# Fostering Innovation in the Strategic Highway Research Program

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**The theme of the Strategic Highway Research Program (SHRP) is innovation and SHRP's Final Research Plans provide a thoughtful guide to the development of new highway technology, materials, and processes. To enhance the environment for innovation in SHRP and more generally in the national highway program, there must be an openness to unusual and novel ideas and the means and incentives to bring about change in the highway product procurement and construction contracting process. Presented here is some of the background material developed to create a climate conducive to the serious consideration of creative ideas and unsolicited proposals, the support of innovation, and the extensive involvement of private industry in SHRP and public-sector highway research. In particular SHRP should encourage the development of widely accepted performance tests and specifications so that there is a foundation for awarding highway product procurement and construction contracts on the basis of long-term performance and life-cycle costs. These would provide the incentive for widespread innovation and the development of premium products and materials not only within the duration of SHRP but also thereafter.**

Planning under the preimplementation phase for the $150 million, 5-year Strategic Highway Research Program (SHRP) was completed in May 1986. This research program seeks to generate technological breakthroughs for highway materials, equipment, and processes in six technical areas: asphalt, long-term pavement performance, maintenance cost-effectiveness, protection of bridge components, cement and concrete, and snow and ice control. The main theme of this research program, "The Search for Innovation: Highways," was outlined in TRB Special Report 202 *(1)* by the Strategic Transportation Research Study (STRS), which called upon the nation to undertake this historic research program.

During the SHRP preimplementation phase three strategies were pursued to create an environment for innovation. The first was to review the nation's current highway technology and identify research activities that have a high probability of extending the frontier of knowledge in the six technical areas that form SHRP. The process resulted in a detailed and integrated research agenda *(2)*. This is a guide to a visionary set of new products, materials, and processes likely to produce a large payoff to the nation in terms of more durable highway facilities and more cost-effective construction and maintenance practices.

The second strategy was to explore the feasibility of earmarking some portion of SHRP funds expressly for innovation. Grants in various sizes could be offered to various sectors of the highway research community to propose novel ideas and to develop prototypes and test their technical and economic feasibility.

The third strategy was aimed primarily at finding ways to increase the innovative resources of the private sector devoted to highway research, particularly in coordination and cooperation with SHRP.

Discussed here are some general principles for fostering innovation, a proposal to earmark a portion of SHRP funding to stimulate innovation, and additional ideas that stemmed from a workshop in which private industry representatives participated. The purpose of the workshop was to find new ways to involve private firms in SHRP and public-sector highway research.

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## GENERAL PRINCIPLES FOR FOSTERING INNOVATION AND CREATIVITY

Early in SHRP's preimplementation phase, the staff identified principles known to be conducive to innovation and creativity. Many of these principles come from the literature on creative problem solving *(3–6)*. Others are derived from sound practices for managing applied research programs *(7–9)*. These principles were intended to stimulate the thinking of AASHTO's Task Force, SHRP's policy-making body, regarding how to create an environment for innovation.

### Incremental Problem Solving or Conceptual Leaps

Novel ideas do not occur within a vacuum. To a large extent radically different and effective ideas are based on previous work and occur within some context. Highly creative and structured problem solving, even the incremental sort, can take researchers a long way from the starting point. Eventually ideas may emerge that appear altogether new, even though they were reached step by step.

The alternative is to jump out of the customary conceptual framework. A term for this that is creeping into the popular lexicon is "jootsing" (jumping out of the system) *(10)*.

SHRP can foster true innovation in two ways: (a) by encouraging very effective, highly structured incremental problem solving aimed at producing novel solutions to specific problems and (b) by trying to stimulate conceptual leaps.

### Courting the Illogical

In normal logic A *and* B cannot be true at the same time. However, too often the transportation research community

remains under the spell of normal logic and sees a problem as a distasteful or insoluble dilemma, A *or* B, black or white. For instance, on the one hand a research engineer may balk at trying to develop a superdurable pavement because of a conviction that it will be uneconomical: initial construction costs will be too high. On the other hand, short-lived pavements mean high subsequent maintenance and traffic management costs.

