Managing Change in the 1980s: Pavements

William A. Phang

When we speak of management with reference to pavements, we refer to management of the resources—human and fiscal—needed to provide and maintain serviceable pavements in a highway system. When we speak about change with reference to pavements, we address change in pavement technology as it responds to social and economic pressures. But when we speak about managing change, we are referring to the management of resources needed to provide and maintain serviceable pavements in an environment of changing pavement technology, as well as changing social and economic circumstances.

Will there be changes in pavement technology? The answer would appear to be yes. There are powerful forces operating in today's society that create conditions for change. First is the continuing rapid increase in the prices of petroleum-based products used in pavement construction and maintenance and the uncertainty in the supply of such materials. Second is the public concern shown for the quality of the environment, which has caused restrictions to nearby accessible sources of high-quality paving aggregates and has increased the difficulty in the disposal of waste materials. Third is the gradual erosion of the proportion of public revenues allocated to highway transportation, perhaps as a consequence of the perception that the current highway system can in most areas accommodate the lower growth in traffic demand observed in recent years, which has been triggered by rising fuel prices. Fourth is the continuing high rate of inflation, which reduces the buying power of the dollar.

This presentation will develop a number of technical approaches that respond, in part, to the motive forces cited above, develop evaluations of benefits of economics and conservation, and point out steps that can be taken by management to take advantage of these benefits.

TECHNICAL RESPONSES: DESIGN

Full-Depth Asphalt

One technical response, which would be welcome regardless of circumstances, is more efficient pavement structures—that is, a more efficient use of pavement materials. Recent results of a long-term evaluation of various pavement structure materials at the Brampton Test Road (1) suggest that we have been too conservative in our past use of a structural equivalency value of 2 for asphalt concrete in terms of granular 'A' base material. The report suggests a higher equivalency value of 3 for any thickness of asphalt concrete over and above 90 mm. A value of 2 would continue to be used for any asphalt concrete 90 mm or less in thickness. Use of this finding would lead to more efficient pavement designs.

Consider, for example, a conventional pavement design used successfully for many years—140 mm of asphalt concrete on 150 mm of granular base, and on 450 mm of granular subbase. This design has a gravel equivalent of 780 mm, which calculates as

$$
\begin{aligned}
H_e &= 90 \text{ mm} \times 2 + (140 - 90) \times 3 && \text{- asphalt concrete} \\
&\quad + 150 \text{ mm} \times 1 && \text{- granular base} \\
&\quad + 450 \text{ mm} \times 2/3 && \text{- granular subbase} \\
&= 180 + 150 + 150 + 300 \\
&= 780 \text{ mm}
\end{aligned}
$$

The quantities of materials per kilometer required to construct a two-lane road with 10-ft gravel shoulders, and with base and subbase extending the full width of the subgrade, are shown in Table 1.

Compare this conventional design with a 290-mm full-depth asphalt pavement. The equivalent thickness of this design is

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Phang is a Senior Research Officer in the Engineering Research and Development Branch, Ontario Ministry of Transportation and Communications, and was recently named Chairman of TRB's Committee on Pavement Condition Evaluation. This paper was presented at the 1981 Annual Meeting of the Roads and Transportation Association of Canada.

$$H_e = 90 \text{ mm} \times 2 + (290\text{–}90) \times 3$$
$$= 180 + 600$$
$$= 780 \text{ mm}$$

This is the same amount as for the conventional design. The quantities of materials required for the same two-lane road with 10-ft gravel shoulders are also listed in Table 1.

For purposes of illustration, prices of $25/ton for asphalt concrete, and $5.50 and $4.50/ton for granular base and subbase materials, respectively, are used to calculate a cost per kilometer of highway. These costs, shown in Table 1, are $171 600 for the conventional design, and $149 700 for the full-depth design, i.e., the thinner full-depth design is lower in cost than the conventional design, even though both designs are equal in terms of structural equivalency values.

The outcome of this kind of comparison obviously depends on the prices used for the various material components. The picture would not be so clear-cut if the price for asphalt concrete were much higher and the prices for granular base and subbase much lower. In addition, the frost protection of the subgrade is altered in the full-depth design (740 mm conventional versus 290 mm full-depth), and compensation for this loss of protection in the form of additional drainage and shoulder waterproofing will reduce this structural advantage. Nevertheless, this example illustrates the possibilities that exist in more efficient use of materials in pavement structures.

