Development of a Construction Price Index for Major Public Transit Investment Planning

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A technique for indexing prices over time and between regions of the country is developed that is responsive to the labor, material, and equipment resource mix and to the different types of each of those resources that are used in typical transit construction projects. Currently available indices are reviewed, and their shortcomings are identified. A review of several actual projects and an analysis of recent trend data show the variations in resource mix among different types of transit projects. A framework is developed for a resource-price-oriented data base and indexing methodology. To illustrate the concept, the methodology is then applied to cut-and-cover tunnel construction. A national index and 20 city indices are computed and compared with currently available indices for general construction projects.

During the system planning and corridor refinement processes for major public transit investments, data from projects completed at one location and time are often used in estimating the cost of implementing a new mode in a different place and at a different time and in projecting the cost of that investment into the future. This paper explores the issues involved in developing indices of transit capital cost that will be useful in this process. The best index currently available is identified. Recent projects are reviewed to identify the need for a more "relevant" transit index. A methodology is developed in which historical experience and current prices are used to produce a basis for a transit capital price index. In this paper, price refers to the resource--for example, wage rate in dollars per hour. Cost refers to the project cost, which is determined by resource prices and many other factors.

CHARACTERISTICS OF PRICE INDICES

The major requirements for an index of regional and time trends in investment projects are as follows:

1. The index should be based on readily available data that are published frequently and have been published for a long time. This enables the user to update prices to the current year and identify trends for projecting future costs.
2. The index should cover a wide range of cities and be comparable between cities to permit regional adjustments for completed projects.
3. If the index is a composite of different quantities and their prices, the method of computing the measure should be available. This would enable the user to identify specific location prices not nationally available and to use these prices to relate national data to a specific project.
4. If the index is a composite of different quantities and their prices, the items in the index should reflect the type of labor, material, and equipment used in transit projects.
5. If the index consists of nonprice items, these should be explicitly identified and documented. Factors such as worker productivity are nonprice items.

REVIEW OF TIME SERIES AND REGIONAL INDICES

Many construction price indices are available. Several indices that are published periodically are described in selected issues of the Engineering News Record (ENR). Several of these indices have both national and local data and would be available at local libraries or from construction contractors. Many of these indexing services also publish cost estimators for specific projects. ENR publishes a construction cost index (CCI) and a building cost index (BCI). These indices are based on fixed quantities of skilled or common labor and selected materials. These indices were started in 1913, and the quantities of the resources were determined in such a way that the cost of the package in 1913 was $100, based on average prices for 20 U.S. cities. The quantities have remained constant since then, and the BCI and CCI based on 1913 satisfy the first three characteristics of a transit price index cited above. ENR also publishes a BCI and a CCI for 20 cities in which each city's index was set to 100 in 1967. This index is good for determining the price changes within a city but not between cities, since the index in each city was normalized to 100 in 1967. Data given in Tables 1 and 2 show how the ENR-based 1913 indices are computed. The quantities of common labor or skilled labor and the materials (steel, lumber, and cement) were chosen to represent an implicit apportionment of resources for some "typical" project. The ENR 1913 base building construction index is recommended for regional comparisons as a preliminary cut at converting data from one city to another.

It is important to recognize that the ENR index does not necessarily represent the correct mix of resources, nor does it account for nonprice factors such as productivity or price factors such as the employer's cost burden for different skills. These will be discussed later.

The 1979 Dodge Guide (1), which is typical of cost-estimating manuals such as those of R.S. Means Company, Inc. (2), and Craftsman Book Company (3), provides cost factors for various public works projects. The Dodge Guide contains regional adjustment factors and labor, material, and equipment unit cost estimates for tunnel, track, power, and train-control capital projects. These unit cost estimates are not aggregate unit costs, such as those needed in system planning or corridor refinement. For example, the cut-and-cover tunnel costs in the Dodge Guide do not represent the total cost for a kilometer of tunneled rail rapid transit line. Costs for site preparation and the tunnel liner are not included. However, they do provide resource breakdowns. The Dodge Guide (1) states that, although the labor costs shown do not include the employer's labor costs (such as fringes), they do include some productivity (80 percent efficiency assumed) and work-rule variations (unfortunately, these are not documented). Labor and material adjustments are developed for major cities within each state. Since equipment is assumed to be contractor owned, no local rates are provided. The reader of the Dodge Guide must bear in mind that labor and material prices are set to a Boston base and thus cannot be directly related to a national-average-based figure such as the ENR. The use of Boston as a cost base and the fact that the Dodge Guide does not document the complete methodology used are drawbacks to these data. The Craftsman guide (3) also shows some typical employer burdens. Both the Dodge and Craftsman publications indicate that employer cost burdens

Table 1. Computation of national and local ENR building construction indices.

