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Author

Harvey, J.

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J. Harvey, UC-Berkeley Pavement Research Center
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Vision for Caltrans/UC-Berkeley Partnered Pavement Research Center

The vision for the Caltrans/UCB Partnered Pavement Research Center is that Caltrans and other partners will have continuously improving state-of-the-art pavement technology to maximize the level of service to the users of Caltrans pavements, while optimizing expenditures on the pavement infrastructure.

Mission for Partnered Pavement Research Program

The mission of the Caltrans/UCB Partnered Pavement Research Center (PPRC) is to perform research, development, advising and training needed to provide Caltrans and other partners with state-of-the-art pavement technology. The technology may be developed by the PPRC, adapted from other sources and verified and calibrated for use in California, developed in partnership with other entities through leveraging with PPRC resources, or gathered directly from other sources, depending upon which method is most efficient.

Time Period and Scope of this Vision

The time period for this vision is approximately the next 10 to 15 years. An attempt has been made to incorporate longer-term trends wherever they can be identified, as well.

This vision is primarily focused on pavements for mobility on land for pneumatic-tire vehicles because that is the primary focus of current Caltrans pavement operations, and Caltrans is the primary sponsor of the Partnered Pavement Research Center and user of its results. However, important partnerships that will benefit Caltrans will likely be formed during this period with organizations that primarily perform research on pavements for air transportation, rail transportation, and maritime land-side transportation.

Part I. Objectives for Partnered Pavement Research Program

The objectives of the Partnered Pavement Research Program are as follows:

Continuous Improvement of the Efficiency of Caltrans Pavement Operations. Most of the materials that will be used in pavements in the next 10 years are already being used today, although there is the potential for some breakthroughs for limited applications. Materials research is still vital because the performance and cost efficiency of current materials can still be dramatically improved by changes in their selection, design, role in the pavement structure, construction, and re-use to improve environmental sustainability. However, improvements in the efficiency of Caltrans pavement operations will be obtained primarily from expanded knowledge of pavement behavior, better and more widespread use of knowledge and data in practice, and increased collection, organization and distribution of critical data.

Caltrans pavement operations can be identified by considering the pavement life cycle (right side of Figure 1). These operations include:

- Field and lab tests of pavement condition and materials,
- Design of rehabilitation, reconstruction, and new pavements, and selection of construction strategy,
- Construction quality control and quality assurance, and engineering of construction productivity,
- Performance monitoring and prediction, and
- Programming and performance of maintenance, rehabilitation and reconstruction activities to optimize network condition.

Improvements in efficiency can be obtained in each of these operations through partnered pavement research. Even greater efficiencies can be obtained from the synergy that arises from changes that affect multiple operations, as opposed to fixing one operation while neglecting the effects on other operations.

To meet this objective, research must be targeted to each of these operations. The research must be prioritized to address:

- short-term problems that Caltrans must address (work requiring several weeks to several years),
- medium-term problems that are identified as providing large efficiency paybacks over longer periods of time, and
- long-term basic research that will provide the key building blocks for new technologies.

Research, development, and implementation of improved pavement technology require good data. The new technology will require good data on which to operate, and tools to perform the operations. To meet this objective this vision document calls for the development of pavement related databases, and database tools to permit the organization and use of pavement data.

Help Caltrans Improve Its Responsiveness to Its Internal and External Customers. The mission of Caltrans is to provide mobility to Californians. Smooth and safe pavements are a key factor in the Caltrans mission. Caltrans objectives include good communication within the organization and with its customers, and quick response to problems. Development and improvement of data, knowledge, and the proper use of data and knowledge will increase communication and responsiveness.

Within Caltrans, information regarding the condition of the pavement infrastructure, projections for its condition, and its costs must be available to all decision-makers from a district pavement designer to the Director. Decision making without data is biased and error-prone, and data without the tools to make sense of them are confusing and useless.

