CONSTRUCTABILITY IMPROVEMENT OF HIGHWAY PROJECTS IN WASHINGTON

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16. ABSTRACT

The ever-increasing amount of construction problems and unnecessary redesigning work during the construction phase of highway projects with the Washington State Department of Transportation (WSDOT) has prompted studies into improving constructability. This report presents the development of a model constructability review procedure and the Highway Constructability Improvement System (HCIS), and demonstrates the use of the system by a design engineer. The information in HCIS is mainly extracted from a critical search of thousands of change orders from five recent years of WSDOT highway construction projects.

By the use of HCIS, engineers at the design office can have access to a bank of knowledge from past construction experiences and be alerted to the constructability aspects of their designs. This allows the design engineers to be aware of what had gone wrong in the past, and avoid repeating similar errors in preparing future design plans and specifications. This will improve constructability of designs at an early stage of a project. The user does not have to refer to other sources for reference while using the system.

It is concluded that in order to avoid similar highway constructability problems, a pre-construction and post-construction review of the project, such as reviewing change orders, is very useful and important. The model constructability review process is a way to standardize the different procedures currently being used by each district. By adopting the standard procedure, the occurrence of commonly shared problems can be reduced to a minimum to achieve a consistency of construction quality in Washington.

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SUMMARY

Constructability concepts identify ways in which construction knowledge and expertise can be more effectively used at various phases of a project (planning, engineering, procurement, and field operations) to optimize construction. The change order review has become an accepted and useful procedure statewide. Such a post construction review is helpful in identifying the problems encountered during a project so that they may be avoided in the future. In addition, a standard highway project review procedure should be followed throughout the duration of the project. This helps avoid overlooking certain details and provides a consistency to all projects which improves the efficiency and quality of the project.

Although a design may be the most efficient, cost effective design on paper, the actual construction may be infeasible, cost prohibitive, or even impossible. Therefore, if design engineers are not given opportunity to remain up-to-date with regards to construction field practices, they should become aware of such constructability problems through computer systems such as the Highway Constructability Improvement System (HCIS).

By the use of HCIS, engineers at the design office can have access to a bank of knowledge from past construction experiences and be alerted to the constructability aspects of their design. This allows the design engineers to be aware of what had gone wrong in the past, and to avoid similar errors in preparing future design plans and specifications. This will improve constructability of designs at an early stage of a project.

HCIS itself is suggested as a complete system for design engineers to get constructability improvement ideas for highway construction projects. Unless detailed standards and specifications are needed, the user does not have to refer to other sources for reference in order to understand these constructability

improvement ideas. This not only eliminates the duplication of information, but also prompts the design engineer of the interrelationship of the different highway construction aspects. In addition, the experience from developing the HCIS showed that hypertext is a very powerful tool for representing a large amount of unstructured and yet interrelated pieces of information.

The HCIS system developed through this project is a prototype with a limited knowledge base. If it is adopted by WSDOT, more construction knowledge should be added from various sources into the HCIS and other information should be modified to maintain current design standards and specifications. Thus, the HCIS may be used as a training tool for new graduating engineers to get acquainted with the WSDOT construction process.

The model constructability review process is suggested as a way to standardize the different procedures currently being used by each district. "Standardizing" procedures will not solve the problem of accomplishing the constructability reviews, but help collaborate among six districts. By adopting the single standardized procedure, the occurrence of commonly shared problems may be reduced to a minimum, through cooperation among six districts, to achieve the consistency of construction quality in Washington.

CHAPTER ONE

INTRODUCTION

PROBLEM STATEMENT

The increasing amount of construction problems and unnecessary re-designing work during the construction phase of highway projects has prompted studies into improving constructability. Such investigation is necessary in order to reduce the number of time-consuming and/or expensive problems presently encountered in various projects. Although there is no such thing as a perfect set of contract plans, there are certainly various aspects of the Plans, Specifications, and Estimate (PS & E) process which, if improved, would result in savings of time and money. The problem addressed in this project is the concern for the quality of engineering design with regard to its constructability.

