FINAL REPORT

CONVERSION BETWEEN NETWORK-LEVEL AND PROJECT-LEVEL UNITS OF MEASURE FOR USE IN A BRIDGE MANAGEMENT SYSTEM

Howard M. Turner, Jr.
Graduate Research Assistant

Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the
Virginia Department of Transportation and
the University of Virginia)

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

July 1998
VTRC 99-R4

ABSTRACT

VDOT is implementing Pontis 3.0 to provide the analytical component of its Bridge Management System (BMS). This system prioritizes bridge maintenance, repair, rehabilitation, and replacement (MRR&R) needs using cost/benefit analysis. The accuracy of this analysis depends on the condition assessment of the structure and the cost data of MRR&R options used in the analysis.

For the network-level analysis a BMS provides, the focus is on what work was done to an element rather than how it was done. To standardize the MRR&R actions taken at the network level, commonly recognized (CoRe) elements have been identified and are used in Pontis. For each element, a set of feasible MRR&R actions has been defined.

How these actions are accomplished is tracked on the project level. Contracted bridge work is managed using industry-standard pay items and quantities. There is a great deal of historical project-level data from previous contracts. However, there has not been any large scale network-level data collection effort.

The purpose of this project was to examine cost management practices in VDOT and to develop an architecture for an automated project-level to network-level cost conversion process. This process should provide accurate updated cost data to Pontis by (1) using pay codes, quantities, and other contract information; (2) combining this information with existing inventory information and new inspection information about the structure; (3) reporting what CoRe feasible action was taken and the associated unit cost; and (4) providing this information in a Pontis-usable format.

The investigation of cost management revealed a number of areas where VDOT could improve its practices. The research addresses potential remedies for some and, in some cases presents potentially viable conversion schemes.

FINAL REPORT

CONVERSION BETWEEN NETWORK-LEVEL AND PROJECT-LEVEL UNITS OF MEASURE FOR USE IN A BRIDGE MANAGEMENT SYSTEM

Howard M. Turner, Jr.
Graduate Research Assistant

INTRODUCTION

The bridge population of the United States is currently at an age that requires considerable effort to maintain safety and serviceability. There were two large booms in bridge construction, during the Depression and in the interstate construction era. The bridges constructed in the 1930s are nearing the end of their useful life, and the bridges built during the late 1950s, 1960s, and early 1970s have reached or are approaching the middle of their life spans. Depression-era bridges must be improved or undergo significant rehabilitation. Bridges from the second construction boom already or soon will require major repairs.[2]

Bridge Management Systems

The simultaneous requirements of these two age segments of the bridge population come at a time when resources are more limited than ever. Limited resources and large demand force highway and transportation agencies to make tradeoffs. These agencies must balance investment, safety, commercial concerns, and a host of other considerations. A Bridge Management System (BMS) uses economic and engineering analysis to determine the optimal allocation of resources to maximize the utility of the bridge network. As of October 18, 1994, Virginia had 20,824 bridges.[3] An automated BMS allows the funneling of this enormous quantity of data into a reasonable, logical, systematic decision-making process.

The decision to allocate resources to bridge activities is a complicated one, involving not only engineering assessment but political implications as well. The persons involved need a reliable, valid analytical method for determining optimal resource allocation. A BMS can provide these persons with recommendations based on data previously unavailable or unmanageable because of its scope. Not only can a BMS determine the funding required for various levels of service, it can also recommend the proper allocation of the bridge budget among competing bridges.

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) recognized and addressed this need, among others. It stipulated six management systems that each state must implement. The Highway Bridge Replacement and Rehabilitation Program (HBRRP) defined the rules for bridge management. HBRRP required that each state implement an automated BMS by 1995. A major part of implementing a BMS is the creation of databases containing cost, condition, and other bridge information. Some of these data were already being collected, under the National Bridge Inspection Program, which required every bridge over 20 feet in length to be inspected and evaluated on a biannual basis. The National Highway Designation Act of 1995 rescinded the mandate for bridge and other management systems. However, many states are continuing to develop and implement BMSs.

Despite mandating the adoption of BMSs, ISTEA gave little instruction as to how to implement one. However, less than 1 year after ISTEA, the American Association of State Highway and Transportation Officials (AASHTO) published their *Guidelines for Bridge Management Systems.* The guidelines were targeted to state agency officials attempting to implement a BMS.[2]

BMSs are intended to provide a decision-making process for evaluating bridge maintenance, repair, rehabilitation, and replacement (MRR&R) options. Using specific constraints and factors, a BMS will recommend the optimal MRR&R strategy for all bridges in a state highway system. An optimal strategy is one that maximizes the utility of the bridge network for a given set of restraints, typically budgetary. Applying the vernacular: "Getting the most [benefit] for your [maintenance] money!"

A key concept to understanding bridge management systems is that the best action for a particular bridge may not be the best action for the entire network of bridges. For example, rehabilitation of one bridge may not provide as much benefit to the bridge network as preventative maintenance on several other bridges. With so many variables, the decision on where and how to allocate resources is very complicated. BMSs automate this process. A BMS considers many factors, predicts future needs, and helps make that crucial resource allocation decision. Because of the focus on the population of bridges, these BMSs are referred to as being "network-level."

Pontis

Pontis, from the Latin *pons* for *bridge*, provides the computer analysis portion of Virginia's BMS. When provided with the proper data, Pontis, developed by Cambridge Systematics, Inc., will analyze the data and formulate a model of Virginia's entire bridge network. Virginia and other states are currently beta-testing Pontis v3.0B2, which runs under Microsoft Windows.

Pontis takes the data stored in its structural and cost databases and models the bridge network. With budget and other constraints, Pontis can form MRR&R recommendations that maximize the effectiveness of such activities. Since it is a network-level model, Pontis is a network-level management tool. It optimizes the level of service of the bridge network, not of each bridge.

Pontis uses mathematical models to simulate the bridge network and predict its needs for the future. Pontis uses three sets of models to generate a strategy:

1. *Preservation models.* This set of models develops a picture of the deterioration of the network, the cost for corrective action, and a policy to preserve the agency's investment.

2. *Improvement models.* This set of models finds and predicts functional deficiencies using traffic growth, user costs, and other costs and benefits. The models also generate strategies to meet functional needs of the future.

3. *Project programming model.* This model integrates the results into a set of policies. It uses both preservation and improvement actions in its recommendation.[5]

Bridge inspections are a critical part of any BMS because they provide the structural condition and deterioration information the BMS needs for its analyses. Pontis requires an Element Level Inspection, which focuses on the individual components of a bridge and their deterioration. In most other inspection programs, including the NBIS, bridges were given one or more summary condition ratings that gave an overall picture of the bridge's condition. However, in Pontis, bridges or large components (e.g., deck, substructure, superstructure) are not given a single rating. Rather, each component of the bridge is rated. These components are called elements.

In Virginia, bridge inspections since October 1995 have included an element-level inspection. With this new inspection approach, the amount of data needed and gathered on bridges is greatly increased, but so is the actual understanding of the bridge's deterioration.[14]

The real strength of Pontis is its ability to manipulate data from a variety of sources. There is a great deal of existing bridge data. Unfortunately, when access is not a problem, the inability to deal with the sheer quantity is frequently enough to prevent the data from being used. Pontis compiles the information in its databases and uses it to model the network and generate costs and benefits of maintenance strategies.

One of these databases contains physical information about the bridges, such as type, major components comprising the bridges, size, location, and other data. In addition to inspections, this database is formed from data already present in NBI form[4] or generated from as-built plans.

Another database incorporates costs. Costs generally come in two forms, agency costs and user costs. Agency costs are the costs the highway agency incurs on any bridge over time, i.e., periodic maintenance, rehabilitation, and replacement. User costs are more of an economics concept and are often much less tangible. They are costs that result from higher vehicle operating costs, delays, high accident rates, and other factors. User costs can be thought of as the penalty paid by the user of a bridge for the deficiencies of the bridge.[9]

Commonly Recognized Elements

Bridge elements are components of a bridge that are "important from a structural, user, or cost standpoint."[2] Elements have been standardized by AASHTO into a set of commonly recognized (CoRe) elements. CoRe elements are intended to form a uniform method of recording bridge information. A task group from state transportation agencies and the FHWA developed CoRe elements. CoRe element information primarily includes element types, units of measure, and possible MRR&R actions.

