Spec. Item 300 Tests)
Age Hardening Resistance (Not Available, Spec. Item 300 Tests)
Constituent Properties
Bituminous Mixture Age (Site Manager (Material Description, Mix Design Description), Not Tested)
Binder Properties
Binder Type (gel-type?) (See Others)
Cont'd on Page 6B

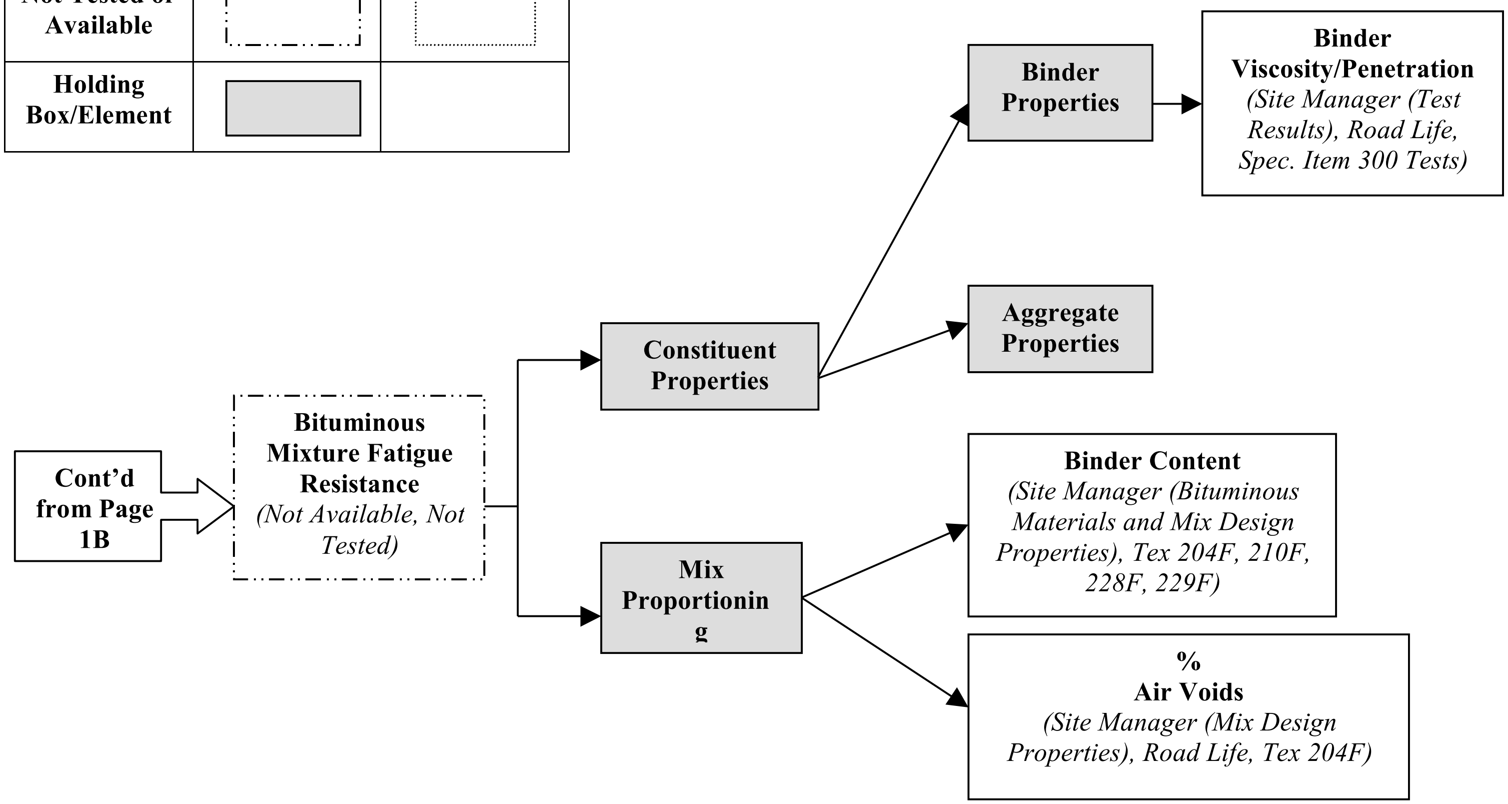
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



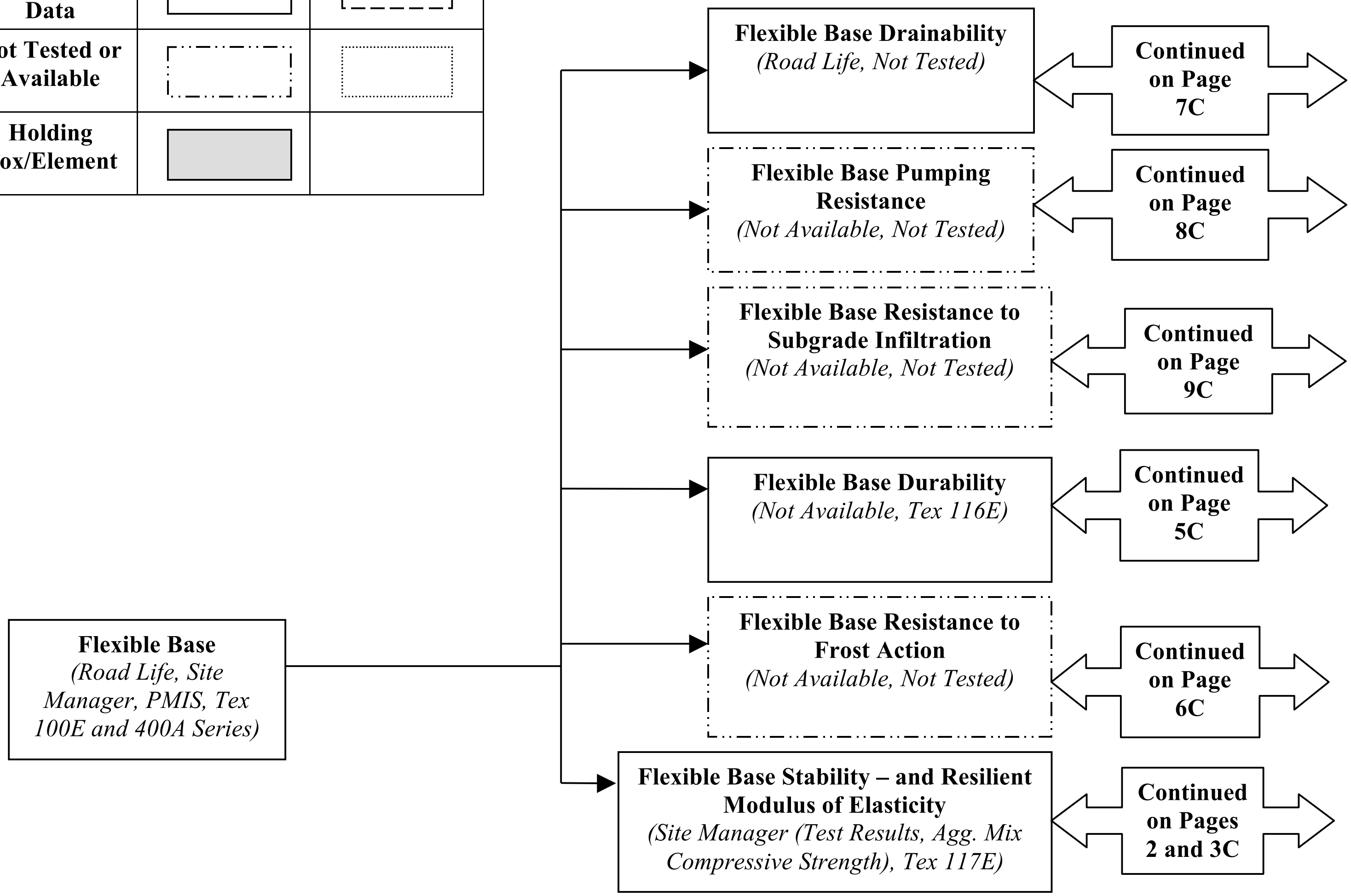
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



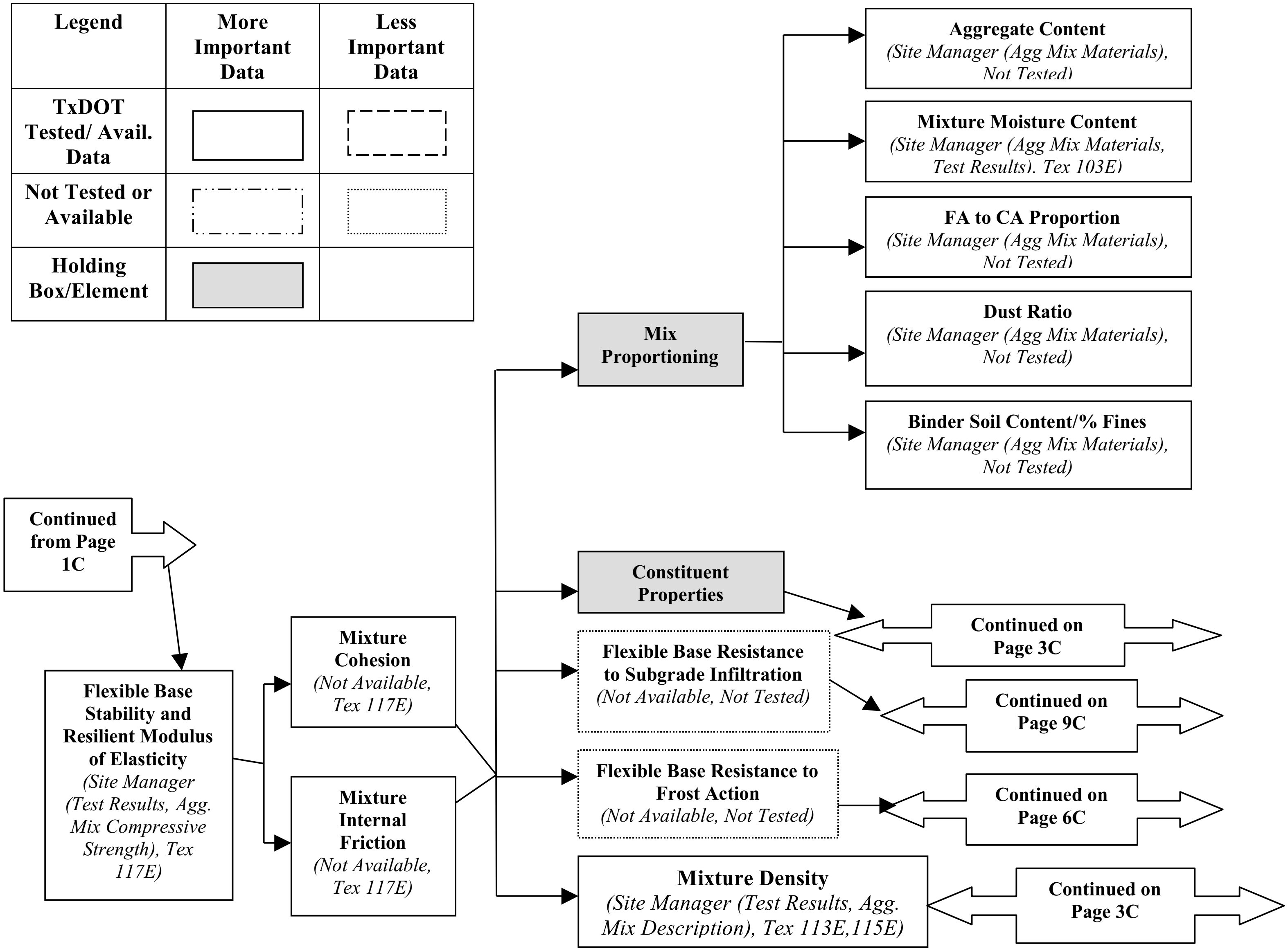
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



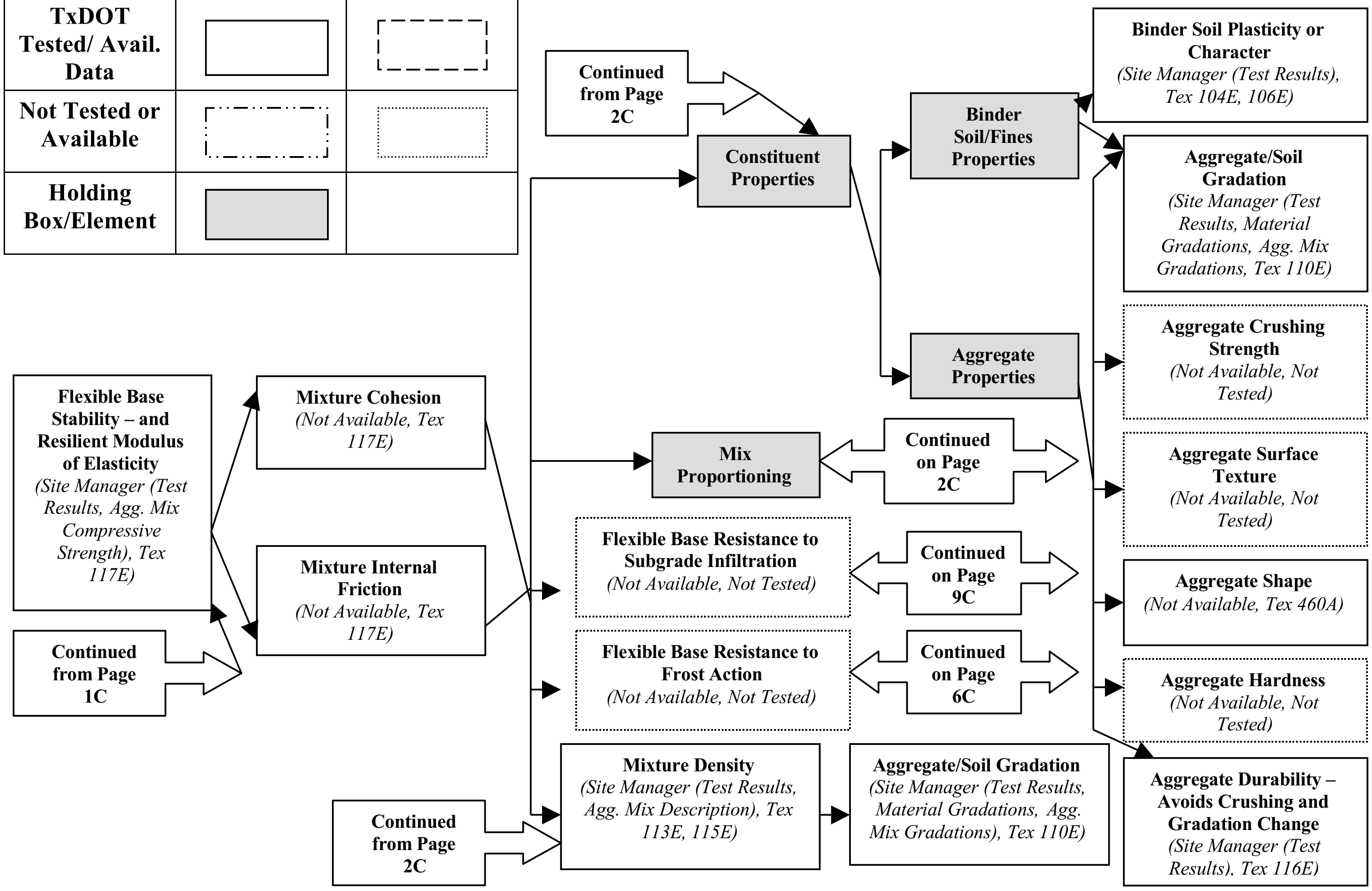
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



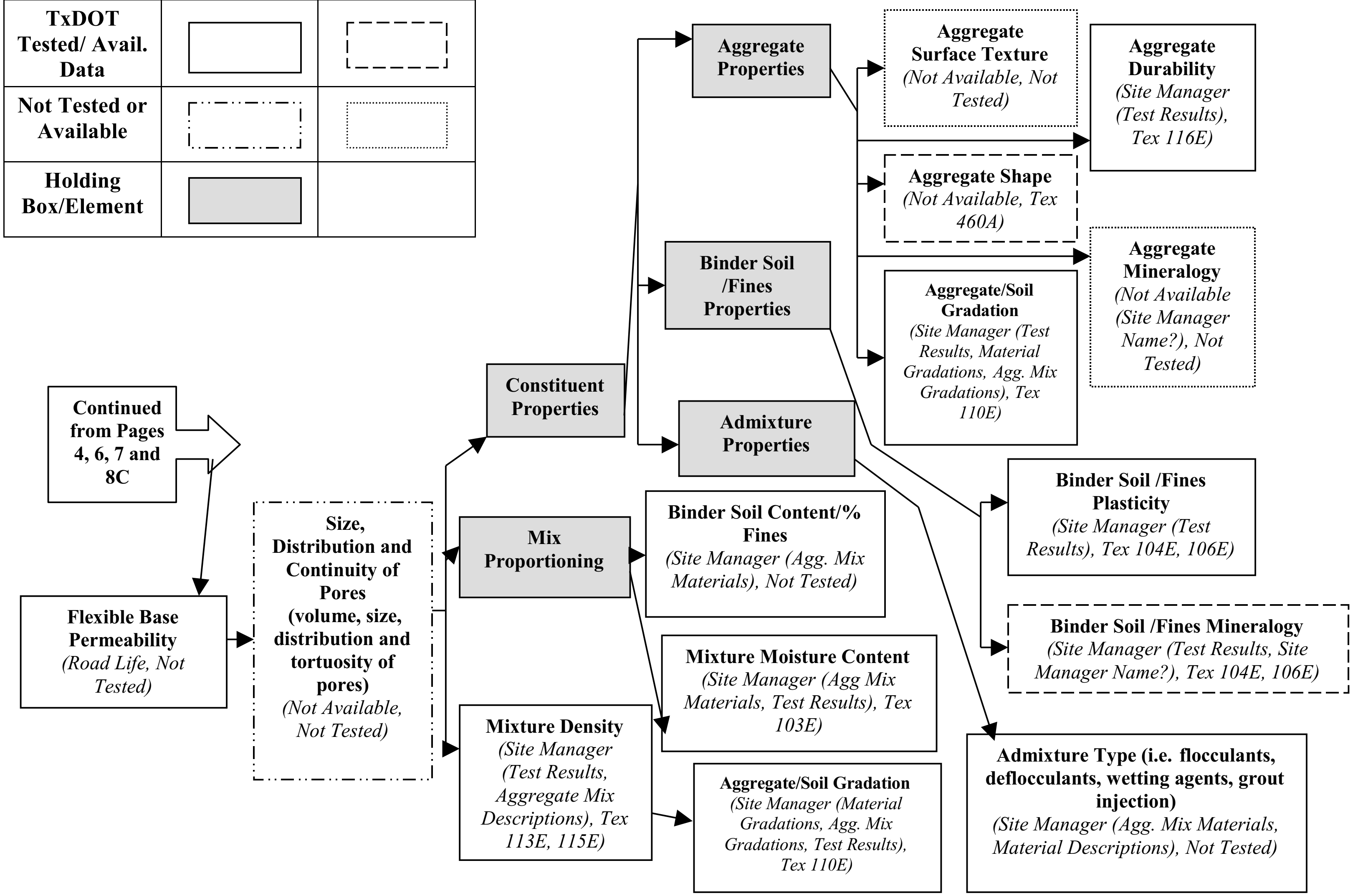
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		