Based on the interviews with various Design & Construction office personnel at the Washington State Department of Transportation (WSDOT), some of the aspects that might be perceived to be problem areas are: (1) lack of communication between design and construction engineers, (2) lack of construction expertise of the design engineer, (3) lack of careful review of PS & E before it is finalized as a contract, and (4) lack of post construction review to identify items which could be improved through better plans.

OBJECTIVES AND SCOPE

The objectives of this research are to identify constructability improvement ideas, develop a model constructability review process, and recommend a comprehensive constructability improvement program for highway construction projects. This was achieved using a two-phase process.

The first phase was the identification of highway constructability ideas and the development of the Highway Constructability Improvement System (HCIS). The HCIS is a computer program which catalogues problem areas which have resulted in change orders. An extensive literature review was performed to identify constructability concepts and ideas from reported research. In addition, specific highway constructability ideas were obtained from examining hundreds of change orders from the previous five years of WSDOT projects. Such a bank of information was used to develop the HCIS.

The second phase of this project involved the establishment of a standard constructability review model. The current review practices regarding constructability and change orders used by each district along with their organization structure were studied. Each district currently conducts a change order review of some kind, but the current process can be improved by a more standardized procedure. A proposed standardized model can be used by all districts with minor modifications made with regard to the district's size and location to significantly reduce the common problems encountered. By modifying the current organization structure of each district to include a constructability review board, a more cooperative relationship between the design and construction divisions can be established.

CHAPTER TWO

LITERATURE REVIEW

Reported research in the area of constructability falls into three broad categories. These categories are: (1) general constructability concepts, (2) effects of applying constructability programs at different stages of a project, and (3) results of specific constructability programs. While the focus of research in the third category is on specific applications, they do demonstrate constructability concepts as well.

The idea of constructability dates back to over a decade ago when it first appeared in "Building and Technology Bulletin", and "Constructability--It Works" (Proctor and Gamble, 1976 and 1977). Then about two years later, an NSF-ASCE (National Science Foundation - American Society of Civil Engineers) study identified constructability, among other topics, as a specific research need for structural engineering (ASCE, 1979). The study pointed out that there is a missing link between design engineers and contractors. For example, problems of constructability of concrete structures occur most often because of the attempt to design slimmer columns. These design, although satisfying the ACI code, constrict space for pouring concrete, and sometimes create difficulty in inserting vibrators.

One of the earlier applications of constructability took the form of an evaluation criteria for value engineering incentives. The design and construction of the I-205 Columbia River Bridge near Portland, Oregon, which took this approach had included constructability as one of the evaluation criteria in a study stipulated in the value engineering incentive clause in the contract documents (Blanchard, 1981). Similarly, using constructability as a criteria, T. S. Ramsey (1984) used constructability as one of the elements in the quality control program of projects, and T. Y. Lin (1984) stated that constructability must be considered before creativity can become reality.

Although all the above cases have used the word constructability, none have provided any rigorous definition of the concept and its specific impacts. It was not until a series of studies led by J. T. O'Connor and the Construction Industry Institute (CII) of the University of Texas in Austin that research effort was directed towards providing a more thorough definition of the constructability concept and a clearer picture on the impacts of constructability programs applied to different situations and at various stages of a project.

By analyzing the construction resource utilization tradeoffs, which result from constructability improvements, in a large industrial construction project, O'Connor (1985) presented some constructability strategies and methods for achieving the more cost-beneficial impacts. His findings point to the need for additional engineering effort for any constructability improvements, and the importance of the designer's role in ensuring economical construction.

Further research done by O'Connor and R. L Tucker (1986) pointed to the requirement of integration between designers and contractors for constructability improvements. An analysis of the constructability problems existing on a large refinery expansion project indicated that designers and contractors possess equal potential for improving project constructability.

With the constructability improvements in mind, techniques to collect improvement ideas were addressed (O'Connor, et al., 1986). The experience with the constructability study at the large refinery expansion project concluded that the most effective constructability data collection program makes use of many data collection techniques and involves many project participants. Project constructability improvement idea collection techniques including voluntary survey, questionnaires, interviews, pre-construction meeting notes, and final project reports were discussed.