Management needs to consider whether the risks in departing from the conventional design are outweighed by the lower costs of the thinner pavement, the effects of such change on the agency program, and the impacts on the industry and the road user.

In the current situation where the quantity of entirely new pavement being built is quite small, the immediate effect of such a change is likely to be small also. However, this makes the perfection of construction techniques and training programs to obtain high-quality work more difficult to attain.

In any case, management needs to explore, at least through some carefully selected projects, the merits and benefits to be gained by use of full-depth asphalt construction.

Concrete Pavements

Another technical response that can be explored lies in the much higher strengths of portland cement concrete. When used in pavement, these higher strengths translate into thinner sections as in full-depth asphalt pavements. However, this very quality of high strength has attached to it other negative interactions with respect to pavement performance that have led to hesitation in its use. As well, because portland cement concretes need first-quality aggregates for durability and high portland cement contents, portland cement concrete is costly. Recent design developments, however, hold promise that performance can be improved, and that concrete pavements can really attain lives of 20-25 years. It is in this area that the benefits of more costly concrete pavements appear. If a concrete pavement can serve for 25 years without major rehabilitation, it may be more cost-effective than an alternative design that lasts 10-15 years and then requires an overlay or other major rehabilitation to make the pavement serviceable over the whole 25 years. These design developments are

1. Lean concrete bases;
2. Driving lanes that are poured wider than usual (4.25 m), but that are painted the standard lane width (3.7 m);
3. Paved concrete shoulders, either partial width or full width, which are tied in by steel bars to the adjacent driving lane;
4. Pavement edge drains;
5. Avoidance of steel that will corrode and cause spalling of concrete;
6. Equipment to "seed" the surface of fresh concrete with highly polish-resistant aggregate; and
7. Avoidance of aggregate that will cause cracking and spalling (D cracking) of the concrete.

In cold Canadian environments the major performance problems with concrete pavements are associated with poor behavior at transverse joints, and with the effects of corrosion of steel. The short random joint spacing (average, 4.7 m) currently in use appears to be successful in

Table 1. Example of thinner, lower-cost design.

	Conventional				Full-Depth			
Material	Thickness (mm)	Quantity (ton/km)	Price ($/ton)	Cost ($000s)	Thickness (mm)	Quantity (ton/km)	Price ($/ton)	Cost ($)
Asphalt concrete	140	2 400	25	60	290	5030	25	125.8
Granular base and/or shoulder	150	6 700	5.5	36.9	290	4350	5.5	23.9
Granular subbase	450	16 600	4.5	74.7				
Total	740			171.6	580			149.7
Equivalent thickness	780				780			

Note: Equivalencies: asphalt concrete – 2 < 90 mm > 3; granular base – 1; granular subbase – 2/3.

Laying mix containing reclaimed asphaltic material (courtesy of Douglas J. Brown).

that very few of the slabs crack, and a high proportion of preformed joint seals is retained for many years. The use of lean concrete bases that are not prone to disintegration due to freeze/thaw action in the presence of salt, in conjunction with the short joint spacings, act together to retard the formation and progression of faulting or stepping. There is sufficient evidence that load transfer dowels will not always prevent faulting.

Wider driving lanes or tied paved shoulders (full or partial width) accomplish a reduction in tensile edge stresses and keep water farther away from the traveled portion of the lane. Thus, the potential for faulting is reduced. The additional concrete used for this purpose increases the total costs, but its use also increases the certainty of longer pavement life (2).

Faulting occurs after fines in the base or adjacent shoulder are eroded from one area near a joint and either are ejected through pumping or deposited in another area near the joint. The presence of water greatly accelerated the faulting phenomenon. In most cases free water for pumping is surface water that penetrates the joint and pavement edge. Rapid removal of this water by pavement edge drains will reduce the pumping activity at the joint. Recently, a technique of plowing in 4-in fabric-wrapped plastic drainage pike has been used very effectively for this purpose. The cost of the operation is quite low, less than $3000/km for both edges of a pavement. Its effect on extending pavement life could be considerable, perhaps five years (3).

Faulting of joints with load transfer dowels may take place as the dowel "works" in the cavity, enlarging it into an oval shape. Larger dowels may reduce this problem. However, corrosion of dowels creates other problems. Seized dowels may result in widening of cracks or in new cracks. Expansion pressure due to corrosion may cause spalling of the concrete above the line of dowels, with rapid subsequent joint deterioration. This kind of problem can be avoided by not using dowels, relying on nonerodable bases such as lean concrete, and using drainage and tied paved concrete shoulders to retard faulting.