Item	Description	Quantity	Unit Price ($) 20-City Avg[a]	Atlanta[b]	New York[b]	Index Value ($) 20-City Avg	Atlanta	New York
Labor ($/h)								
Common	Avg of heavy and building construction labor; union base rate and fringes	200 h	11.22	7.73	13.56	2244	1546	2712
Skilled	Avg of bricklayers, structural ironworkers, and carpenters; union base rate and fringes	68.38 h	14.78	11.66	17.97	1010	797	1229
Material								
Structural steel ($/cwt)	Avg of 3 mills	25 cwt	18.12	18.12	18.12	453	453	453
Lumber ($/1000 board ft)	Carload lots, avg of 2x4 pine and fir	1088 ft	341.20	290.44	337.50	371	316	367
Cement ($/ton bulk)	Truckload lots, bulk	1.128 tons	56.31	48.82	50.30	63	55	56

Note: cwt = hundredweight.
[a]Price on January 3, 1980. [b]Price on January 10, 1980.

Table 2. National and local building construction indices showing regional comparisons.

Item	Index National ($)	Atlanta ($)	Atlanta/ National	New York ($)	New York/ National	New York/ Atlanta
Material (steel, lumber, and cement)	887	824	0.93	876	0.99	1.06
Construction cost (common labor and material)	3131	2370	0.76	3588	1.15	1.51
Building cost (skilled labor and material)	1997	1621	0.81	2105	1.05	1.30

average 25 percent of the wage rate. The hourly wages in the Craftsman publication (3) are consistent with the values reported in the ENR (4). In summary, for system planning purposes the Dodge Guide data are useful for labor, material, and equipment resource breakdowns and as a check on the ENR values but should not be used as a regional or time-series index.

Indices published by various federal agencies have often been used as surrogates for a transit cost index. The Federal Highway Administration (FHWA) index--"Price Trends for Federal-Aid Highway Construction," published quarterly--is based on national average contract bid prices for a composite mile of Interstate highway, involving specific amounts of excavation, portland cement concrete and bituminous concrete surfacing and reinforcing, and structural steel and structural concrete. This index is useful for defining national trends in highway costs and excavation, structure, and surfacing costs. It is not published on a regional basis, contains only material prices, and contains nonprice factors involved in contract bidding. The U.S. Department of Commerce composite construction cost index (5) is another aggregate index. This index is a ratio of the estimate of total new construction put in place in current dollars to the corresponding estimate in 1972 dollars. This estimate does not use a constant quantity; hence, it measures the combined result of price changes as well as changes in the relative weights of different types of construction. This index does not seem particularly useful for application to transit planning. Although it is readily available and has been published for a long time, it does not have regional values nor does it contain specific quantities that would enable a local planner to relate national data to a specific project. There is no reason to suggest that the quantities of material, labor, and equipment for construction put in place are representative of transit construction. The Bureau of Labor Statistics monthly producer price indexes (PPIs) for relevant quantities could be used. For example, an aggregate finished-goods index such as the machinery and motive products index (PPI codes 11 and 14) has many of the same elements as transit hardware (vehicles, elevators, and power equipment). However, there is no transit hardware in this (or any other) PPI, and the PPIs have never been correlated with transit finished goods.

Time-series indices are used in transit investment planning to adjust costs from past years or other places to current time and place. Time-series indices are also used to forecast future-year prices. In the economic analysis of alternatives (present value), general inflation can be ignored; however, if the prices of a particular item are changing at a different rate than general inflation, this rate of real price inflation should be considered. If the appropriate index is deflated by the consumer price index (CPI) (assuming the CPI measures general price inflation), the resulting index can be used as a measure of real price inflation.