As research on the application of the constructability concept progressed, the effects of constructability improvements at different stages of a project were addressed. The earlier applications which focused on the conceptual stage of a project, as noted above, and in the work done by C. B. Tatum (1987), shifted their focus to the engineering and procurement stage (O'Connor, et. al., 1987), and then to the field operations stage (O'Connor and Davis, 1988).

While the above literature showed the development of the constructability concept, the most comprehensive aggregate of the research in this area is recorded in the three publications by the Construction Industry Institute: Constructability (A Primer) (1986), Guidelines for Implementing a Constructability Program (1987), and Constructability Concepts File (1987).

The awareness of issues connecting to constructability and the application of constructability improvement ideas are evident from some recent publications. Two examples of constructability improvement application in concrete construction include a precast concrete stay-in-place forming system for lock wall rehabilitation, where a constructability demonstration phase was included after the design phase (U.S. Army Corps of Engineers, 1987); and a redesigning of large 100-ton concrete panels into smaller panels for better constructability through contractor involvement in the design stage (Wallace, 1987).

A demonstration of designer/contractor interaction was seen in a water injection facilities project with full involvement of the owner's and the contractor's construction expertise to simplify construction methods, reduce the number of interdependencies in various field operations, and to consider the limited resource capabilities of the local contractors (Eldin, 1988).

Further examples involved a constructability issue in pavement construction: providing adequate support for construction equipment by the base material (Highlands and Hoffman, 1988), and the construction of complex structures which require considerable engineering input from the design office to back up the construction staff on site (Gee, 1989; Pearson, 1989).

Thus, in recent years, many design engineers have returned to the basics by asking, "How will a contractor build my design?" By subjecting design plans to a constructability review, time and money may be saved and many legal claims may be avoided (ASCE, 1986).

CHAPTER THREE

CONSTRUCTABILITY PRACTICES IN WASHINGTON

Currently, the basic standard procedure, beginning with the planning phase through the design and construction phases to the post-construction review, are followed by all district. Variances among districts in complying with such a basic standard procedure are relatively small. This chapter discusses the past practices of Headquarters and Districts 1, 4, and 6 in Bellevue, Vancouver, and Spokane, WA, respectively.

HEADQUARTERS

Due to the varying locations, size, and population of the different districts, each district may have its individual needs. Having basic standard procedures that are followed by all districts helps to avoid many common problems and provides a consistency which can lead to improved quality and efficiency. All three districts studied in this chapter have developed and used some type of change order review process to identify the types and causes of predominate problems and to propose recommendations to reduce them. Certain areas may need to be reviewed for possible modification to improve constructability. The past activities by Headquarters are discussed next.

Pre-Contract and Contract Engineering Review

In 1984, a review procedure criteria for pre-contract and contract engineering activities was created by Headquarters (Korf, 1984: The procedures of this memo have been recently revised by Buss, IOC of 5-9-91). The methodology involved a survey of the various districts to ascertain their current practices to assure proper reviews of these engineering activities. Headquarters is responsible for the preparation of technical instructions in engineering practices. The Assistant Secretary is responsible for keeping informed of the design and construction problems encountered in each district.

The activities by the districts include conducting a thorough pre-contract review before the plans are submitted. Also, for construction of structures over $1,000,000, the project engineer is to meet with the more experienced construction staff to review the supervision and control procedures to assure proper survey techniques, adequacy of inspection, etc. The District Administrator is responsible for establishing and maintaining procedures within the district so that the construction and design staff are aware of each project engineer crew's expertise.

<u>Construction Administration Review</u>

During January and February, 1985, a Construction Administration Review study was conducted by Headquarters to provide a current analysis of the administrative practices, requirements and policies within WSDOT and determine how they affected the state/contractor relationship (Berentson, 1985). The scope was limited to the construction phase of a project to discover perceived problems and provide suggestions for improving or streamlining the departmental practices. Some of the issues analyzed were:

1. Uniformity between Districts,
2. WSDOT/Contractor relationships,
3. District/Headquarters interface,
4. Problem areas in orderly conduct of administration or work,
5. FHWA requirements and overview, and
6. Delegation authorities.