To be responsive to the public, Caltrans must provide quantitative information and accurate and timely planning information regarding pavement operations that will affect the traveling public, local communities, and the environment when solving pavement related mobility problems. Reliable, accurate and timely information regarding pavement operations is required for Caltrans to have effective two-way communication with its customers.

The databases and tools described in this vision document are intended facilitate this objective by putting information in the hands of Caltrans decision-makers so that they can make timely and informed decisions. The databases and tools are also intended to provide Caltrans with information that can be used to communicate with the public regarding the duration, cost, life, condition, and construction duration for Caltrans pavement projects. The information should also improve Caltrans communications with its pavement contractors (in both directions), and Caltrans ability to assess the quality and productivity of their work.

<u>Improve the Sustainability of Pavement Structures.</u>
Caltrans includes within its goals, sensitivity to the needs of the environment, and a role as good stewards of public resources. Research that increases the sustainability of the pavement infrastructure will help Caltrans meet both goals.

Sustainability of the pavement infrastructure is defined for this vision document as achieving a state of pavement operations in which acceptable pavement network serviceability can be maintained over the period in which pavements will be needed for mobility, without unacceptable degradation of the environment or unbearable costs. At this time, the end of the period in which pavements will play a large role in mobility cannot be identified, although it is certain that the vehicles operating on the pavements and the pavements themselves will certainly change.

It is expected that the trend of defining pavement problems within larger systems to account for the full impacts of the pavement industry will continue (Figure 2). It is expected that current movement within the pavement industry towards increased sustainability will accelerate, and that typical pavement system problem identification boundaries of the “pavement network” and “transportation facility network” will increasingly be expanded to a “sustainable transportation infrastructure” (Figure 2).

The most significant increases in sustainability of the pavement infrastructure over the next 10 years will likely be obtained by

- reducing the long-term rate at which finite natural resources (currently these primarily consist of new aggregate, asphalt, hydraulic cements, and steel) will need to be produced for use in pavements,
- decreasing the number and extent of construction operations that need to be performed,
- decreasing traffic delays caused by pavement operations, and
- decreasing vehicle operating costs (fuel, wear and tear) associated with pavement serviceability.

Currently identified means of achieving these objectives include

- increased life and serviceability of pavement structures and paving materials in them through better construction, design, maintenance, rehabilitation, and reconstruction,
- re-use of existing pavement materials and waste materials from other industries, but only where the re-use is cost effective and where it does not prevent repeated re-use, and
- increased integration of design, construction, planning, and traffic management.

<u>Maintain a Strong Research and Academic Instuction Program in Pavements in California.</u>
To achieve the three objectives described above, effort must be concentrated in two areas. First, practical development and implementation must exist in the industry (defined as government, private industry, and academia). Second, academic research and a steady stream of people entering the industry who have a fundamental grounding in the academic fields of pavements and related subjects must continue. Without these two components, the pace of change within the pavements industry will not be adequate to meet the challenges that it faces.

It must be recognized that as the system boundaries in which pavement problems exist are expanded, the scope of expertise that is applied to pavement problems must also be expanded. It is still vital that academic research be performed on pavement materials and the response of pavement structures to traffic and the environment, but that alone is not sufficient to adequately solve the problems that must be addressed. Increasingly, expertise in fields such as construction management, information technology, instrumentation and electronics, planning, traffic management, solid mechanics, operations research, and geotechnical engineering must be brought to bear on pavement problems.

It must also be recognized that implementation of changes in the pavements industry will require a trained and motivated work force. New people must continuously enter the industry who have a strong academic background in pavements, as it is broadly defined above. In addition to attractive compensation, these new people must be motivated to study pavements and enter the industry by the prospect of entering a rapidly evolving field, which values and uses the knowledge, talent, and energy that they contribute. This is best achieved for many jobs in the pavement industry through initial training in an academic environment. If all pavements training is obtained on the job, the new people entering the industry will primarily learn what has been done in the past, not what should be done in the future.