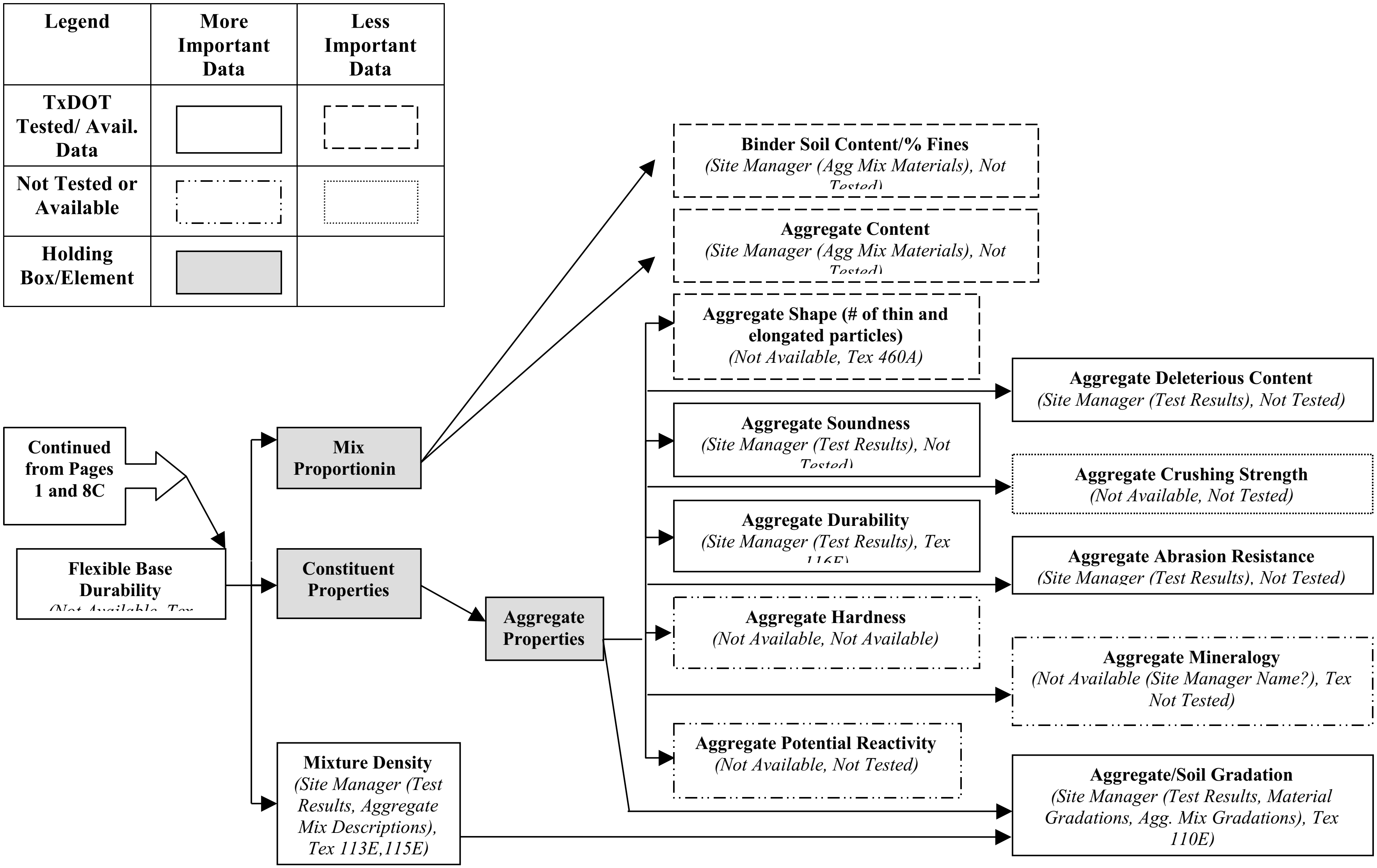


Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		

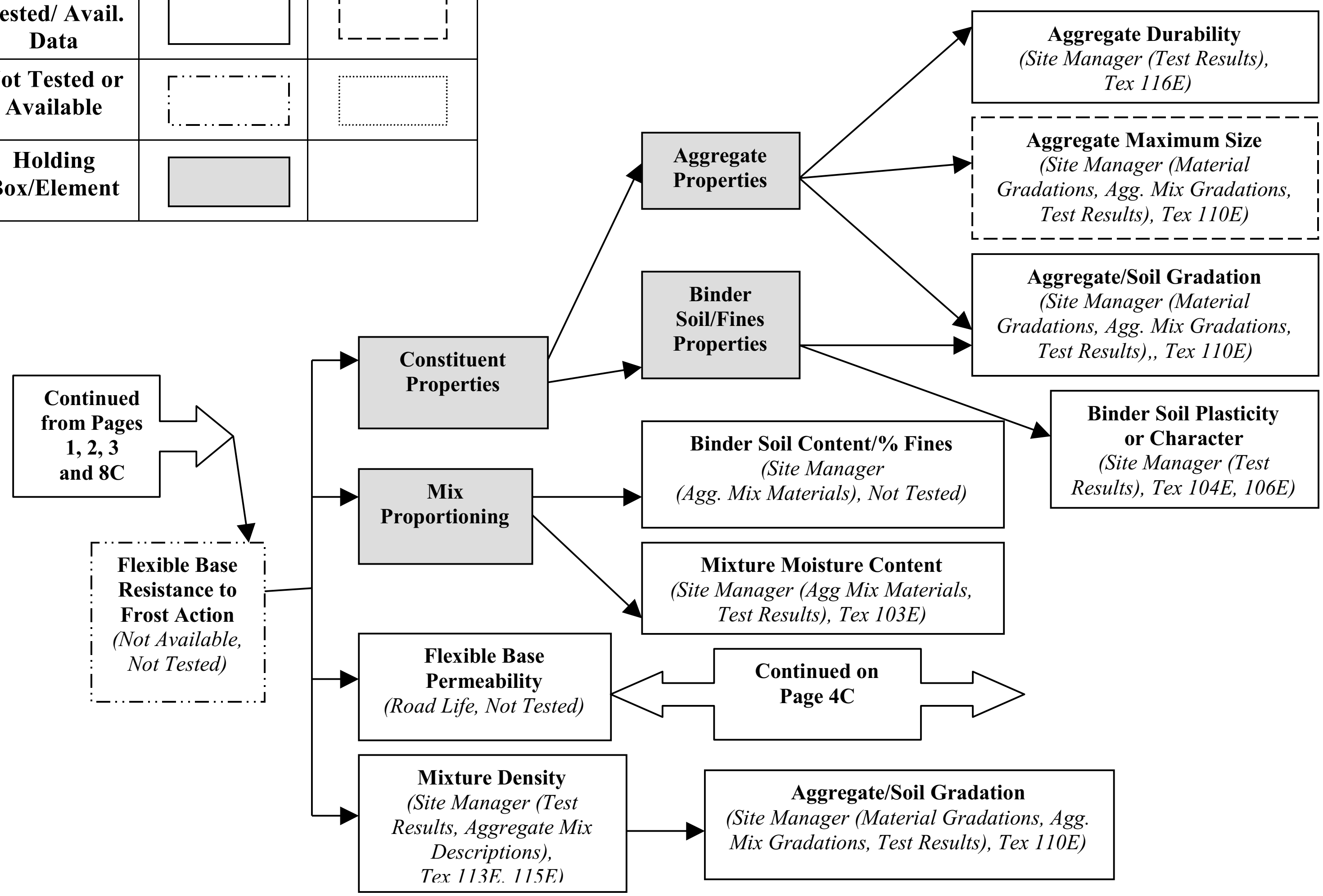


Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		

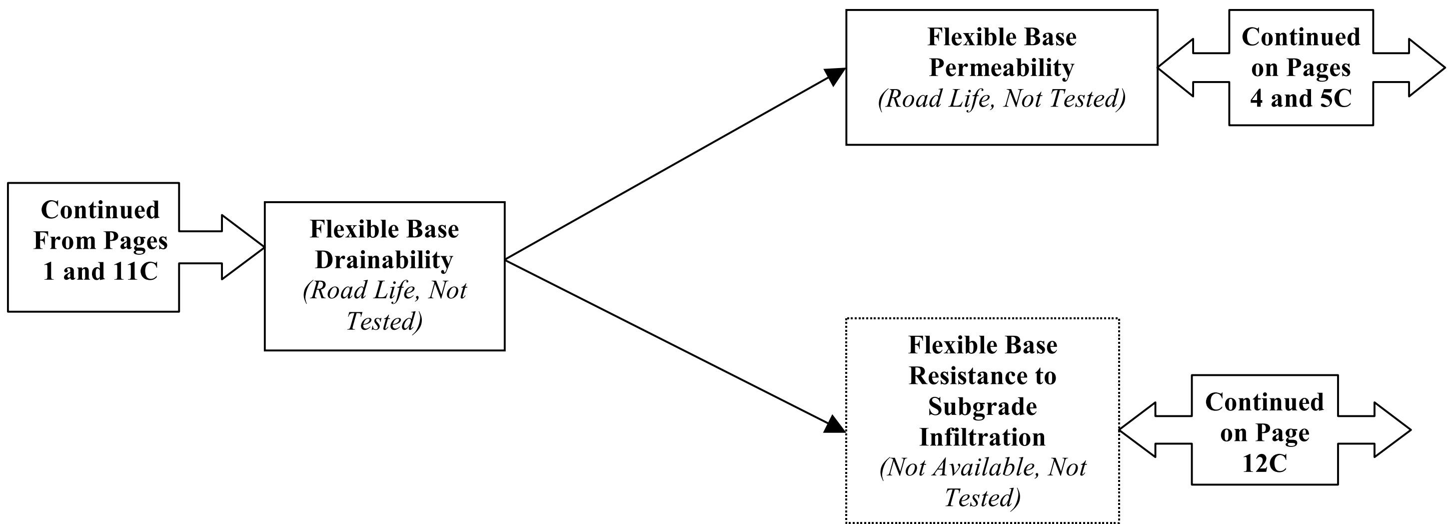


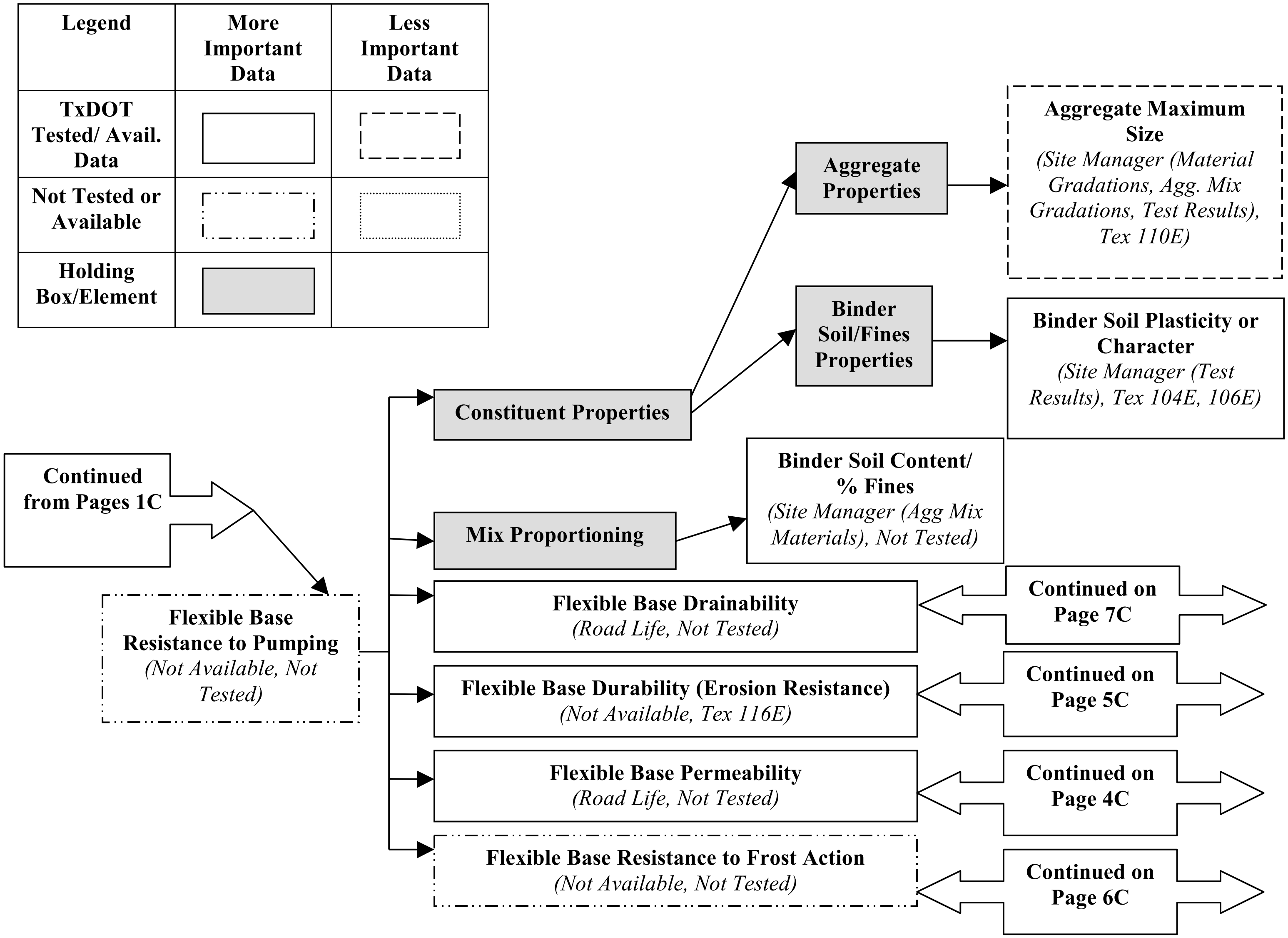

Legend
More Important Data
Less Important Data
TxDOT Tested/ Avail. Data
Not Tested or Available
Holding Box/Element
Continued from Pages 1 and 8C
Flexible Base Durability
Mix Proportionin
Constituent Properties
Mixture Density
(Site Manager (Test Results, Aggregate Mix Descriptions), Tex 113E,115E)
Aggregate Properties
Binder Soil Content/% Fines
(Site Manager (Agg Mix Materials), Not
Aggregate Content
(Site Manager (Agg Mix Materials), Not
Aggregate Shape (# of thin and elongated particles)
(Not Available, Tex 460A)
Aggregate Deleterious Content
(Site Manager (Test Results), Not Tested)
Aggregate Soundness
(Site Manager (Test Results), Not
Aggregate Crushing Strength
(Not Available, Not Tested)
Aggregate Durability
(Site Manager (Test Results), Tex
Aggregate Abrasion Resistance
(Site Manager (Test Results), Not Tested)
Aggregate Hardness
(Not Available, Not Available)
Aggregate Mineralogy
(Not Available (Site Manager Name?), Tex Not Tested)
Aggregate Potential Reactivity
(Not Available, Not Tested)
Aggregate/Soil Gradation
(Site Manager (Test Results, Material Gradations, Agg. Mix Gradations), Tex 110E)

Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		

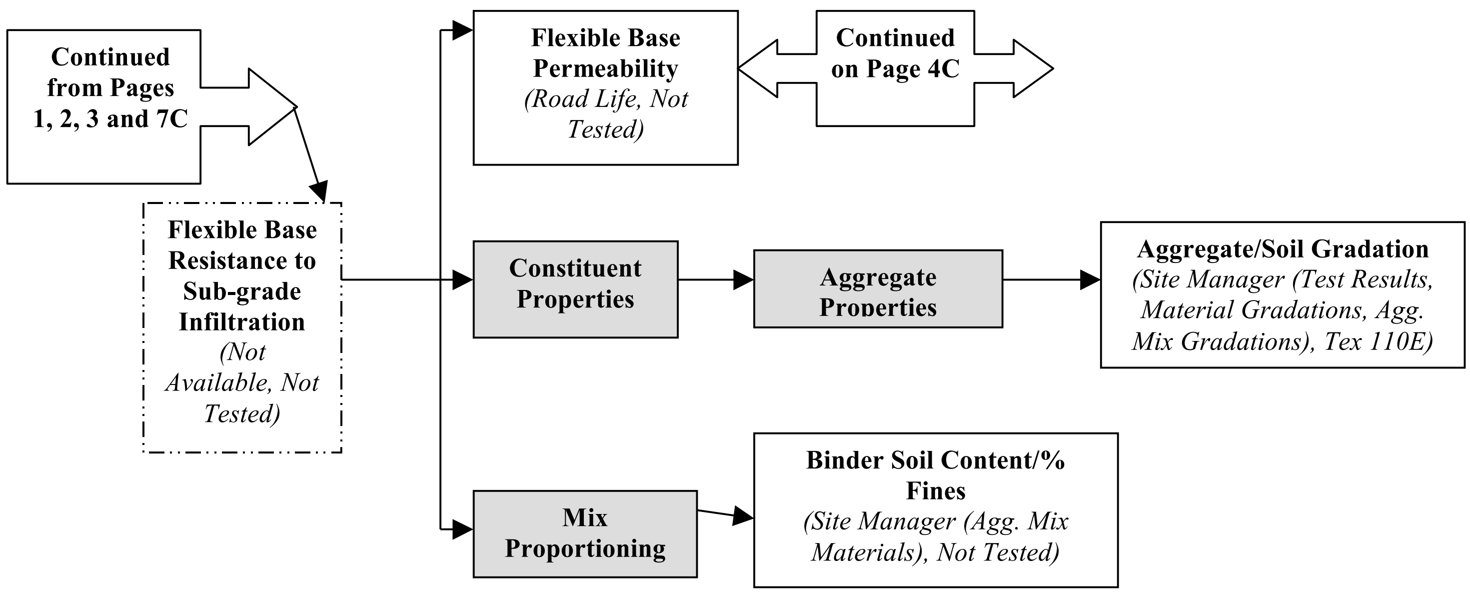


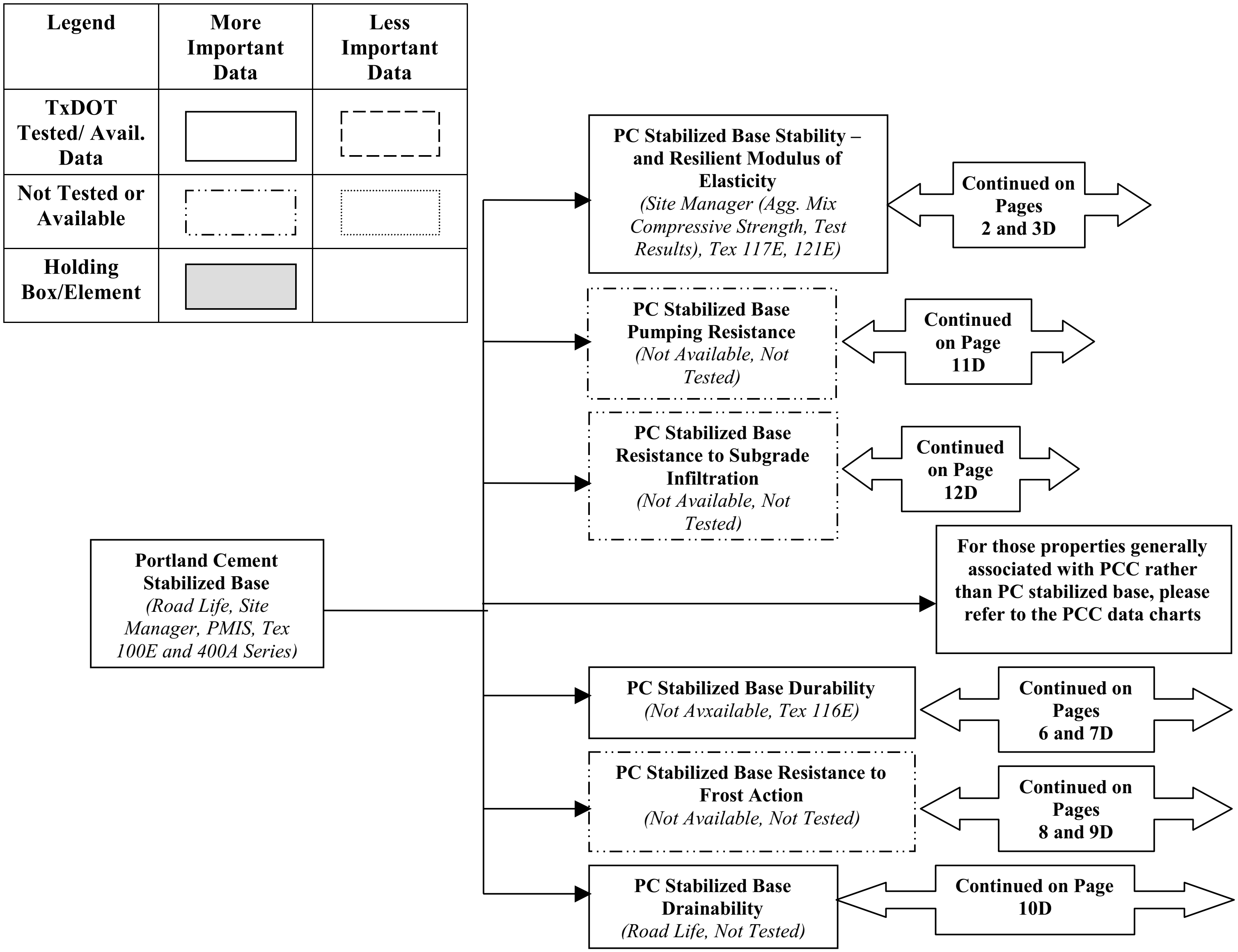
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



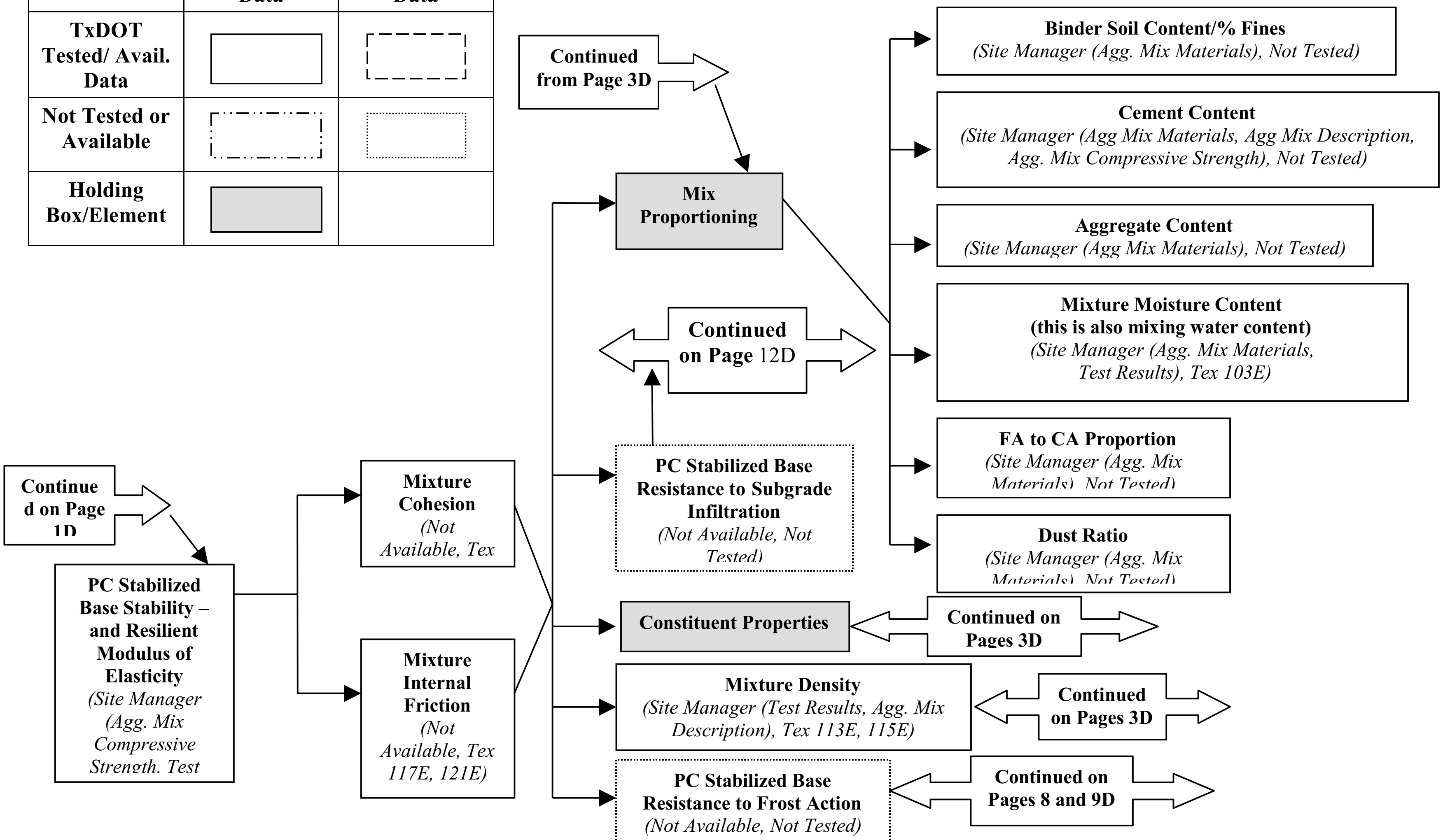

Legend
More Important Data
Less Important Data
TxDOT Tested/ Avail. Data
Not Tested or Available
Holding Box/Element
Aggregate Maximum Size
(Site Manager (Material Gradations, Agg. Mix Gradations, Test Results), Tex 110E)
Aggregate Properties
Binder Soil/Fines Properties
Binder Soil Plasticity or Character
(Site Manager (Test Results), Tex 104E, 106E)
Constituent Properties
Binder Soil Content/ % Fines
(Site Manager (Agg Mix Materials), Not Tested)
Continued from Pages 1C
Mix Proportioning
Flexible Base Resistance to Pumping
(Not Available, Not Tested)
Flexible Base Drainability
(Road Life, Not Tested)
Continued on Page 7C
Flexible Base Durability (Erosion Resistance)
(Not Available, Tex 116E)
Continued on Page 5C
Flexible Base Permeability
(Road Life, Not Tested)
Continued on Page 4C
Flexible Base Resistance to Frost Action
(Not Available, Not Tested)
Continued on Page 6C

Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		

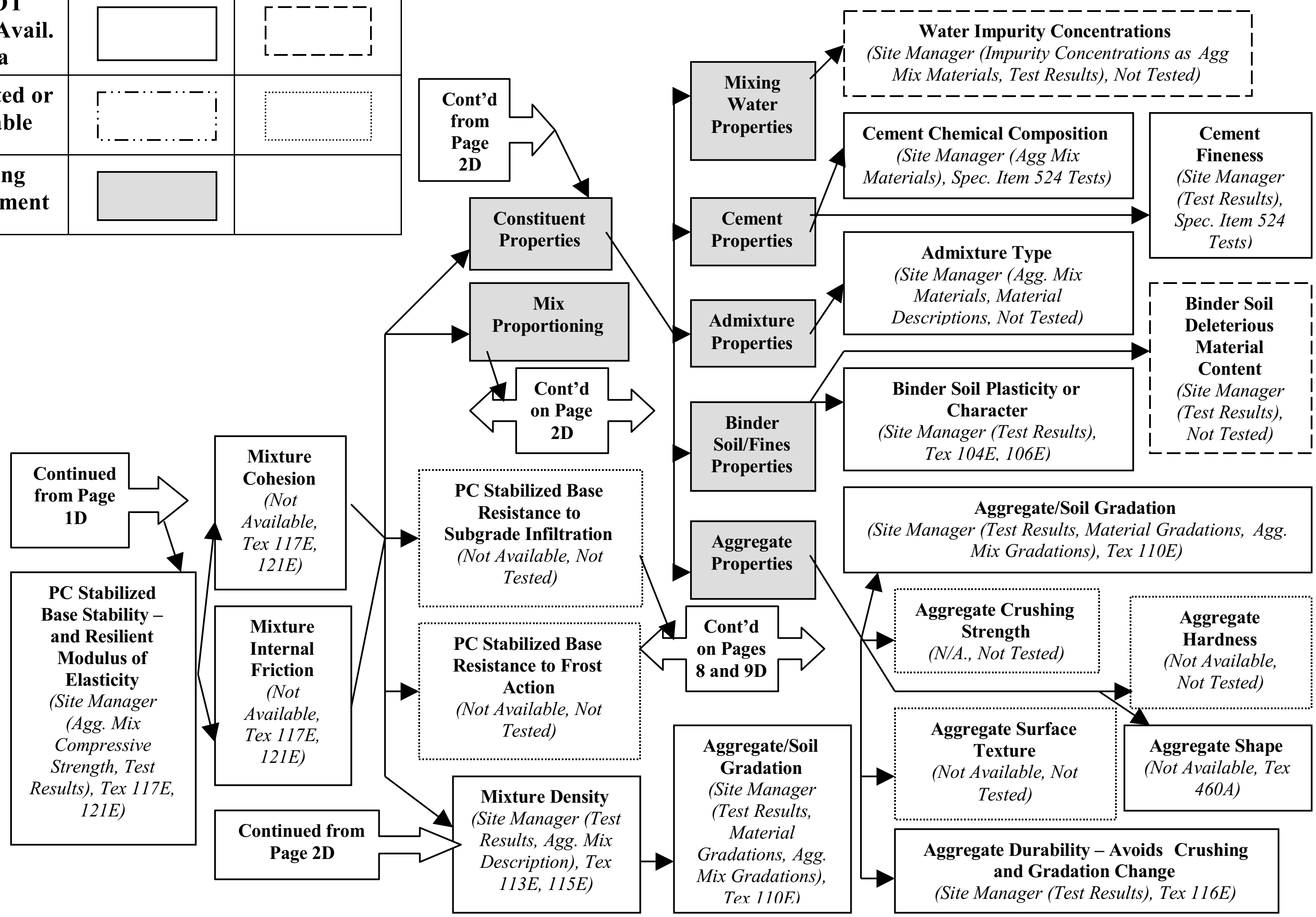



Legend
More Important Data
Less Important Data
TxDOT Tested/ Avail. Data
Not Tested or Available
Holding Box/Element
PC Stabilized Base Stability – and Resilient Modulus of Elasticity
(Site Manager (Agg. Mix Compressive Strength, Test Results), Tex 117E, 121E)
Continued on Pages 2 and 3D
PC Stabilized Base Pumping Resistance
(Not Available, Not Tested)
Continued on Page 11D
PC Stabilized Base Resistance to Subgrade Infiltration
(Not Available, Not Tested)
Continued on Page 12D
Portland Cement Stabilized Base
(Road Life, Site Manager, PMIS, Tex 100E and 400A Series)
For those properties generally associated with PCC rather than PC stabilized base, please refer to the PCC data charts
PC Stabilized Base Durability
(Not Avxailable, Tex 116E)
Continued on Pages 6 and 7D
PC Stabilized Base Resistance to Frost Action
(Not Available, Not Tested)
Continued on Pages 8 and 9D
PC Stabilized Base Drainability
(Road Life, Not Tested)
Continued on Page 10D

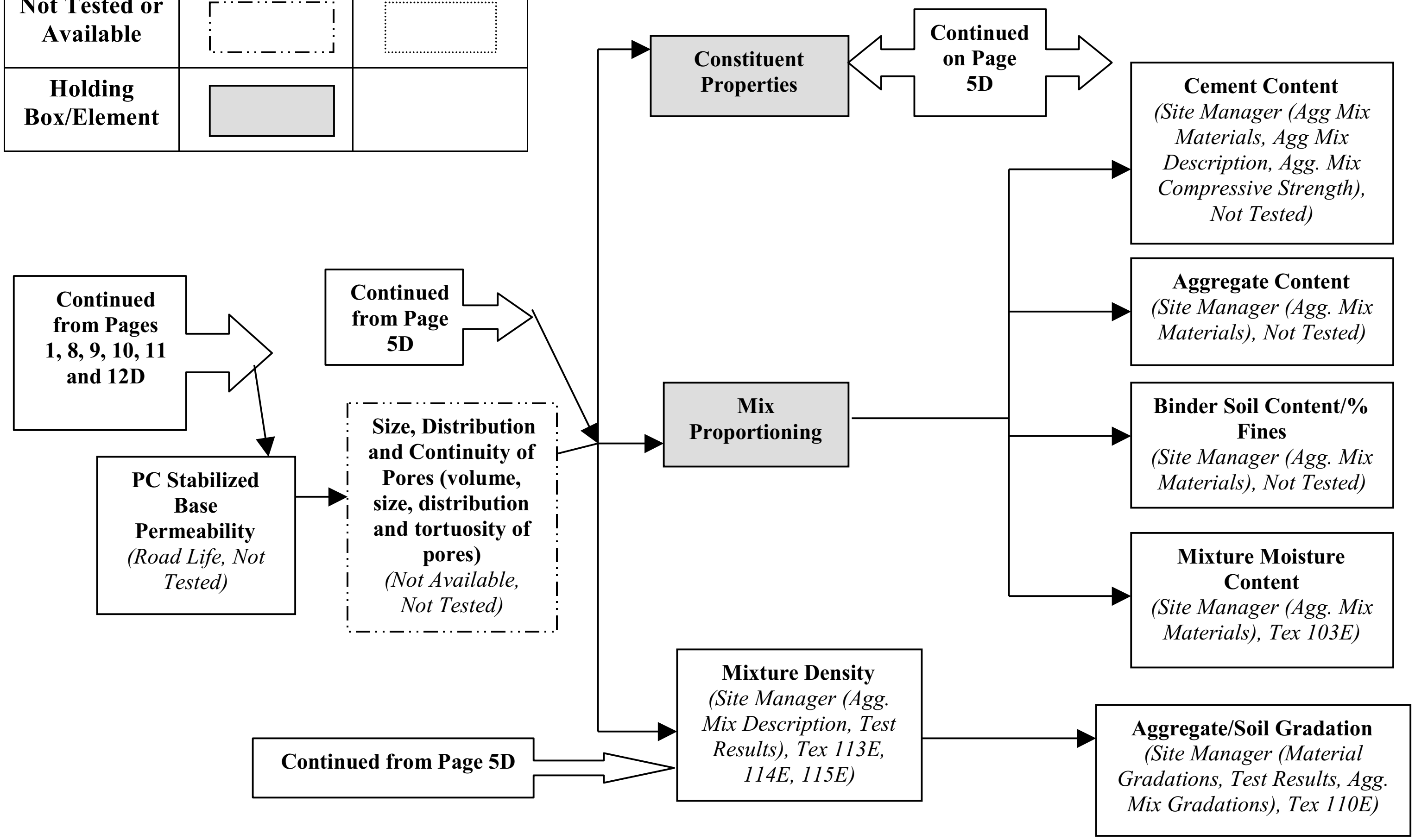
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



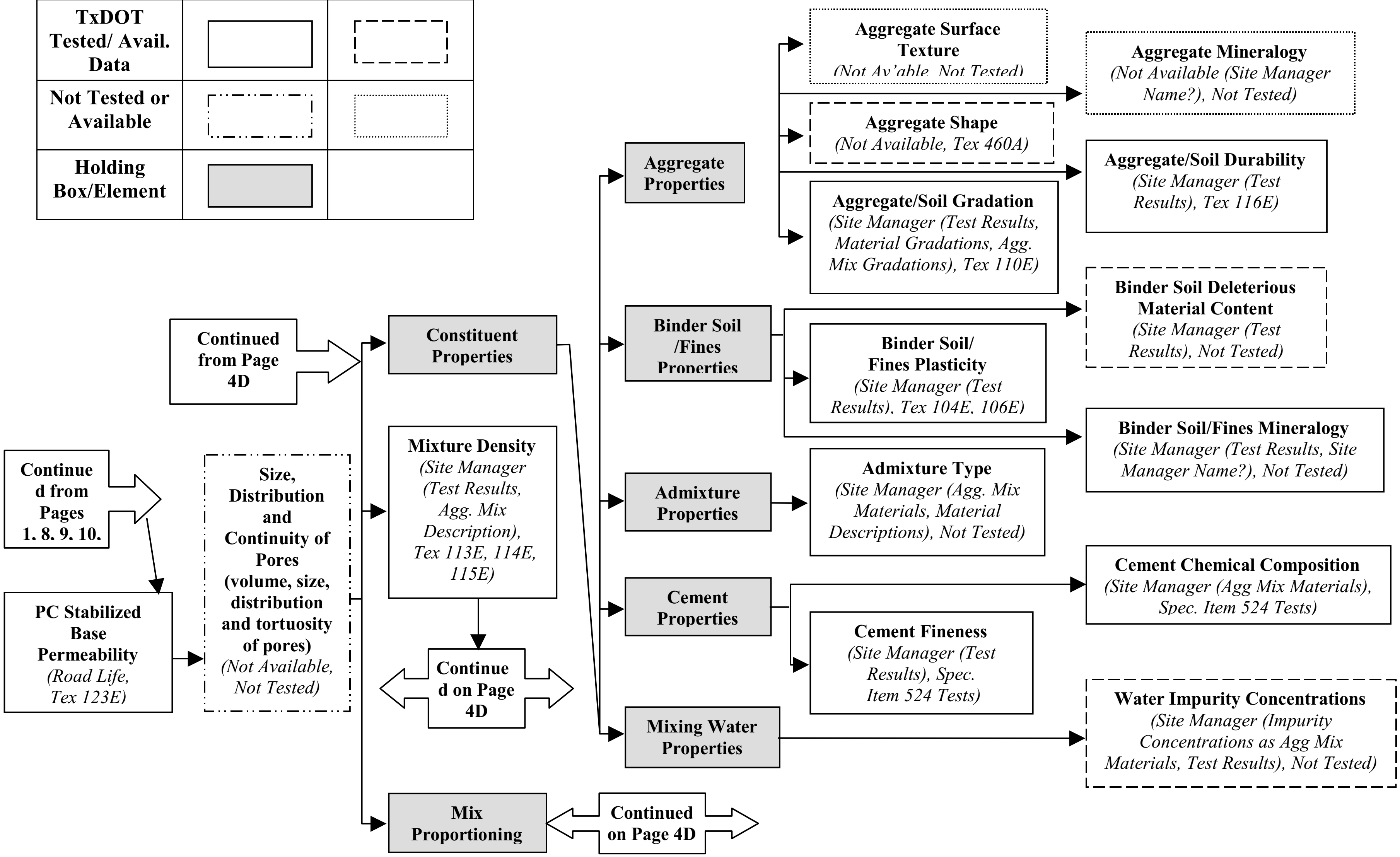
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



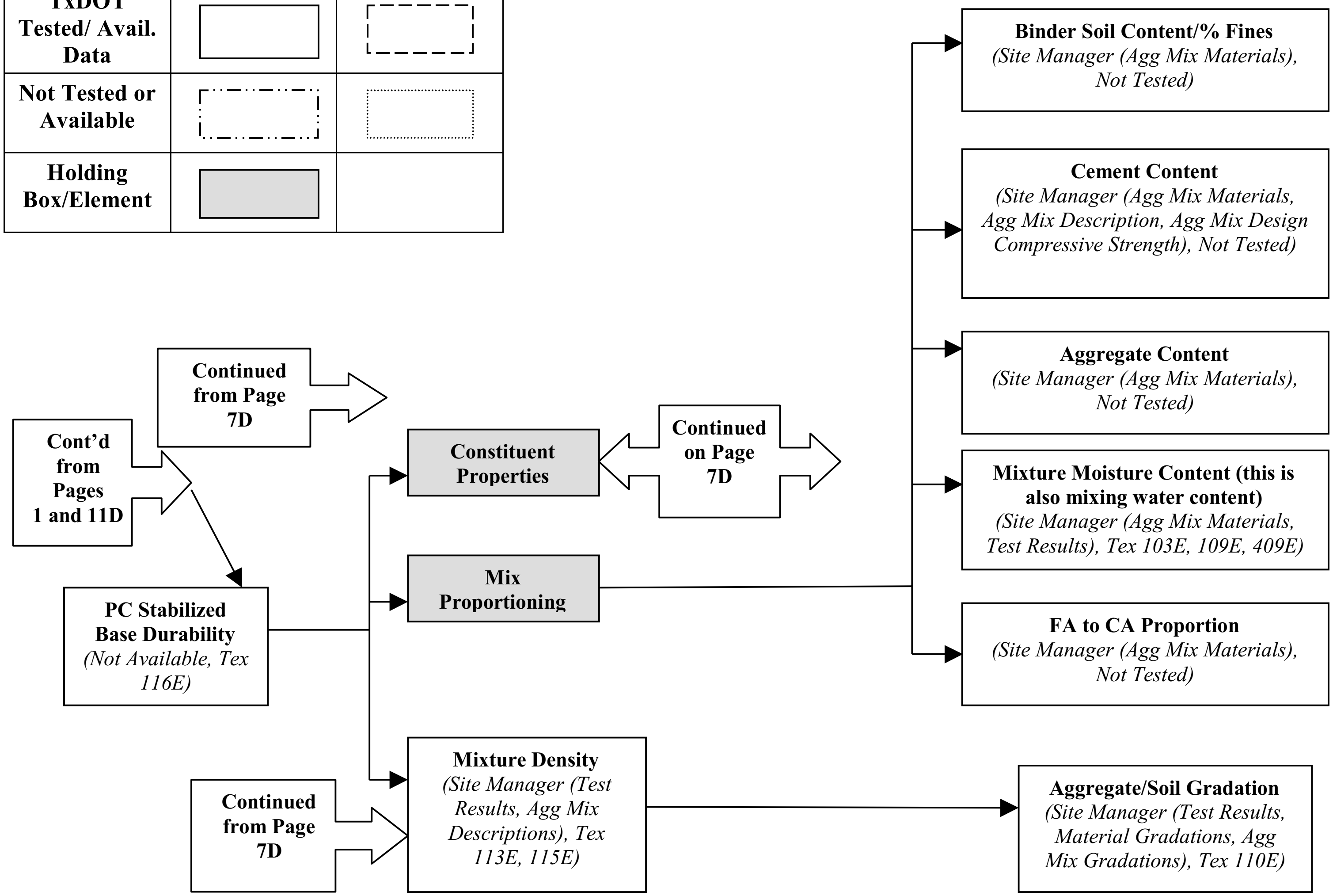
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



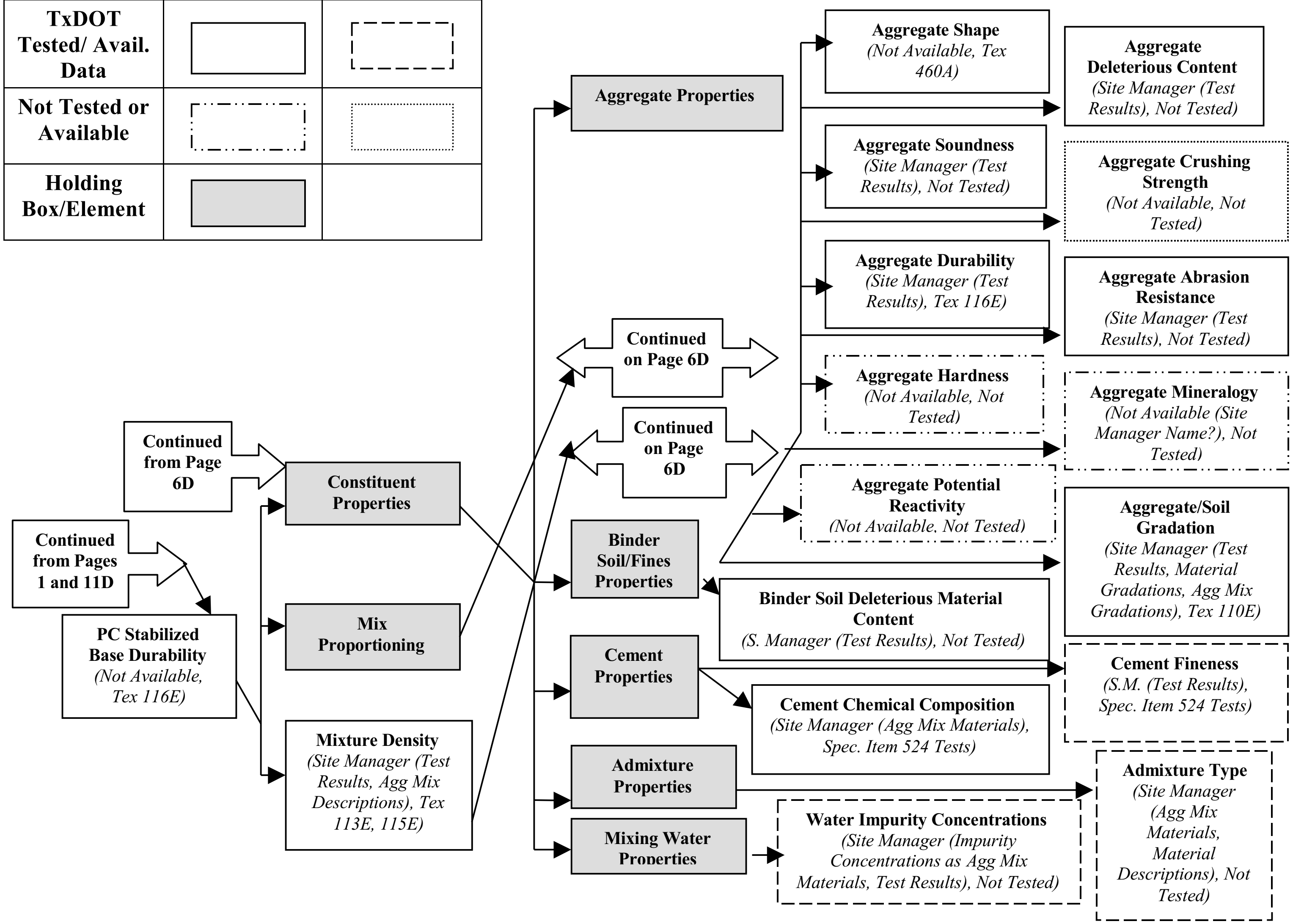
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