A single CoRe element can incorporate only those components of a bridge that are made of the same material, deteriorate in a similar fashion, can be inventoried with units that are easily measured by inspectors, and have units that are meaningful at the network level for deterioration modeling.

All major components of a bridge can be defined as CoRe elements, from elastomeric bearings to timber decks.[1] In addition, VDOT has defined several elements that are frequently found in Virginia's bridges or that it wishes to track specifically. These elements are called state-specific elements and are used in addition to CoRe elements. They are used and tracked just like CoRe elements but are not uniform from state to state.

Condition States and Feasible Actions

Condition states record the condition (or equivalently the amount of deterioration) of an element. In Pontis, condition states run from 1 to 5, least to most deteriorated. Each CoRe element, and sometimes groups of CoRe elements, has unique condition states. Each CoRe element also has a specific set of repair activities that may be performed, its feasible actions. When Pontis makes its repair recommendations, it does so by suggesting one of the feasible actions. There are at least two feasible actions associated with each condition state for each element.[1]

Cost Management

The development of BMSs has brought new attention to the collection and management of cost data, especially since network-level data have previously not been required. Many states are having difficulty using their existing cost data in their new BMS. This is true in Virginia, where cost data are gathered and stored by the Contract Section of VDOT's Construction Division, which uses historical project-level cost data. With the implementation of Pontis, a need exists to convert this project-level data into network-level data.

Nationwide, few departments of transportation have adequate network-level cost data to use in their BMS. In most cases, the cost data do exist and are recorded. However, few use actual data from projects to validate the BMS figures, and many have no established system to detect poor or faulty cost data. It is a widely held belief that inadequate cost data represent the greatest weaknesses of an analytical BMS.[10] Correspondingly, valid and complete cost data could easily be the greatest strength of a BMS. Finding the data that do exist and "massaging" it into a useful format is the problem.

The basic requirements of network-level and project-level units are simple: network-level costs need to match the units used in the BMS, and project-level costs should match units used in the construction industry. For example, the repair of a bridge deck is measured in square yards at the network level. Tracking the condition of a deck this way makes good sense for a BMS. The percentage of deck area in disrepair is a very good indicator of the quality of service the deck provides. However, the square yardage (or percentage) of deck in disrepair does not provide a lot of information to a contractor who may wish to repair the deck. The repair may require square yards of patching, cubic yards of concrete, pounds of reinforcing steel, tons of asphalt, etc. These quantities will vary based on the type of repair, depth of the deck that requires repair, and many other factors that are "hidden" in a simple square yardage number. These are the units a contractor must use to record and bill for services and materials and are the classic examples of project-level units.

To demonstrate the level of detail at which various transportation agencies track costs, Table 1 shows cost data available at various levels of detail (of 31 states responding). *Contract* refers to data about the cost of a project that does not distinguish individual bridges or elements. *Bridge* refers to cost data about a particular bridge. *Element* means that the state can provide cost data on specific types of elements (such as CoRe elements). For example, four states responded that they record cost data at the element/action level, meaning they track the cost of a particular repair action (such as a CoRe feasible action) for individual bridge elements.

Table 1. Level of Cost Detail Available

Detail	Replacement	Functional/Structural	Maintenance
Contract	22	22	11
Bridge	29	28	17
Element	13	15	10
Project/action	7	7	3
Bridge/action	10	10	7
Element/action	4	4	4
Element/condition state/action	0	0	0

Adapted from Thompson and Markow, 1996.

The need for good cost data cannot be underestimated. "In most departments of transportation, the ability to collect and manage cost data are the biggest impediment to the agency's ability to successfully implement a bridge management system."[10] However, a massive historical cost data collection effort would not provide a good return on investment. It may be possible to develop and implement new means of managing data with reasonable additional effort and cost. The requirements of a network-level BMS for unit cost data are different from those of a project-level estimating system, but the source data are obviously very closely related. Automated storage, analysis, and conversion utilities would be an efficient means of addressing the problem.

PURPOSE AND SCOPE

This research examines current cost management practices used by VDOT in the context of Virginia's BMS. Moreover, it develops the framework of a method to convert existing project-level cost data to network-level cost data for use in Virginia's BMS. The method allows the agency to develop reasonably accurate network-level cost data for maintenance, repair, and rehabilitation of 22 of the most commonly repaired, maintained, or rehabilitated CoRe elements. Replacements are excluded from the study.

APPROACH

The 1994 VDOT *Road and Bridge Specifications*[13] was reviewed to familiarize researchers with state-of-the-practice bridge maintenance and repair. The engineering estimating (EO-3) system's item code set was obtained and imported into a Microsoft Access database for manipulation. The research team studied inspection procedures and methods in a bridge inspection training session and became familiar with the CoRe elements through AASHTO's *Guide* and the *Virginia Element Data Collection Manual*.[14]

The general approach to developing a conversion scheme for an individual CoRe element (or group of elements with similar condition state/feasible action language) is to identify the work items associated with that element, determine possible combinations of these that may indicate certain feasible actions, and compare this to actual contract data.

Flowcharting and Logic

The work items that compose MRR&R activities for CoRe elements such as decks and joints are often unique to those types of elements. In many cases for these elements, the units of measure are the same as well. For example, joint repairs are recorded in both project- and network-level units as linear feet. However, when more general items such as "Class A4 Concrete–23 cubic yards" appear, determining which action or element to assign such an activity to is more difficult.

The process of elimination seems to be the best approach. The majority of work items can be assigned to elements by going through the contracts and eliminating those work items that obviously match up with specific CoRe elements. This eliminated all work items in some cases, and in most cases eliminated about 80%. Those items that do not match are marked for further examination.

With the remaining work items, any information at all can be helpful in determining where they belong. The item code frequently helps by separating superstructure items from substructure items. Material type is also a useful delineator. Sometimes units of measure can be of help. The combination of certain materials can also be a good indicator of what has taken place. For example, when concrete and reinforcing steel are shown, a complete element unit has usually been constructed. When these fragmented bits of information are all that are available, a systematic, logical approach must be used. Exactly what data are necessary? It varies by element, but there are some basic criteria.

Criteria for Study

The criteria for "good" data are simple: (1) an element-level inspection must have been performed before contracted MRR&R work, and (2) an element-level inspection must have been performed after the work was complete. Recall that replacements have been excluded from the study.

Since element-level inspections have been included in all bridge inspections since October 1995, the first criterion is met on any bridge inspected since that time. Most bridges are on a 2-year inspection cycle (some longer), and at the time of this writing, many bridges had not yet been through the cycle. For the most part, element-level inspections are recorded on paper and stored in a file along with the standard inspection data (personal communication, Bill Dunlap, Bridge Safety Inspection Team Leader, Northern Virginia District). Some of these element-level inspections are being keyed into Pontis at VDOT's Central Office (personal communication, Fred Dotson, Assistant Division Administrator, VDOT's Central Office).

The second criterion is met for all contracts with a completion date after October 1995. All bridges that have had major work performed are reinspected at the conclusion of the project. Along with this safety inspection (a B-6 inspection sheet), an element-level inspection is generally performed.

FINDINGS

Virginia's Cost Data Management

Review of Estimating Procedure

The estimates on bridge MRR&R contracts originate in the district office. District bridge engineers develop a maintenance or repair estimate using the EO-3 computer system. The EO-3 system uses cost data from the last 18 months (contained in a price bank) and attempts to use the most specific information available, specificity including factors such as highway type and location of materials at the county level. If specific data are not available, it will default to a more general type, until eventually statewide information from an "item cost" table is used. After the district engineer's estimate is completed and the project is advertised, the estimate is sent to VDOT's Construction Division, where the estimators go to the job site and identify any local factors that may affect unit prices. This forms a cost-based estimate. After this adjustment, the Construction Division compares the low bid to their estimate. If the bid is let, the low bid prices are entered into the EO-3 computer system for continuous updating of the price bank.