The academic program in pavements must itself be subject to constant reevaluation and improvement. Areas of academic research must be identified and prioritized to provide the short-, medium- and long-term information required to solve pavement problems. Investment of limited research funds in "solutions looking for problems" must be avoided.

The curriculum in pavements must also keep pace with research and changes in the industry, while maintaining an appropriate balance between information that can be used when the student enters the industry, and basic information that will not change. In particular, the role of critical and systematic thinking and its application to pavement problems must be paramount. A solid academic grounding in the basic theory and practice of pavements significantly aids the application of critical thinking to pavement problems.

<u>Increase the Pace of Change through Partnered Research.</u>
Most problems in pavement research are fundamentally the same around the world. However, without calibration for local materials, environmental conditions, traffic, construction practices, and legal and institutional contexts, the solutions to these problems often do not work well. A principle of the vision described in this document is that research will be partnered to avoid repetition of work that is underway elsewhere and avoid the "not invented here" mentality. This includes actively identifying other organizations interested in the same problems, collaboration to take advantage of capabilities and experience that they may have, and sharing of work where time and resource efficiencies can be obtained.

<u>Increase the Pace of Change Through Training and Access to Technology.</u> Research provides no benefit to Caltrans unless it is implemented. Implementation often requires an effort of similar proportion to the research and development itself. The key steps to implementation include:

- technology transfer to key decision-makers who will authorize implementation,
- the final stages of development that prepare the research results for inclusion in the agency's system (specifications, design guides, software, policy documents, etc.),
- technology transfer to the people who actually evaluate, design, build and manage the pavements, and
- follow-up to the research and technology transfer based on feedback from the users.

In all of these steps it must be remembered that change does not happen unless people take ownership and make it happen, regardless of the documents, software, reports or other materials that are available from the research. This critical fact makes the technology transfer and interaction with decision-makers a requirement for success for all research. The vision described in this document will require an effective technology transfer program if it is to be successful. This requires an effective strategy for transforming the research results into tools and databases that the users can actually use, and an effective strategy for training them not only to use the tools and databases but to understand the limitations and assumptions of the underlying research.

Part II. Overview of Databases and Tools for Caltrans Pavement Technology

To achieve the objectives for the Partnered Pavement Research Program, the vision for Caltrans pavement technology requires databases, tools and expertise that will be used in the processes by which Caltrans provides high quality pavement infrastructure to its customers.

The interaction of the databases and tools in the pavement process is shown in Figure 1. The interactions of the databases and tools are complex. However, these interactions are made simple by the linking of the information in the databases with common indices, as is described below.

Databases

Databases provide the means for storing, indexing, sorting, accessing and reporting information about the pavement system. In this vision, the databases also provide the data used by the tools for pavement analysis and prediction of future performance, and management of the pavement system. The tools may or may not be embedded in the databases. The databases are essential to effective management of the pavement system because they provide Caltrans with past, present and future information of the pavement system. Without the databases, Caltrans management will have difficulty in developing statistically sound answers to fundamental questions, including, for example:

- What is the performance of current strategies as a function of traffic, environment and structure?
- What are life cycle costs of different strategies, based on actual performance? In different regions?
- What are the effects of construction quality on performance and life cycle cost?
- What is the optimal allocation of resources for the yearly and 10-year plans for maintenance, rehabilitation and reconstruction?
- What are the optimal strategies for minimizing traffic delays for rehabilitation and reconstruction projects, and what are the trade-offs between performance and traffic delay for each project?
- What is the existing structure of a specific pavement in need of rehabilitation (material types, thicknesses and properties), and what was the quality of construction?
- How effective are new pavement and rehabilitation design procedures in predicting pavement performance?
- How have our mainline test sections performed, so that we can learn from them?

The databases must be linked, at a minimum, through location identification indices such as route, district, county, post-kilometer, lane number, and direction; through time indices such as date; and through accounting indices such as Expenditure Account (EA) and construction item code. This will permit easy access to variables from different databases by the analysis and reporting tools. Use of GIS coordinates as a link is also a promising option.