The review team acquired the information through interviews with 15 different groups including contractors, State personnel and the Federal Highway Administration (FHWA). For example, they found that the State/Contractor relationship were normally good with very few instances of major adversarial relationships. The importance of standardization and consistency in policies, communication practices, and training programs was emphasized.

DISTRICT 1

District 1 is the most populated district in Washington state, being near the heart of the Seattle area. Because of its large size, the design and construction divisions may function almost as separate entities. Possible difficulties with this approach may be the discontinuity of the project when it is transferred from the design to the construction division. This can be advantageous, however, in discovering overlooked errors or potential construction problems by viewing the project from a different perspective. Nevertheless, unless proper feedback is given to and received by the design engineer, problems of the engineering design with regard to constructability will reoccur. Steps towards improving constructability included the formation of the District Administrative Review Board which has now evolved into the Professional Excellence Committee and the Change Order Review Committee.

District Administration Review Board

The District 1 Administrative Review Board was formed in June, 1984 to review problems that occur under construction, to determine what went wrong, and to formulate a method or policy to prevent a similar occurrence (Bockstruck, 1988). District 1 Administrative Review Board has evolved into the two district committees: the Professional Excellence Committee and the Change Order Review Committee.

Professional Excellence Committee

The Professional Excellence Committee meets quarterly for the purpose of recognizing those people who are deserving of praise for good quality work. The committee members consist of all staff level positions with the District Operations Engineer as chair (Bockstruck, 1988). Nominations are received from peers, co-workers, and supervisors. The committee then reviews the accomplishments and determines what recognition is appropriate for the nominee.

Change Order Review

The District 1 change order review is an annual process created around 1987 to review change orders on all projects completed within the year with the exception of those with claims pending. The objective of the review is to identify the reasons for the change orders and propose recommendations and policies to help reduce them. This process is conducted by the Change Order Review Committee of the District Administrative Review Board. The committee consists of the Construction, Maintenance, and Project Development Engineers. Included in the reviews are the construction project and assistant construction engineers, in addition to any others who wish to attend.

The review consists of six major parts (Smith, 1988, 1989 and 1990):

1. Review Process: The change orders are first sorted into the categories established by the review committee. Currently, there are 10 standard categories as outlined in Table 3.1 and explained in detail in Appendix E.

2. Contracts Reviewed: The change orders from the included projects are then reviewed.

3. Discussion: The various categories of change orders are compared with previous years with regard to both number and dollar value.

4. Effects on Contract Cost: The cost of change orders are also compared. This is important since a decrease in number is not necessarily indicative of an decrease in cost.

5. Conclusions: This involves a summary of the findings including areas of improvement, persisting problems, and new troubled areas.

6. Recommendations: Recommendations regarding possible modifications of the review process and improvements in constructability are made.

Table 3.1 District 1 Change Order Categories

Code	Reason for CO	Code	Reasons for CO
0	Necessary Change Order	5	Maintenance Problems
1	Need More Investigation	6	Minor Scope Changes
2	Signal/Illum. Proj.	7	Engineering Errors
3	Policy & Design Change	8	Administrat. Changes
4	Mind Changes	9	Plan Errors

Year to year comparisons are very useful in showing the areas of persisting problems and those which have been improved. As shown in the 1987 to 1989 comparisons in Table 3.2, the year 1989 showed a decrease in the number of change orders, but an increase in cost from 1988. This was the opposite of what happened the previous year when 1988 had an increase in numbers, but a substantial decrease in cost.