Under the logic of creativity both A and "not A" can be true. One may have low initial construction costs and low maintenance expenses. Innovative thought searches for ways to sidestep or transcend dilemmas and to render trade-offs inconsequential.

### Encouraging Counterintuitive and Contradictory Ideas

To encourage innovation SHRP needs to cultivate ideas that are counterintuitive or even contradict the conventional wisdom. Invention often comes from a tinkerer, a lonely genius, or some free-wheeling team or task force that had a brainstorm. But a great idea is not enough. Innovators need the strength to champion their ideas or they need a beneficent patron to provide the encouragement, support, means, and will for implementation. SHRP has to seek out and support individuals with unusual ideas and shelter such free thinkers until their ideas are demonstrably infeasible.

SHRP needs also to try to stimulate spontaneity and unusual thought patterns. A serious type of playfulness and casual thinking is in order—for example, metaphorical thought. Metaphors point to useful analogies. To say "transportation is weather forecasting" suggests that it is important to be able to predict moisture, humidity, and snow and ice conditions. These conditions clearly have a bearing on all six SHRP topics but most obviously on the mechanisms of setting and strength development in concrete, bridge protection, and snow and ice control. Weather forecasting involves advanced techniques of remote sensing, communications, and early warning of problems. By thinking of highways metaphorically as weather forecasting, new perspectives and ideas begin to emerge that may have practical value.

SHRP also needs to create crucibles—intense problem-solving situations—in which those with very different or opposing perspectives wrestle with research dilemmas and seek innovative solutions.

### Internalizing Externalities

Every perspective is bounded. Creative solutions usually require stepping outside those bounds. Conversely, bringing the outside perspective inside, or internalizing externalitics, may be required, which is a well established and desirable principle in economics and psychology, as well as the kind of change that leads to innovation. An individual's perspective may be enlarged to encompass unfamiliar views by serving on a multidisciplinary team. Still another way to internalize externalities is to complement one perspective with its opposite:

Maintain/improve: A highway research team composed of construction engineers should be complemented with maintenance engineers, and vice versa.

Young/old: A group of senior, seasoned professionals should be complemented by young professionals fresh from the universities and conversant with the state of the art as well as speculative and unproven ideas.

Public/private: A group of public officials should be complemented by some from private enterprise.

Expert/lay person: A group of experts should be complemented with articulate lay people.

Micro/macro: A group with a tendency to look at everything as a unique problem should be complemented by those who can see each unique problem as a part of a larger interrelated set of problems and who are sensitive to gestalt properties—phenomena evident in the whole but invisible in the parts.

Hard/soft: "Hard" engineers should interact with "soft" engineers and vice versa. Ultimately the products of hard engineering will be used for decision making and will depend on the soft side of engineering—top-quality software, database management, planning, and decision-making tools. Particularly difficult will be the melding of the now incompatible perspectives of (a) emphasizing the extension of the physical life of pavements and (b) making decisions based upon economic life, which derives from such concepts as life-cycle cost analysis.

Producer/user: Engineers and planners build and sell transportation products and services. Their views should be complemented by the user—the customer. The idea to research what level of pavement smoothness the highway user desires, at different costs, is good. It forces engineers to look at the problem not from their customary viewpoint but from that of the user. *A Passion for Excellence (9)*, the sequel to *In Search of Excellence (8)*, emphasizes two points that make successful companies: innovation and staying close and listening to the customer.

Highway/vehicle: SHRP tends to focus on the roadway, but an inverted perspective, one that approaches the problem from the standpoint of vehicles, is useful. From this perspective come such ideas as reducing pavement deterioration by regulating tire pressure of heavy trucks or the concept of designing trucks to fit the highway instead of the reverse.

### Constructing Counterfactuals

A powerful and commonly used technique for producing innovation is to visualize a future that has solved a problem intractable in the present. By working backward from the future visualization, one is often led to a solution to the current problem. SHRP should give free play to counterfactual thinking and guided fantasies, and try to create a climate for bridging novel conceptions of the future and current practices.