The level of detail included in the databases will depend upon the cost of collecting the information, weighed against the impact of the information on the ability of Caltrans to understand and improve its operations. That the detail required for different variables will likely also change with time as specific questions are answered or new problems arise.

Design Input Database

The Design Input Database contains the input values for variables used in the design of new pavements, rehabilitations and reconstruction projects. These variables include, for example:

- materials properties, such as stiffnesses, strengths and assumed construction quality, and whether the design input values were from laboratory tests, or assumed from past data in the Design Input Database or Construction Quality Database.
- traffic, including equivalent axles loads or load spectra, tire pressures, and axle types,
- environment, including temperature profiles and rainfall, either regional or specific for a location,

- deflections, back-calculated stiffnesses, thicknesses and other non-destructive or partially destructive test information regarding the existing structures of rehabilitation and reconstruction projects, and
- desired reliability levels included in the design.

The Pavement Design Tool can use information from the Design Input Database, and may be embedded in it. Data from all new designs will go into the database.

Construction Productivity Database

The Construction Productivity Database contains data collected from construction projects regarding construction productivity, quantities, construction operations, sequencing, and information about specific operations such as asphalt concrete cooling rates, equipment types. It is likely that detailed data from urban projects will be of greater importance than from rural projects, since those locations will require development of strategies that minimize traffic delays.

The Construction Productivity Estimation Tool will use information from the Construction Productivity Database to evaluate the duration and impact of various design strategies and construction sequences, and may be embedded in it.

Construction Quality Database

The Construction Quality Database will contain quality control and quality assurance data from construction projects for variables that directly affect pavement performance, and any additional data that is collected that affects pavement performance or level of service. The data will come from field tests and laboratory tests of field samples. Examples include:

- Asphalt concrete mix design information, and as-built thickness, air-void contents, gradations, asphalt contents, stiffnesses, strengths and fatigue properties,
- Hydraulic cement concrete mix design information, and as-built thicknesses, water/cement ratios, cement contents, gradations, strengths, and chemical durability test results,
- Unbound base, subbase and subgrade as-built thicknesses, compactions, water contents, gradations, and plasticity information,
- Specifications and special provisions used for the project, and
- Smoothness and deflection data collected just after construction is completed.

The Construction Quality Database will be able to provide reports and perform calculations required during the construction project, such as pay factor calculation and quantity summing. It will also provide a means for measuring the effectiveness of specifications and special provisions.

The Pavement Design Tool will use information in the Construction Quality Database to estimate pavement performance using as-built values, as the final stage of the design process.

Pavement Performance Database

The Pavement Performance Database will contain information regarding the performance of in-service pavements. Examples include:

- Traffic data, including ADT, truck classification counts, and weigh-in-motion data,
- Condition survey data, quantifying the types, extents and severities of distresses observable on the pavement surface and shoulders, collected by human surveyors and non-destructive automated devices (if possible),
- Pavement smoothness data, both in terms of summary IRI, and more detailed pavement profiles or calculated values that can be used to identify distresses not visible to human or automated condition surveyors, such as rigid pavement faulting,
- Maintenance activities, including sealing, patching, etc., and

- Potentially, other non-destructive data that can be collected routinely regarding the pavement structure, such as deflections, back-calculated stiffnesses, water contents, voids beneath slabs.

This database will be able to provide reports regarding the state of the pavement network. The data will be used by the Pavement Management and Information Tool to provide optimize allocation of resources, predict future needs, provide models to evaluate the performance of different strategies, and other analyses and reporting functions.

Research Databases

Development of new pavement technology requires understanding of current strategies, operations and performance, and estimation of the performance of changes to Caltrans' strategies and operations. The four databases described above will provide information regarding the past. The Partnered Pavement Research Center database contains information regarding strategies and operations being evaluated for potential future implementation, including laboratory test results, Heavy Vehicle Simulator test results, analysis results, reports, and more detailed information from mainline pavements than can be included in the four main databases.