The EO-3 system relies on "Item Codes" to describe activities. These item codes are listed and published by the Construction Division. They are divided into categories and describe the various items of work performed on highway jobs. The EO-3 system provides the entire state with unit costs for various activities. The item codes are project-level data.

The EO-3 item code set contains almost 3,100 records. A typical record includes the item code, the description, the unit of measure, and the specifications section describing the item.

The items are coded by a 5-digit item code and are grouped with other similar items. For example, most of the item codes for joint materials are adjacent. For bridges in general, the item codes for most MRR&R activities are grouped into two major sections: the 68000's and 69000's groups. The 68xxx activities are superstructure repairs and maintenance, and 69xxx activities are for the substructure. Other 6xxxx activities for the most part describe new construction. These are not hard and fast rules but are reliable rules-of-thumb.

Sometimes an activity may have multiple specification sections. In this case, the record frequently is a material, such as Class A4 concrete, which has material properties described in one section and installation methods described in one or more other sections. Frequently in an estimate, the words PLAN or ATTD appear in the specifications field. In these cases, the procedures describing the use or installation of the item are contained in the plans or as an attachment, respectively. In this case, an item may have identical descriptions and units but may have multiple entries with different item codes. In the case of different units, such as square yards or tons of asphalt, there may also be multiple item codes for the same activity or material.

The EO-3 item code set is being updated for implementation into VDOT's new estimating system, which while under development was known as BAMS but will be called TRNS.Port when implemented. The item code set will be transferred over to the new system, retaining the current format.

Reviewed Inspection Procedures and References

The *VDOT Element Data Collection Manual* is designed to complement the *AASHTO Guide for Commonly Recognized Structural Elements*. The *AASHTO Guide* provides a brief description of the elements, condition states, and feasible actions. The *VDOT Manual* contains more detailed descriptions of the elements and condition states, but does not include feasible action information. In both references, CoRe elements are grouped together according to type of structural element and similarity of deterioration behavior. Core elements 1-99 are reserved for deck elements, 100-199 for superstructure elements, 200-299 for substructure elements, and 300-399 for miscellaneous elements.[1] The *VDOT Manual* also contains a number of elements that are not in the *AASHTO Guide*, state-specific elements 700-799.

After a contract is completed on a bridge, a post-work safety inspection is performed at the request of construction personnel. This inspection describes briefly the work done, condition of the structure, and recommendations for further work, if necessary. Bridge inspection personnel are responsible for these and regularly scheduled inspections. These data are contained on Sheet B-6 of the inspection. Accompanying the safety inspection is an element-level inspection. An element level inspection uses a preformatted inspection sheet. In general, an element level inspection includes the element type and its quantities in various condition states.

Findings from Clemson University Study (DAGS)

Work at Clemson University has created what may be an important part of an automated system. The Data Analysis and Generation System (DAGS) is a computer program that stores network-level cost data and performs basic statistical analyses on them. DAGS works only with network-level data, i.e., both output and input must be in network-level units. DAGS is a useful tool for spotting outlying data points, identifying trends in costs attributable to geographic location or other factors, and converting cost data into the proper computerized database format for Pontis.

Findings from the DAGS research indicated a need to concentrate collection and analysis efforts on specific elements and actions. To study the data effectively, 22 CoRe elements were selected based on the number of data points collected during the DAGS research. These selections were compared to their prevalence in bridges in a specific district of South Carolina. The results indicated that these elements constituted major components of the element population. The elements identified in the DAGS study also appear to be involved in a significant portion of the work performed in Virginia. This being the case, this research focused on these 22 elements, listed in Table 2.

Table 2. CoRe Elements of Interest

Division	Element	Description
Deck Elements	12	Concrete Deck – Bare
	13	Concrete Deck – Unprotected, AC Overlay
	26	Concrete Deck – Protected w/ coated bars
Slabs	38	Concrete Slab – Bare
	39	Concrete Slab – AC Overlay
Superstructure	107	Painted Steel Open Girder
	109	Prestressed Concrete Open Girder
	110	Reinforced Concrete Open Girder
	126	Painted Steel Through Truss
	152	Painted Steel Floor Beam
Substructure	202	Painted Steel Column
	205	Reinforced Concrete Column
	206	Timber Column
	215	Reinforced Concrete Abutment
	234	Reinforced Concrete Cap
Other Super/Sub	301	Pourable Joint Seal
	302	Compression Joint Seal
	311	Moveable bearing
	313	Fixed Bearing
	330	Metal Bridge Railing
	331	Concrete Bridge Railing
	333	Misc. Bridge Railing

From Elzarka, Bell, and Sanders, 1996.

How This Work Fits into Virginia's BMS

If implemented, where would an automated conversion system fit into the current BMS structure? Since one of the most important components of a BMS is an automated feedback loop (in this case to report costs), the system must fit into the existing feedback structure.

Part of a practical option for Virginia may be to incorporate the DAGS system. With the DAGS system, the feedback loop would include three computer programs (Pontis, DAGS, and the new conversion system). Project-level data go into the new system, are converted to network-level data, are fed into DAGS, are converted to Pontis format, and are used by Pontis for MRR&R recommendations. Figure 1 shows how this feedback loop would fit into Virginia's BMS.

The Conversion Process

As a first attempt at performing a network- to project-level conversion, data from a small number of bridges in Northern Virginia were gathered and analyzed. Inspection data were mailed from the Northern Virginia district office and contract documents were gathered from the Contracts section of the Construction Division office in Richmond. The data gathered included interim estimates, preconstruction element level inspections, and miscellaneous contract documents.

By looking at the work items and their quantities in the estimate, the research team was able to assign most activities to a CoRe element (see Table 3).

Table 3. Assigning work activities to CoRe elements.

Code	Item	Element	Reason for assignment to element
68090	Bridge Deck Grooving	Deck	Deck
68247	Asphalt Concrete Type SM-2A	Deck	Roadway surface material, w/ 68xxx item code
68316	Type A Scarifying	Deck	Roadway surface treatment, w/ 68xxx item code
68320	Type B Patching	Deck	68xxx item code, steel superstructure
68330	Type C Patching	Deck	68xxx item code, steel superstructure
68560	Pre. Elastomeric Joint Removal	Joint	by definition
68570	Expansion Joint Removal	Joint	by definition
68624	L/SF Hydraulic Cement Concrete	Deck	(see next paragraph) 68xxx item code
69076	Shotcrete, Class B	Abutment	69xxx=substructure, only sub CoRe=215

Work Item 68624 provides an excellent example of the sequential decisions that must be made by an automated system, rather than the intuitive feel that an engineer uses to arrive at the same conclusion. The following describes this sequential decision making process for this work item.

Latex/silica fume hydraulic cement concrete can be used in a variety of ways, including for patching, deck overlays, and various other repairs to concrete elements. Since the item code