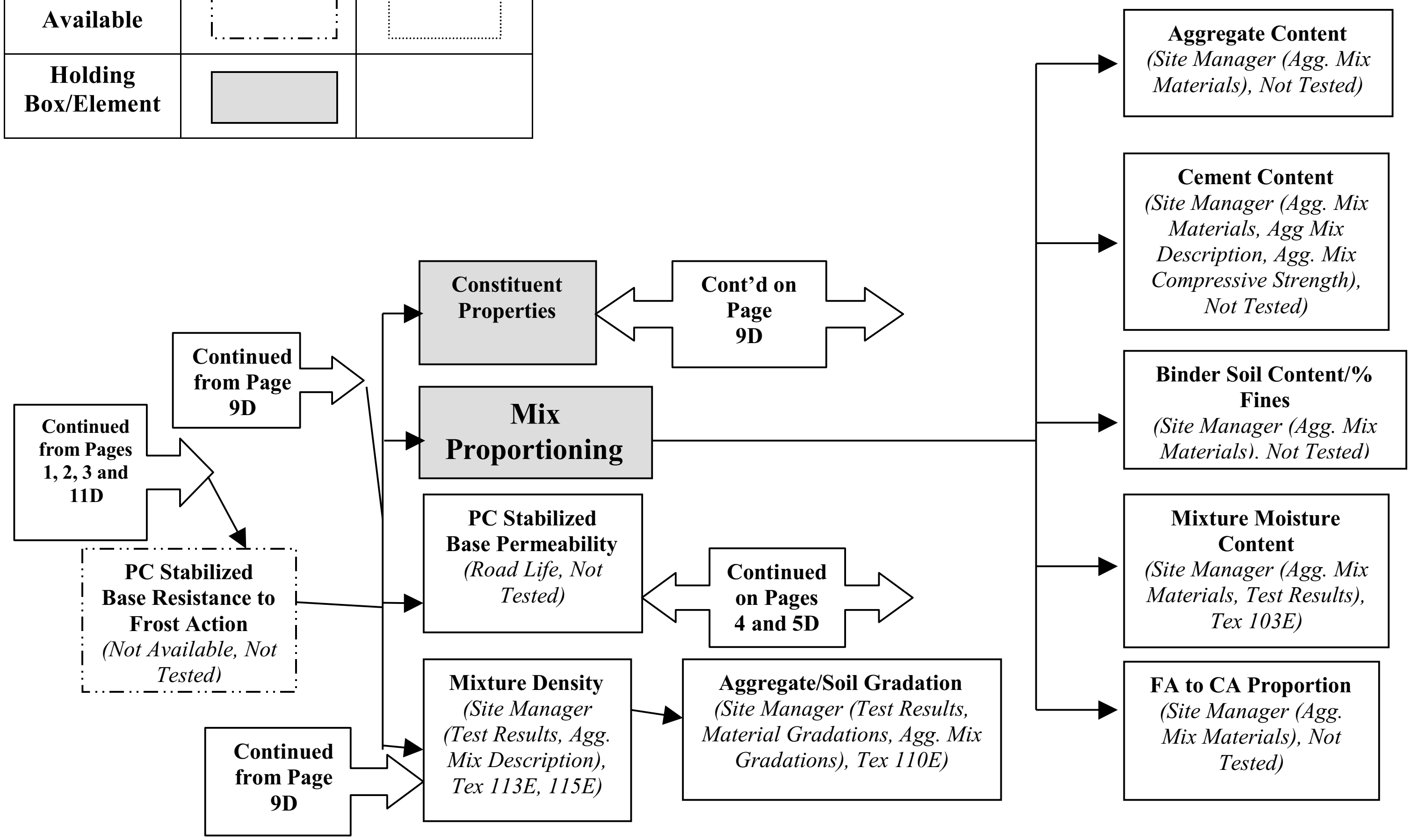
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



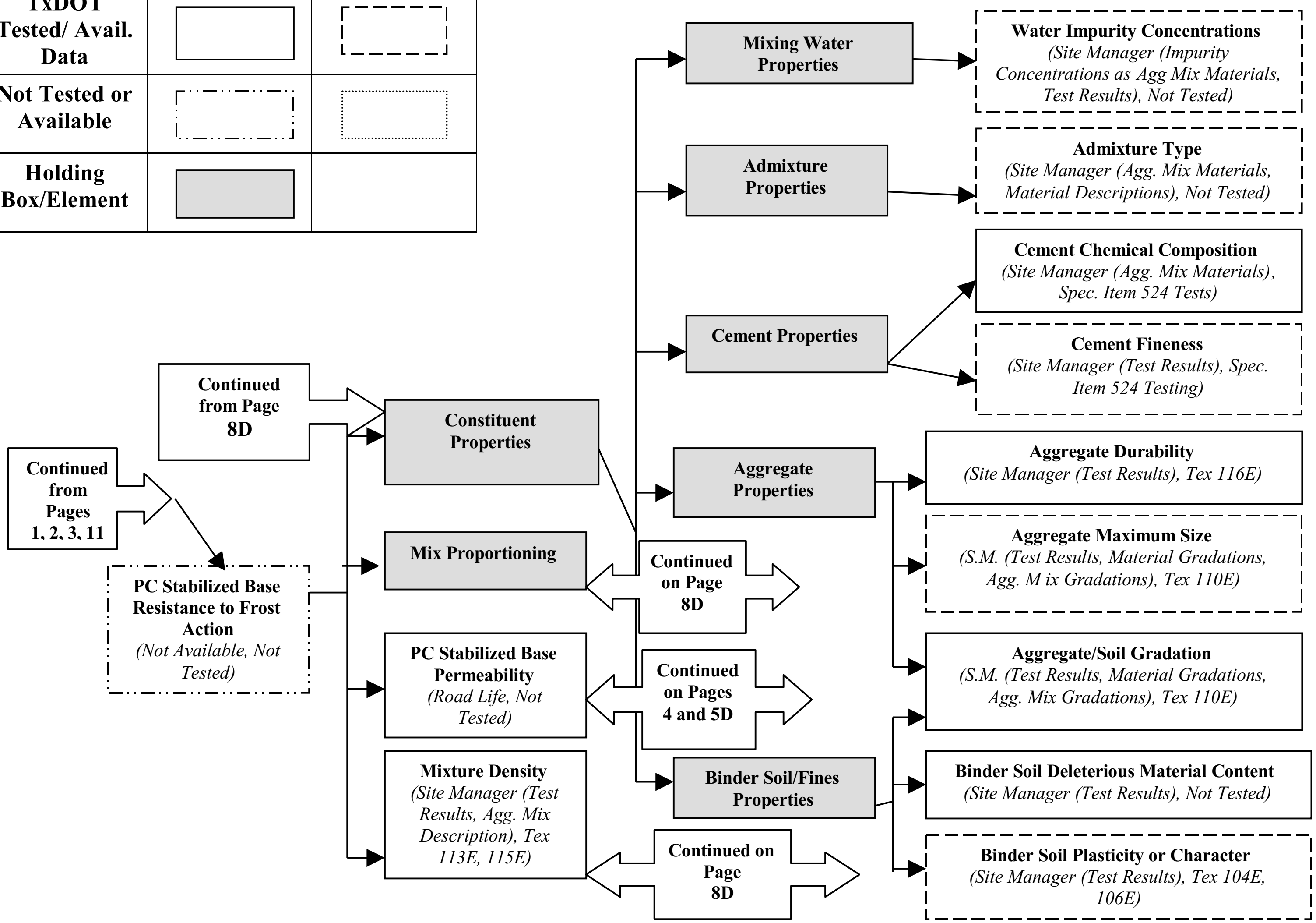
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



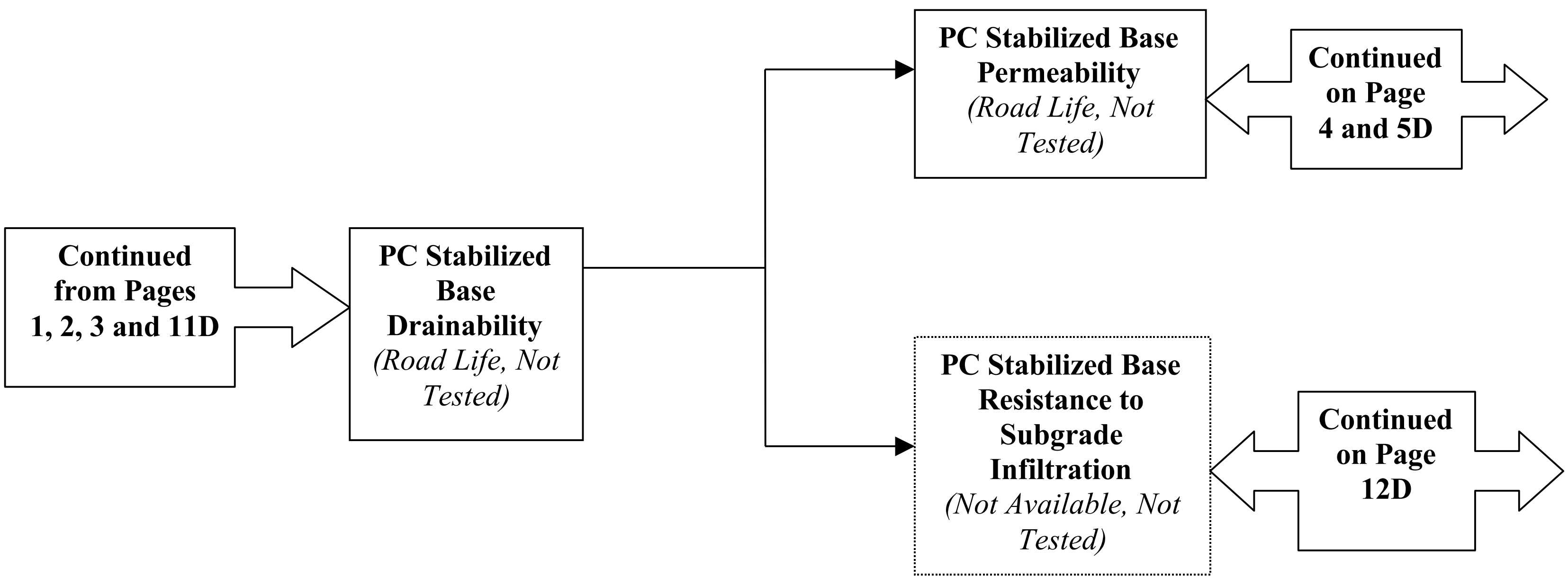
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



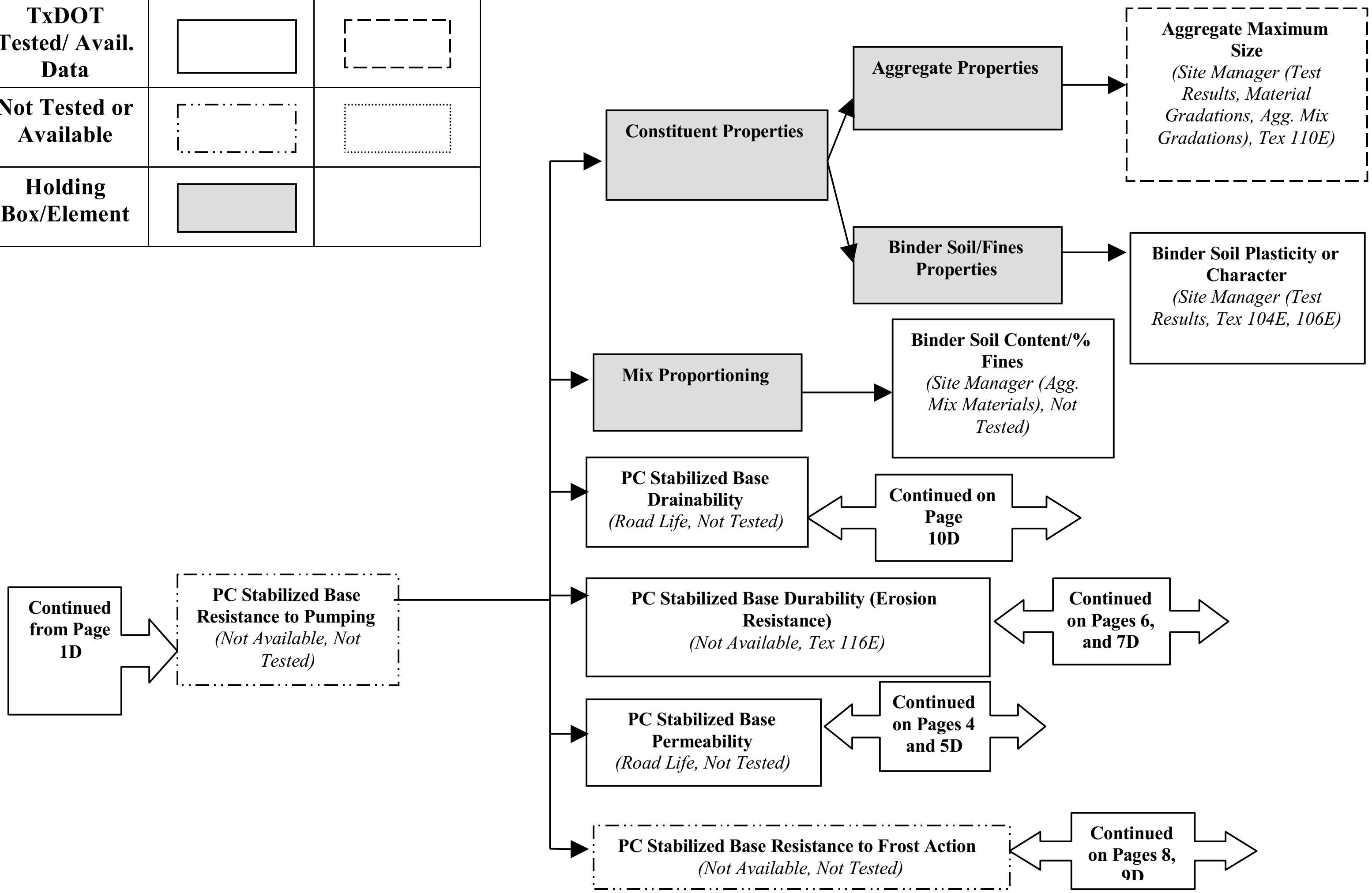
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



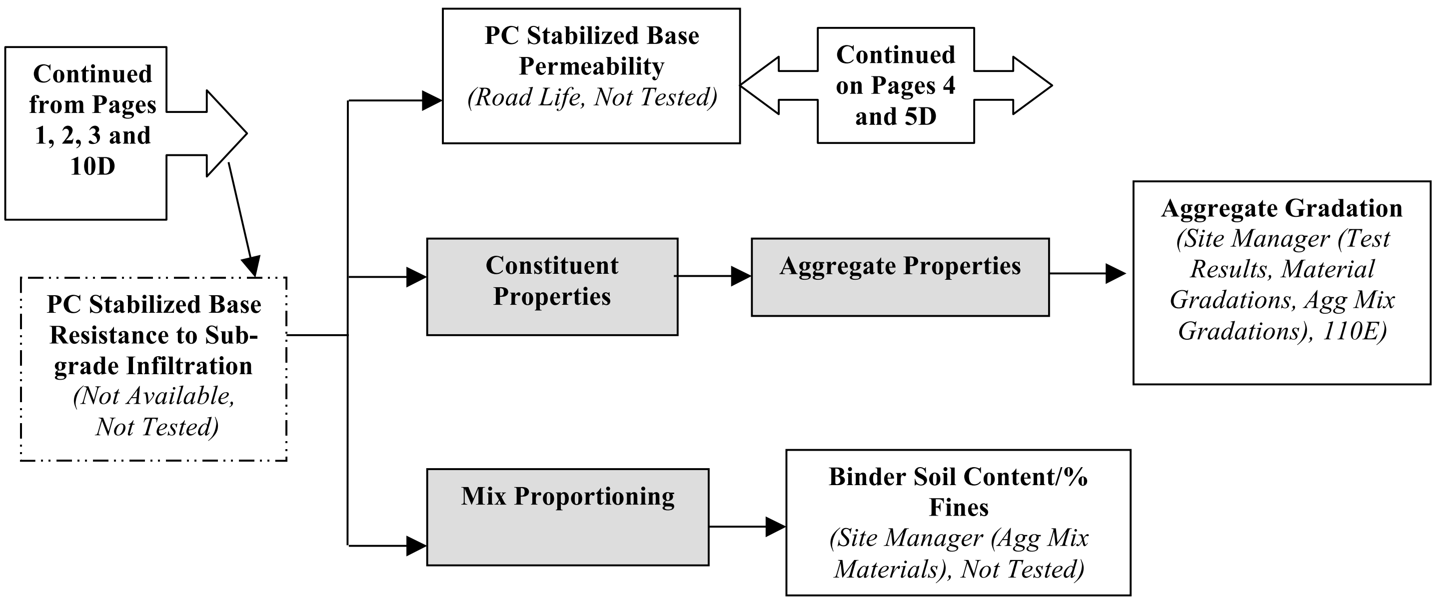
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



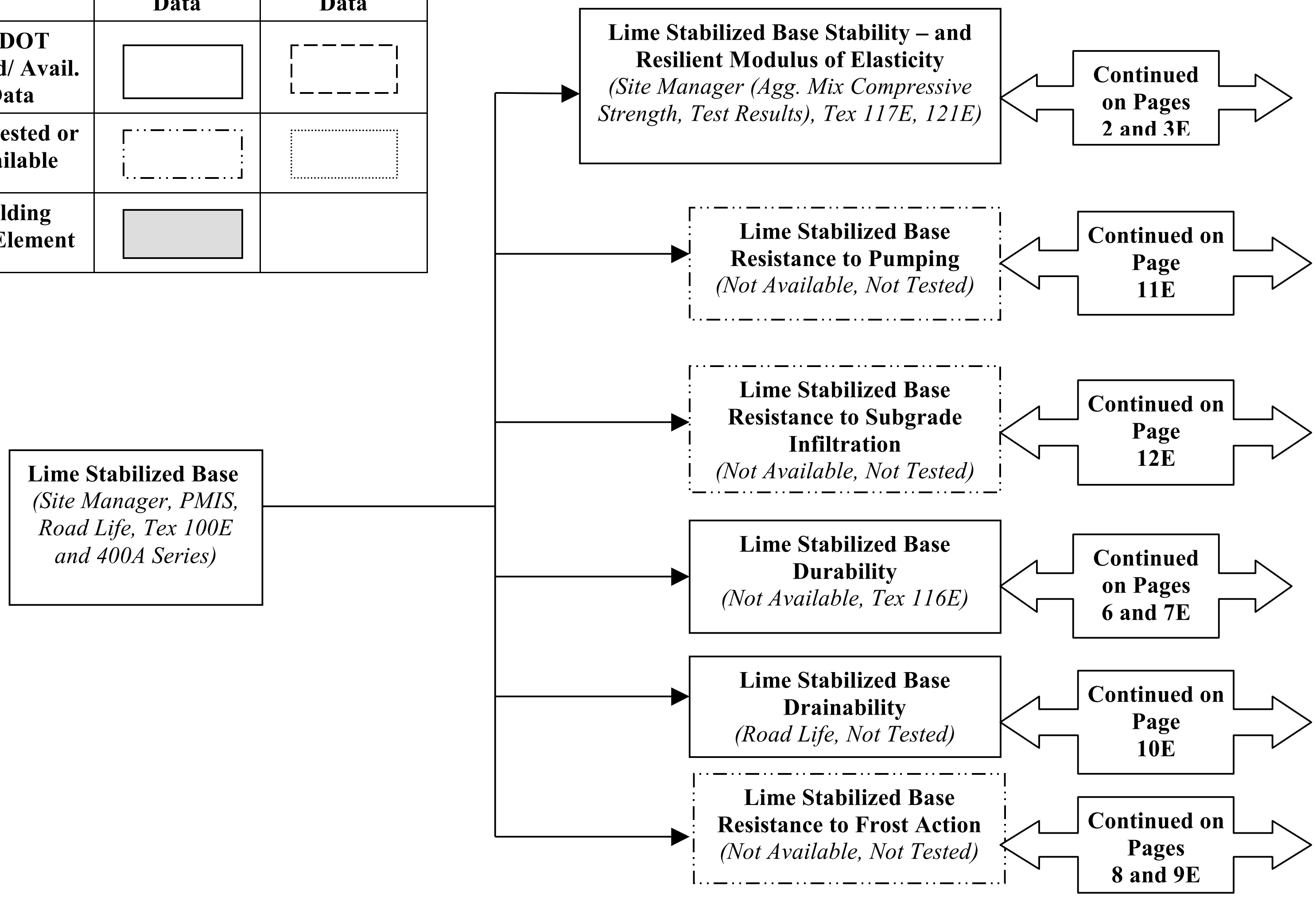
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