An example of a persisting troubled area was reported to be Administrative Changes (category 8). This category accounted for a significant percentage of the total for both the numbers and cost of change orders for all three of the years shown. District observed that this might be largely attributable to the fact that supplemental agreements for major overruns and underruns are assigned to this category. Examples of improved areas are category 1 (more site investigation) and category 2 (more signal and illumination investigation). There were decreases in both cost and number in 1989 compared to 1988. Categories 0 & 9 are also decreasing while categories 3 & 8 are increasing, which leads one to believe that design is getting feedback from construction resulting in better information gathering in the design phase.

Table 3.2 Change Order Comparisons for 1987 to 1989 (Smith, 1988, 1989, 1990)
(Accepted Contracts October 1987 through September 1989)

CATEGORY	0 Nec C/O	1 Inv Need	2 Inv Need Sig/Ill	3 Policy Change	4 Mind Change	5 Main. Prob	6 Scope Change	7 Engr Error	8 Admin Change	9 Plan Error	TOTAL
Number of Change Orders											
1987	136	35	21	5	16	4	4	7	52	42	322
%	42%	11%	7%	2%	5%	1%	1%	2%	16%	13%	
1988	79	45	18	11	22	13	4	7	93	49	341
%	23%	13%	5%	3%	6%	4%	1%	2%	27%	14%	
1989	60	27	12	25	9	6	6	7	91	30	273
%	22%	10%	4%	9%	3%	2%	2%	2%	33%	11%	
Dollar Values ($000)											
1987	1644	175	52	69	307	19	165	83	-164	349	2699
%	61%	6%	2%	3%	11%	1%	6%	3%	-6%	13%	
1988	597	317	123	-166	71	40	88	20	153	-10	1233
%	49%	26%	10%	-13%	6%	3%	7%	2%	12%	-1%	
1989	538	203	44	203	33	212	69	41	277	173	1793
%	30%	11%	2%	11%	2%	12%	4%	2%	15%	10%	

Modified Review Used for the I-90 Project

For some projects which may be so large or unusual, the criteria may be modified to better meet the needs of the individual projects. An example of such is the Interstate 90 project involving the section from Bellevue to Seattle which had its own review team. Slight modifications were made to the ten standard categories, and three additional ones were included to tailor the change order review to its specific needs (Aye, 1989).

DISTRICT 4

District 4 conducted a study of all change orders from the previous four years between 1980 and 1983 (Ferguson, 1985). The contracts were identified by running a report from the Headquarters T6020 file, which is the data base for the Monthly Construction Report. All the change orders associated with these contracts were then obtained from the construction office records. Each change order was reviewed and classified by assigning a code number from the list below which best fit the reason for the change order.

Table 3.3 District 4 Change Order Categories

Code	Reason for CO	Code	Reason for CO
1	Plan Error	13	Claim Related
2	Added Work	14	M/WBE Related
3	Design Change	15	Fuel Cost Adjustment
4	Construction Error	16	Materials by Voucher
5	Deletion of Work	17	Ton to CY Conversion
6	Changed Conditions	18	Traffic Ctrl Related
7	Change to Special	19	Added work by Traffic
8	Local Agency Request	20	Added work by Maint.
9	Substitution of Mat'l	21	Constr. Staging Prob.
10	Quant. 25% (SS 1-04.6)	22	Non-Spec. Material
11	Utilities Related	23	Air/Water Pollution
12	Soils Related		

Frequently, there is some history behind a change order which is not apparent by only reviewing the change order. Since considerable judgment was involved in classifying each one, all were classified by the same person in an attempt to provide some uniformity. Obviously some may fit two or more of the categories; however, only one was chosen for each change order. A new computer file was created which contained the following data (Table 3.4) for each contract/change order. Then from this file, reports were generated using Mark IV and SPSS.

Table 3.4. District 4 Change Order Information File

Contract Number	Change Order Number
State Route	Proposed by (Contr. or DOT)
Description/Title	Net Dollar Change
Award Date	Reason for Change (1-23)
Completion Date	Change in Working Days
Award Amount	Approved by (Dist. or HQ)
Final Cost	Construction Project Engineer
Contractor Name	
Sub-Program	
Improvement Type	

The number, classification, and dollar amount of the change orders were analyzed and conclusions were made. The number of change orders coded "design change" (category 3) appeared excessive. However, this diversity was partially attributable to the fact that there are 22 categories to group common types of change orders and "Design Change" appears to acquire the miscellaneous items.