Early loss of high surface friction on limestone concrete pavements due to polishing of the soft aggregates may be avoided by transversely grooving the wet concrete with steel tines. However, this operation may result in rough surfaces that are usually quite noisy. Recently, equipment was developed in Belgium to distribute and embed a layer of highly polish-resistant aggregate in the surface of fresh concrete placed either in forms or with a slip-form paver. This type of surface is no more noisy than an asphalt surface and provides the needed surface friction properties at relatively low cost (4).

The combined effects of all of these new developments should certainly increase the lives of concrete pavements built in a Canadian environment. The question of whether such increase in life is cost-effective when compared with other designs still remains to be answered. However, as the price of asphalt is apparently rising at a faster rate than portland cement, concrete pavements are becoming more competitive in first cost. To take advantage of this situation, North Carolina requested bids on alternative concrete and asphalt designs (5). The state department of transportation took the risk of weighting the bid of the asphalt design (by as much as 23% of the initial cost) to account for its much earlier overlay requirement. While the concept is sound, one should have a high degree of confidence in the projected ages at time for the rehabilitation of each alternative design in order to prepare a sound, acceptable evaluation of weighting.

In recent years there have been many attempts to predict pavement lives, for both concrete and asphalt pavements (6, 7). It is possible that in the 1980s these methods may be sufficiently refined to provide the desired degree of confidence in the estimated ages. It would then be practical to make valid comparisons among a wider range of alternative designs. This is one of the attractive concepts of a pavement management system (at a project level).

Are the risks of changing to new concrete designs worthwhile? Can the construction industry produce the quality of product we need, considering there has been very little of this type of pavement built in Canada in recent years? If the answers to these questions are decidedly positive, then management must take steps to first prove the benefits and then to develop the construction programs.

TECHNICAL RESPONSES: CONSTRUCTION

Sulfur

The practicability of using sulfur as a replacement for part of the asphalt in sulfur-extended asphalt (SEA) mixes has been proven over the last few years. In cold Canadian environments, SEA mixes have a performance advantage over regular asphalt mixes due to the stiffening effect of the sulfur at high temperatures. This reduces the tendency of SEA mixes to rut under traffic, thus permitting the use of a higher penetration grade of asphalt cement for minimizing low temperature transverse shrinkage cracking.

The probability that SEA mixes will become common in the 1980s is considered by some as remote. The reason is that the price of sulfur has skyrocketed from about $45/ton in 1978 to about $100/ton in 1980, and no generally available surplus supplies are likely before the 1990s (8). A simple comparison of binder costs between current conventional asphalt and SEA mixes is shown in Table 2. For the current situation, where asphalt is $200/ton and sulfur is $100/ton, binder costs for a 40/60 SEA mix is $10.16/ton compared with $11.00/ton for a conventional mix. This is a marginal advantage that may not exist in areas of high transportation costs, or that could disappear due to the additional costs of handling, storing, heating, and blending the sulfur. Nevertheless, because there are probably performance advantages to be gained by using SEA mixes in our Canadian environment and to further solve and put to rest any remaining environmental and other questions concerning the use of sulfur in pavement construction, it is desirable that more projects with SEA mixes be placed and observed. Also, because recycling of pavements is developing into a major rehabilitation technique, the feasibility of recycling SEA mixes must be addressed more comprehensively. At this time recyling of SEA mixes, in batch mix plants only, has been tested and found to be free from hazardous environmental problems (10).

When do you use sulfur to take advantage of its superior performance? When do you use sulfur because of the cost advantages? These are questions that must be considered by management in the coming years. The technology is ready to be put in place, now.

Drainage

The importance of internal structure drainage is becoming clearer, and promising new developments in this area include the use of filter fabric-wrapped aggregate, the use of porous base layers, and the placement of pipe drains along pavement edges.

It has been demonstrated in experiments such as waterproofing shoulders that pavement damage during the winter and early spring may be caused primarily by water entering the pavement structure from the surface through cracks, pavement edge/shoulder joints, and the adjoining granular shoulders. Sealing the cracks and waterproofing the shoulders are methods of excluding surface water. Experience shows, however, that these measures are almost never 100 percent effective, and that they become even less effective after a number of years. Drainage of the water before much damage can be done is another way of solving the problem (drainage can be used in addition to sealing and waterproofing). Pipe drains are not new developments, but filter fabric wrapping appears to extend the working life of the drain, i.e., the pipe and the surrounding material do not get plugged as quickly. The cost of plowed-in fabric-wrapped 100-mm plastic pipe drains along pavement edges, complete with about three outlets per kilometer, costs approximately $1350/km. Observations show no reduction in flow after two years.