Figures 1 and 2 show the real price growth of the ENR BCI and the FHWA highway construction index and the 20-, 15-, 10-, and 5-year real rates of growth in these indices (CPI = 100). These rates of growth are summarized below:

Period	Index (%) ENR	FHWA
1960-1980	1.07	2.37
1965-1980	1.08	2.76
1970-1980	0.87	2.94
1975-1980	-1.81	1.26
1960-1980	1.75	2.66

The first four trends are calculated from the actual end points, whereas the last trend is calculated from the estimated end points (the R^2 of the fitted lines is 0.86). Construction prices and costs have been growing between 1.7 and 2.6 percent faster than the CPI over the past 20 years. The increasing volatility in the real indices over the past 10 years suggests that the factors that affect these indices need to be understood.

The use of real price index trends to forecast

Figure 1. Real FHWA road construction index.

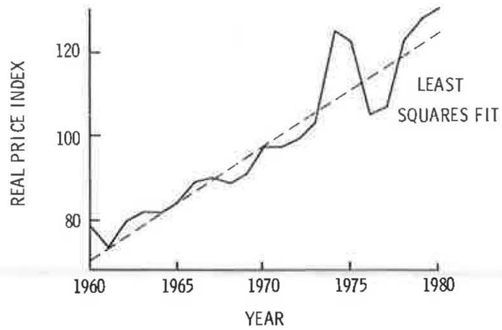
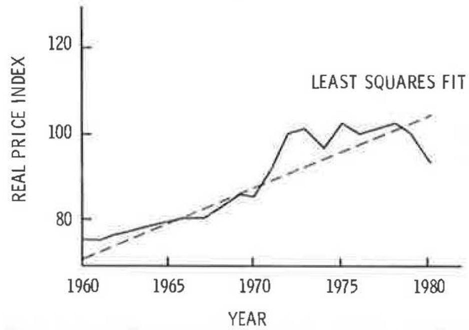


Figure 2. Real ENR building cost index.



costs assumes that (a) input factors are accurate surrogates for costs and (b) the relation between the CPI and the real price index will remain constant over the forecast period. The CPI or gross national product (GNP) deflator or other general price index need not be forecast for an economic analysis. However, for financial analysis, actual dollar expenditures need to be forecast. A recent study by Data Resources Cost Forecasting Service, Inc., for FHWA (6) developed price indices for highway construction for use in forecasting costs. This study used input prices, market conditions, and general macroeconomic assumptions to forecast the percentage of actual dollar changes in highway costs.

RESOURCE MIX

A review of the labor and material adjustments in the Dodge Guide (1) as well as those given in Table 1 indicates that the regional prices are different for these two resources while the equipment is assumed constant. Equipment is not included in the ENR indices. These resource price differences suggest that it is important to know the mix of resources for different types of transit projects. Table 3 gives the resource mix as a percentage of project expense for three different types of tunnel construction and the procurement and installation of track and power subsystems. The percentages were developed from the unit cost data given in the Dodge Guide (1). This review illustrates that for tunnel construction the labor cost varies between 35 and 67 percent of the total job cost, the material cost varies between 17 and 33 percent, and the equipment cost varies between 16 and 32 percent, depending on the construction method. Track-work cost is 96 percent materials and power costs are 42 percent labor and 46 percent materials.

Data given in Table 4 (4) show that the current national ENR construction index is 72 percent common labor cost and the current national ENR building index is 56 percent skilled labor cost. These data indicate that currently available indices are deficient in representing the resource mix used in transit construction. If all resources had the same price in every region or city, or if all prices were changing at the same rate, regional indices and resource-specific indices would be unnecessary. This is not the case. Table 5 (4) indicates that there is a wide variation in prices for different types of labor and, within each skill, a wide range between cities. Recall from Table 2 that the New York CCI was 151 percent of Atlanta's whereas the New York MCI was only 106 percent of Atlanta's. This undoubtedly reflects the high cost of unskilled labor in New York. Thus, it would be appropriate to develop an indexing methodology and transit price index that could capture the resource mix of typical transit projects.

Table 3. Resource mix for three types of tunnel construction from Dodge Guide unit cost data.

	Percent of Total Project Cost		
Project Type	Labor	Material	Equipment
Cut-and-cover tunnel with slurry wall, 45 ft wide by 45 ft deep	35	33	32
Bored tunnel in clay with compressed air, 20-ft diameter with liner	67	17	16
Shield-driven tunnel without air, 20-ft diameter with liner	35	28	37
Track work (ballast, tires, rail)	2	96	2
Power (rail, cables, substations)	42	46	12

Table 4. Resource mix: national ENR indices.