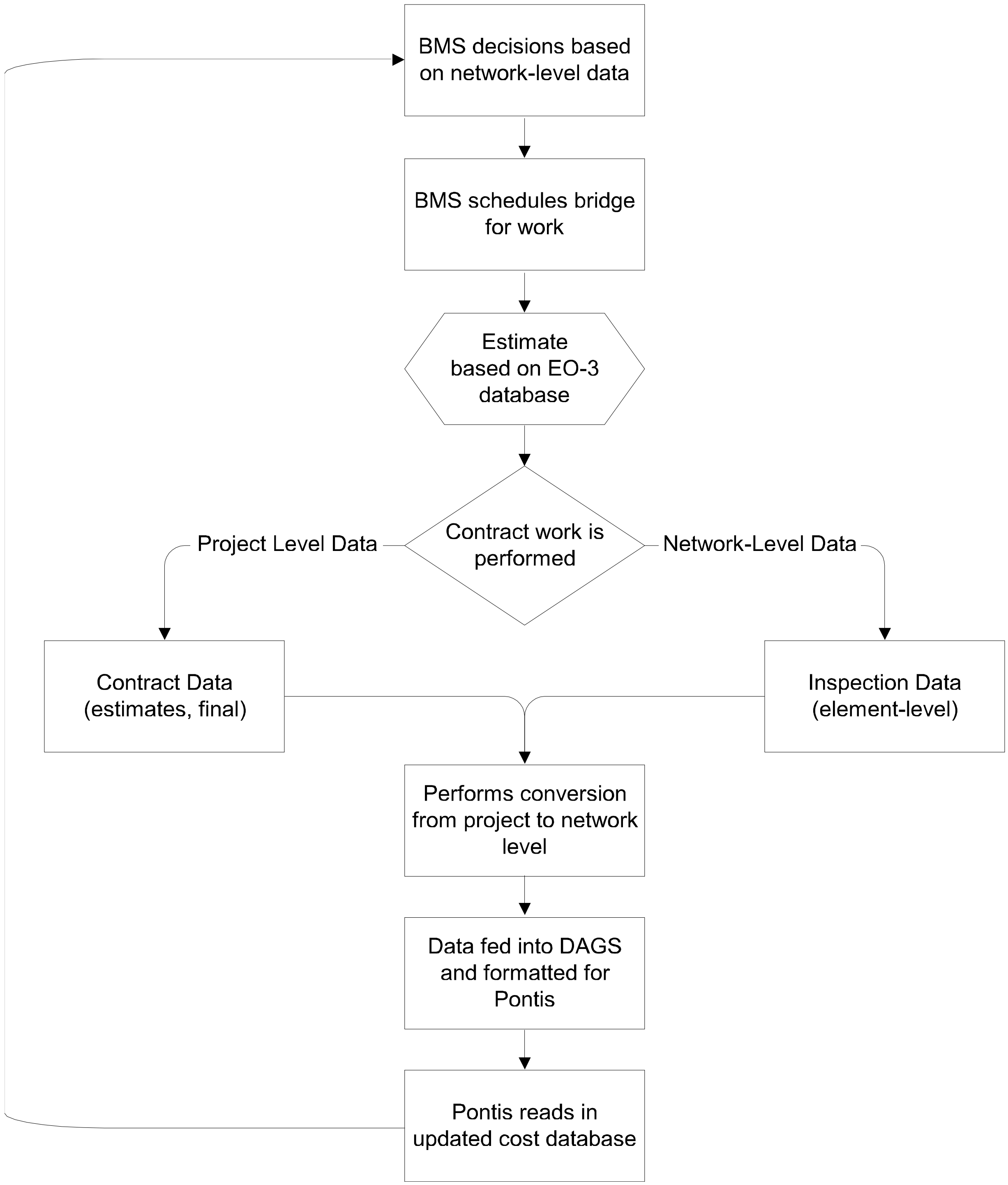

Figure 1. Data Flow for Project-Level to Network-Level Conversion

indicates it is a superstructure item, the substructure concrete is eliminated as a possibility. That leaves the deck and three superstructure items. In this particular instance, the three superstructure items are made of steel, so that eliminates them, which leaves the deck. However, looking at the contract quantity of the latex/silica fume hydraulic cement concrete reveals that it could not have been used as an overlay. Also, the fact that asphalt was used to overlay the deck supports this – placing an asphalt overlay over a new latex or silica fume overlay is not common practice in Virginia. So it must have been used for patching. The specifications say that if latex/silica fume concrete is used for patching, it must be included in the cost for the patching, unless it is done at the discretion of the VDOT engineer. Therefore, since it appears as a separate item, and must have been used for patching, the VDOT engineer must have required its use and it can be assigned to the deck for purposes of cost.

Starting with the deck element, quantities for each work item were compared to the quantities on the inspection sheet. In some cases, the quantity of certain work items approximates the quantity of repaired element. Summing the dollar amounts of all the work items assigned to a particular element, and knowing the quantity of element repaired (either through inspection or contract information), it is easy to compute a unit price. Problems arise when trying to assign work items to their proper elements and determining quantities when units of measure are incompatible.

After the deck element was completed, joint elements were done in the same fashion. Using additional contracts and hypothetical scenarios, the remainder of deck types and joint types were completed. What resulted was the beginning of a logical system of recognizing and identifying the costs associated with repairing CoRe elements.

Flowcharts are presented to describe the conversion process from project-level unit costs to network-level unit costs of the 22 CoRe elements. Many of the CoRe elements share common condition states and feasible actions. Capitalizing on these characteristics, the flowcharts are able to represent each of the 22 elements (with the exception of CoRe element 206, Timber Columns), as well as several additional elements.

Concrete Decks and Slabs

A great deal of data was available for MRR&R activities of concrete decks in Virginia. Unfortunately, at the time of this study, most of it failed to meet the study criteria. The lack of a pre-work element-level inspection required the research team to incorporate into the unit conversion process a method for approximating the condition state of the deck before the work. This step will be unnecessary in the future because those conditions states will be available for all structures.

Condition state language for concrete decks is based on percent of deteriorated deck area (see Figure 2). Feasible action language is based on patching activities and the addition of protective systems. Given the initial condition state of the deck (through inspection or approximation), the feasible actions were determined. In this case, the addition of an overlay is a potential feasible action for each condition state. Knowing the condition state and feasible action, a network-level unit cost can be computed using the sum of the costs of the project-level unit costs associated with it (in this case, the sum of the patching costs and overlay costs). Since concrete slabs share condition state and feasible action language, they can be treated as decks. Table 4 describes the elements covered by this conversion process.