Innovations occurring in fields outside transportation can serve as guides to the future. Rapid progress in material science, remote sensing, nondestructive testing, robotics, computer hardware and software, artificial intelligence, and financial management, when combined, can suggest a future in some ways very different from today. Visualizing how this constellation of new technology might be applied to highways and what highway practice might consist of 5 years from now can lead to thinking about what steps to take in order to build a more productive future that represents a conceptual leap from current thinking.

### Nurturing Competition

Private firms and others are increasingly finding that competition sparks innovation. Indeed, competition is no stranger to

architecture, engineering design, and the research community. Design contracts are frequently awarded on the basis of design competition, and consulting firms and research organizations regularly compete on the basis of qualifications or innovative proposals for research contracts. The competitive process normally results in a better product. Innovation within SHRP is more likely to occur if SHRP nurtures competition aimed at producing novel ideas.

### Leveraging Research Dollars

Research programs like SHRP should use their limited resources to stimulate innovation and find ways to engage as many people as possible in productive, focused, creative, and unconventional thinking.

These are not incompatible terms. Corporations, whose survival depends upon constant innovation, create a climate in which research is structured but unfettered. Breaking habitual thought patterns must be consistent with the research agenda and business at hand and put in the service of creating new products or procedures that yield profits in the private sector.

Analogously, SHRP must yield net benefits in the public sector, and is more likely to do so if it can induce large numbers of thoughtful people to work on a carefully worded research agenda.

### Loose-Tight Goals and Objectives

Research objectives must be carefully worded to stimulate innovation. The problem statements must be clear, but not so focused to be prejudiced against novel ideas.

In the area of snow and ice control, if the overall objective were a new way to overcome the bonding between ice and pavement, it would be too narrow. In contrast an overall objective of solving the problem of keeping vehicles from facing icy or snowbound roads invites broader, more creative thinking. Indeed, SHRP research may lead to the invention of a new type of snow fence, better bad-weather warning systems, new types of pavement to which ice does not adhere, new deicing chemicals, and electronic signs that recommend less hazardous routes to motorists.

## EARMARKING FUNDS FOR INNOVATION

During the preimplementation phase, SHRP's Advisory Committee for Overview and Integration recommended to the AASHTO/SHRP Task Force that SHRP seek unsolicited proposals to bring about technical innovation and create an open program for innovative research.

The Advisory Committee for Overview and Integration grappled with the question of what incentives should be provided to researchers. Any level of funding devoted expressly to stimulating innovation should be large enough to create a critical mass and result in meaningful new ideas, but should not be so large as to detract from SHRP's general tenor and focus on the six technical areas prescribed in the Strategic Transportation Research Study [Special Report 202 *(1)*]. Nor should the level of funding devoted to innovation be so large that suggestions for innovation would result in questioning the basic thrust of SHRP, for which a consensus had already been built.

In short, the majority of SHRP's resources should be devoted to carrying out research tasks recommended by the contractors for the six technical areas as described in the SHRP Research Plans *(2)*, but some modest portion of SHRP's funding might be applied to stimulating innovation. Perhaps 2 percent of the $150 million, 5-year program, or $3 million, could be devoted to sparking innovation. The $3 million would not have to be divided equally over the 5-year period nor equally among the six research areas, although initially $500,000 could be reserved for each. Rather the money could be spent where it would do the most good, on promising opportunities as they arose. There should be several checkpoints when innovative suggestions would be evaluated, developed further, dropped, or held in reserve for a more suitable time.

The $3 million could be dispensed in the following manner.

First, SHRP could define primary and secondary research objectives in each of the six technical areas: asphalt, long-term pavement performance, maintenance, bridge protection, cement and concrete, and snow and ice control.

Second, through a variety of means, including issuance of Requests for Proposals (RFPs), conducting student and faculty research competitions, and holding brainstorming sessions, SHRP could gain ideas for innovative technology in each of the six technical areas. SHRP could offer the prospect of large cash awards, grants, or other incentives such as profitable contractual arrangements to colleges and universities, research-oriented consulting firms, research institutes and laboratories, private industrial firms, industry associations, and state, local, and federal government.