Additional research databases may be developed by the PPRC, other contract organizations and Caltrans Research.

Together, the four operations oriented databases and the research databases will be used to develop new pavement technology.

Tools

Tools are used to perform tests, analyses, simulations, calculations and reports. They interact with the four databases.

It is envisioned that these tools will be available to industry as well as Caltrans. Common usage will lead toward better communication between Caltrans and industry, and within Caltrans, by providing valid, quantitative information to all parties in their decision making processes.

New Pavement, Reconstruction and Rehabilitation Design Tool

The New Pavement, Reconstruction and Rehabilitation Design Tool (hereafter referred to as the Design Tool) is used to perform the following activities:

- Process design input information, such as traffic data from weigh-in-motion stations, non-destructive field test data and laboratory test data from the Design Input Database, for use in pavement design and analysis,
- Analyze various pavement structures for specific projects and provide estimates of pavement performance for different levels of reliability, to aid the pavement designer in selection of required materials and thicknesses for each strategy evaluated (for example reconstruction of an existing freeway pavement with a flexible pavement or a rigid pavement, or rehabilitation with an asphalt concrete overlay),
- Provide construction cost estimates for each strategy,
- Provide a pavement performance estimate for the as-built structure, considering actual construction quality using information from the Construction Quality Database, and
- Provide life cycle cost estimates for each strategy (traffic delay estimates can be included based on construction delays estimated using the Construction Productivity Tool, provided a standard traffic delay estimation process is developed).

The Design Tool will be based on mechanistic-empirical principles, using current state-of-the-art information and methods from around the world, and information developed from research specific to California sponsored by Caltrans and other organizations.

The Design Tool will specifically address rehabilitation and reconstruction strategies, as well as new pavements, for both flexible and rigid pavements.

The mechanistic-empirical philosophy for the Design Tool will permit rapid and cost-efficient evaluation of new materials, structures and construction quality using standard laboratory tests and computer analysis. This will provide a first-cut analysis of the viability of new strategies, without the need to proceed directly to costly mainline pavement test sections that require decades of observation before conclusions can be drawn. New technologies that appear promising based on the results of the Design Tool calculations can then be evaluated through Accelerated Pavement Testing (with the Caltrans Heavy Vehicle Simulators) or mainline tests sections, with a much greater confidence of positive results.

The method will also be able to develop information for policy decisions regarding the impacts on pavement life of changes in traffic, such as repetitions, loads, tire pressures and axle configurations. The method will be able to consider these traffic variables, which the current design methods cannot do well because it is based entirely on historical data collected in the 1950s, 1960s and 1970s when fewer repetitions, lighter loads and lower tire pressures were the norm.

The Design Tool will also be able to explicitly consider the widely different environmental regions in California and their impact on pavement performance for different types of pavement structure.

The Design Tool can be used to develop rational pay factors for pavement construction QC/QA based on performance prediction instead of judgement. The interaction of different variables can be considered as well, such as asphalt content and air-void content in asphalt concrete, or flexural strength and slab thickness for hydraulic cement concrete. This will provide appropriate disincentives to keep contractors from collecting a large bonus for good control of one variable, while taking a small penalty for another variable, the interaction of which produces poor pavement performance.

Materials design will be integrated into the Design Tool where applicable. An important example is the design of asphalt concrete mixtures to obtain properties required for adequate performance with respect to fatigue cracking, rutting and thermal cracking. A mechanistic-empirical process for specifying required performance with regard to these distresses based on laboratory tests and analysis will be included in the Design Tool. In some cases, such as for rutting of asphalt concrete, a fundamental understanding of the problem must still be developed, which can then be rationalized in scope to produce economical and practical design procedures.