The data were summarized from 140 completed contracts awarded between January 1, 1980, and December 31, 1983, having a total of 1,647 change orders (average 11 per contract). However, 60% of these change orders involved changes and/or added work to the project design that were minor in nature. The total dollar amount was $103 million, with the net dollar change being +$5.7 million (5.5% of contract volume or about what was set up for contingencies) (Ferguson, 1989).

DISTRICT 6

Usually, the project office that designs the project also builds it in District 6. Having one group responsible for both the design and construction provides a continuity in the project. It eliminates possible misunderstandings of the design plans by the construction division and the time required for the division to familiarize itself with the plans. District 6 also developed the "Stages of Review on a Construction Project" (Putas, 1989).

Stages of Review on a Construction Project

This review format is an organized approach in completing a construction process. By following the step-wise procedure shown in Table 3.5, there is less chance of certain details being overlooked. In addition, applying it to all cases develops a consistency among projects which may benefit efficiency. A copy of this process has been distributed to all districts. With little or no modifications, similar procedures can be developed for each.

Table 3.5. Stages of Review on Construction Projects

No.	Stages	Description of Activities
1	Priority Array	Dist. determines funding priority
2	Project Scoping	Projects scoped by project engr.
3	Project Prospectus	First estimate of project cost
4	Design Report	Reviewed by district and HQ
5	PS & E Package	Review by dist., sheet at a time
6	Contract Plans	Designer builds project
.7	Project Review	Change orders discussed annually
8	Other Meetings	Exchange of information monthly

CHAPTER FOUR

COLLECTION OF CONSTRUCTABILITY IMPROVEMENT IDEAS

The pool of constructability improvement suggestions for highway construction in Washington state was gathered from three main sources: the literature review, WSDOT personnel, and a change order study. This chapter discusses the examples of the construction problems, the causes of the problems, and the actions taken to resolve them.

IMPROVEMENT IDEAS FROM WSDOT

From the literature review, a number of different studies regarding general constructability concepts, constructability improvement suggestions, and case studies were discovered. Despite the variety of different projects and conditions to which the constructability concept was applied, certain items seem to be commonly shared among most projects. The following is a compilation of some of the concepts that should be considered in any project all of which are WSDOT standard practice.

1. Designs should be simplified and standardized.
2. Simplified designs should not imply drawing simplification.
3. A contract drawing should not show too many details.
4. Buildability of the design should be considered.
5. Constant communication should be made among all parties.

With regards to WSDOT personnel, the information was derived from their current district procedures and a statewide survey conducted by WSDOT Headquarters on plans improvement. These improvement ideas were collected from various sections and different levels of personnel of all six districts of WSDOT, hence providing a good prospective from both the views of the design and construction engineers. The following are some examples of the concerns expressed by WSDOT personnel.

1. Road shoulders:
   Design road shoulders with the understanding that the road will be widened; thus, when this occurs, the shoulders will not have to be torn out.

2. Quantity estimating:
   Spend time to become more comfortable with quantity estimations because major item overruns and underruns by more than 25 percent are difficult to deal with during construction due to the lengthy change order process.

3. Water lines:
   When designing water lines suspended underneath structures, carefully plan the depth and size required for the hardware placed and the amount of room necessary for insulating the pipe.

4. Training and Experience:
   Be sure that WSDOT personnel are properly trained in their current positions, especially those of requiring decision making.

5. Communication:
   Early and constant communication is essential throughout the Division and among all parties. For example, feedback should be given continually from the construction engineer to the design engineer to prevent design errors from occurring or being repeated.

6. Standardization:
   Standardization and uniformity regarding District policies and procedures, both within and among all Districts; communication procedures, and training programs are important to consistency and efficiency.

7. Contract Plan Quality:
   Improving plan quality is a major step in improving overall constructability by eliminating many of the problems resulting from incomplete or inaccurate contract plans.