Trenches in which a layer of filter fabric is placed and the trench backfilled with clear stone with a pipe embedded in the stone are more effective than a 100-mm pipe because of the much larger surface area, but they cost more than pipe alone. This type of drain is very effective in cut areas, at intercepting surface water infiltrating downslope under the pavement, or groundwater flow due to a high water table.

A porous layer in the structure composed of bituminous-bound open-graded stone, extended out under the shoulders, is an excellent way of draining the structure. However, there is the possibility of water being trapped by vegetation growing over the exposed face of the layer. A porous layer plus pavement edge drains is of course an excellent combination, but costs are very high. While the benefits of such drainage are positive in terms of extending pavement life, they need to be quantified so that trade-offs with costs may be evaluated.

Our task for the 1980s with respect to drainage is the improvement of construction techniques for installation of drains and drainage layers, and the documentation and observation of installations to acquire the performance and cost records needed to evaluate the trade-off of benefit with cost.

Waterproofing

Complementing the developments in structure drainage have been corresponding developments in sealing pave-

Table 2. Comparison of binder costs for conventional and sulfur-asphalt mixes.

Price per Ton Delivered		Binder Cost per Ton of Conventional Mix or Equivalent Volume of SEA Mix				
Asphalt Cement	Sulfur	Conventional Mix (5.5% AC)	Equivalent 40/60 SEA (31% reduction of AC)		SEA Mix 5.0% Total Binder, 45/55 SEA (35% reduction of AC)	
$200	$ 75	$11.00	AC	$ 7.62	AC	$ 7.20
			S	1.90	S	2.21
				$ 9.52		$ 9.41
$200	$100	$11.00	AC	$ 7.62	AC	$ 7.20
			S	2.54	S	2.90
				$10.16		$10.15

ment cracks. These developments are in the improved material properties of the crack-fill substance and in the way the material is applied.

Cracks in asphalt pavement have in past years been filled with materials designed for joints in concrete pavements, or have had asphalt emulsions sprayed over them (blotted with stone chips). Neither of these methods have been successful, because movement at these cracks in the winter can make a 30-mm crack out of a 10-mm crack, i.e., require an extension of 300 percent at very cold temperatures. In the case of concrete joint sealants, which are stiff enough to resist penetration of aggregate at high temperatures, the sealant is so stiff at low temperatures that the bond with the face of the crack fails. Asphalt cement residue from emulsion sprays fails because there is not an adequate quantity of material at the crack to survive the extension and because at low temperatures asphalt cements are too stiff to stretch far without breaking.

Recent developments in crack fillers have been the creation of crack-filler materials that will stretch significantly more at low temperature than previously, and improvement in the knowledge of application of these materials. One of the major oil companies has modified a hot-poured concrete joint-filler material to have a very low modulus of elasticity even at low temperatures, and the material has the ability to recover its original shape. Adhesion of this material to the crack is particularly effective when a special fast-drying primer is used before application. The most successful application of hot-poured crack fillers appears to be with a crack that has been routed wide enough so that the material can flow easily into the aperture, from about 10 to 20 mm wide, primed over an area extending 20-30 mm on each side of the crack, and overfilled with the hot-poured material so that the level is about 1-3 mm above the pavement surface and the edges of the crack are completely covered over a width of about 5 mm. The height of overfill reduces on cooling to ambient temperature. Properly designed crack-filling material will not crack under traffic, and for asphalt pavements there is little concern about penetration of stone chips. The low-modulus materials will not affect ride quality and may be soft enough in winter to deform rather than break under the impact of snow plows. To keep the cost of using the low-modulus material competitive with other types of crack fillers, the routing may be made quite shallow, possibly no more than 10 mm deep. This would provide just enough of a material reservoir to permit a 200-300 percent extension without too much thinning. In this case, the width of overfill should be somewhat greater, perhaps 15 mm on each side of the crack.

A stringent requirement of the more sophisticated formulations of joint and crack fillers is the need not to overheat the material. Overheating destroys the desirable properties and can cause early failures. To obviate overheating, special oil-jacketed heaters have been manufactured, and some are equipped with a wand to facilitate pouring the material into cracks. Hot material circulates through the wand when it is not in use and when it is returned to its holder.