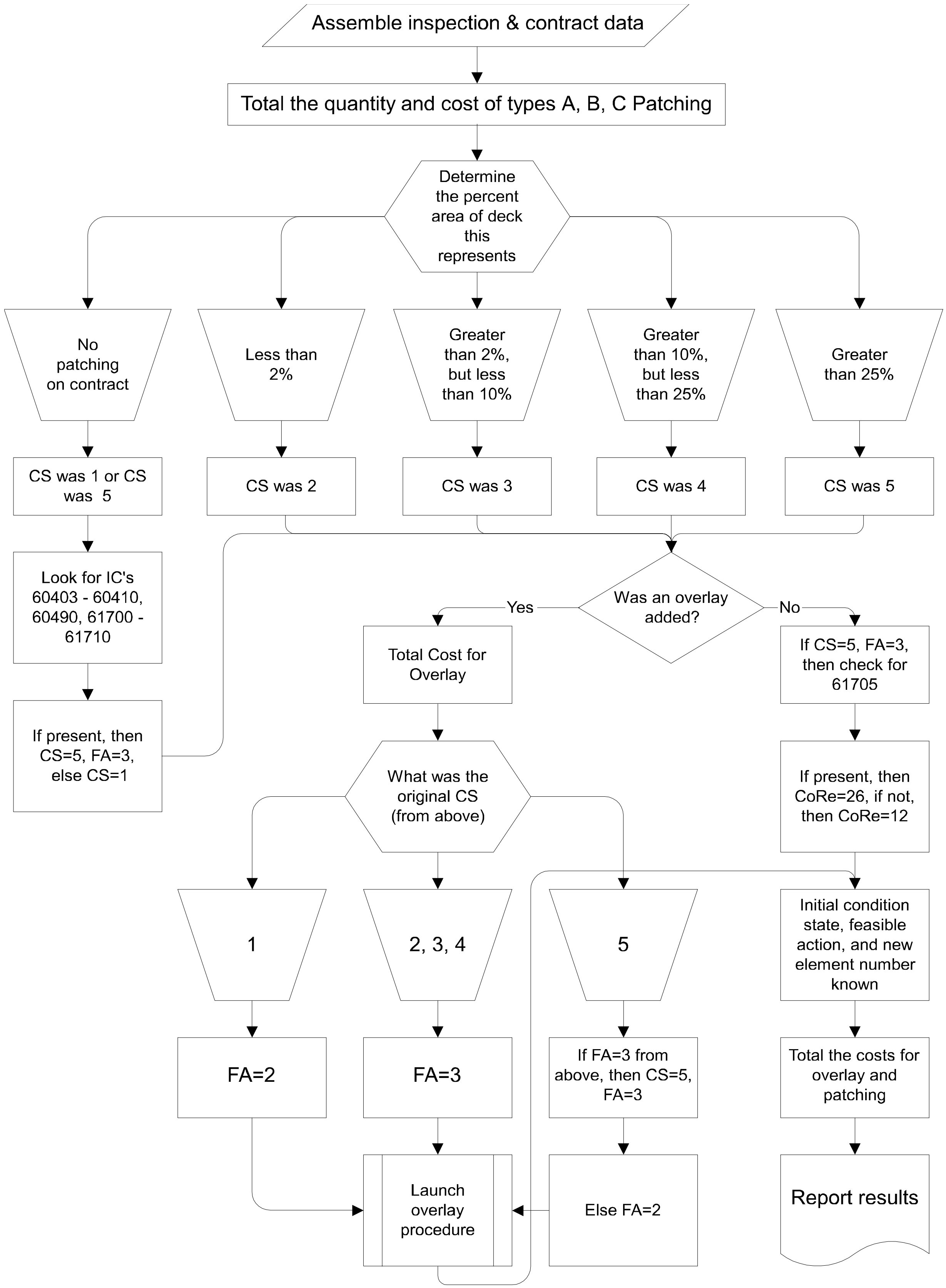

Figure 2. Concrete Decks

Table 4. Elements Covered

Element	Description
12	Concrete Deck – Bare
13	Concrete Deck – Unprotected, AC Overlay
14	Concrete Deck – Protected, AC Overlay
18	Concrete Deck – Thin Overlay
22	Concrete Deck – Rigid Overlay
26	Concrete Deck – Protected w/ coated bars
38	Concrete Slab – Bare
39	Concrete Slab – Unprotected, AC Overlay
40	Concrete Slab – Protected, AC Overlay
44	Concrete Slab – Thin Overlay
48	Concrete Slab – Rigid Overlay
52	Concrete Slab – Protected w/ coated bars

With the addition of an overlay, deck elements can enter as one CoRe element and exit as another. Although costs associated with any work done should be assigned to the initial CoRe element identification, it is important to the BMS that this action be recorded. Thus, the proposed conversion methodology builds this capability into the overlay procedure (see Figure 3).

Joints

A great deal of data was also available for MRR&R activities of joints. Unfortunately, most of the data failed to meet the criteria for study. Without a prework inspection, even the CoRe element is unknown. Again, the author developed a method for approximating prework element-level inspections (see Figure 4).

Joints are described based on their seals. Two joint types use different seals but otherwise may be indistinguishable from each other. Therefore, although there are often exceptions, it is assumed that the type of seal used to repair the joint was the same as the type originally used in the joint. This in turn means there was no element transformation. The type of seal listed in the estimate will identify the CoRe element. If no seal was used, the joint is one of the two types with no seal, and it is more difficult to determine which CoRe element the joint is. However, the estimate may contain information that will help. Table 5 describes the specific elements covered by this conversion process.

Table 5. Elements Covered

Element	Description
300	Strip Seal Expansion Joint
301	Pourable Joint Seal
302	Compression Joint Seal
303	Assembly Joint Seal
304	Open Expansion Joint