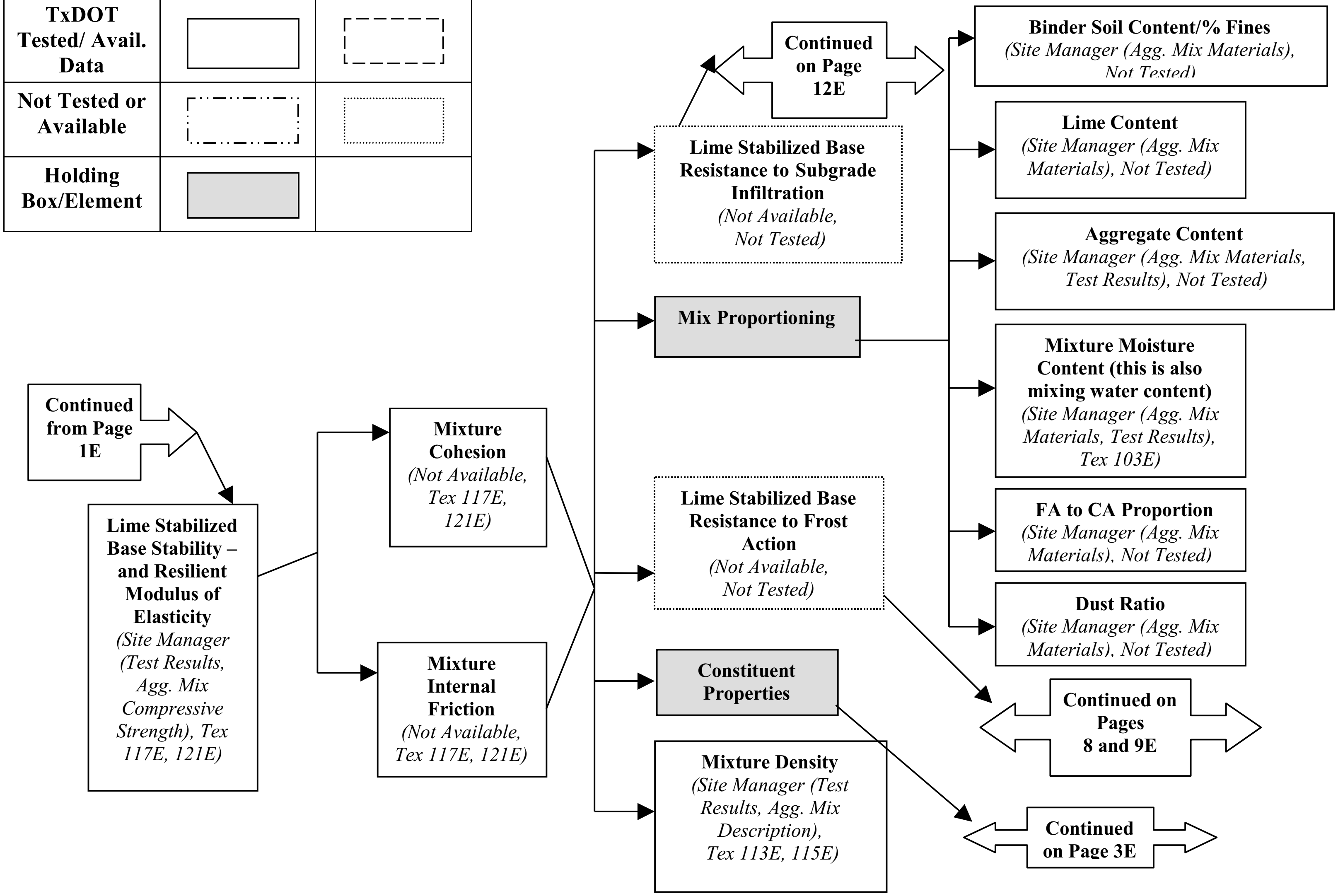
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



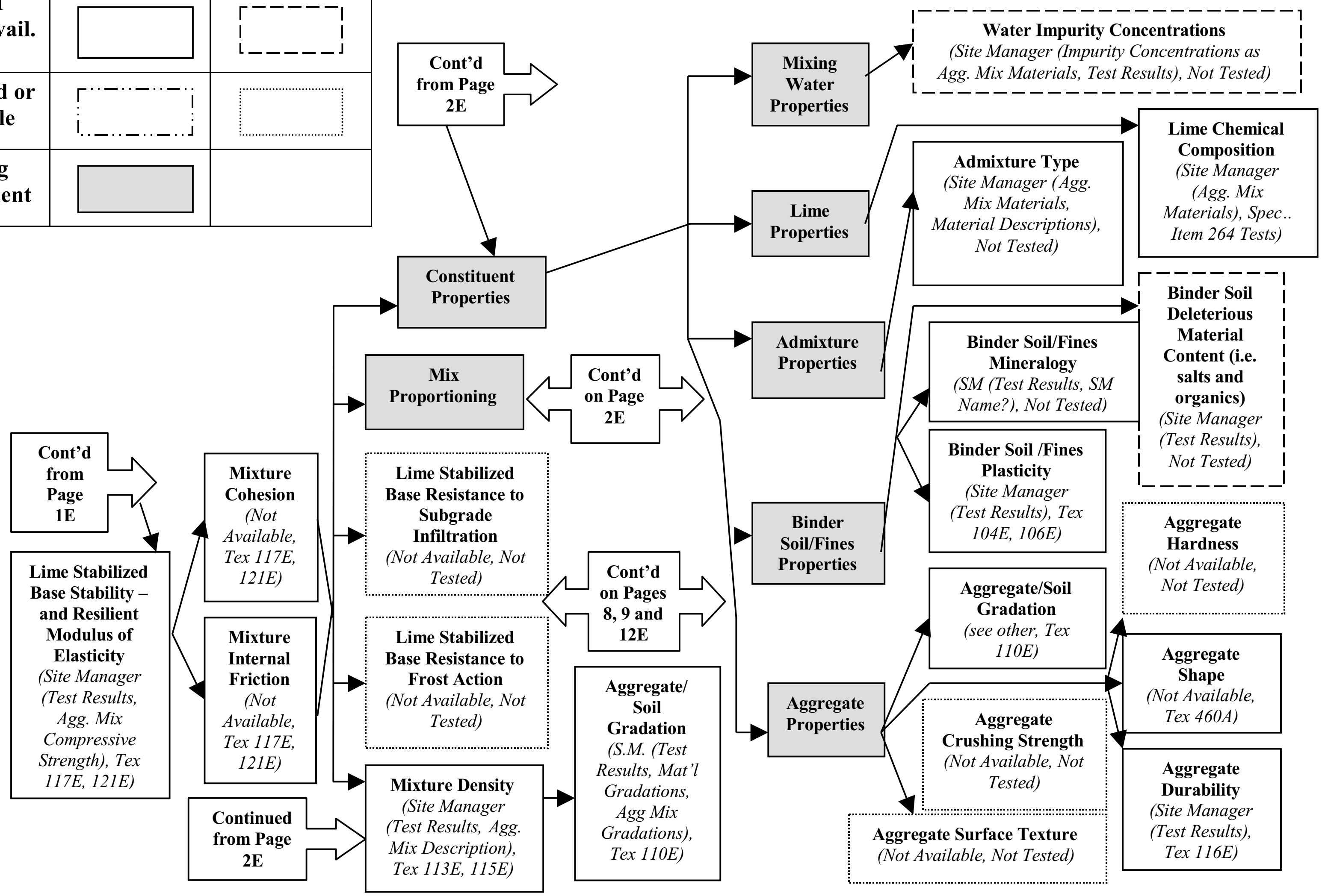
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



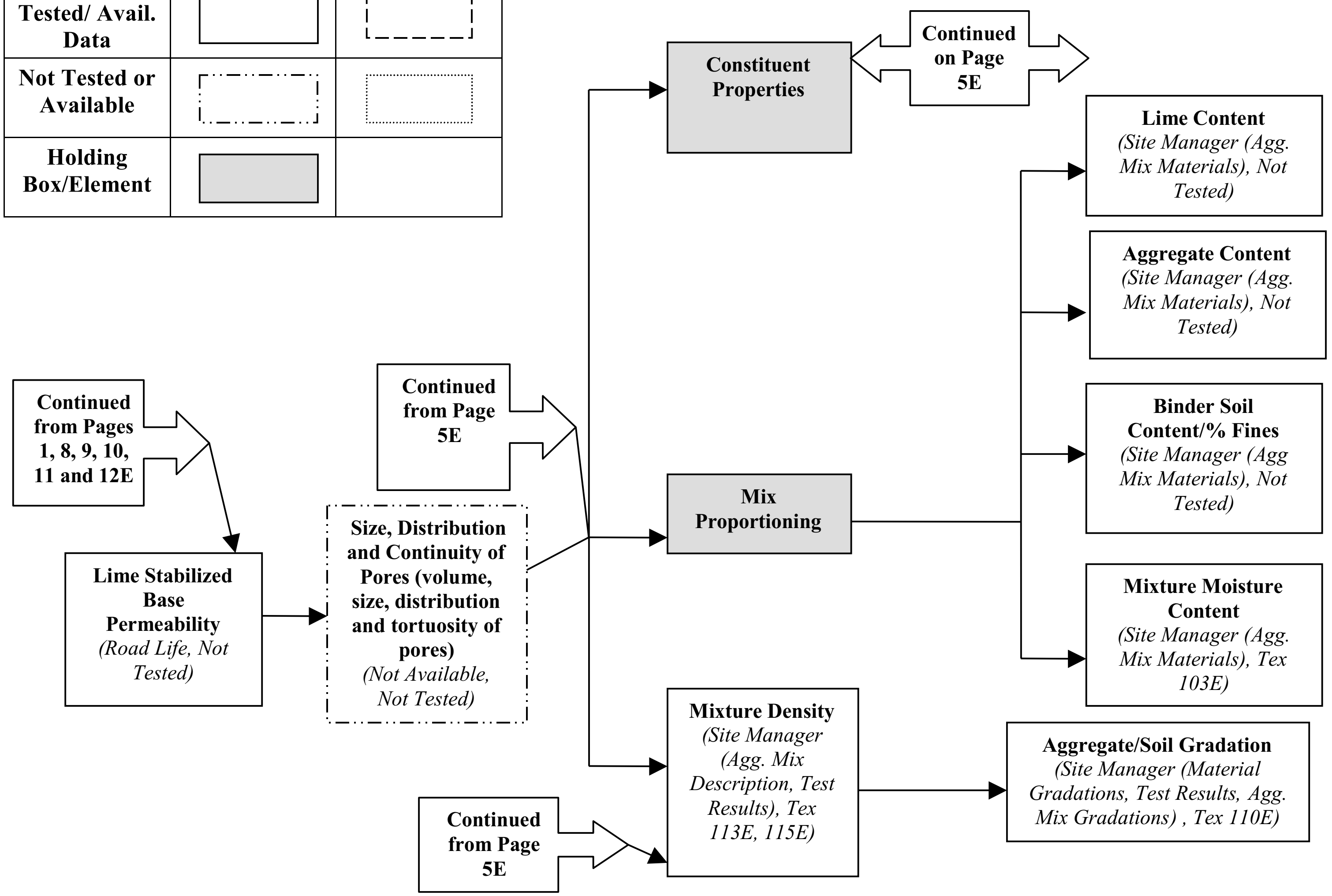
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data	(solid box)	(dashed box)
Not Tested or Available	(dash-dot box)	(dotted box)
Holding Box/Element	(shaded box)	



Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
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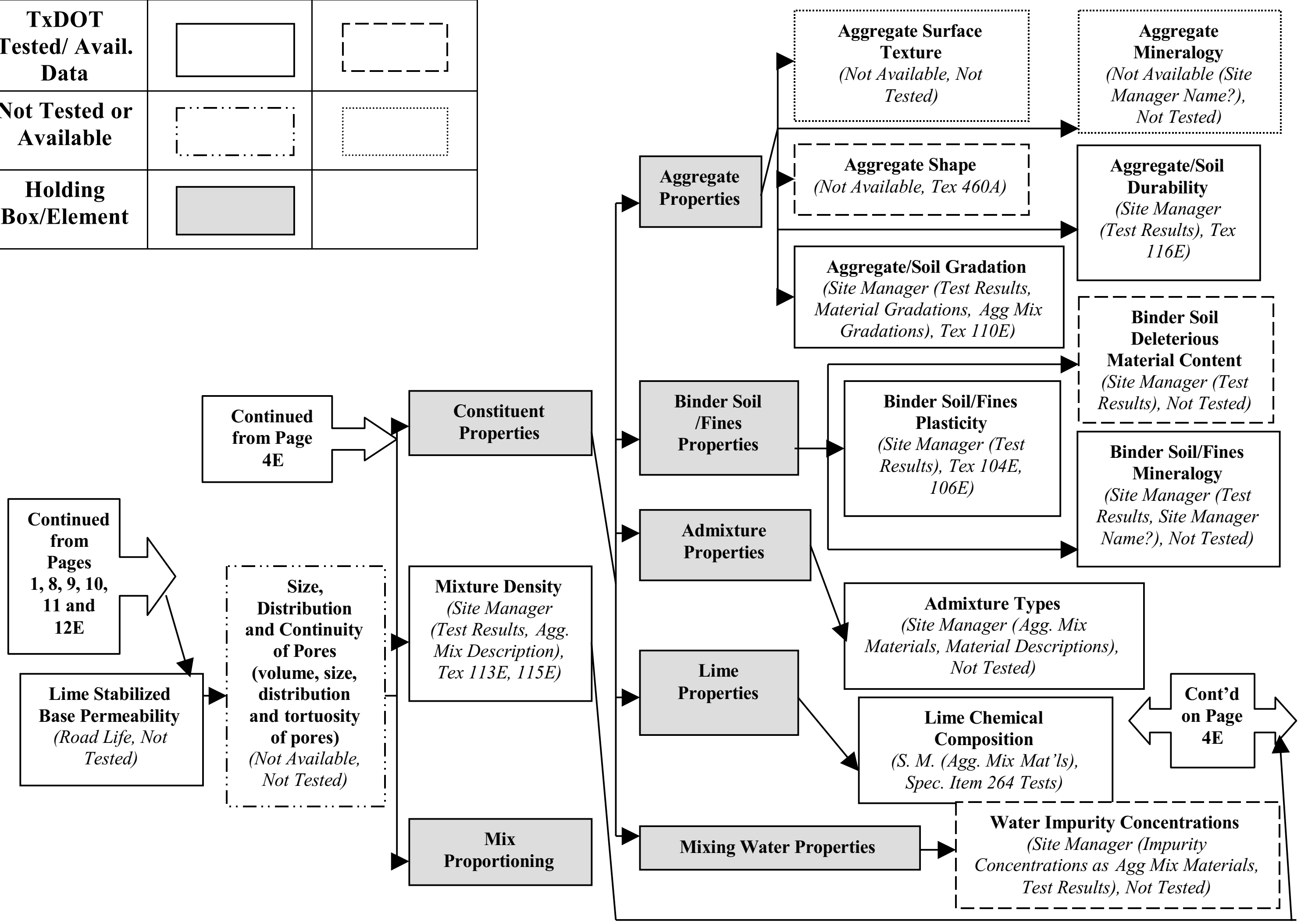
Holding Box/Element		