Third, for each technical area, panels of experts could select the most innovative and promising ideas. SHRP advisory committees, subcommittees, or contractors might serve in this role. Professional resources for the review process could come from AASHTO, TRB, ASCE, ITE, National Science Foundation consultants, colleges, universities, and federal, state, or local government. These panels could award small grants to further develop innovative proposals most likely to yield a large payoff and be implemented by the end of the 5-year research program. Grants could be offered to the proposers if they were qualified to more fully develop the proposal and if not, to others (e.g., universities or consultants).

Fourth, the panels could evaluate the more fully developed proposals and make a judgment about investing more in each idea. The amount of additional investment would be tailored to the size of the expected payoff and the feasibility of delivering a practical, economical, and implementable product by the end of SHRP. Funding could be dispensed in increments as progress on innovation unfolded. Usually up to $500,000 could be awarded in any single technical area to fully develop innovative ideas. More, however, might be available in a single area if an innovation there were exceptionally promising while ideas in other areas were less so.

## INDUSTRY PARTICIPATION

During the SHRP preimplementation phase several obstacles to industry participation in highway resarch, especially the kind leading to innovation, were identified:

1. Too much of the materials market is controlled on the basis of lowest cost;

2. The climate for change is not present nor given sufficient priority;
3. The market is fragmented, frequently parochial, and characterized by an indomitable spirit of independence, both in technical and management activities;
4. There are no generally accepted criteria for evaluating materials and structural performance, and a variability of views is not uncommon even within the same highway agency; and
5. There is a barrier to the acceptance of research and hence an inability to maximize its payoff *(11)*.

To address these obstacles SHRP held a workshop in which 11 individuals knowledgeable about the highway research and development process conducted a brainstorming session regarding how to involve private industry in generating new technology, materials, or processes directly for or in coordination with SHRP. Half the participants were from private industry: General Motors, 3M Corporation, Dow Chemical Company, Owings-Corning Fiberglas, and the National Asphalt Pavement Association. The remainder were Chief Executive Officers of state departments of transportation, SHRP staff, TRB staff, and representatives from the academic community.

The group originally generated more than 100 ideas, which fell into three broad categories:

1. Need for procurement based on performance criteria instead of lowest initial cost,
2. Ways to develop a strong public–private-sector research partnership, and
3. Need for a research champion.

SHRP staff distilled, refined, and added to these ideas to produce a variety of proposals to stimulate the involvement of private industry in SHRP and more generally in highway research and development (R&D) for the public sector. The following discussion concerns the first two categories.

## Procurement Based on Performance Specifications

Public highway agencies have a legal requirement to procure new materials, processes, and technology from the lowest bidder. Highway agencies also award highway construction contracts in a similar manner. The lowest bid is typically defined as the lowest initial cost and fails to take into account long-term performance, life-cycle costs, or a long-run benefit-cost ratio that captures user benefits. Product and construction specifications are usually based on material and engineering characteristics and normally do not stipulate future performance.

In contrast many private firms try, through accelerated testing, to simulate long-term performance. Some also use economic, risk, and market analyses to decide whether to fully develop a product from a prototype and to manufacture, market, and distribute it. Products are improved or dropped in response to market feedback. New products and features are introduced so fast in some markets (obsolescence is as short as 3 years in the electronics industry) that observation of product performance over long periods like 10 or 20 years is irrelevant. Yet private industry finds that it must take life-cycle costs into account and build durability and quality into products from the start. The public highway sector could emulate the private sector more than it has in the past.

Information is currently available to draw conclusions concerning some aspects of long-term performance of highway facilities and products, and it is lacking regarding other aspects. For example, engineers understand fairly well how pavement serviceability (a measure of ride quality) deteriorates over time for rigid and flexible pavements under many environmental conditions. There is a much poorer understanding of pavement distress over the long run.

Similarly across the spectrum of private firms and public highway agencies, performance tests—or the basis for conducting them—exist for some features of highway facilities and products. For other features, both tests and a basis for conducting them are nonexistent. Clearly there exist performance tests for highway lighting. Manufacturers of light bulbs have developed performance tests pertaining to illumination and service life. But performance tests related to the extent of air void entrainment in concrete are lacking.