One benefit to be gained by preventing water penetration in cracks is the retardation of the adverse affects associated with crack-related structural weaknesses. Traffic over cracks filled with water tend to eject fines from underlying granular layers, which will depress and cause multiple cracking and alligatoring. It is manifestly important to seal cracks as soon as they appear so as to gain the largest benefits from crack sealing. It is also clear that if the crack has progressed to a multiple cracking stage, the benefits of sealing a large length of crack must be balanced against some more positive method of maintenance, such as hot-mix patching.

Management's role concerning this development in the 1980s is one of organizing the processes leading to cost-effective programs of crack sealing. This includes the collection of data on the performance and cost needed to evaluate the effectiveness of various materials and crack filling techniques.

TECHNICAL RESPONSES: MAINTENANCE

Recycling

In the last few years the techniques and equipment to do hot mix recycling of asphalt pavements have progressed beyond the experimental stages. Hot mix recycling is now an established process available to the highway industry, albeit still new to many, and with problems still to be solved. The incentive to carry out recycling stems from the fact that by reusing the asphalt binder and aggregate in the old mix, the amounts of new asphalt cement and aggregate needed for the recycled mix are reduced, perhaps by as much as 70 percent (and sometimes by nearly 100 percent). In spite of the added cost for recovering and transporting the old pavement to the plant, savings of about 20 percent on the cost of new mix are confirmed by many sources (11) for high reclaimed/virgin mix ratios.

Integrating this new process with the other well-known overlay alternatives for pavement rehabilitation is one of the tasks for management in the 1980s. Guidelines are needed for use by designers dealing with the selection of full-depth or partial-depth reclaiming, the recycled mix ratio, the virgin aggregates, and the new asphalt binders and rejuvenators. Specifications and special provisions of contract are needed for use by contractors and quality assurance staff. Policy decisions are needed to determine, for example, the disposal of excess salvaged pavement, to decide on methods of measurement and payment, to set limiting criteria on use of recycling, etc. A plan needed for the development of these guidelines, specifications, special provisions, and policies can be made the responsibility of a task force or steering committee.

Dissemination of information on hot mix recycling and the operation of training programs for construction and design staff are essential steps for successful and fruitful use of the hot mix recycling process. The Roads and Transportation Association of Canada is currently working on a jointly funded project of the Provinces and Transport Canada to develop information for these purposes.

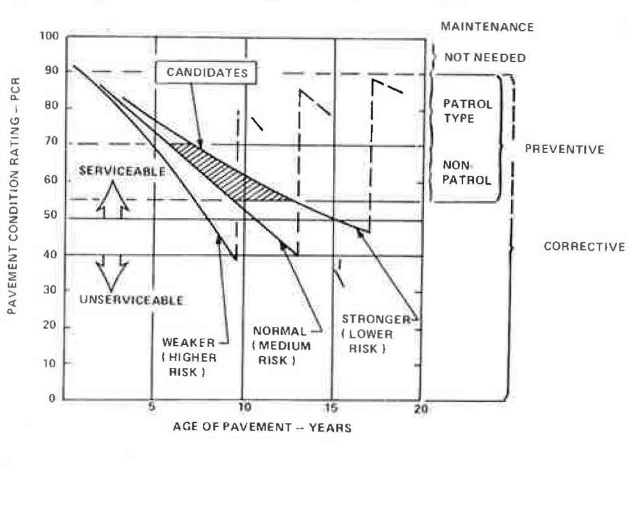
Well-Timed Maintenance

As a new pavement is exposed to traffic and climate, it begins to deteriorate in functional serviceability as well as in structural integrity. The rate of deterioration is a function of the materials, the thickness of the pavement and subgrade, the amount of traffic, the severity of climatic effects on the materials of the pavement and subgrade, and the quality of maintenance imposed on the pavement. One of the tasks of management in the 1980s is the choice of type and timing of preventative and corrective maintenance and of rehabilitation activities, so as to make the most effective use of maintenance funds. The development of planning schedules for maintenance and rehabilitation will maximize the cost effectiveness of these activities through the extension of pavement life and provide as high a level of serviceability throughout the life as is compatible with available funds. These are very complex criteria to satisfy, but they can be met by some of the more sophisticated computer programs currently being developed by many agencies as pavement management tools. Within the next few years the technology of pavement management will be continually improved to a level where the difficulties in introducing and using the results of optimization programs will be mostly solved. There remains, however, the very real management problem of accepting and fitting a pavement management system into an already functioning administrative process.