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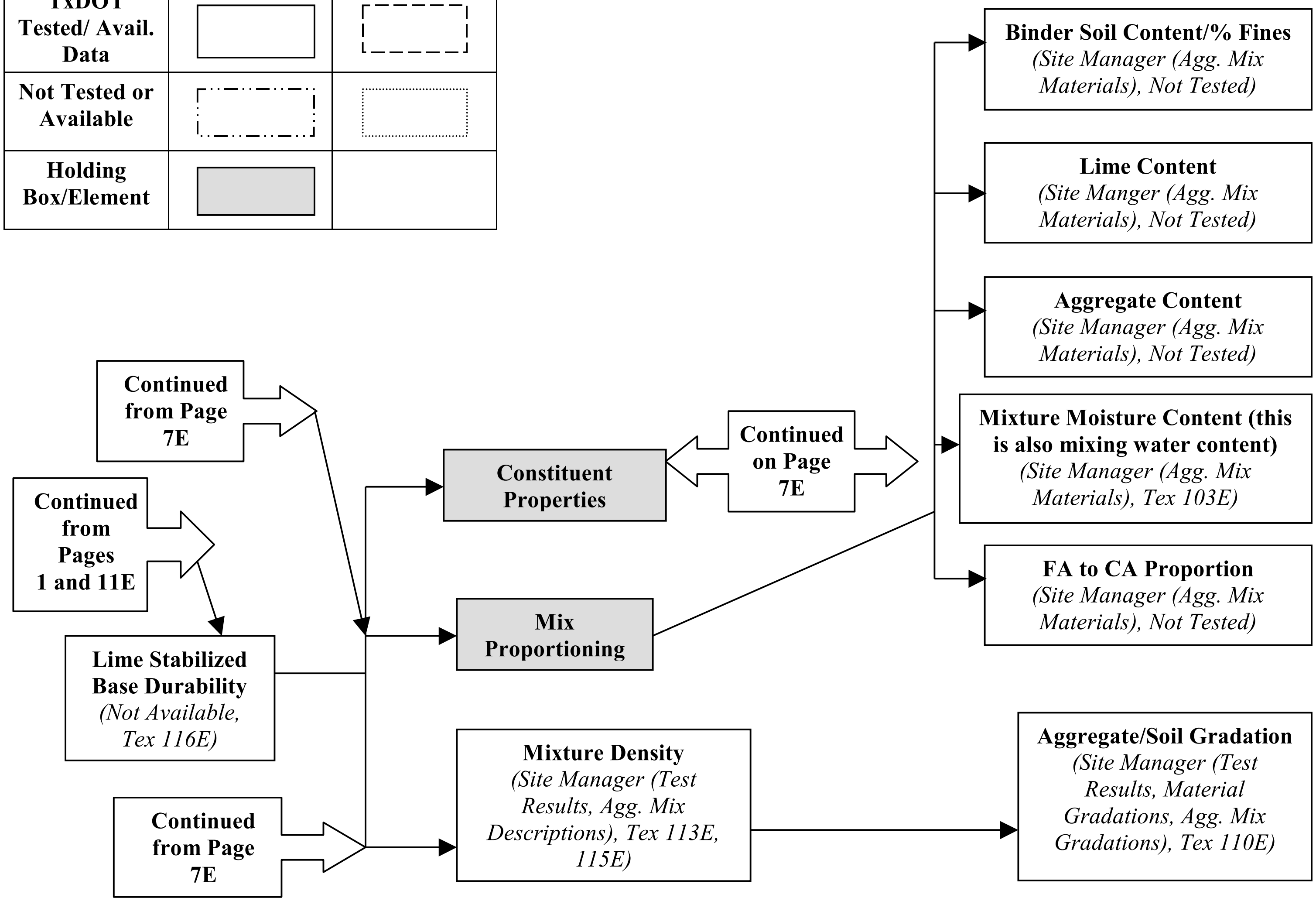
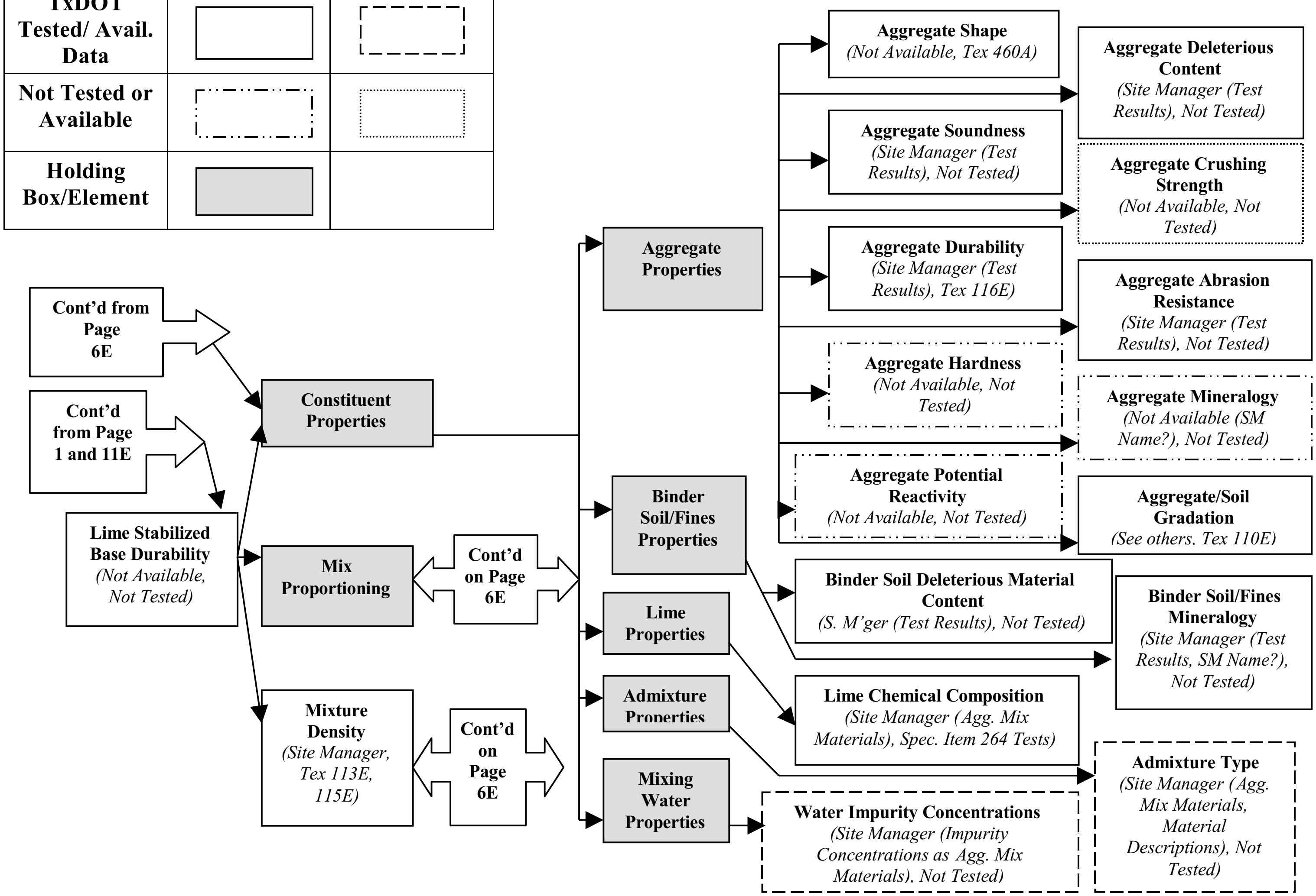
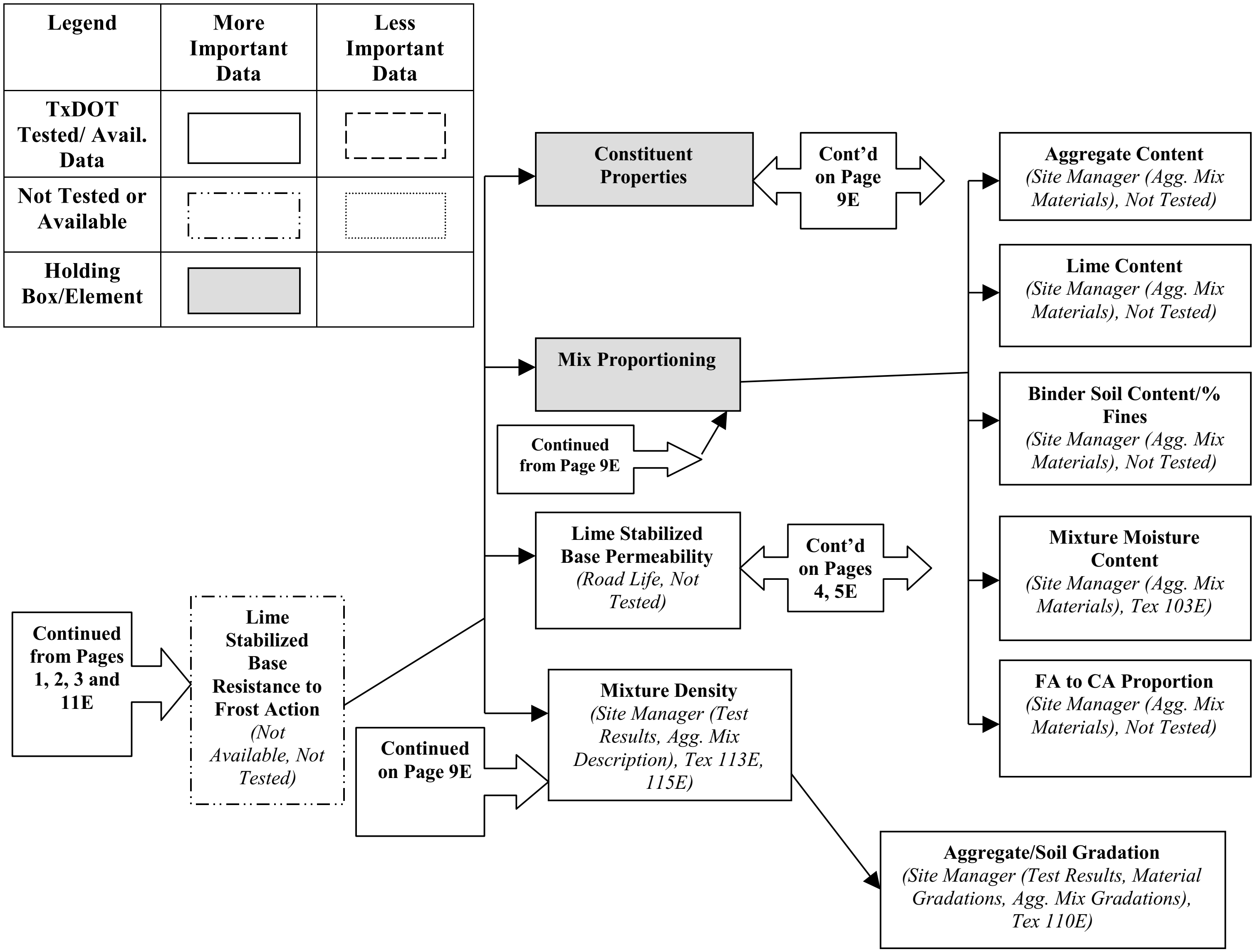
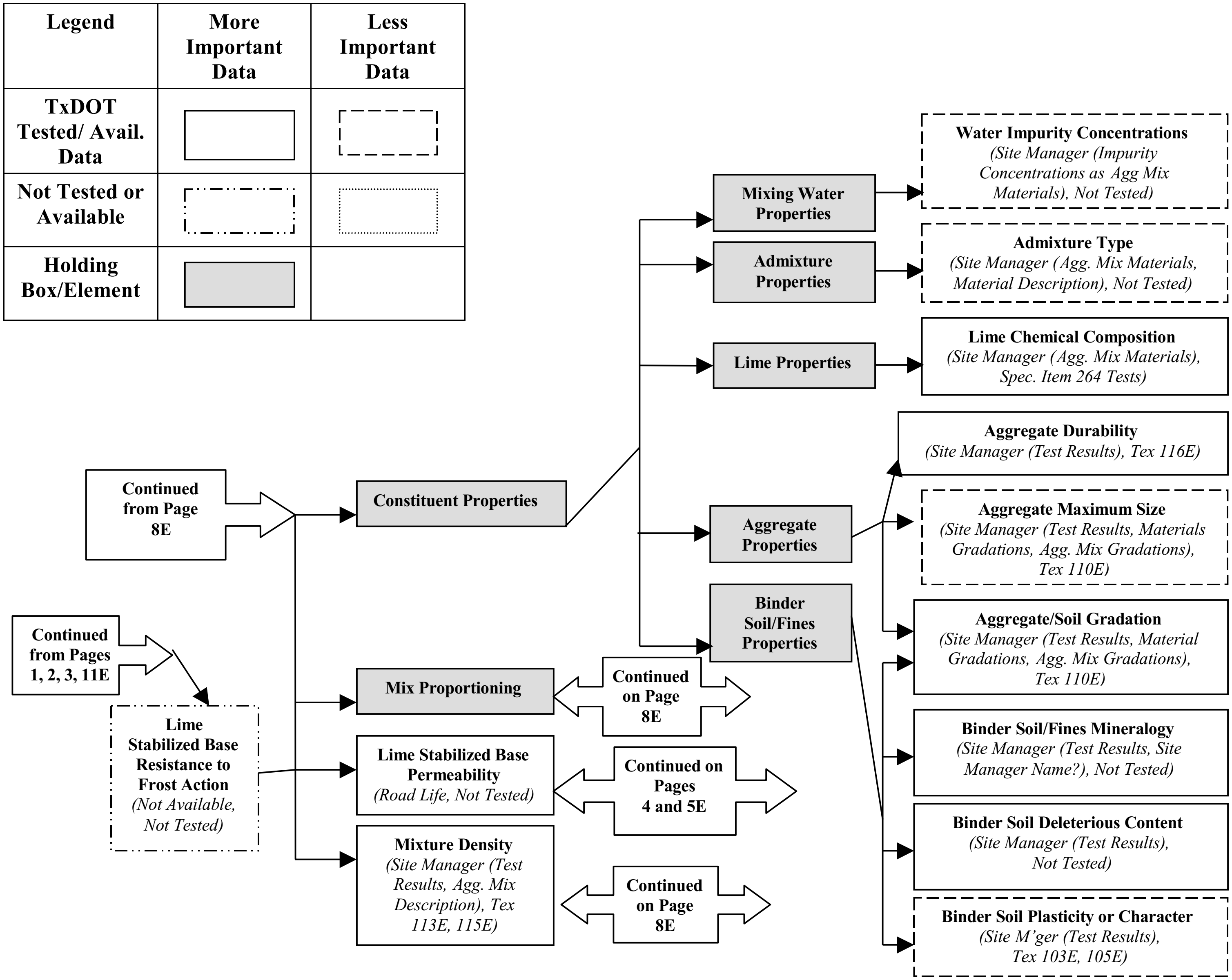
Holding Box/Element		



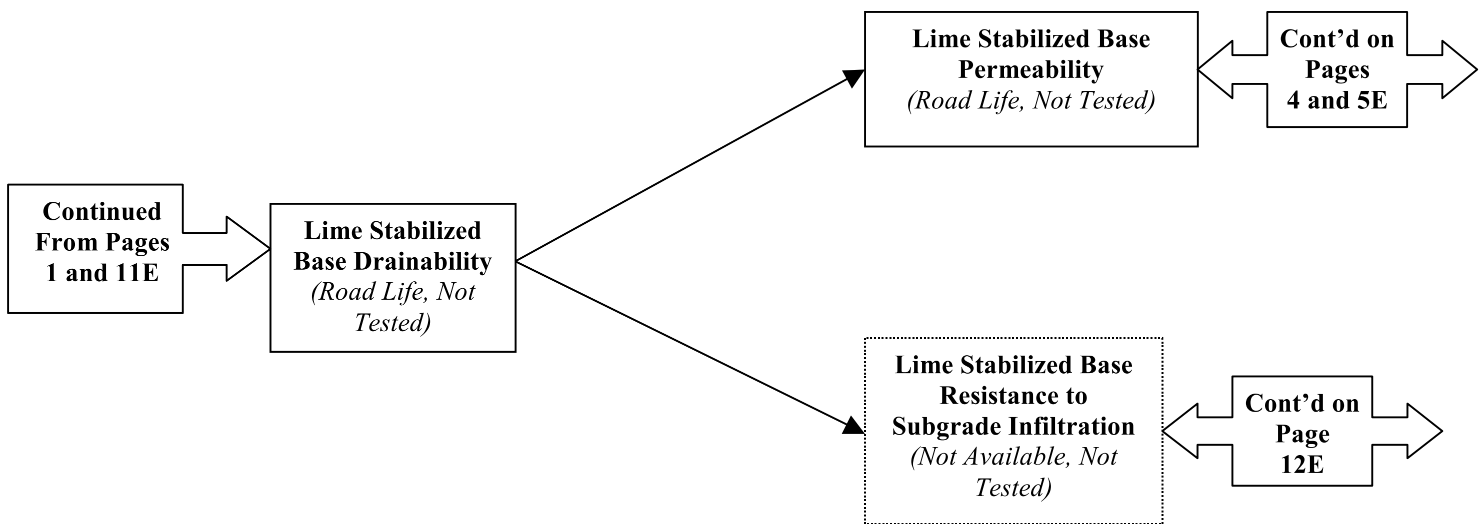
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



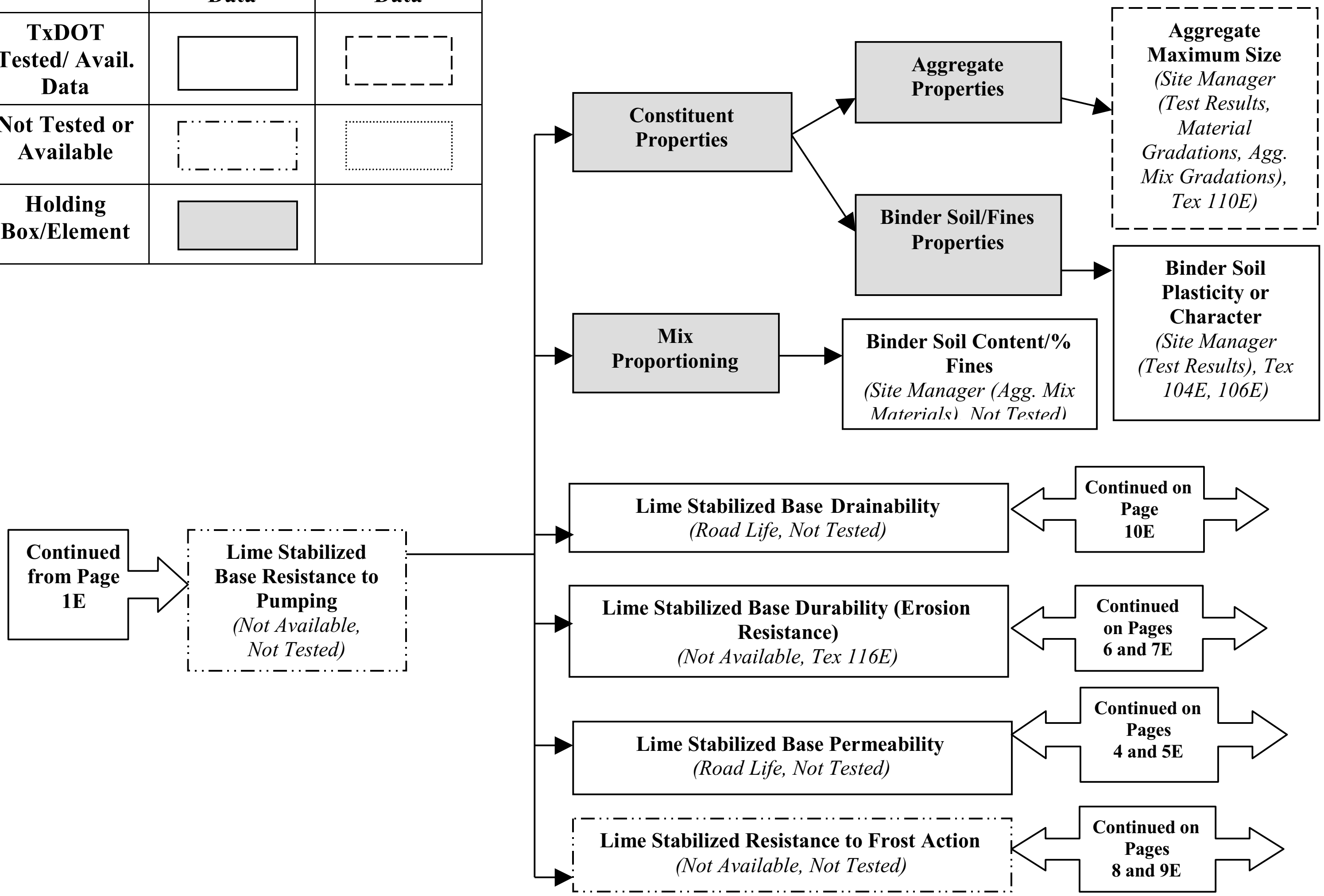

Legend
More Important Data
Less Important Data
TxDOT Tested/ Avail. Data
Not Tested or Available
Holding Box/Element
Constituent Properties
Cont'd on Page 9E
Aggregate Content (Site Manager (Agg. Mix Materials), Not Tested)
Lime Content (Site Manager (Agg. Mix Materials), Not Tested)
Mix Proportioning
Binder Soil Content/% Fines (Site Manager (Agg. Mix Materials), Not Tested)
Continued from Page 9E
Lime Stabilized Base Permeability (Road Life, Not Tested)
Cont'd on Pages 4, 5E
Mixture Moisture Content (Site Manager (Agg. Mix Materials), Tex 103E)
Continued from Pages 1, 2, 3 and 11E
Lime Stabilized Base Resistance to Frost Action (Not Available, Not Tested)
Mixture Density (Site Manager (Test Results, Agg. Mix Description), Tex 113E, 115E)
FA to CA Proportion (Site Manager (Agg. Mix Materials), Not Tested)
Continued on Page 9E
Aggregate/Soil Gradation (Site Manager (Test Results, Material Gradations, Agg. Mix Gradations), Tex 110E)


Legend
More Important Data
Less Important Data
TxDOT Tested/ Avail. Data
Not Tested or Available
Holding Box/Element
Water Impurity Concentrations
(Site Manager (Impurity Concentrations as Agg Mix Materials), Not Tested)
Mixing Water Properties
Admixture Type
(Site Manager (Agg. Mix Materials, Material Description), Not Tested)
Admixture Properties
Lime Chemical Composition
(Site Manager (Agg. Mix Materials), Spec. Item 264 Tests)
Lime Properties
Aggregate Durability
(Site Manager (Test Results), Tex 116E)
Continued from Page 8E
Constituent Properties
Aggregate Maximum Size
(Site Manager (Test Results, Materials Gradations, Agg. Mix Gradations), Tex 110E)
Aggregate Properties
Binder Soil/Fines Properties
Aggregate/Soil Gradation
(Site Manager (Test Results, Material Gradations, Agg. Mix Gradations), Tex 110E)
Continued from Pages 1, 2, 3, 11E
Mix Proportioning
Continued on Page 8E
Lime Stabilized Base Resistance to Frost Action
(Not Available, Not Tested)
Lime Stabilized Base Permeability
(Road Life, Not Tested)
Continued on Pages 4 and 5E
Binder Soil/Fines Mineralogy
(Site Manager (Test Results, Site Manager Name?), Not Tested)
Binder Soil Deleterious Content
(Site Manager (Test Results), Not Tested)
Mixture Density
(Site Manager (Test Results, Agg. Mix Description), Tex 113E, 115E)
Continued on Page 8E
Binder Soil Plasticity or Character
(Site M'ger (Test Results), Tex 103E, 105E)

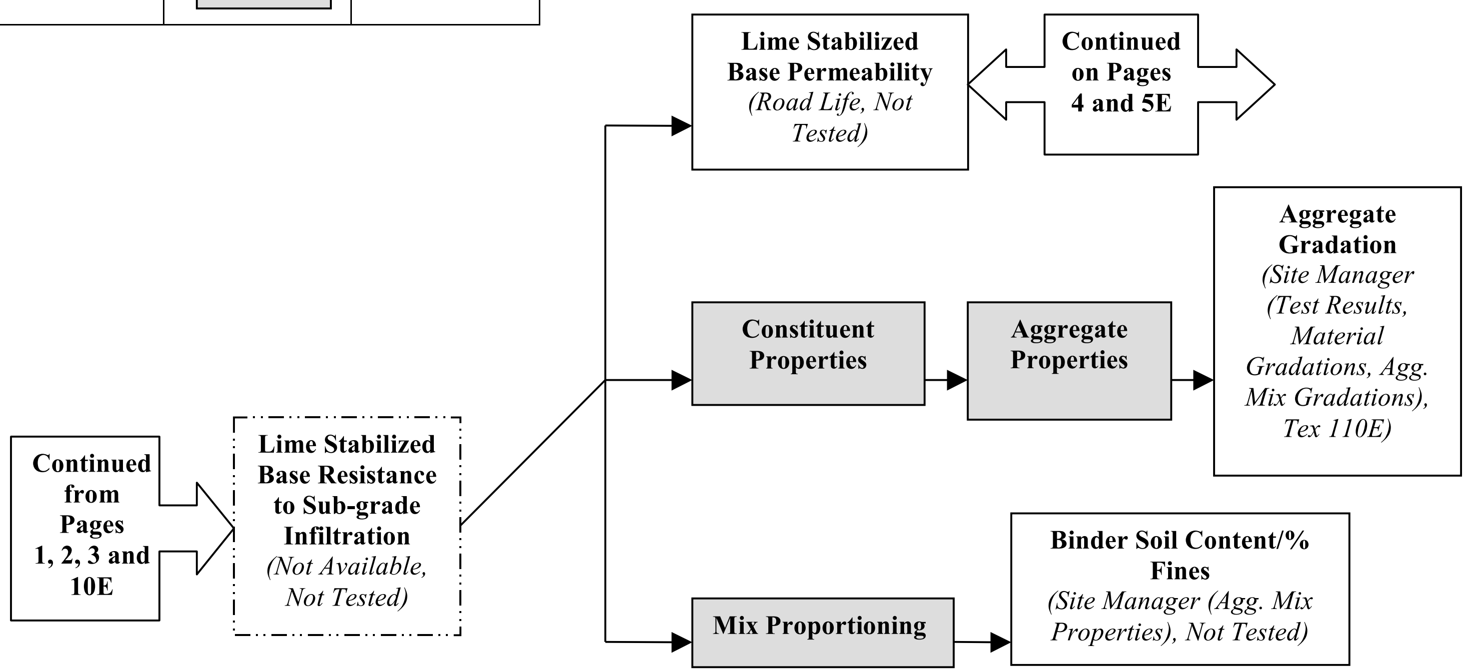
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



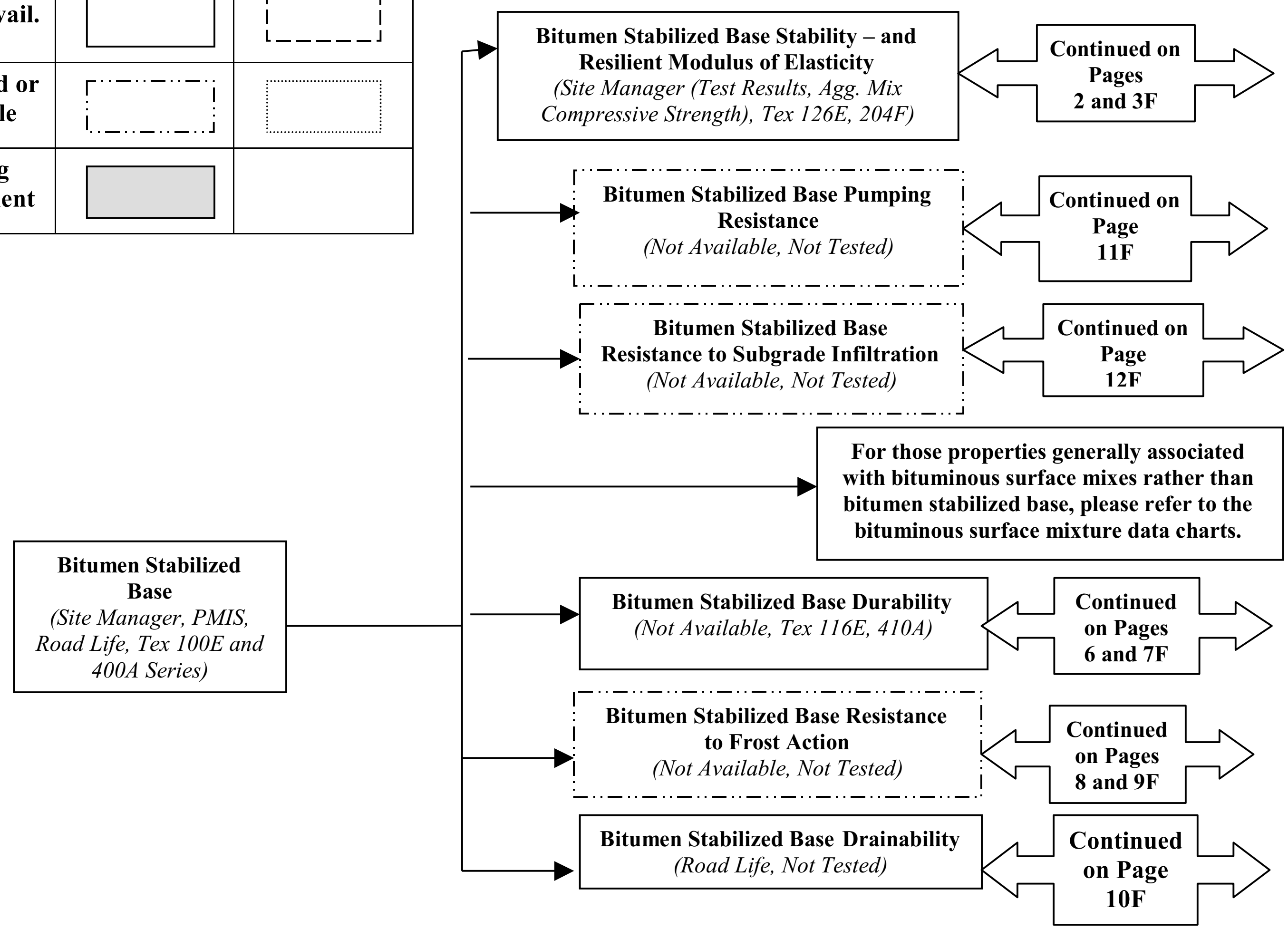
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		