Index	Item	Percent
CCI	Labor	
	Unskilled	100
	Percent of total index value	72
	Material	
	Steel	51
	Cement	7
	Wood	42
	Percent of total index value	28
BCI	Labor	
	Carpenters	33
	Metalworkers	33
	Bricklayers	33
	Percent of total index value	56
	Material	
	Steel	51
	Cement	7
	Wood	42
	Percent of total index value	44

Table 5. Wage rates for 20 cities in 1979.

	Wage Rate ($/h)				
Skill	Lowest City	Fifth Lowest City	Median City	Fifth Highest City	Highest City
Common labor					
Construction	7.18	7.96	10.42	12.07	13.68
Building	7.18	8.47	11.14	12.09	14.82
Carpenter	10.60	11.81	13.49	14.76	17.30
Ironworker	11.39	13.14	14.20	15.81	18.84
Electrician	12.65	13.44	15.22	16.05	20.70
Hoist engineer	10.67	11.57	14.34	15.10	16.61
Crane operator	10.67	11.73	14.63	15.37	18.60
Truck driver	7.93	9.64	10.69	12.15	14.58

SPECIFICATIONS OF RESOURCE TYPES WITHIN EACH RESOURCE CATEGORY

The use of comparative indices implies the selection of measurable items to develop the index. For example, for their construction index the ENR selected union-based heavy construction labor, mill prices for structural steel, 2x4 lumber delivered in carload lots, and bulk cement. Since a tunnel index must reflect the types of labor and materials that go into a tunnel, some research in this area is necessary. Data from actual projects, which suggest the type of labor and materials used and the relative proportion of each type, are summarized below:

1. Massachusetts Bay Transportation Authority (MBTA) Haymarket Extension, including tunnel, track, power, and signal work:

Item	Percent of Total
Labor hours	
Unskilled	18
Carpenters	11
Metalworkers	6
Bricklayers	2
Electricians	11
Operators	9
Other	43
Material cost	
Steel	14
Cement	15
Wood	3
Electrical	14
Other	54

2. MBTA Haymarket Extension, yards and shops:

Type of Labor	Percent of Total Labor Hours
Unskilled	32.5
Carpenters	8.1
Metalworkers	8.4
Bricklayers	1.4
Electricians	11.1
Operators	3.3
Other	35.2

3. Sixty-Third Street tunnel, New York:

Type of Labor	Percent of Total Labor Hours
Unskilled	15.9
Carpenters	23.8
Electricians	2.6
Operators	5.3
Other	52.4

4. Archer Avenue Extension, New York (fifth month of work):

Type of Labor	Percent of Total Labor Hours
Unskilled	20.5
Carpenters	11.7
Operators	33.8
Other	34.0

5. Second Avenue Extension between 97th and 105th Streets, New York:

Type of Labor	Percent of Total Labor Hours	
	Excavation	Concreting
Unskilled	36.6	75.5
Carpenters	14.5	10.0
Metalworkers	2.3	
Bricklayers		1.2
Operators	9.2	
Other	37.4	13.3

6. Second Avenue Extension between 110th and 120th Streets, New York:

Type of Labor	Percent of Total Labor Hours	
	Excavation	Concreting
Unskilled	19.1	53.6
Carpenters	17.0	14.2
Operators	21.2	7.1
Other	42.7	25.1

The data on the MBTA Haymarket Extension are an extract from a Bureau of Labor Statistics survey of that transit construction project. The labor-skill breakdown in item 1 includes power, track, and signal as well as tunnel. These data indicate that the skilled to unskilled labor ratio is 80:20 and that carpenter, electrician, and equipment operator are the most significant skill areas. Item 1 also gives the percentage of total material cost for various materials used in the Haymarket Extension. Concrete, steel, and electrical products dominate. Item 2 gives a similar disaggregation of a yard and shop job. In this case, the skilled to unskilled ratio is 67:33, and carpenter, electrician, and metalworker are the most significant skill areas.