A major advantage of performance specifications is that they encourage research and development. If the performance specifications are geared to the long run, R&D is likely to lower life-cycle costs. Left free to meet a long-term performance specification in any manner chosen, a manufacturer or highway contractor will have a strong incentive to increase productivity through innovation, provided that the rigors of competition are also involved.

In summary, the information on long-term performance of highway facilities and products is spotty, and many types of performance tests have yet to be developed. Yet enough information is available to begin to change the current specification process to reflect life-cycle costs for products that will be affected by SHRP.

### *Develop Model Performance Specification on Which Contract Would Be Awarded*

There are two possible types of long-run performance specification. The first pertains to behavior of the highway facility or product in real time. Performance is not evaluated until some substantial block of time has elapsed. This sort of specification might stipulate that after 15 years, a performance measure shall not fall below some value $X$.

The second type of performance specification is based upon an accelerated test. Suppose the Accelerated Loading Facility (ALF) being built for SHRP were operational and mobile. Then it might be possible to develop a performance specification based on an ALF test. The specification might require that a newly built pavement be able to withstand the equivalent of 100,000 loadings simulated by ALF over several months without having a measure of performance (present serviceability index, rutting, cracking) fall below $Y$.

Sweden has recently been experimenting with performance specifications as an alternative to their traditional process. The Swedish concept calls for "terminal functional requirements" (performance specifications) for a "room," a length and cross section of road. The highway agency specifies geometric characteristics and performance that must be met at the end of some lengthy period. The functional requirements are expressed in quantitative mechanical or electronic measures.

The client furnishes boring logs for subsurface conditions to bidders, who assume responsibility for the full roadway section, not just the surface. The contractor guarantees the work for 5 to 10 years and is responsible for structural repairs during the period. The contractor provides insurance (a bond) against failure to meet the specifications. It must also insure itself against going out of business during the guarantee period. The Swedish experiment also addresses the bonding capacity of the contractors. The contractors guarantee their work for the first 2 years and rely on insurance for the balance of the performance period.

The proposal here is to develop a model performance specification and award a contract based on it as a demonstration project. This project can pertain to highway projects, products, materials, or processes. The demonstration project should be one that, if successful, would have broad ramifications and could be applied widely in regard to either a specific highway feature or equipment (flexible pavements, bridge decks, drainage, instruments for condition assessment) or bring about substantial change in the current contract letting or procurement process.

### *Industry-Proposed Long-Term Performance Tests*

Developing a model performance specification and awarding a contract based on it can be considered a first step toward changing the current specification process. Widespread change may depend, however, on the development of many additional performance tests, both feasible and infeasible to implement today.

Given the huge market opportunities, there is incentive for private industry to propose performance tests that the public sector could use to formulate long-term performance specifications. These tests must correlate well with long-term performance. It is likely that industry is already in a position to propose a variety of performance tests for at least some highway products on the basis of their past R&D and product-testing efforts.

The process of arriving at tests that can support performance specifications is a delicate one. A test proposed by a firm is a two-edged sword. It can be a way to open up a new market for a new product that meets the test and an associated performance specification. At the same time it can be a way to restrict competition. Firms that participate in setting standards and specifications in the computer industry face this problem all the time. The problem is compounded in the highway sector where understandably public highway agencies insist that they have a role in protecting the public's interest.

Precisely how should these tests be proposed and evaluated so that they can become fully accepted by the public sector and form the basis for performance specifications? There are at least three ways to accomplish this.

First, the highway industry could rely upon existing institutions. Industry currently provides input into the process for formulating specifications of the American Association of State Highway and Transportation Officials (AASHTO), the American Society for Testing and Materials (ASTM), and the National Electrical Manufacturers Association (NEMA). AASHTO's materials subcommittee writes specifications with industry input. ASTM is largely an industry group whose specifications are usually similar to those of AASHTO. NEMA is an industry association that sets specifications for electronic equipment, including traffic signals. All these institutions work with testing laboratories to develop uniform and reliable tests. "Round robin" testing by different laboratories is necessary to determine the variability of a test procedure and develop reliable tests within acceptable tolerances. With encouragement from SHRP and industry leaders, AASHTO, ASTM, and NEMA might agree to evaluate more performance tests proposed by industry.