IMPROVEMENT IDEAS FROM THE CHANGE ORDER STUDY

Change orders of past highway construction projects were examined. From the few thousand change orders available from WSDOT, issued in different projects during the past five years, about four hundred change orders that apply specifically to highway construction were critically examined. The construction problems, causes of the problems, and solutions to the problems in terms of a change in either material, construction methods, or design, were recorded and summarized. About two dozen constructability improvement ideas were identified from the change order study.

The evaluation criteria for change orders were that they should be specific enough to provide a solution to the encountered problem, but general enough so that their possible occurrence is not limited just to the specific case. As shown by the multitude of reasons resulting in change orders, constructability problems cannot be attributed to a single cause or area. However, to provide some organization to the list, the change orders are categorized by their major causes.

Roads

1. Tack coat applications for asphalt (Ref: CONTRACT 3044, c/o 8).
   Typical reasons for underrun include:
   a. When a lighter rate of application for CRS-2 on Class D asphalt pavement is applied than a heavy one.
   b. when rubber binder is added to the Class D asphalt while the standard fog seal applied to Class D asphalt is deleted.
   c. When Class D mix is placed over a Class G prelevel. This gives an underlying surface that was new, dense, and uniform requiring less tack than on old, open irregular surfaces.

2. Pavement overlay preparation (Ref:Contract 3596, c/o 3).
   Remove the thermoplastic pavement markings prior to Bituminous Surface Treatment (BST) or Asphalt Concrete Pavement (ACP) overlays to avoid damage to new surfacing due to the melting of the markers upon heated application. It provides a better bond between the new and the old surfacing.

3. Sign bridges and sign mounting details (Ref: CONTRACT 2867, c/o 26).
   Check to make sure that sign bridges have mounting brackets before trying to mount sign, and provide the brackets if they are absent.

4. Sidewalk and curb construction (Ref: Contract 2879, c/o 5).

Where applicable, monolithic placement of the curb, sidewalk, and driveways will simplify construction and provide a sounder structure.

5. Guard rail applications (Ref: Contract 2980, c/o 11).
   Furnish and install "Modified Beam Guard Rail" in lieu of the "Beam Guard Rail Type I" for cases such as an existing retaining wall located too closed to the edge of pavement to place Type I Beam Guard Rail. The guard rail posts would hit the retaining wall.

6. Guard rail post design (Ref: Contract 2809, c/o 3).
   When there are steep existing fill slopes on which a guard rail must be placed, standard 6 foot length posts may not provide minimum rail height so included provisions to use longer posts as required.

7. Median barrier (Ref: Contract 2816, c/o 14).
   When the difference in elevation of pavements on opposite sides of the median barrier is 2'0" or greater, the depth of the barrier should be increased below the lower pavement accordingly and a footing should be added to this barrier.

8. Single faced barriers (Ref: CONTRACT 2866, c/o 45).
   Do not use non-standard barriers if they do not provide a sufficient safety increase for the increased cost.

9. Business area curbs (Ref: Contract 2902, c/o 12).
   When designing curb and gutters in front of business establishments that require large delivery trucks to enter and exit, use a 55 foot driveway in lieu of a 30 or 35 foot driveway to provide easy access.

10. Groundwater problems (Ref: Contract 2917, c/o 3).
    If artesian springs conflict with proposed roadway orientation, provide dewatering wells, if applicable, unless the water demand for that watershed is greater than or equal to its capacity.

Traffic

1. Signal controller location (Ref: Contract 2896, c/o 1).
   Locate the signal control equipment on the same corner of the intersection as the power source. This will aid the maintenance of the signal and also save money in construction costs.

2. Intersection expansion (Ref: Contract 2893, c/o 1).
   When an additional approach lane of traffic is to be added to an existing traffic actuated signalized intersection, be sure to include an additional vehicle detection device for this lane that can be integrated into the existing signal system.