Item 3 gives the skill breakdown for the 63rd Street tunnel project in New York. In this case, the skilled to unskilled labor ratio is 80:20 and carpenter and miner are the dominant types of skills. Item 4 gives an example of a slurry-wall construction job. The skilled to unskilled labor ratio is again 80:20. Items 5 and 6 give excavation and concreting costs for two cut-and-cover jobs (no slurry wall). In the two jobs, the skilled to unskilled labor ratio is 70:30 for excavation and 35:65 for concreting. The concreting ratio is the only large deviation from the previous 80:20 pattern. From Table 4, it can be seen that the ENR overstates the labor contribution, particularly if the construction index is used. Within the skilled-labor area, carpenters are certainly an appropriate choice for inclusion in the transit cost index as are metalworkers and ironworkers. For transit projects, either electricians or operators should replace the wage rates for bricklayers used in the ENR. For material resources the ENR indices overstate the use of wood, and in the case of a complete project they understate the use of electrical material. The ENR BCI does not include equipment costs, which, according to the Dodge Guide (Table 3) are significant.

INDEXING METHODOLOGY

This section describes how to develop price indices for transit projects. Once developed, these indices can be used to relate transit project costs between different cities and different time periods. Costs can be forecast based on representative input prices.

To develop transit price indices, the following elements are necessary: (a) a data base hierarchy that relates input prices to unit or total costs, (b) a methodology for creating the index baseline, and (c) a set of time-series data on input factors. For system planning and corridor refinement studies, a major transit investment can be disaggregated into the following subsystems: guideway structure, stations, track, power, signal, vehicles, yards and shops, management, and land acquisition (each measured in dollars).

Total sytem cost can be defined as

$$\text{SYSTEM} = \sum_I \text{SUBSYS (I)} \quad (1)$$

where I is the index of subsystems, e.g., guideway.

The relative importance of the subsystem to the total system expense is a function of the unit cost and quantity of that subsystem. For subsystems such as guideway, the unit costs vary considerably depending on the type of construction, the elevation, and the development intensity of the site. Thus, subsystem-type indices may be developed for several types, as shown in the following example of a guideway subsystem. The guideway structure involves considerations of elevation and construction method, and the construction method in turn includes tunneling, which breaks down into the following construction methods (subsystem types): (a) cut-and-cover with or without slurry wall, (b) soft ground bore with or without air, (c) soft ground shield with or without air, and (d) hard rock bore, all measured in dollars per linear foot.

The subsystem cost would be defined as

$$\text{SUBSYS (I)} = \sum_J \text{SUBTYPE (I,J)} \times \text{QUANT (I,J)} \quad (2)$$

where J is the index of subsystem types, e.g., cut-and-cover tunnels, and QUANT (I,J) is the quantity of subsystem type, e.g., miles of cut-and-cover tunnels. The remainder of this section illustrates how an index would be developed by using the following subsystem type as an example: guideway tunnel, cut-and-cover construction, with slurry wall.

The unit cost resource mix for the subsystem type variable is defined as

$$\text{SUBTYPE (I,J)} = \sum_K \text{RESOURCE (I,J,K)} \quad (3)$$

where K is the resource, e.g., labor. For example, for a 45-ft-wide by 45-ft-deep tunnel, the resource cost per linear foot can be defined as follows (1):

RESOURCE (I,J,1) = labor = 701
RESOURCE (I,J,2) = materials = 656
RESOURCE (I,J,3) = equipment = 638

The resource type for each resource can then be defined as

$$\text{RESOURCEL (I,J,K,L)} = \text{fraction of RESOURCE (I, J, K) due to COMPONENT (L)} \quad (4)$$

where L is the type of resource K, e.g., carpenter.

For example, suppose that research on slurry-wall tunnel construction projects yields the resource-type mix shown below, where each fraction represents the relative contribution of each type to the total labor, material, or equipment expense:

Resource	Type	Contribution
Labor	Heavy construction	RESOURCEL (I,J,1,1) = 0.4
	Carpenter	RESOURCEL (I,J,1,2) = 0.2
	Ironworker	RESOURCEL (I,J,1,3) = 0.2
	Crane operator	RESOURCEL (I,J,1,4) = 0.2
Material	Steel	RESOURCEL (I,J,2,1) = 0.333
	Concrete	RESOURCEL (I,J,2,2) = 0.333
	Wood	RESOURCEL (I,J,2,3) = 0.333
Equipment		RESOURCEL (I,J,3,1) = 1

Representative categories are used here and would be used in actual index computation for simplification. The representative categories should (a) be major input resources and (b) have available measurable items.