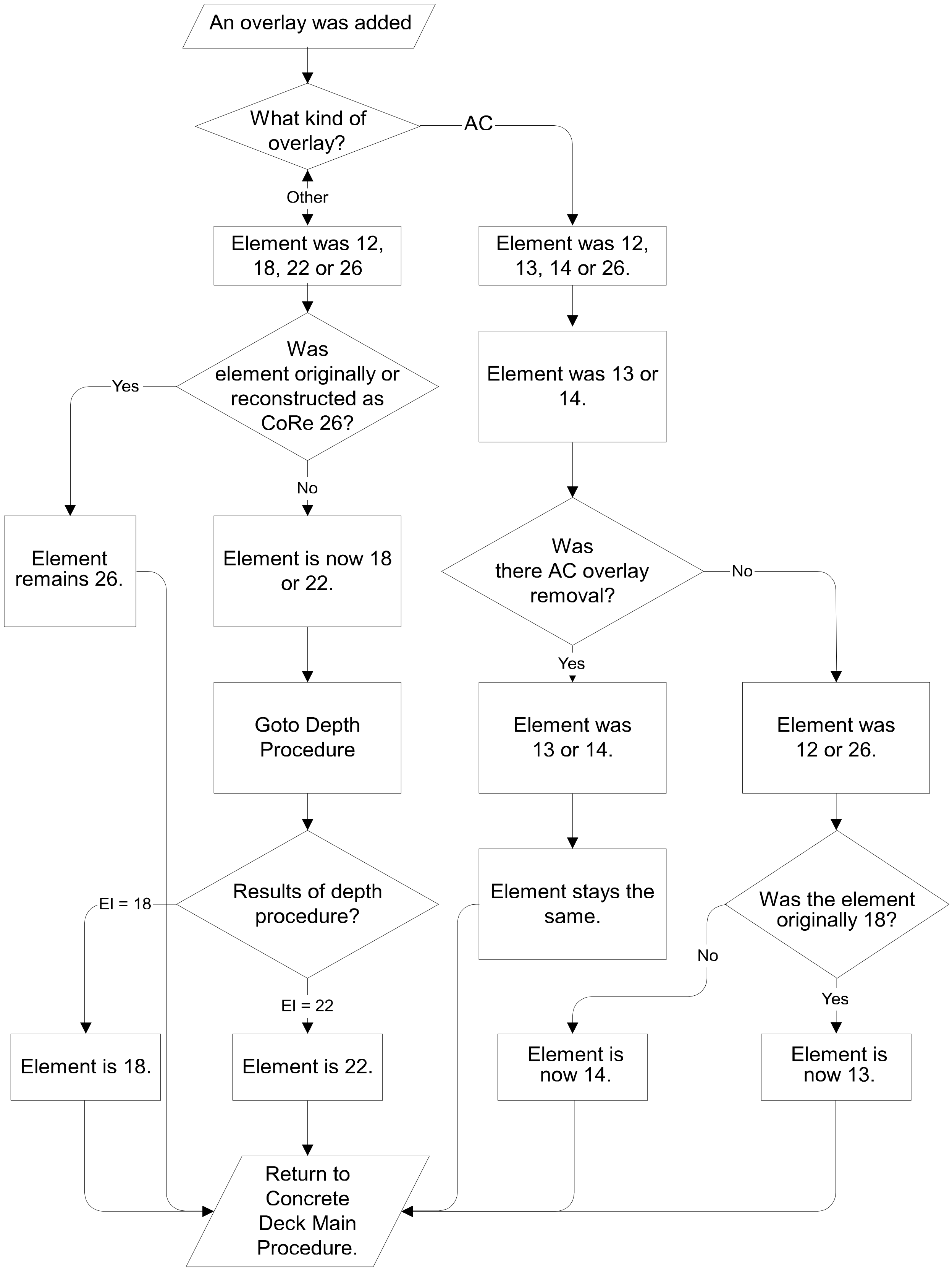

Figure 3. Overlay Procedure

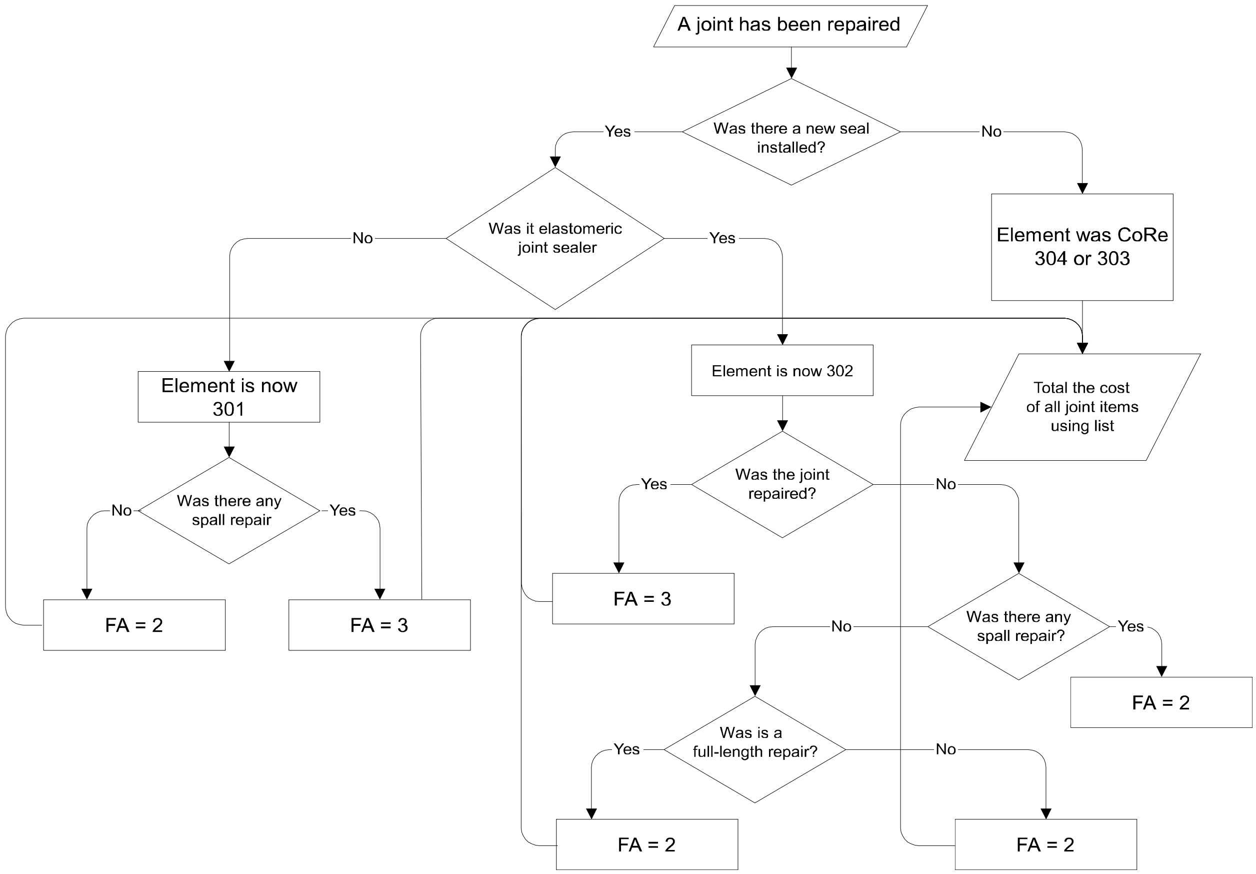

Figure 4. Joints

Despite the vague nature of element identification without a pre-work inspection, element misidentification is not a huge concern. The majority of contracts gathered indicated that most of the repair work encountered will use elastomeric joint sealer. In those cases with non-sealed joints, such as CoRe elements 303 and 304, it is generally impossible to identify CoRe element information without the prework inspection, and thus a unit conversion is impossible.

Painted Steel Elements

One contract was available that featured painted steel elements. The information in *Road and Bridge Specifications* made it possible to formulate a general conversion process for many examples of paint work (see Figure 5).

Road and Bridge Specifications describe painting activities as a lump sum attached to a particular structure. Painting activities also include lump sum amounts for disposal of materials and environmental protection. Since these activities are nearly always part of any painting project, they should be included in the overall cost of MRR&R work on a painted element. Table 6 describes the specific elements covered by this conversion process.

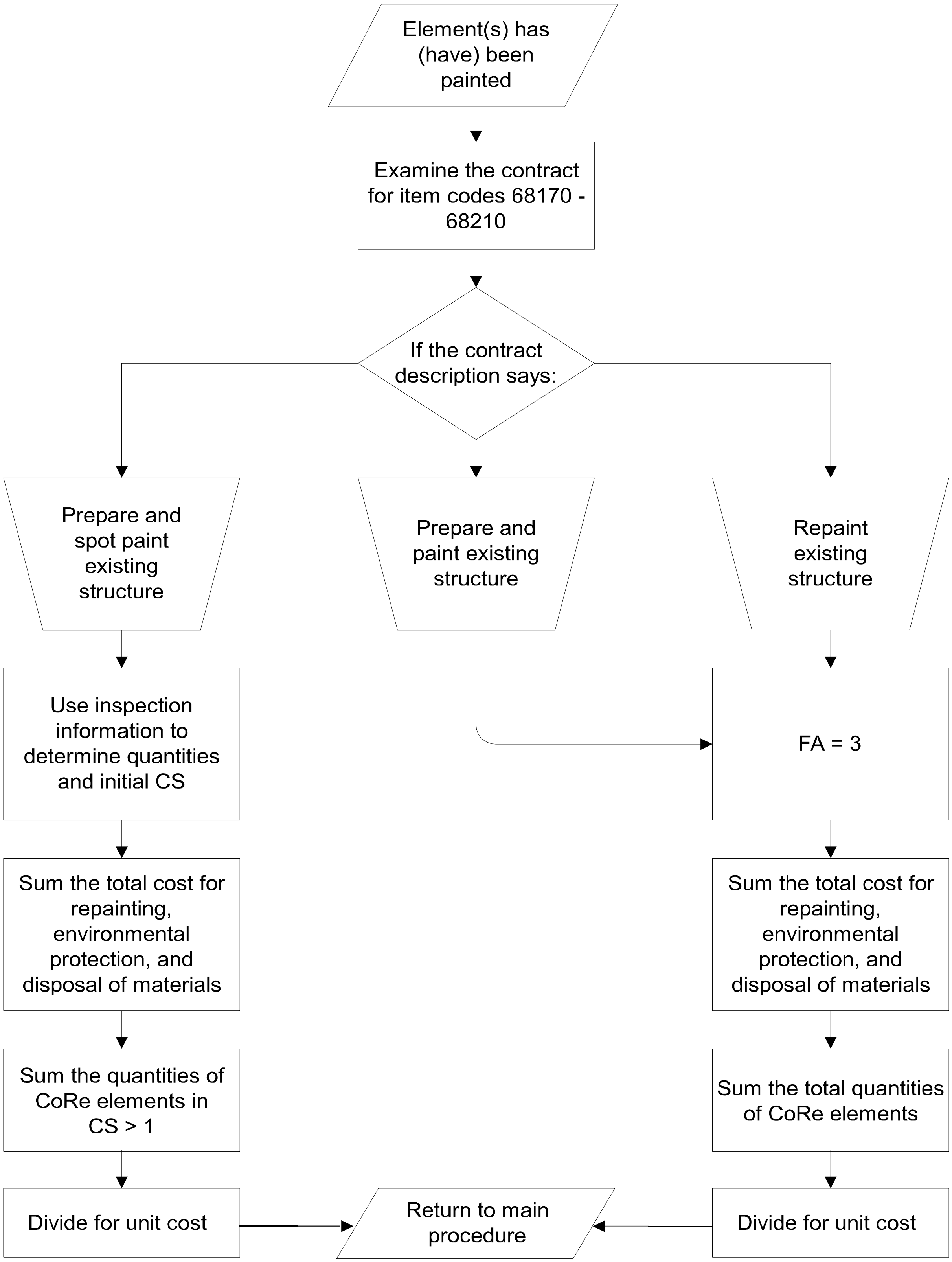

Figure 5. Painted Steel Elements

Table 6. Elements Covered

Element	Description
102	Closed Web/Box Girder
107	Open Girder/Beam
113	Stringer
121	Through Truss (bottom chord)
126	Through Truss (excluding bottom chord)
131	Deck Truss
141	Arch
152	Floor Beam
202	Column
231	Cap

For those projects that feature the entire structure being repainted, this conversion process should be accurate. It is reasonable to assign the costs to the entire quantity of elements, since the total cost of painting is, in fact, the cost required to paint every unit of every element, regardless of whether the element was in good or poor condition.

Bearing Elements

Despite the prevalence of bearing MRR&R work in the Clemson study, the data collected contained no examples of bearing repair. A general approach was determined to be unfeasible.

Rail Elements

Despite the prevalence of railing MRR&R work in the Clemson study, the data collected for this study included only one example of railing work. A general approach was formulated (see Figure 6).

Patching, painting, or replacement, depending on the material, generally constitutes the repair of railings. Therefore, railing repair can be broken down to essentially two feasible actions: rehabilitate or replace. Since replacements were excluded from this study, rehabilitation is the only feasible action considered. The railing material is a key piece of information and is available from either pre- or postwork inspections. Table 7 describes the specific elements covered by this conversion process.