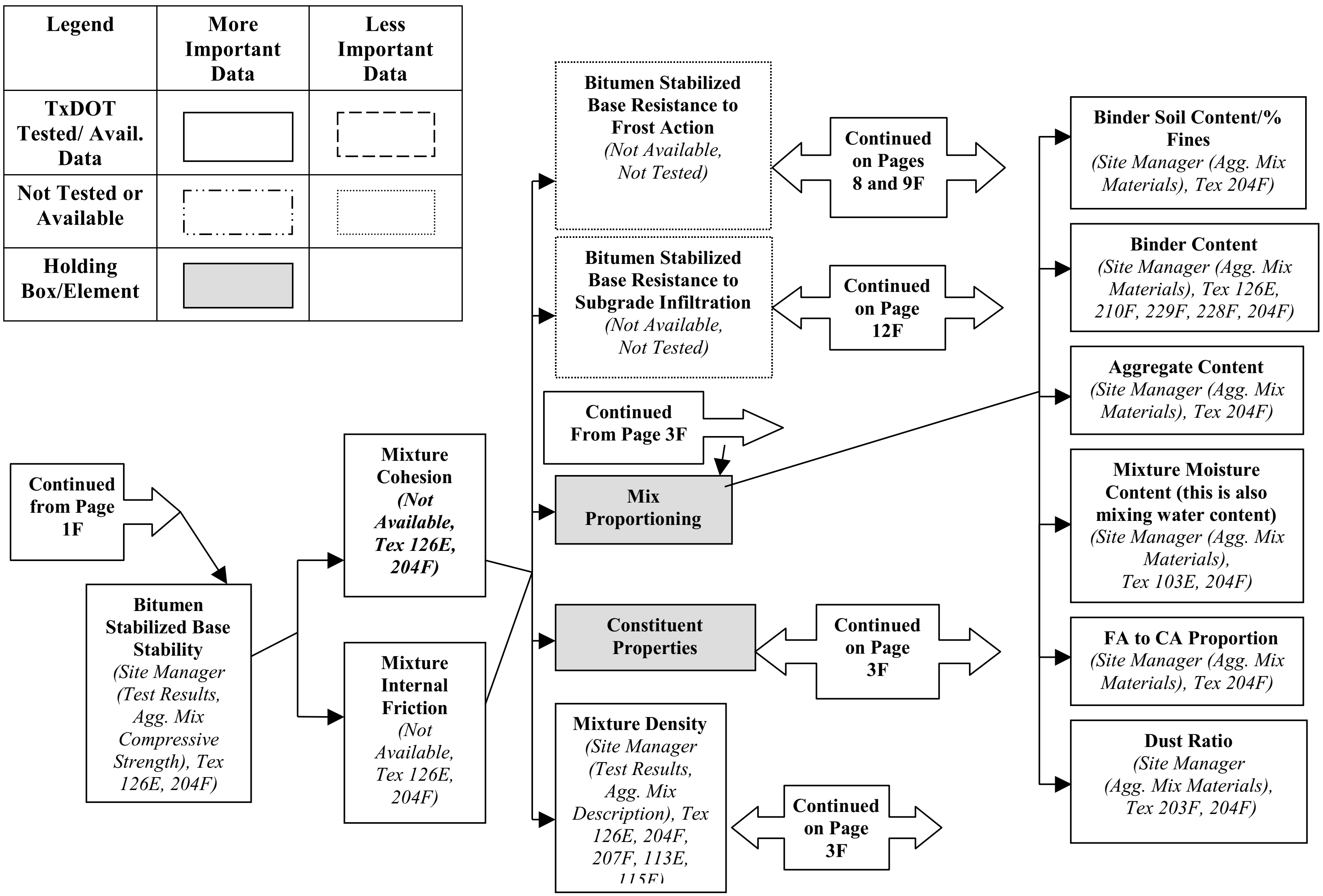


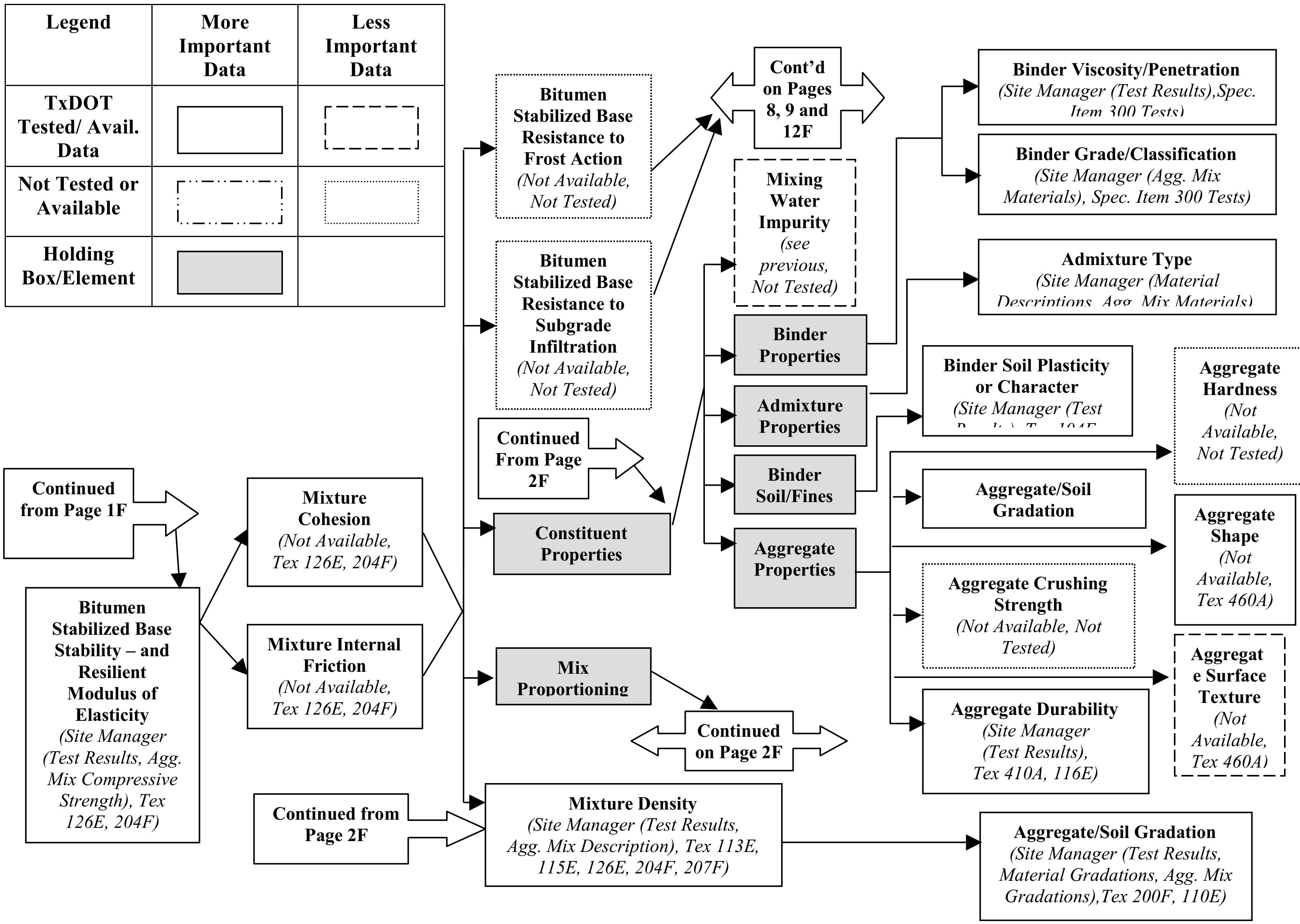
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



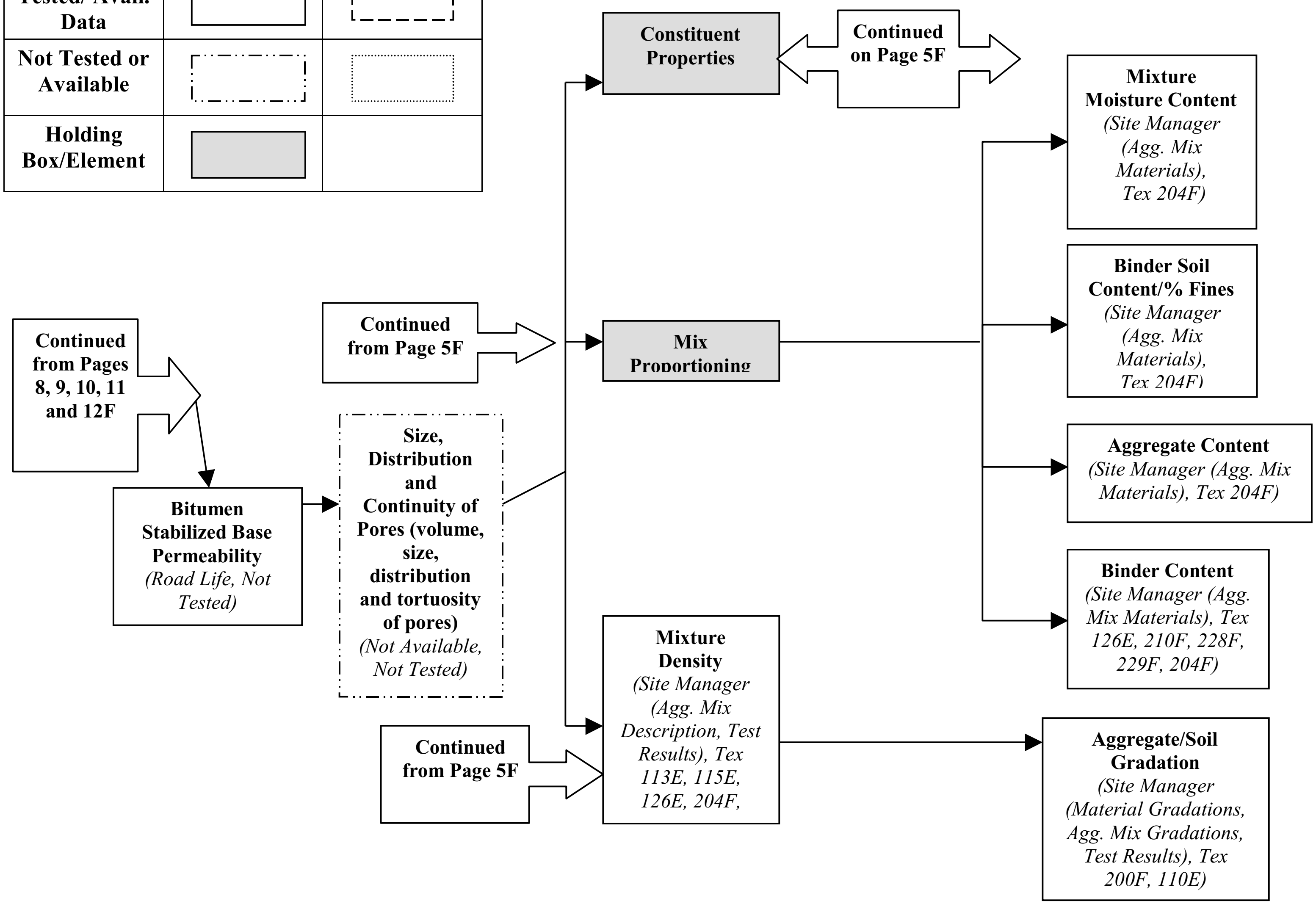
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



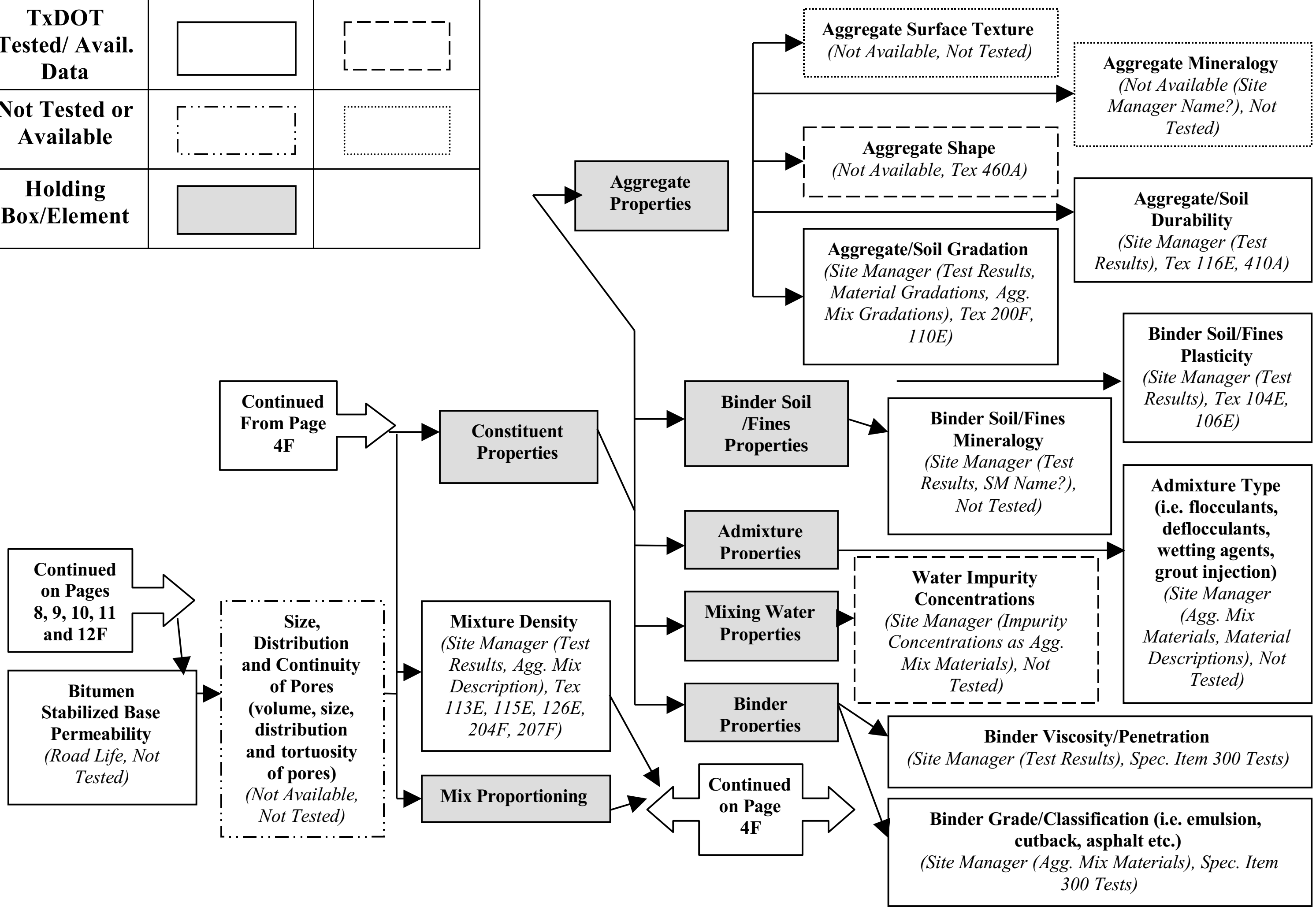

Legend
More Important Data
Less Important Data
TxDOT Tested/ Avail. Data
Not Tested or Available
Holding Box/Element
Bitumen Stabilized Base Resistance to Frost Action (Not Available, Not Tested)
Continued on Pages 8 and 9F
Bitumen Stabilized Base Resistance to Subgrade Infiltration (Not Available, Not Tested)
Continued on Page 12F
Continued From Page 3F
Mix Proportioning
Continued from Page 1F
Bitumen Stabilized Base Stability (Site Manager (Test Results, Agg. Mix Compressive Strength), Tex 126E, 204F)
Mixture Cohesion (Not Available, Tex 126E, 204F)
Mixture Internal Friction (Not Available, Tex 126E, 204F)
Constituent Properties
Continued on Page 3F
Mixture Density (Site Manager (Test Results, Agg. Mix Description), Tex 126E, 204F, 207F, 113E, 115F)
Continued on Page 3F
Binder Soil Content/% Fines (Site Manager (Agg. Mix Materials), Tex 204F)
Binder Content (Site Manager (Agg. Mix Materials), Tex 126E, 210F, 229F, 228F, 204F)
Aggregate Content (Site Manager (Agg. Mix Materials), Tex 204F)
Mixture Moisture Content (this is also mixing water content) (Site Manager (Agg. Mix Materials), Tex 103E, 204F)
FA to CA Proportion (Site Manager (Agg. Mix Materials), Tex 204F)
Dust Ratio (Site Manager (Agg. Mix Materials), Tex 203F, 204F)


Legend
More Important Data
Less Important Data
TxDOT Tested/ Avail. Data
Not Tested or Available
Holding Box/Element
Bitumen Stabilized Base Resistance to Frost Action (Not Available, Not Tested)
Cont'd on Pages 8, 9 and 12F
Binder Viscosity/Penetration (Site Manager (Test Results),Spec. Item 300 Tests)
Binder Grade/Classification (Site Manager (Agg. Mix Materials), Spec. Item 300 Tests)
Mixing Water Impurity (see previous, Not Tested)
Bitumen Stabilized Base Resistance to Subgrade Infiltration (Not Available, Not Tested)
Admixture Type (Site Manager (Material
Binder Properties
Admixture Properties
Binder Soil Plasticity or Character (Site Manager (Test
Aggregate Hardness (Not Available, Not Tested)
Continued From Page 2F
Binder Soil/Fines
Aggregate/Soil Gradation
Continued from Page 1F
Mixture Cohesion (Not Available, Tex 126E, 204F)
Constituent Properties
Aggregate Properties
Aggregate Shape (Not Available, Tex 460A)
Aggregate Crushing Strength (Not Available, Not Tested)
Bitumen Stabilized Base Stability – and Resilient Modulus of Elasticity (Site Manager (Test Results, Agg. Mix Compressive Strength), Tex 126E, 204F)
Mixture Internal Friction (Not Available, Tex 126E, 204F)
Mix Proportioning
Aggregat e Surface Texture (Not Available, Tex 460A)
Aggregate Durability (Site Manager (Test Results), Tex 410A, 116E)
Continued on Page 2F
Continued from Page 2F
Mixture Density (Site Manager (Test Results, Agg. Mix Description), Tex 113E, 115E, 126E, 204F, 207F)
Aggregate/Soil Gradation (Site Manager (Test Results, Material Gradations, Agg. Mix Gradations),Tex 200F, 110E)