Given the percentage contribution of each type of labor, material, and equipment resource to the total of each resource category, the relative contribution of each resource type to the subsystem-type unit cost can be calculated as

$$\begin{aligned}\text{COMPONENTX (I,J,K,L)} &= \text{\% of COMPONENT (L) in SUBTYPE (I,J)}\\ &= [100 \times \text{RESOURCE (I,J,K)} \\ &\quad \times \text{RESOURCEL (I,J,K,L)}] / \text{SUBTYPE (I,J)}\\ &= \text{contribution of COMPONENT (L) to SUBTYPE (I,J) price index}\end{aligned} \quad (5)$$

To continue the example, the percentage of total index for each item is calculated as follows:

Type of Resource	Percent of Total Index
Heavy construction labor	COMPONENTX (I,J,1,1) = (701/1995) x 0.4 = 14
Carpenter, etc.	COMPONENTX (I,J,1,2-4) = (701/1995) x 0.2 = 7
Steel, etc.	COMPONENTX (I,J,2,1-3) = (656/1995) x 0.333 = 11
Equipment	COMPONENTX (I,J,3,1) = (638/1995) = 32

Equations 2-5 have been used to develop the relative contribution of each resource input to unit cost. The final item in the data base is the input price of each resource, which can be defined as

$$\text{INDEX (C, T, K, L)} = \text{price of COMPONENT (L) of resource (K) in city (C) at time (T)} \quad (6)$$

For example, the price of carpenter (L) labor (K) in Philadelphia (C) in January 1980 (T) would be defined as INDEX (C,T,K,L) = 15.00. January 1980 would be the base year for this index.

To compute the subtype baseline index (equal 100), the average value of each index price is computed as follows (assuming 20 cities with available data):

$$\text{INDEX (T,K,L)} = \sum_C \text{INDEX (C,T,K,L)}/20 \quad (7)$$

This is the 20-city average price from the data base of index items of this component.

The average prices of the index items in our example at T = January 1980, over 20 cities, are given below:

Item	Unweighted Avg Price
Labor ($/h)	
Heavy construction	INDEX (T,1,1) = 11.07
Carpenter	INDEX (T,1,2) = 14.83
Ironworker	INDEX (T,1,3) = 14.83
Crane operator	INDEX (T,1,4) = 14.83
Material	
Steel ($/cwt)	INDEX (T,2,1) = 29.37
Concrete ($/yd³)	INDEX (T,2,2) = 40.38
Wood ($/1000 board ft)	INDEX (T,2,3) = 357.1
One equipment type, one price	INDEX (T,3,1) = 1

Given a set of baseline average prices, the quantity of each item in the baseline index can be computed as follows:

$$\text{QINDEX (T,K,L)} = \text{COMPONENTX (I,J,K,L)}/\text{INDEX (T,K,L)} \quad (8)$$

This is the quantity of the item in the baseline index. It is analogous to the 200 h of common labor in the ENR CCI and is simply the relative weight of COMPONENT (L) divided by the price at the time the index is started. In our example, the computations of the 20-city index baseline quantities are as follows (T = January 1980):

Item	Baseline Quantity
Heavy construction (h)	QINDEX (T,1,1) = 14/11.07 = 1.26
Carpenter, ironworker, crane operator (h)	QINDEX (T,1,2-4) = 21/14.83 = 1.42
Steel (cwt)	QINDEX (T,2,1) = 11/29.37 = 0.37
Concrete (yd^3)	QINDEX (T,2,2) = 11/40.38 = 0.27
Wood (million board ft)	QINDEX (T,2,3) = 11/357.1 = 0.03
Equipment	QINDEX (T,3,1) = 32/1 = 32

To compute the value of the subsystem index for a particular time and place, the baseline quantities are multiplied by the local prices at a given time, as follows:

$$\text{VINDEX}(C,T) = \sum_{KL} \text{INDEX}(C,T,K,L) \times \text{QINDEX}(T,K,L) \tag{9}$$

where C is the city of interest.

As an example, the component values of the index for cut-and-cover tunnel with slurry wall for Atlanta on January 1980 are computed below:

Item	Atlanta Value		QINDEX		VINDEX Component
Heavy construction labor	7.73	x	1.26	=	9.7
Skilled labor	11.51	x	1.42	=	16.3
Steel	28.40	x	0.37	=	10.5
Concrete	34.75	x	0.27	=	9.4
Wood	288	x	0.03	=	8.6
Equipment	1	x	0.32	=	32.0

The Atlanta price for heavy constuction labor, $7.73/h, is multiplied by the baseline quantity of 1.26 h computed above to determine the contribution of heavy construction labor to the January 1980 total index for Atlanta: 86.5.