Table 7. Elements Covered

Element	Description
330	Metal Bridge Railing (uncoated)
331	Concrete Bridge Railing
333	Misc. Bridge Railing
334	Metal Bridge Railing (coated)

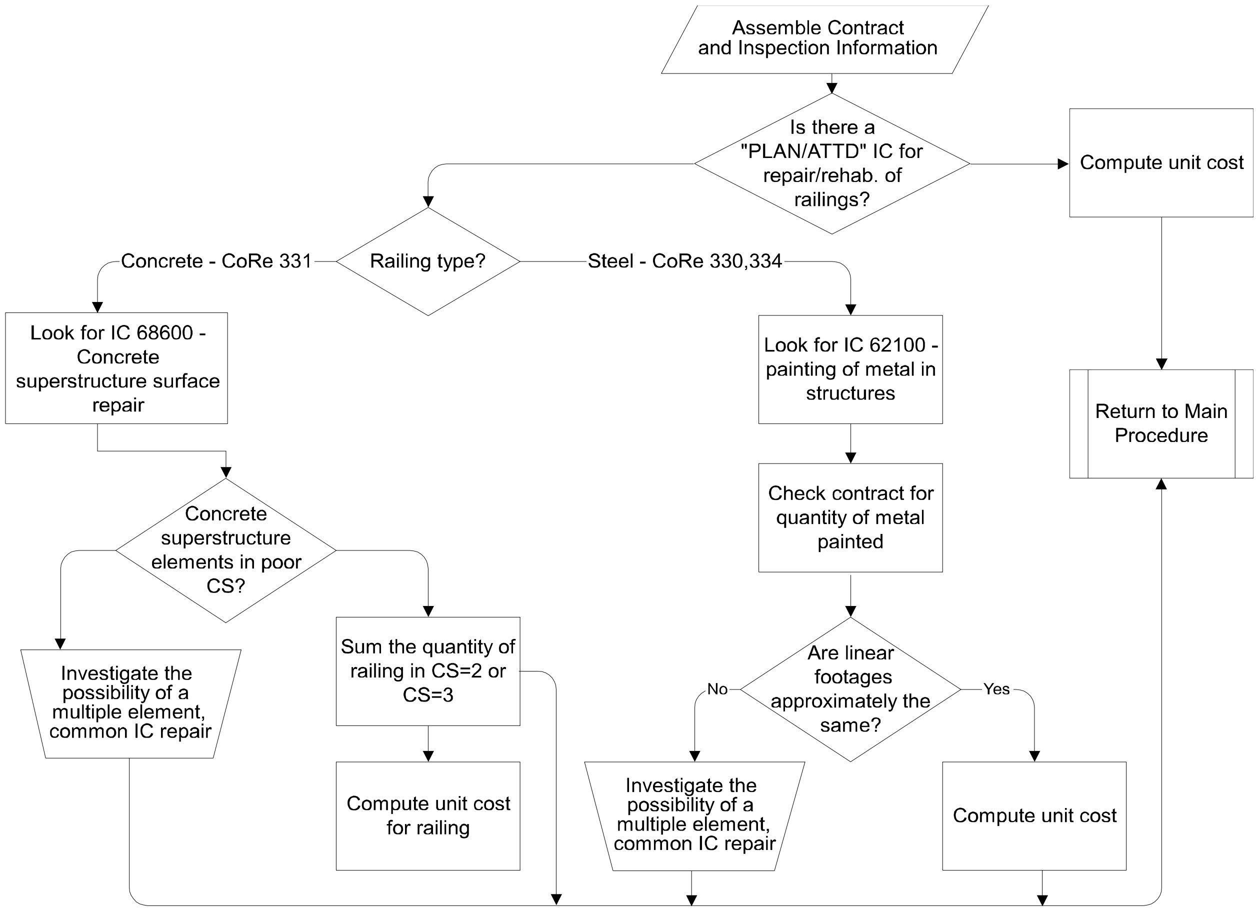

Figure 6. Bridge Railings

Because of the inherent ambiguity of "miscellaneous bridge railing," only concrete and metal railings were considered. Often painting and replacement are the only practical feasible actions available for metal railings. Generally, rehabilitation is practical only for concrete railings. Since replacements are excluded from this study, the methodology covers only painting for metal rails.

Concrete Elements

There was a small quantity of data available describing MRR&R activities of concrete elements. Unfortunately, none of it was accompanied by prework element-level inspections.

Elements such as these concrete CoRe elements are exactly those this study was intended to target. These elements have common condition state language and common repair and rehabilitation item codes. If a project does not meet the criteria for study, it is extremely difficult to design a unit conversion scheme. Approximating the prework element-level inspection is not feasible, as many of the elements could have been worked on with the same item codes.

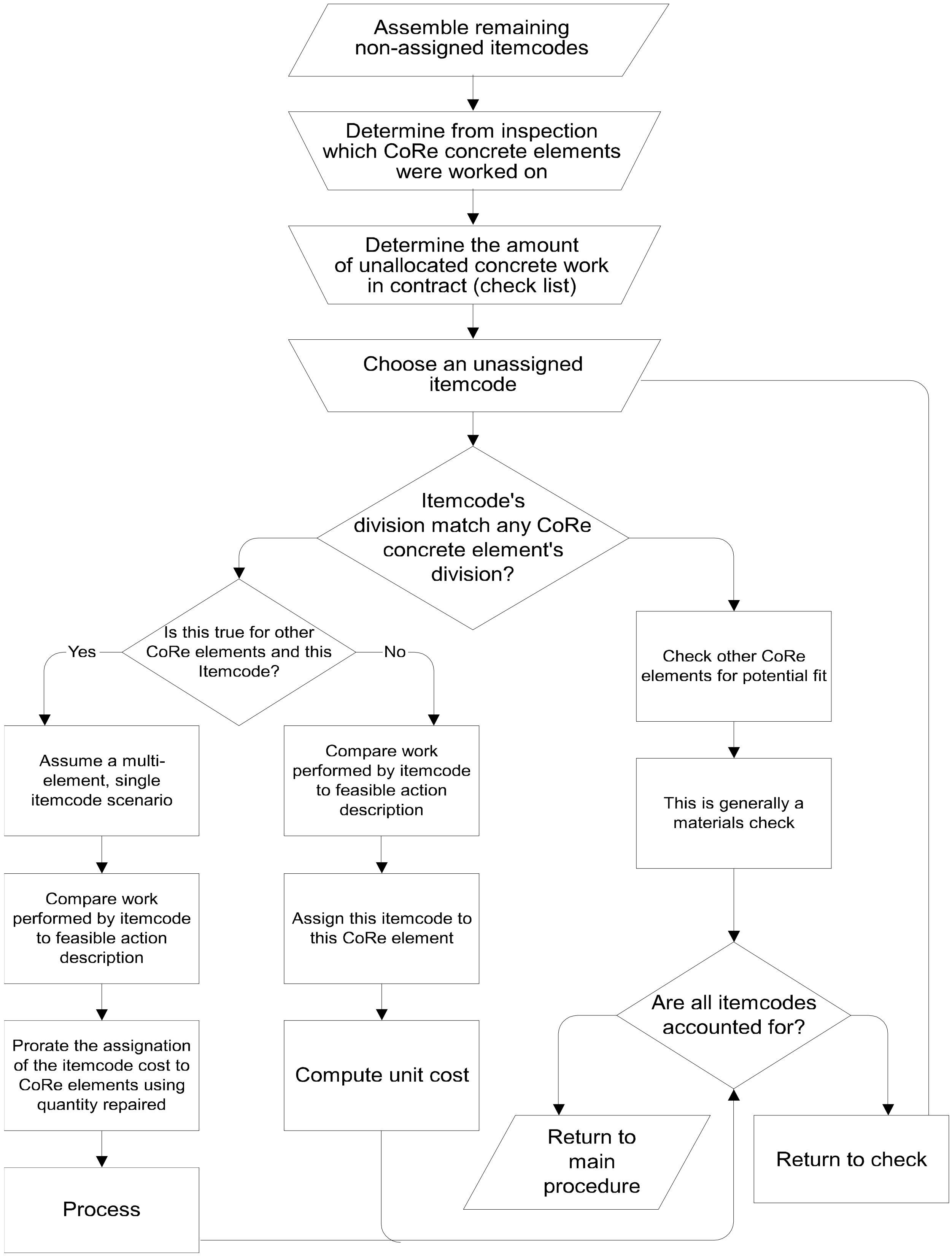

Figure 7. Concrete Elements

The design of a unit conversion scheme for these elements hinges on how they and their work items fit into the rest of the project (see Figure 7). The basic idea (harking back to the introduction) is to assign those item codes associated uniquely with certain CoRe elements, thereby leaving those "general" or non-uniquely-associated item codes on the menu for assignation. Table 8 describes the specific elements covered by this conversion process. Concrete elements such as these pose a real problem with their common network- and project-level information (CoRe inspections and item codes). Therefore, any conversion scheme relies on the successful completion of previous conversion schemes to eliminate most of the work items and reduce the contract data to those items that are not associated with a specific CoRe element or feasible action.