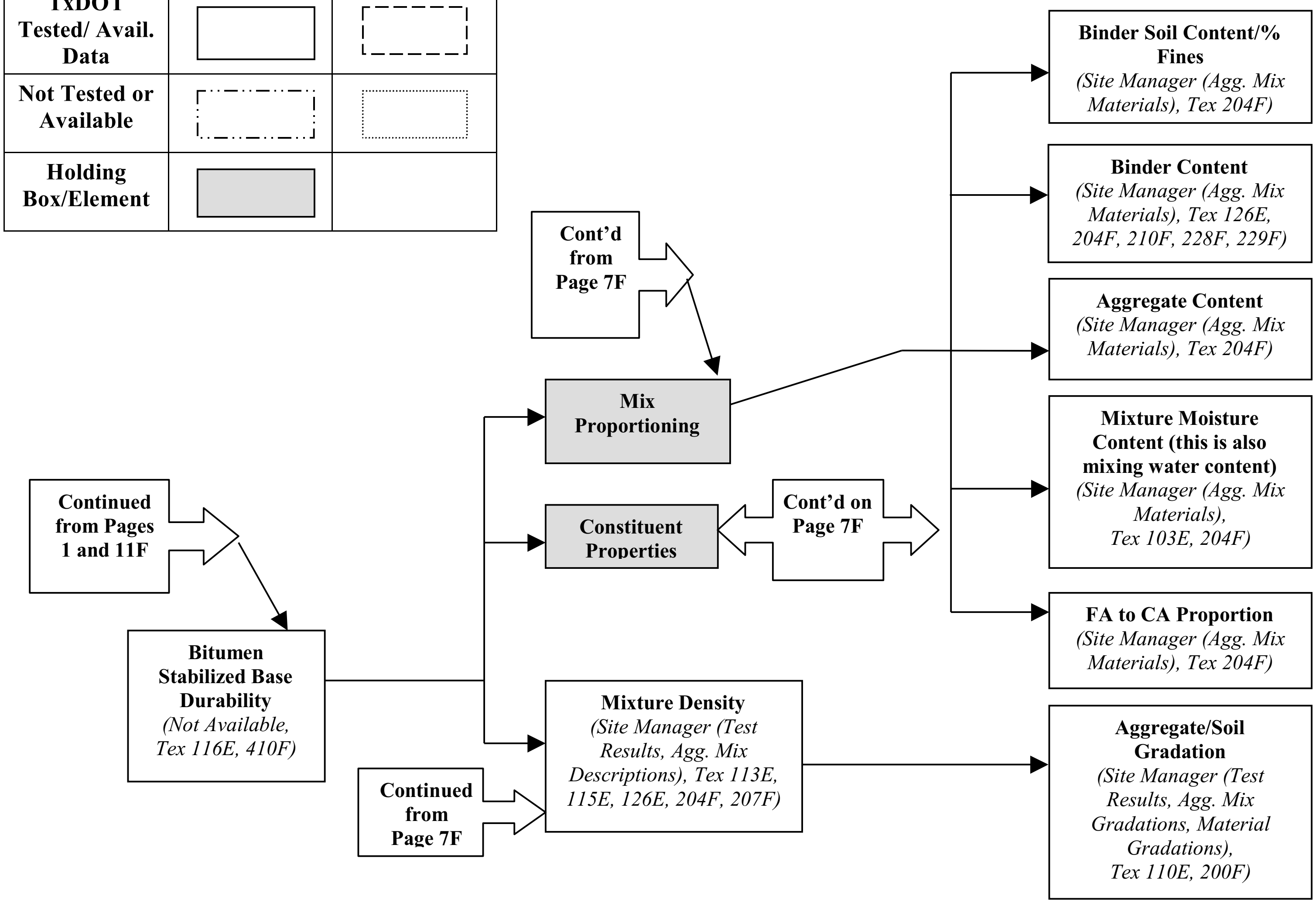
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		

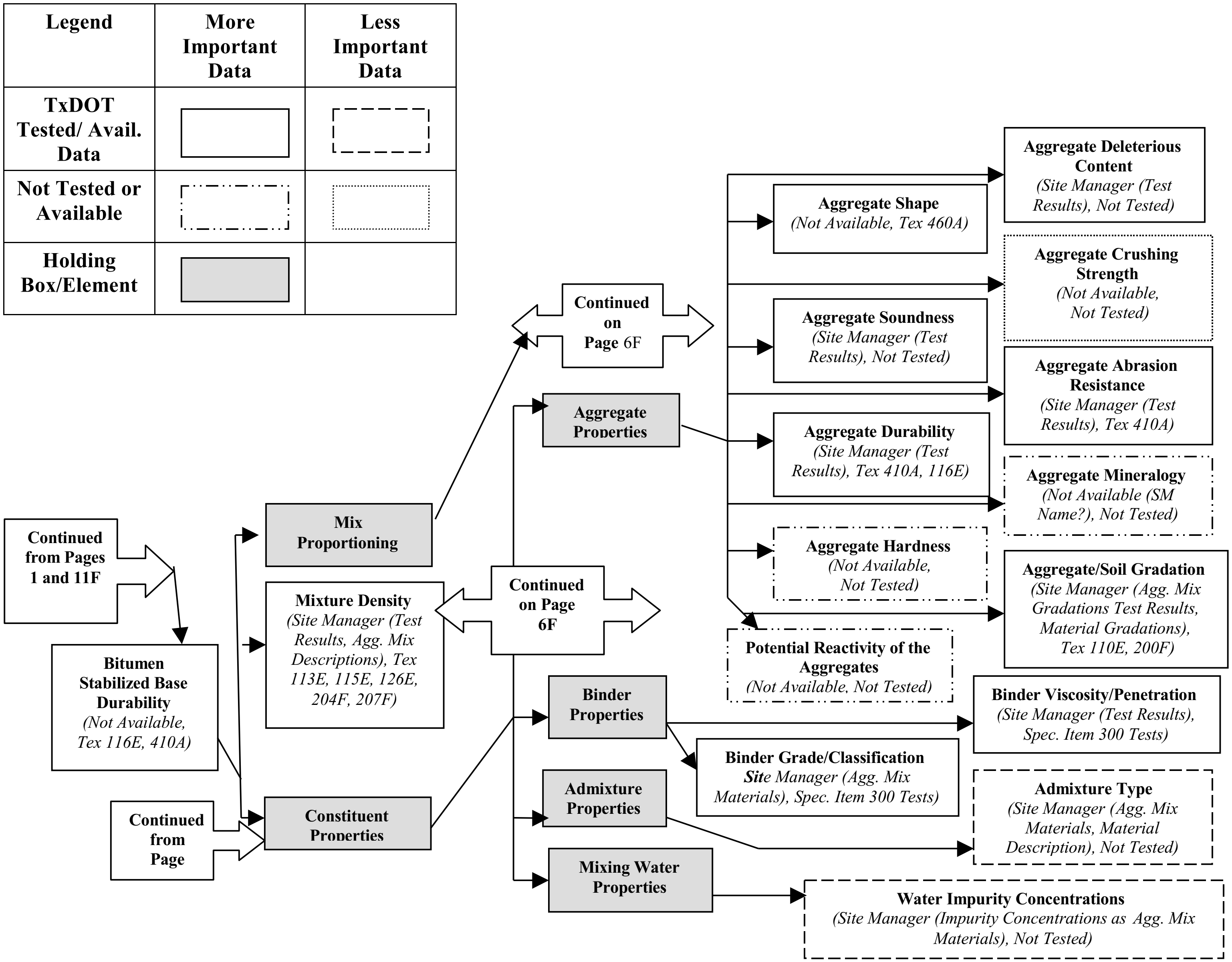


Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		

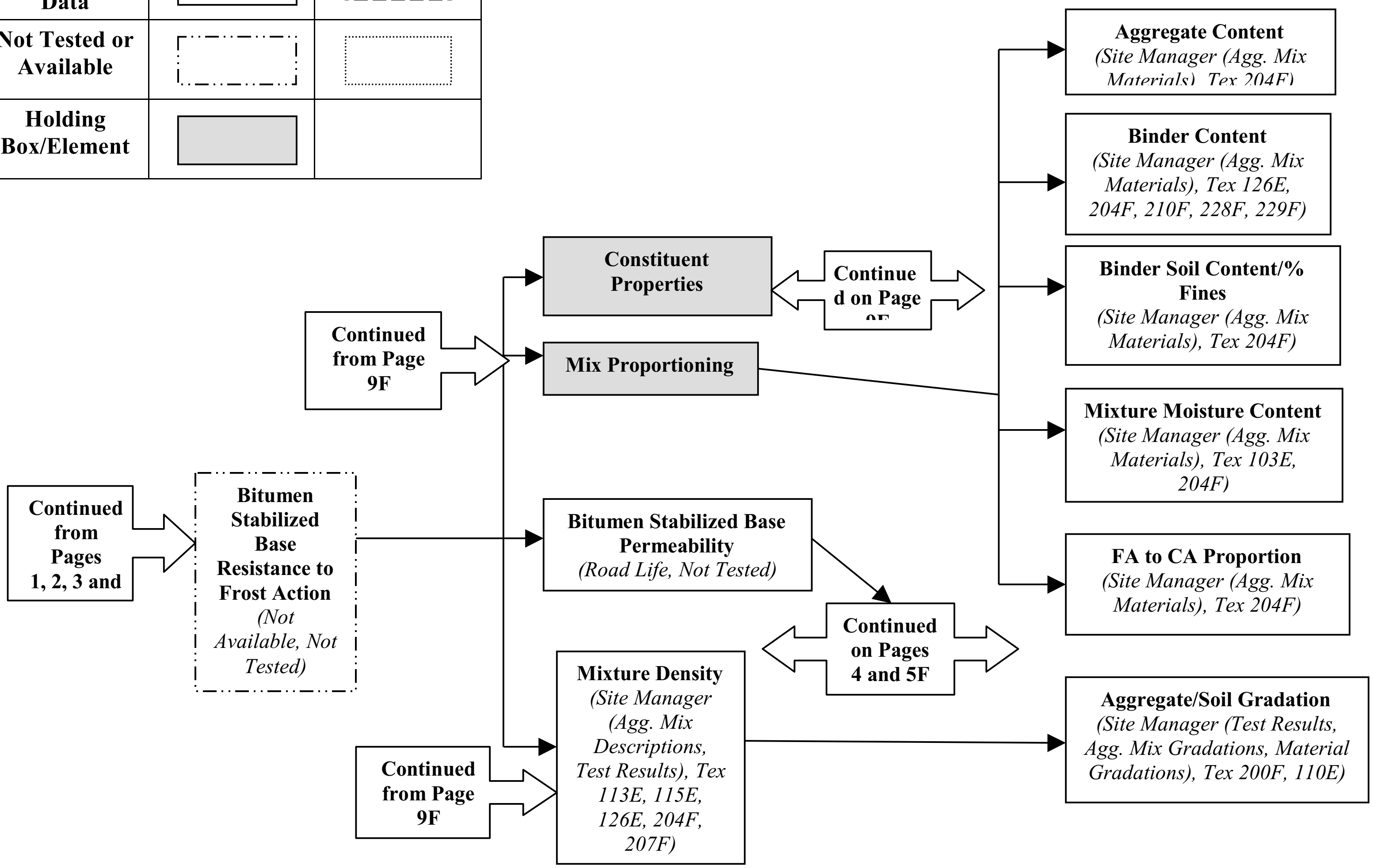


Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		

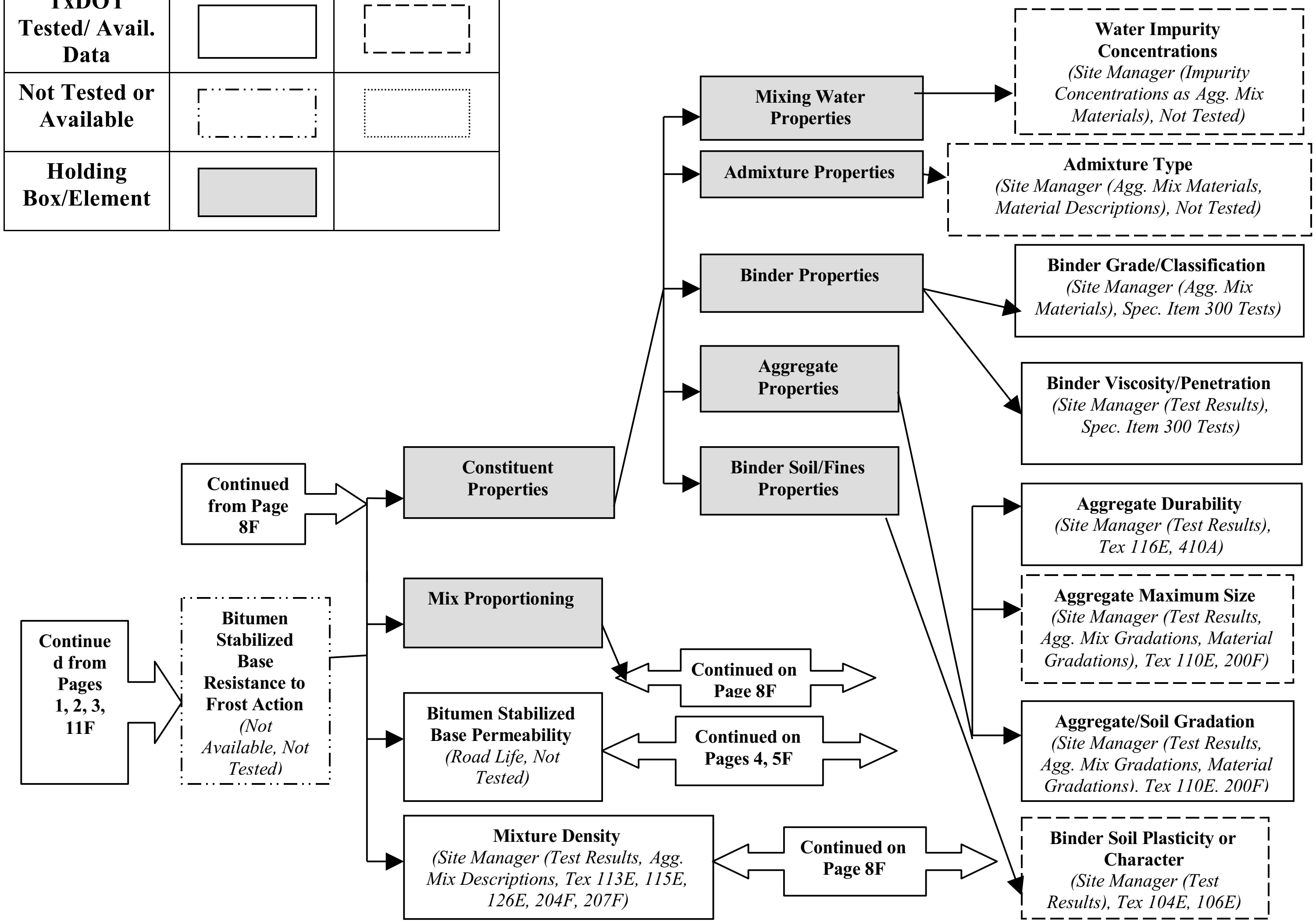



Legend
More Important Data
Less Important Data
TxDOT Tested/ Avail. Data
Not Tested or Available
Holding Box/Element
Continued on Page 6F
Aggregate Properties
Aggregate Deleterious Content (Site Manager (Test Results), Not Tested)
Aggregate Shape (Not Available, Tex 460A)
Aggregate Crushing Strength (Not Available, Not Tested)
Aggregate Soundness (Site Manager (Test Results), Not Tested)
Aggregate Abrasion Resistance (Site Manager (Test Results), Tex 410A)
Aggregate Durability (Site Manager (Test Results), Tex 410A, 116E)
Aggregate Mineralogy (Not Available (SM Name?), Not Tested)
Aggregate Hardness (Not Available, Not Tested)
Aggregate/Soil Gradation (Site Manager (Agg. Mix Gradations Test Results, Material Gradations), Tex 110E, 200F)
Potential Reactivity of the Aggregates (Not Available, Not Tested)
Continued from Pages 1 and 11F
Mix Proportioning
Mixture Density (Site Manager (Test Results, Agg. Mix Descriptions), Tex 113E, 115E, 126E, 204F, 207F)
Continued on Page 6F
Bitumen Stabilized Base Durability (Not Available, Tex 116E, 410A)
Continued from Page
Constituent Properties
Binder Properties
Binder Viscosity/Penetration (Site Manager (Test Results), Spec. Item 300 Tests)
Binder Grade/Classification Site Manager (Agg. Mix Materials), Spec. Item 300 Tests)
Admixture Properties
Admixture Type (Site Manager (Agg. Mix Materials, Material Description), Not Tested)
Mixing Water Properties
Water Impurity Concentrations (Site Manager (Impurity Concentrations as Agg. Mix Materials), Not Tested)

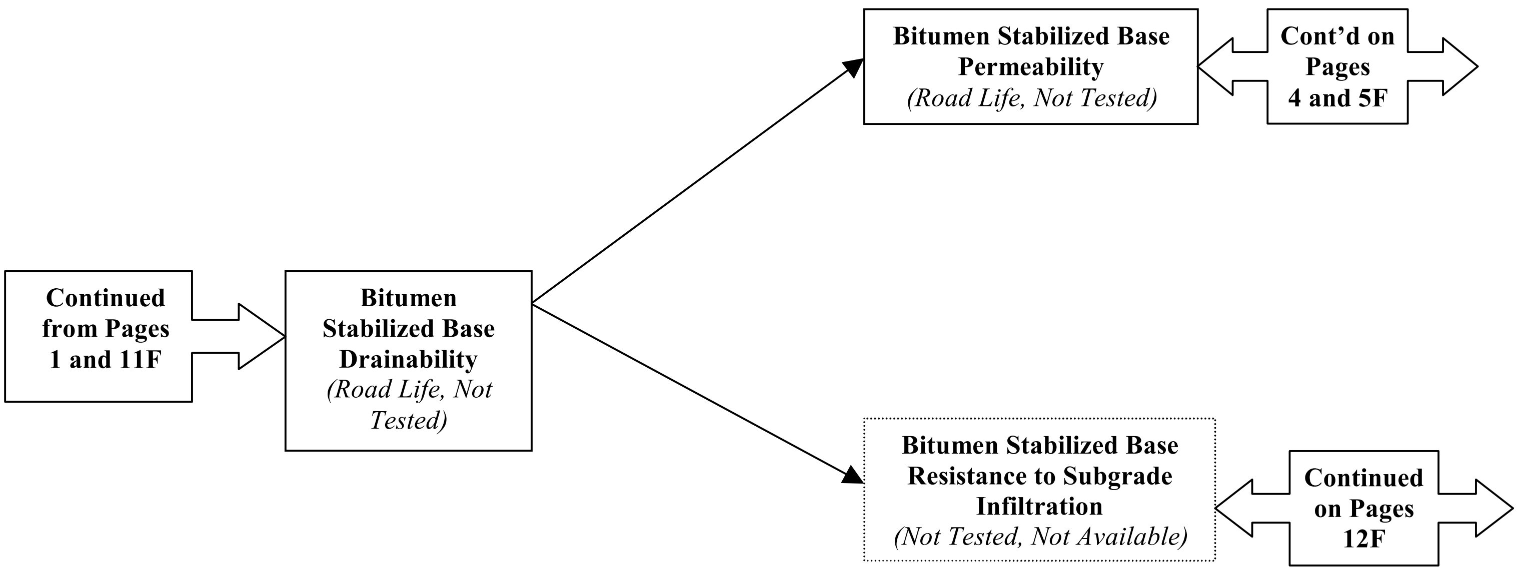
Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element		



Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
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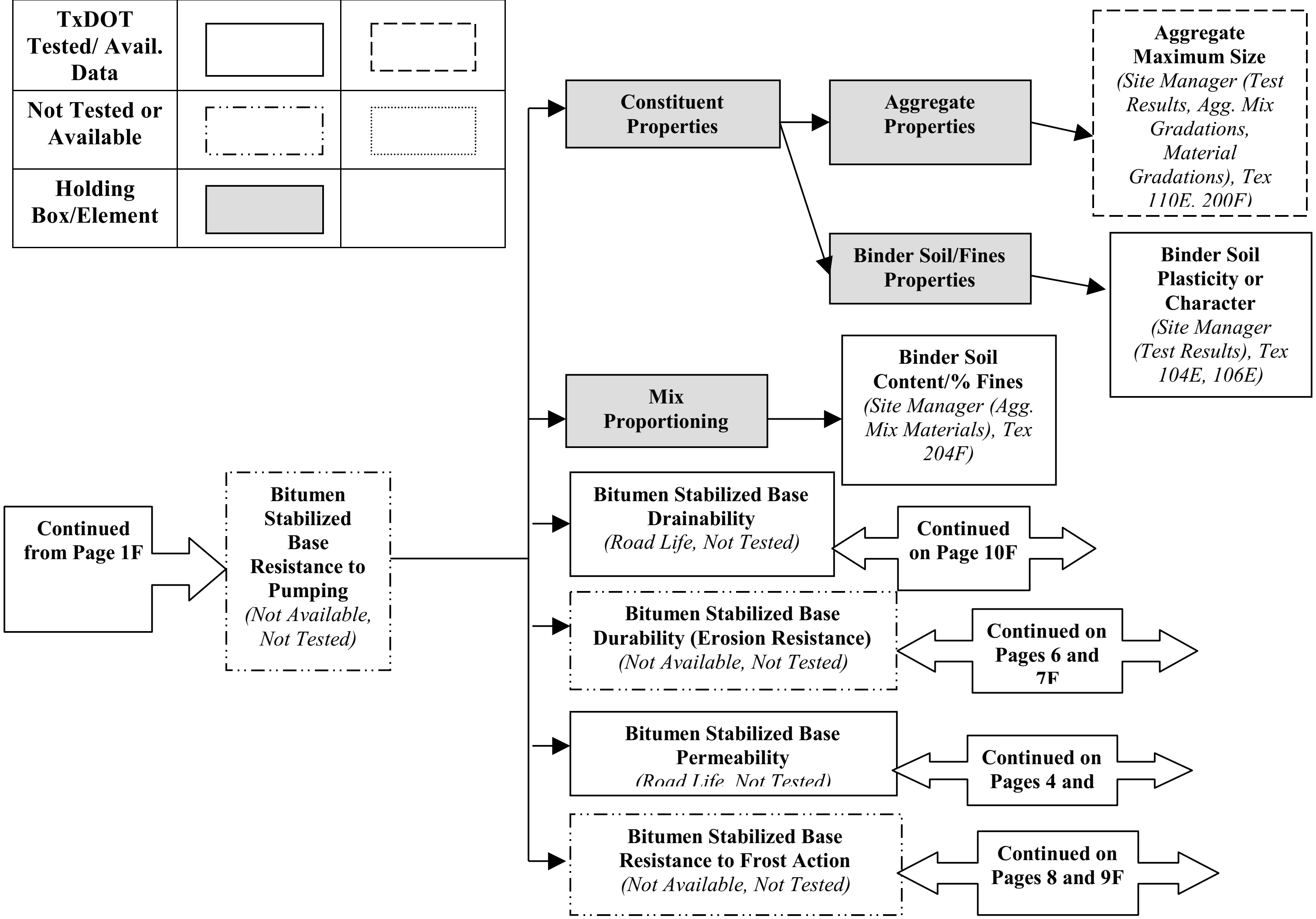
Holding Box/Element		



Legend	More Important Data	Less Important Data
TxDOT Tested/ Avail. Data		
Not Tested or Available		
Holding Box/Element