A second option is to include in the current procurement process for new highway products a requirement that firms propose a long-term performance test along with their competitive bid for supplying the product. Firms might submit bids to supply a product in two stages. First, they would propose a long-term performance test. The government would then request AASHTO, ASTM, NEMA, or other organizations to evaluate the tests and pick the best one. The traditional competitive bidding process would follow. The performance test could serve as part of the basis for selecting the best bid, monitoring the performance of the product over time, or setting performance specifications. SHRP with industry support could encourage FHWA and AASHTO to try this procurement process as a demonstration.

The third option is to rely upon a nontraditional institution whose mission includes developing acceptable performance tests to serve as the basis for performance specifications. An independent testing laboratory, discussed later, is one possibility.

### *Feasibility Study of Independent Testing and Certification Organization and Warranty System*

An independent testing laboratory could conduct tests fundamentally different from the traditional ones performed by the existing materials testing community. Instead government could contract with an independent testing organization to develop and conduct performance tests for highway facilities and innovations that emerge from SHRP.

As a result it would be easier to devise performance specifications that reflect life-cycle costs. Also, it would provide some of the brick and mortar to pursue novel procedures for letting highway construction contracts, such as that developed in Sweden.

Part of this proposal also calls for investigating warranty systems or insurance arrangements to enable contractors to guarantee performance. This was a key part of the contractual arrangement in the Swedish experiment.

In short, it is suggested that an RFP be issued to independent testing laboratories and insurance underwriters to conduct a feasibility study of (a) an independent testing and certification organization for highway facilities, products, and technology and (b) a warranty system with insurance to guarantee performance the costs of which would be paid by contractors or private industry, as the case may be.

Funding for the feasibility study might not be required. A good feasibility study might provide strong leverage for its implementation. Many testing firms and insurance companies

might be interested in this concept and be willing to investigate it as a part of their normal effort to find new business. If funding were required for a study, perhaps either SHRP or a consortium of private industry firms could put up $25,000 to $50,000.

Topics addressed by the feasibility study are as follows; they fall into two categories, one pertaining to testing and the other pertaining to a warranty system with insurance:

1. Testing

- Mission of organization;
- Feasibility of developing and conducting performance tests and devising performance specifications;
- Short- and long-run costs predicated first on testing a few highway products or facilities and then later on testing a broad array;
- Alternative methods of covering costs, including requiring contractors or private industry, or both, to cover all costs;
- Test reliability;
- Ability to certify performance;
- Safeguards against low testing standards that everyone can meet; and
- Test liability exposure.

2. Warranty system and insurance

- Identify alternative warranty and insurance procedures for guaranteeing performance of highways and highway products:
  a. Examples from Europe and other countries,
  b. Other options that the insurance industry may propose;
- Costs of different warranty systems and insurance;
- Options for covering costs
- Product and tort liability (limits on second- and third-party liability); and
- Effect of FHWA's advance notice of proposed rulemaking to eliminate the prohibition against guaranteeing performance for some highway products.

### *Specify in Generic Form Use of New Products*

At the brainstorming session it was suggested that if a major corporation were initially allowed to capture 80 percent of the market for a new product in a state, within 4 years there would be six major companies bidding against it. As long as bids were based upon performance and included maintenance contracts, many firms would be attracted to the market.

Although this suggestion has merit, no state is likely to guarantee a market for a proprietary product. A state or the federal government could, as an alternative, specify that a particular type of product be used, even if only one company produces it.

There is already an important precedent for doing this. FHWA desired a way to protect reinforcing bars from corrosion. FHWA developed and publicized criteria for determining how to evaluate a product's ability to retard or eliminate corrosion. Next they invited private industry to develop a corrosion-resistant reinforcing bar that would be evaluated using the criteria and stipulated that the best product would be required in new bridge decks on the federal-aid highway system. FHWA specified a type of product that would be required, not a proprietary product. Once the firm that developed the best product, an epoxy-coated rebar, began selling it, other firms sought to enter and compete in the market. The result over time has been lower cost and better corrosion-resistant rebars.