Column 1 in Table 6 gives the 20 cities in the index. Column 2 gives the results of applying the baseline index quantities developed in this paper for cut-and-cover tunnel with slurry wall and the prevailing January 1980 prices in 20 U.S. cities. The 20-city average value of the index is 100. Column 3 gives the ordering of the cities from lowest to highest index value. Column 4 gives the value of the index if equipment is excluded. Recall that equipment was 32 percent of the index but that no regional values were used. In column 2, each city's index included 32 for equipment. Column 4 is equal to column 2 minus 32 divided by 68. The use of a national value for equipment implies that contractors' costs for equipment are independent of location. Columns 5 and 6 give the rank order of cities and the index value of the ENR BCI normalized to January 1980. The difference between this index and the ENR is most dramatic for cities that have low material costs relative to labor (Cincinnati and Pittsburgh) or for cities that have high material costs relative to labor (Boston). This example has focused on one subsystem-type index. However, it is obvious that, once the subtype indices are developed, they can easily be combined for the project of interest, as follows.

First, compute the contribution of each COMPONENT (L) to the system cost as determined by its contribution to the subsystem-type index [COMPONENTX (I,J,K,L)] computed in Equation 5 and the subsystem, as follows:

$$\text{COMPONENTY}(I,J,K,L) = \text{COMPONENTX}(I,J,K,L) \times [\text{SUBTYPE}(I,J) \times \text{QUANT}(I,J) \div \text{SYSTEM}] \tag{10}$$

Then add up the contribution of the COMPONENT (L)'s to the system cost over all subsystem types and subsystems, as follows:

$$\text{COMPONENTZ}(K,L) = \sum_{IJ} \text{COMPONENTY}(I,J,K,L) \tag{11}$$

The average price, INDEX (T,K,L), is then computed as in Equation 7. The baseline quantity for each system component is then computed as follows:

$$\text{QINDEX}(T,K,L) = \text{COMPONENTZ}(K,L)/\text{INDEX}(T,K,L) \tag{12}$$

The value of the system index at any given place and time can then be computed as shown in Equation 9.

This section has focused on the use of an index for regional comparisons. Another aspect of this indexing methodology that is important but is not shown here is the development of time series from which projections of future prices can be made. Since the data base is based on measurable items, relevant time series can easily be developed.

Given the desirability and feasibility of developing such an index, the following additional steps are recommended:

1. Additional analysis of completed projects is necessary to determine the resource and resource-type mixes for different subsystems.
2. The components applicable to each resource type need to be defined.
3. Finally, a data base and equations are created on the computer so that index items for each resource type can be updated and the relations can be manipulated for different types of subsystems, locations, and times.

Table 6. Twenty-city index for cut-and-cover tunnel with slurry wall.

City	Including Equipment Component	Excluding Equipment Component: Rank	Excluding Equipment Component: Index	ENR BCI: Rank	ENR BCI: Index
Atlanta	86.5	1	80.1	1	85.2
Birmingham	86.8	2	80.6	2	87.2
New Orleans	90.1	3	85.4	3	90.5
Dallas	92.4	4	88.8	4	90.6
Baltimore	94.7	5	92.2	6	96.0
St. Louis	96.6	6	95.0	7	97.3
Denver	97.4	7	96.2	5	94.5
Minneapolis	97.5	8	96.3	9	99.0
Kansas City	99.5	9	99.3	8	98.4
Cincinnati	99.5	10	99.3	14	103.7
Pittsburgh	100.0	11	100.0	16	104.0
Chicago	101.8	12	102.6	12	102.4
Philadelphia	102.0	13	102.9	15	104.0
Seattle	102.2	14	103.2	11	99.8
Detroit	103.1	15	104.6	17	107.7
Cleveland	105.1	16	107.5	13	102.6
Boston	107.4	17	110.9	10	99.2
Los Angeles	108.7	18	112.8	18	108.4
New York	108.8	19	112.9	19	111.6
San Francisco	113.3	20	119.6	20	117.4

SUMMARY AND EXTENSION TO NONPRICE FACTORS AFFECTING REGIONAL COSTS

The proposed transit price index will provide a reasonable way to

1. Provide transit professionals a means of tracking the resource costs most applicable to their work and
2. Provide planners, designers, and researchers a means by which to better compare costs of projects constructed at different times and places [currently used surrogates such as the ENR and producer indices

(formerly WPIs) suffer from inappropriate resource and resource-type mixes].