Construction Productivity Tool

The functions of the Construction Productivity Tool are as follows:

- Analyze information from past construction projects, to aid in predicting the productivity of future projects,
- Identify construction productivity constraints so that policies can be developed to mitigate the effects of the constraints,
- Support selection of optimized rehabilitation processes to maximize construction productivity and minimize traffic delays, and
- Estimate the optimized production for rehabilitation and reconstruction projects, and the associated hours of closure required to complete a project.

The Construction Productivity Tool will use past data from the Construction Productivity database, and design information generated by the Design Tool. Once a set of strategies has been designed using the Design Tool, the engineer can estimate project construction durations using the Construction Productivity Tool. Various construction strategies can be analyzed to determine those with the shortest durations, or lowest costs.

Traffic delay costs can be included in life cycle cost analysis using construction duration information from the Construction Productivity Tool, provided Caltrans adopts a standard, and easy-to-use method, for calculating network traffic delay costs.

Traffic management plans can be developed in conjunction with evaluation of construction strategies, providing information regarding the impact of traffic closure constraints on construction productivity, and the impacts of construction strategies on construction durations. For example, a requirement that the contractor be able to evacuate a lane with two-hour notice, may constrain construction strategies so that the project takes 10 weekend closures to complete instead of 6 weekends if the contractor is guaranteed a continuous 55-hour weekend closure.

The Construction Productivity Tool will also be of use to contractors in evaluating innovative strategies, which could reduce the bid costs for rehabilitation and reconstruction projects.

Pavement Management and Information Tool

The Pavement Management and Information Tool (hereafter referred to as the PMI Tool) performs the following functions:

- Database management, and
- Decision support.

Database management activities include storing, sorting, retrieving, and reporting the data in the Pavement Performance Database.

Decision support activities include prediction of future condition of the network under various strategies, calculation of costs, and optimization of investment in maintenance, rehabilitation and reconstruction. Optimization is defined as selection of the set of strategies for the network that achieves the largest increase in level of service for the network for a fixed budget, or the set of strategies that maintains a desired level of service for the network for the least cost.

In current state-of-the-practice pavement management decision support systems, the condition of each link in the network in the next year is predicted in terms of probabilities of change to a new condition category, based on the condition in the current year. The probabilities are calculated from performance prediction models developed from historical data. The accuracy of the models depends in large part on the inclusion in the Pavement Performance Database of all variables that affect pavement damage, the quality of the data collected, and good statistical modelling.

Optimization requires performance models, cost models and the network constraints. The optimization provides the optimal fractions of the network that should be in each condition category in a given year, from which a list of projects can be developed. The optimization analysis can provide an indication of the budget required to maintain the network in a given condition (or level of service), or improve the condition of the network. It can also provide an indication of the deterioration of the network if an adequate budget is not available, and the budget increase needed to maintain a steady state average condition.

The performance models in the PMI Tool can be used to determine the mean and variance of life for different rehabilitation, maintenance, reconstruction and new construction strategies if pertinent data is included in the Pavement Performance Database. The PMI Tool estimate pavement life as a function of climate region, facility type, traffic, and construction quality, provided those variables are accessible in the Pavement Performance Database, and Construction Quality Database.

An initial estimate of pavement performance can be made immediately after construction is completed, using either the Design Tool (mechanistic-empirical models) or the PMI Tool (empirical models), or both, as an initial indicator of a project's life cycle. Eventually, estimates from the Design Tool and the PMI Tool should converge as improvements are made in both. With this initial estimate, the timing of maintenance, rehabilitation, and reconstruction can be programmed. This estimate will be made using as-built data from the Construction Quality Database. This will provide Caltrans decision-makers with quantitative support as they develop long- and short-term budgets and project development lists. Eventually, this preliminary life estimate may be used to assess quality pay factors based on performance prediction, as opposed to end-result data.