It is proposed to follow the example of the epoxy-coated rebars, and to encourage FHWA or some states to require the use in highway projects of some new products recently developed by private industry or developed during SHRP. One possibility might be to specify that calcium magnesium acetate (CMA), a less corrosive and more environmentally benign deicing agent than road salt, be used on 10 percent of the federal-aid system—on roads through environmentally sensitive areas and on long structures. Feasibility studies have indicated that CMA would be 10 times as expensive to produce on a large scale as road salt. But a requirement to use CMA on a substantial portion of the U.S. highway network is likely to induce many private firms to produce CMA, compete with one another, and eventually find innovative ways to bring the cost down.

### *Contract with Industry to Perform SHRP Research and Retain Patents and Licensing Rights*

This concept call for "no-risk research" for private industry. Simultaneously it provides industry with ample incentive to market its products. In return for SHRP funding, industry would share some of its profits with the government.

The following example reveals this concept more fully. SHRP will be seeking to develop many new types of equipment for nondestructive testing of concrete in bridge pavement. In the concrete technical research area alone, SHRP will be seeking new equipment to determine the water–cement ratio, free moisture in aggregates, permeability, air void entrainment, consolidation, adequacy of curing, and the residual service life.

Participation by private industry will be key to successfully developing this kind of equipment and instrumentation. Manufacturers like Hewlett-Packard and General Electric are widely known for their capability to develop new technology. To engage such firms in SHRP research, SHRP would issue RFPs to industrial firms for each type of equipment. The RFP would state that SHRP would provide a certain amount of funding to conduct the research and the contractor that wins the award would retain all proprietary rights, patents, and licenses. The RFP would seek competitive proposals and state that they would be judged on the basis of (a) the qualifications of the firm and its ability to deliver and (b) the firm's best offer for sharing the proceeds of its research with government.

### *Demonstration Project on Three Different Levels of Long-Term Performance*

This proposal represents a way to award contracts for highway construction or new products on the basis of long-run performance. To use highway construction as an example, suppose that contractors were invited to submit separate bids for a highway facility with 10-, 20-, or 30-year service life. A contractor may wish to submit a bid on one or all three levels of service life. The highway agency would then convert the bids to a common measure, such as the number of years of service per dollar, and award the contract on the basis of the lowest bid.

The highway agency could even devise a procedure for calculating the discounted cost savings of one bid over another and use that as the criterion to award contracts.

### *Model Contracts for Highway Construction and Highway Product Procurement Process*

A large number of the proposals presented so far involve defining novel procedures for letting highway construction contracts or engaging private industry in R&D for the public highway sector. The various types of contractual procedures discussed so far are as follows:

- Develop a model performance specification and award a contract based on it;
- Include in the current procurement process for new highway products a requirement that firms propose a long-term performance test along with their competitive bid for supplying the product;
- Develop a contractual procedure similar to Sweden's calling for terminal functional requirements and a warranty and insurance system to guarantee performance;
- Specify in generic form that several new and cost-effective highway products be used in a substantial number of highway projects;
- Contract with industry to perform SHRP research and allow them to retain patents and licensing rights; industry would compete for contracts through competitive bids and would return a fee to government; and
- Invite separate bids on three different levels of long-term performance of a highway facility, product, material, or process.

In addition, many states have been experimenting with the contract-letting process in order to encourage contractors to be innovative and lower costs. Some of these procedures include design-build and detail-build projects and value engineering.

In a design-build project contractors bid both on the design and the construction of a project. They are given substantial freedom in the design stage to develop a prescribed project concept. The freedom allows for innovation and the contractor can trade off the advantages of certain design features against construction costs.

The design-build concept could be expanded to "design-build-and-maintain." This emphasizes life-cycle performance by putting competitive pressure on firms to minimize not only initial costs but maintenance costs as well. An ideal bid selection criterion would be to award a contract to the firm that proposes to deliver the product for the smallest discounted life-cycle costs or discounted net benefits (i.e., this would include user benefits and initial and maintenance costs, while avoiding externalities such as wetland damage or haphazard toxic waste disposal).

The design-build concept has proved practical in relatively few cases in the United States, though it is fairly widespread in Europe. State highway agencies find design-build impractical where there are (a) significant environmental effects to address, (b) right-of-way acquisition, and (c) utility relocation. The complexity of these activities and the need to protect the public interest interfere with the freedom to innovate that the design-build concept offers.