Table 8. Elements Covered

Element	Description
109	Prestressed Concrete Open Girder
110	Reinforced Concrete Open Girder
205	Reinforced Concrete Column
215	Reinforced Concrete Abutment
234	Reinforced Concrete Cap

CONCLUSIONS AND RECOMMENDATIONS

The investigation clearly showed the problems in portions of the BMS because of the inherent dissonance of network-level and project-level units. Network-level units work very well for modeling behavior, and project-level units are deeply ingrained in the construction industry. Neither system is capable of producing the results of the other, but a link must be developed.

Unfortunately, two dominant factors prevented this project from developing a workable automated conversion system: (1) identification of the sample population of contracts and bridges, and (2) incomplete data. Both of these problems are symptoms of a root problem: the lack of a functional work accomplishment recording system. The BMS requires work accomplished data, as does any useful cost management system. Although the work-accomplishment recording problem is a large one, addressing it is crucial to the success of the BMS.

Identifying the Population of Bridges

A critical part of this research was establishing the sample population. Ideally, the way to establish this sample population would be to assemble a list of those bridges that have recently had contract work completed on them. However, at this writing, the author was unable to locate or generate a simple list of structures meeting this qualification. There are published lists of projects sent to bid. However, completion dates are difficult to determine. On a district level, there are pockets of maintenance and/or construction personnel who are aware of ongoing and recent projects, but details are scarce and the sources lack uniformity. Contract personnel can also find historical data, but in all cases it requires a great deal of effort and personnel-hours on the part of persons other than the research staff to obtain them.

Fortunately, an effort underway at VDOT's Central Office to computerize element-level inspections will likely improve this situation as it develops.

To identify bridges and projects suitable for this type of study better, the author suggests that a few comments be added to the postwork element-level inspection. On many B-6 inspection sheets, inspectors write down the type of work done on the bridge. If they would do the same on the accompanying element-level inspection, cost and bridge management researchers would have a better idea of what actually happened in the field when examining data related to work accomplished. There is work underway to develop a set of "standard comments" for the element-level inspection manual to help automate notes inspectors commonly make. If this effort would incorporate a set of standard comments for postwork element-level inspections into the larger body of standard comments, then with little additional effort this recommendation could be met.

Incomplete Data on the Population

For those bridges that did meet the basic criteria for study, the information available was frequently incomplete. The major cause of this was the lack of a prework element-level inspection, although in some cases the contract data was inadequate. Without actual projects to test the conversion architecture against, clearly its validity is questionable. In those cases where general information is insufficient to allow the formulation of a conversion scheme, actual data are a necessity.

Lack of a Prework Element-Level Inspection

This problem should be resolved with time. The simplest solution is to wait until bridges have been through their inspection cycle and thus have had an element-level inspection. As these data become available, the conversion process can be tested on a project-by-project basis. After enough data are accumulated, statistical significance can be attached to an analysis.

Exceptions

Some groups of work items may appear so infrequently that it is not feasible to rely on an automated conversion system, which inherently will provide quality results only on a very aggregate level. Some groups of work items are simply too elaborate and complex to allow an automated conversion. In these cases, the work items must be segregated and handled separately, probably by hand. The automated conversion system should include a mechanism for recognizing and "flagging" such situations. Thus, the inability of this study to handle certain scenarios should help identify such exceptions for further examination. Further work on future contracts will do the same.

Replacements

Despite being a major component of bridge MRR&R options, replacements generally can not provide useful information to the cost management system. In cases where an element is replaced by a like element, there are useful data. However, when an element or an entire division of elements is replaced by dissimilar elements (e.g., a steel superstructure and timber deck are replaced by a concrete box culvert), that data may fall between the cracks of the cost and BMSs. Perhaps in cases such as these, the level of detail provided by an element-level tracking system is too focused, and tracking at the bridge or bridge/action level is more appropriate. The automated conversion system should again be capable of flagging such situations.

Electronic Data Storage and Retrieval

A centralized data storage and retrieval system, whether mainframe or client-server, would help the management of cost data. The advent of BAMS/TRNS.Port may address this issue, but it is important that the information be retrievable from a variety of directions. For example, it should be possible to query bridge inspection information given a maintenance project number, or vice versa.

On-line access to VDOT information such as the EO-3 item code set, the *Element Data Collection Manual,* and other references can speed access to important information. It also engenders a sense of availability and response to concerns without any VDOT personnel being directly involved in the transfer of this information. With the advent of Internet home pages, such information could be made available fairly easily. As an example, with relatively little effort, the *Element Data Collection Manual* was placed in an operational home page format. To continue this example, with this resource on line, inspectors using pen-based notebook computers can browse the manual locally, thereby eliminating the need for hard copies of manuals in the field.

Perhaps most important, the standard VDOT procedures for activities such as advertising a project or letting a bid should first be uniformly established within the responsible divisions and then made available to others, both inside and outside VDOT. The standard sequence of events that comprise the estimating process can be flowcharted and published (on paper and electronically) without the *a priori* release of proprietary or confidential information. Fortunately, there is some effort being made on this front as part of the BAMS/TRNS.Port implementation process.

REFERENCES

1. American Association of State Highway and Transportation Officials. (1994). *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements.* Washington, D.C.

2. American Association of State Highway and Transportation Officials. (1993). *Guidelines for Bridge Management Systems.* Washington, D.C..

3. Bailey, A.V. II, and M.T. Kerley. (1994). *Work Plan for the Bridge Management System.* Richmond: Virginia Department of Transportation.

4. Cambridge Systematics, Inc. & Optima, Inc. (1991). *Pontis Executive Summary, Technical Manual, and User's Manual: A Network Optimization System for Bridge Improvements and Maintenance*. Cambridge, Mass.

5. Cambridge Systematics, Inc. (1996). *Pontis 3.1 Draft User Manual*. Cambridge, Mass.

6. Elzarka, H., L. Bell, and S. Sanders. (1995). *Bridge Management System Phase II Final Report: Volume II. A Standardized Cost Database for the Pontis BMS.* Clemson, S.C.: Clemson University, Department of Civil Engineering.

7. Elzarka, H., L. Bell, and S. Sanders. (1996). *Cost Data Generation for the Pontis BMS, Research Final Report and DAGS Users Manual.* Clemson: S.C.: Clemson University, Department of Civil Engineering.

8. Markow, M.J., F.D. Harrison, P.D. Thompson, E.A. Harper, W.A. Hyman, R.M. Alfelor, W.G. Mortenson, and T.M. Alexander. (1994). *Role of Highway Maintenance in Integrated Management Systems.* NCHRP Report 363. Washington, D.C.: Transportation Research Board.

9. O'Connor, D., and W.A. Hyman. (1989). *Bridge Management Systems.* FHWA-DP-71-01R. Washington, D.C.: U.S. Department of Transportation.

10. Thompson, P.D., and M.J. Markow. (1996). *Collecting and Managing Cost Data for Bridge Management Systems.* Synthesis of Highway Practice NCHRP 227. Washington, D.C.: Transportation Research Board.

11. Virginia Department of Transportation. (1994). *Road and Bridge Specifications.* Richmond.

12. Virginia Department of Transportation. (1996). *Element Data Collection Manual.* Charlottesville: Virginia Transportation Research Council.