Laboratory and Field Testing Tools

Laboratory and field testing tools will be required to provide input to the Databases and Tools. Broad areas where Caltrans will need to upgrade testing and measurement capabilities through equipment purchase, development of new methods, and staff training, or will need to change methods of processing data currently being collected, are as follows:

- Non-destructive pavement condition data, including pavement deflections and back-calculated stiffnesses, moisture conditions, pavement layer thickness, rut depths, crack detection, joint faulting, joint load transfer, and smoothness,
- Laboratory test data to provide input to mechanistic-empirical design methods,
- Traffic data, including truck type counts, axle loads (as opposed to reducing all traffic information to ESALs), and potentially lateral wander distributions, truck speeds, tire pressures and axle configurations,
- Construction quality information, as obtained from laboratory design tests, and corresponding field QC and QA testing,
- Construction productivity information, and
- Maintenance, reconstruction and rehabilitation histories for all activities performed on the Caltrans network.

Expertise

A key requirement for the implementation of the vision described in this document is the enhancement of the pavement technology expertise within Caltrans and industry.

- Policy makers will need to be trained to use the information generated by the databases and tools to make policy decisions, make appropriate decisions regarding problems that are identified by the information, and manage the continuous change that will be required to keep the vision for Caltrans pavement technology current,
- Managers will need to be trained to use the tools for performing sensitivity analyses to provide comprehensive statistically sound information to policy makers for the development of new policies, for overseeing the pavement technology operations of staff, and for providing support to staff operations. Managers will also be the driving force in the continuous process of improving the Databases and Tools,
- Pavement “front-line” technology staff in Design, Construction, Maintenance, Traffic Operations, Materials, and Capital Outlay will need to be trained to use the Tools, and to access the Databases to input new information and to develop information for input to the Tools, and
- Industry will need to be trained to use the Tools that it needs to provide innovative solutions.

At all levels of Caltrans and industry, a better basic understanding of pavement behavior, and life cycle cost concepts, will need to be developed.

Academia will need to play a role in improving pavement technology training, through partnerships with Caltrans and industry.

Interactions of Databases and Tools

A strategy and tactics for integration of the Databases and Tools will need to be developed so that they are compatible with each other, and so that they can be upgraded periodically without losing their ability to interact. This will involve integration of software, specifications, bureaucratic processes, information flow, equipment and methods.

Impacts of Vision on Current Caltrans Processes

The vision described in this document will have impacts on the following pavement operations of Caltrans:

- Design
- Construction
- Maintenance
- Rehabilitation and Reconstruction
- Traffic Operations
- Maintenance, Rehabilitation and Reconstruction Project Programming
- Research and Development of New Pavement Technology

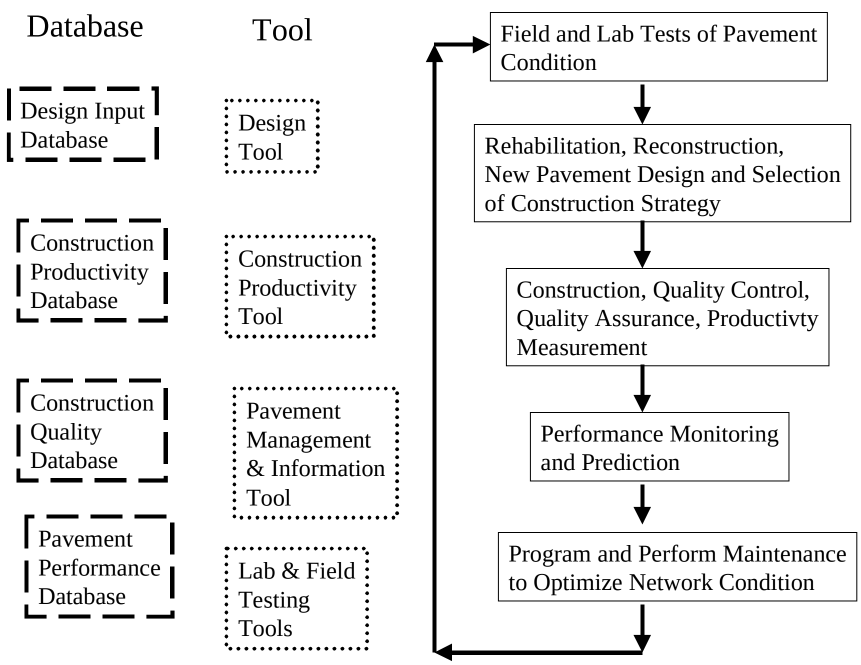

Figure 1. Interactions of tools and databases used to perform Caltrans pavement functions.