To provide some flexibility in the design stage, at least one state highway agency has used a detail-build concept, in which the key design features are specified and the contractor is left to add minor details and construct the facility. This offers some room for innovation in the design stage.

A more widely applied approach is to attach a value-engineering rider to the contract, which says that if the contractor can identify a more cost-effective design solution and successfully implement it, he can share the savings with the state, say 50 percent of the cost reduction.

Both the detail-build and the value-engineering concepts could also be expanded to included maintenance over the project life as part of the contract.

Because the contractor would have responsibility for the facility over its service life, the problem arises of the ability of the firm to guarantee performance. The average lifespan of highway construction contractors is probably shorter than durable pavements lasting 20 or 30 years. How do firms that remain in business an average of 10 or 15 years guarantee that they will maintain the facilities they constructed and guarantee that performance meets specifications? Similarly how does a private firm with a short life expectancy guarantee the long-run performance of its new products? Another problem is how highway contractors and private industry firms protect themselves against tort liability.

It is proposed here that a small task force of legal experts in private industry and the public highway sector direct a study that would produce a set of model contracts for highway construction and the highway product procurement process. The study would look to both American and European experience for guidance. The model contracts would offer a wide variety of ways to

1. Reward long-run cost performance,
2. Provide incentive for innovation,
3. Guarantee against failure to perform or meet long-term performance specifications, and
4. Protect against tort liability.

The intent of the study would be to produce some contracts that might be used by SHRP with private industry to develop new products, materials, or processes called for in SHRP's six technical research areas.

A valuable by-product would be model contracts that state and local highway agencies could use to select contractors that will improve the long-term cost performance of new and rehabilitated highways.

### *Study Application of SHRP Research Results to Public-Sector Decision-Making Process*

Public- and private-sector decision-making processes differ sharply, impeding the cooperation and input of industry in the innovation process. Suggestions offered at the brainstorming session to increase conformity included "understand the different public-sector and private-sector motivations," "show industry how to make a profit (in the public sector)," and "standardization of terminology could be a big help."

The study suggested here would anticipate how the public sector is likely to convert to a decision-making process more

like that of the private sector once SHRP has produced substantive results. The study would recognize existing obstacles to behaving more like the private sector, such as the reliance on low bid on front-end costs and fragmentation of the industry—in short, market failure. It would anticipate a construction contract and product procurement process that changes from material to performance specifications and rewards superior life-cycle cost performance. Results of SHRP are also likely to permit the public sector to think in terms of

1. Depreciation of extremely durable capital assets;
2. Creation of capital recovery accounts;
3. More extensive use of present-value analysis and internal rate of return to make short- and long-term investment and maintenance decisions (in other words, much greater reliance on life-cycle cost analysis);
4. Possibly more frequent entry into the capital markets for financing (despite more stabilized gas tax financing), thus forcing the consideration of short-versus long-run financial trade offs;
5. Sounder decisions regarding whether to build more durable (higher quality) projects or to perform more miles of work (greater quantity); and
6. Risk analysis of R&D expenditures for new highway technology.

Ultimately there could even be legislation that requires a shift from categorical funding to block grants. Such legislation would recognize that it is more cost-effective to give state highway agencies more freedom in substituting maintenance dollars for rehabilitation and new construction dollars. Data from SHRP's long-term pavement performance study and other technical areas are likely to provide justification for this type of legislative change.

### Public-Private Partnership

Results of the brainstorming session suggested that private industry had much to contribute directly to the SHRP innovation process. Private industry could loan staff, offer laboratories and proving grounds for testing, and provide industry teams that include business managers. Several forms of SHRP–industry partnerships were proposed: a common data base for researchers in university, business, and government; contractual relationships for sharing risks and benefits; joint efforts to establish research objectives; and, perhaps most important, help to devise means for establishing performance specifications.

Industry will not offer its resources with little to gain in return. SHRP must establish clear objectives, targets, or guidelines for industry participation that do not hamper industry's R&D process and impede their access to markets or significantly restrict remuneration.

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