One of the major conclusions of two Pavement Management Workshops held in Phoenix, Arizona, and Charlotte, North Carolina (13), was that for successful implementation of a pavement management system a commitment must be made by top-level management to support implementation and provide the resources needed. Some of these benefits are noted below:

1. Benefits to administration—Budget requirements can be prepared based on specified performance standards, or, alternatively, estimates of performance can be provided based on budget constraints; objective data are used in supporting budget requests; user costs (benefits) can be identified; improved pavement performance information and forecasting are possible; and objective information is available to describe the condition of the pavements in the network.

Ways to identify candidates for preventative maintenance (courtesy of W. A. Phang and G. J. Chong).



2. Benefits to operations (construction and maintenance)—Provides a basis for allocation of resources; provides a basis for improvements in materials requirements and construction specifications; and factual information is available to review and evaluate the quality of construction and maintenance activities.

3. Benefits to design—Information is provided from which alternative pavement designs can be evaluated; data are provided to permit updating of design methodologies and specification requirements for materials; factual information is provided to evaluate environmental factors on pavement performance; procedures are provided to optimize selection from among alternative design and rehabilitation options; and cost and energy optimization of design alternatives is facilitated.

Pavement management systems are complex and need sophisticated computer programs to grind out the most cost-effective solutions. There is a simple concept that can be used with some confidence to provide "good roads at low cost" (13). This concept entails the application of less costly types of maintenance, at a time in the life of the pavement which is sufficiently in advance of the progression of distresses to allow maximum advantage of the maintenance treatment in extending pavement life. As pavement conditions deteriorate, the appropriate treatment to be used becomes more and more expensive until, as a limit, reconstruction becomes necessary. The concept encourages preventive maintenance, discourages very heavy corrective maintenance, although this is sometimes necessary, and endorses early surface rehabilitation before complaints start coming in.

During the past decade of development in pavement management systems, the question most asked by managers was, Can I afford one? During this decade that question has to be, How much is it costing me because I don't have one?

CONCLUSION

The intent of the foregoing presentation of current technology developments in the pavement area is to pose a challenge for management in the 1980s: Use these "new" techniques to improve the effectiveness of each dollar spent on pavements.

However, the role that highways and pavements play in the social and economic development of a county, city, province, or country is so basic that there may be a tendency to overlook their importance and to downgrade the financial and political support provided for these facilities. The challenge for top management in the 1980s lies in the development of alternative strategies to deal with lower budgets, rising prices, and the effects of inflation on the purchasing power of the dollar. It lies also in being able to present to administrators convincing and persuasive arguments for the preservation of a primary and secondary network of highways, as well as for the construction of those new facilities needed for our growing population.

The investment that has been made in the highway transportation infrastructure over the years amounts to many billions of dollars. Pavements represent a most significant proportion of that vast sum. It is the larger task of management in the 1980s to guard that investment, and to provide the forward looking perspective that will ensure not only an adequate highway system, but one that answers to the needs of the future.

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ADDITIONAL COMMENT

Page 8 of the May-June issue of ***Transportation Research News*** quotes TRB Executive Director Deen as stating that the trucking industry is a $50 billion industry and that there was therefore a need for more TRB activity in the trucking field. The point can be argued even more forcefully since trucking revenues are closer to $150 billion if one includes both intercity and intracity components.

NCTRP Publishes First Report, Assesses Results

The National Cooperative Transit Research and Development Program (NCTRP), which was initiated in November 1980, is now operating at full speed. The first two reports in the ***Synthesis of Transit Practice*** series have been published and are being distributed. These syntheses cover cleaning equipment and procedures for transit buses and enforcement of priority treatment for buses on urban streets, respectively.

To mark the publication of the reports, TRB hosted a meeting on June 7, at which representatives of TRB and NCTRP met with representatives of the Urban Mass Transportation Administration (UMTA), the American Public Transit Association (APTA), and the Urban Consortium for Technology Initiatives/Public Technology, Inc., all of whom are involved in NCTRP as detailed below, and members of the press.

Among those present were Charles Gargano, Deputy Administrator, UMTA; Richard S. Page, General Manager, Washington (D.C.) Metropolitan Area Transit Authority and a member of TRB's Executive Committee; Jack R. Gilstrap, Executive Vice President, APTA, and also on the TRB Executive Committee; and David Perry, Acting