In addition to the price of the resource, many other factors affect the cost of a job. If one views cost as output x productivity x resource price x overhead, it can be seen that the price index will define one part of the cost picture. Productivity can be related to region-specific work rules and job specifications such as traffic control requirements, supply uncertainty, and weather. Overhead costs reflect market and institutional costs. Foster and others (7) identify market factors such as the bidding climate and institutional and support factors such as insurance, building permits, financing, real estate acquisition, geologic investigation, construction management, engineering design, and legal and community costs that affect the overhead rate on any job. Once the effects of price, time, and location (as represented by the transit price indices) have been determined, indices of productivity and overhead factors can be analyzed to understand costs.

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REFERENCES

1. Dodge Building Cost Services. 1979 Dodge Guide for Estimating Public Works Construction Costs, 11th annual ed. McGraw-Hill Information Systems Co., New York, 1978.
2. Means Cost Guide. R.S. Means Company, Inc., Duxbury, MA, 1978.
3. National Construction Estimator, 27th annual ed. Craftsman Book Co., Solana Beach, CA, 1978.
4. Market Trends. Engineering News Record, March 22, 1979.
5. Construction Cost Indexes for 1915-78. U.S. Department of Commerce, Construction Review, Vol. 25, No. 12, Dec. 1979.
6. Data Resources Cost Forecasting Service, Inc. Forecasting Highway Construction Costs. FHWA, Rept. FHWA-DL80-005, Feb. 1981.
7. E.L. Foster and others. Economic Factors in Tunnel Construction. U.S. Department of Transportation, Rept. UMTA-MA-06-0025-79-10, Feb. 1979.

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Nondestructive Monitoring of Chloride in Bridge Decks with a Mobile Neutron-Gamma Spectrometer

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A mobile, self-contained instrument for rapid, nondestructive monitoring of chloride content at the reinforcing-bar level in portland cement concrete bridge decks has been developed to field prototype stage and tested on a range of concrete specimens and on five bridge decks in Texas. The instrument uses the technique of neutron-induced gamma-ray spectrometry with a 400-μg californium-252 sealed neutron source. Two measuring heads provide the capability for depth discrimination and enable chloride contents to be measured at the reinforcing-bar depth irrespective of surface washout, salt encrustation, the presence of overlays or membranes, and different depth distributions of chloride content. The sensitivity to chloride obtained depends on the required depth discrimination and speed of measurement but is normally sufficient to detect chloride concentrations below the corrosion threshold of approximately 300 mg/kg (~1.2 lb/yd^3).

The chloride-induced deterioration of reinforced portland cement concrete (PCC) is one of the most important problems currently facing the highway industry (1). All PCC bridge decks to which deicing salts have been applied and all PCC structures exposed to sea salts are susceptible. As little as 300 mg/kg (~1.2 lb/yd^3) of chloride ion counteracts the passivity of the steel reinforcing and allows electrochemical corrosion to proceed rapidly. The onset of rapid corrosion can be very difficult to detect because the depth distribution of chloride concentration can vary due to factors such as surface washout or accumulation of salt and because the concrete surface may have been covered with a protective overlay or membrane.

In addition to membranes and asphalt overlays, other materials impermeable to chloride are being used both at repair sites and in new construction. Any test method should be capable of monitoring chloride content without interference from any of the materials used in bridge decks. The present test method is to remove pulverized core samples taken at various depth increments by means of a rotary hammer and to analyze them in the laboratory by using a wet chemistry-potentiometric technique. This method is time consuming, labor intensive, and traffic disrupting. Its destructive nature makes it unsuitable for sampling below impermeable membranes and requires refilling of the sample holes. Furthermore, because of the small sample size and the heterogeneity of concrete, more samples than might otherwise be needed have to be taken to yield a survey of acceptable accuracy (1).

The main objective of the project described here was to develop a field instrument and test procedure for rapid, in situ, nondestructive determination of chloride ion content in PCC bridge decks and other reinforced concrete members at the level of the outermost mat of reinforcing steel. A detailed feasibility study (2) resulted in the choice of neutron-induced gamma spectrometry as the preferred method of measurement. The unique advantage of neutron-gamma spectrometry is that the incident neutrons and emitted characteristic gamma rays have