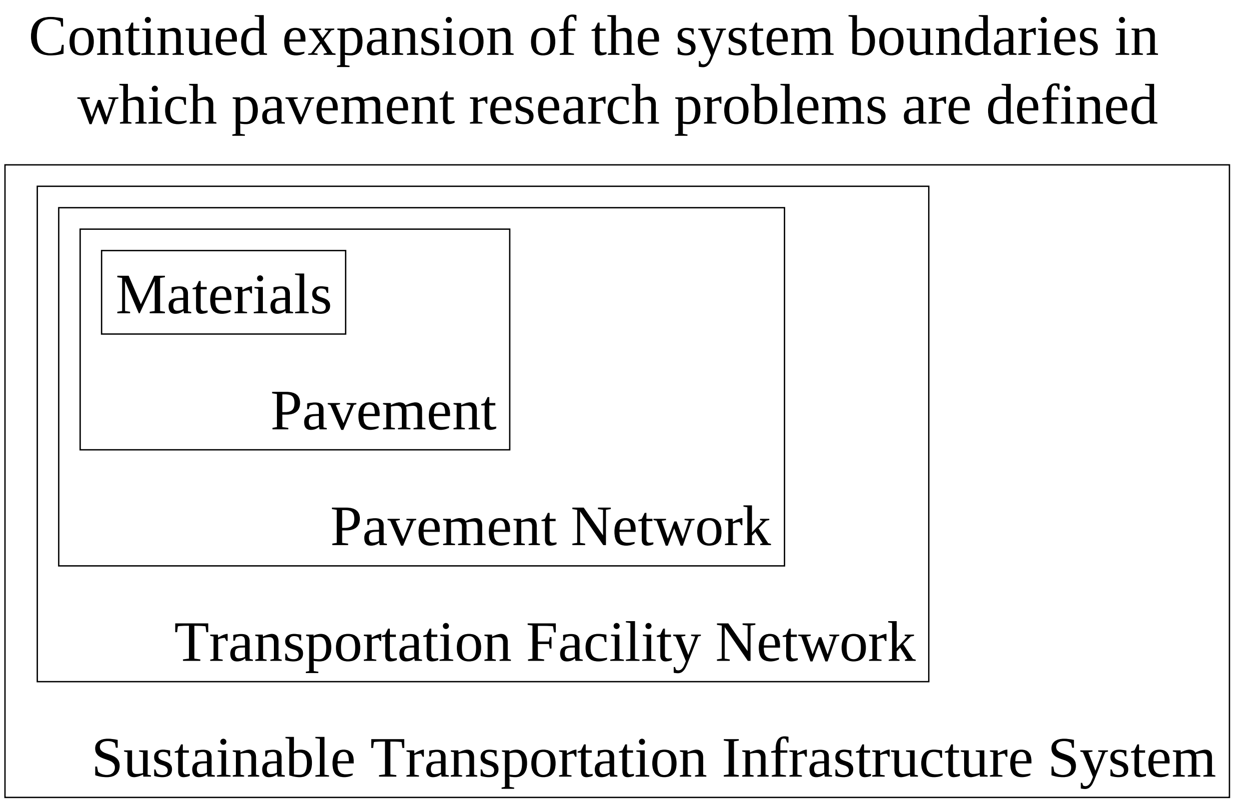

Figure 2. System boundaries for pavement problem definition, expanding to include sustainability of the transportation infrastructure.