3. Traffic illumination(Ref: CONTRACT 2867, c/o 32).

Provide an additional junction box for illumination system (installed adjacent to, and at a lower elevation than the service cabinet) to eliminate the possibility of water entering the service cabinet through the conduit.

4. Construction safety (Ref: Contract 2955, c/o 6).
Instead of having daily lane closures for construction traffic control, use concrete barriers to separate the lanes under construction from those available to traffic. This practice will reduce disruption and inconvenience to the travelling public and also improve safety for both the public and the construction personnel.

Structures

1. Prestressed girders.
Check that the steel reinforcing protruding from the end of prestressed girders does not interfere with the protruding reinforcement of the wall or column on which the girder is to be placed.

2. Bridge replacement (Ref: Contract 2947, c/o 14).
When designing a replacement bridge, make sure the existing bridge's pilings will not interfere with the pilings for the replacement bridge.

3. Retaining wall drainage (Ref: Contract 2812, c/o 15).
Provide for proper drainage on top of a retaining wall by incorporating a 2 percent downward slope in either the direction of the front or the rear of the wall, whichever is more appropriate. If the slope is towards the back of the wall, it is recommended that a drainage structure of some kind also be used such as a drainage ditch.

4. Expansion joints (Ref: Contract 2973, c/o 17).
Apply three coats of A-9-73 paint to field fabricated expansion joints instead of galvanizing, before welding. This will improve the quality and strength of the welds.

Drainage Structures and Water Distribution

1. Concrete inlet (Ref:Contract 2908, c/o 11).
Be sure to install Concrete Inlets and Drain Pipes at locations staked by the Engineer to improve drainage of low spots during winter snow conditions. The ridge of snow under the guard rail and along the shoulders prevents the water from draining off of the roadway, this creates a ponding situation which freezes when the temperature drops.

2. Irrigation systems (Ref: CONTRACT 2872, c/o 1.).
Consider increasing the PVC plastic pipe size if the substitution will not effect the design of the irrigation system. By increasing the

pipe size, flow characteristics would be improved and the system would be more adaptable to future expansion if needed.

3. Culvert riprap usage (Ref: Contract 2965, c/o 19; Contract 2894, c/o 7).
   RipRap should be used at the culvert inlet to prevent the following:
   a. scouring and siltation inside the culvert structure.
   b. erosion of the roadway sideslopes around the culvert especially when sideslope erosion is a problem. This could be the case when a naturally occurring stream's flow pattern is too complicated to redirect.

4. Bridge drainage (Ref: Contract 2839, c/o 3).
   Bridge drains will create hazards to motorists if the feathered asphalt depth to the drain is greater than two inches. Provide measures to avoid this condition.

Earthwork

1. Excavation (Ref: CONTRACT 3040, c/o 5).
   Be aware of failures that may result from the more weathered condition of the formation at one end of the cut. To avoid the problem slope/lay the failed area back to remove slide condition.

2. Embankment (Ref: Contract 2965, c/o 27).
   If slope stability or slope erosion is a problem, armor the slopes with light riprap to contain embankments and prevent siltation, and quarry spalls to prevent surface erosion.

CHAPTER FIVE
DEVELOPMENT OF THE HIGHWAY CONSTRUCTABILITY IMPROVEMENT SYSTEM (HCIS)

With a mass of constructability ideas extracted from the change orders, the next task is to present these ideas so that the design engineer can efficiently search through the change order summaries and obtain constructability improvement ideas related to highway construction projects. This allows the design engineers to be aware of what had gone wrong in the past, and to not repeat similar errors in preparing future design plans and specifications. This will improve constructability of designs at the earliest stage of the project.

Thus, this chapter explains the research approach and software selection process used to develop the prototype Highway Constructability Improvement System (HCIS). It also discusses how the HCIS program works and how one goes about using it.

RESEARCH APPROACH AND SOFTWARE SELECTION

Hypertext

While the pieces of information extracted from the change orders seem scattered and fragmented, they are interrelated in many cases and in different ways. However, their interrelationships are mostly nonlinear and hard to be organized into a practical structured manner. This led to the decision of employing the technology called *Hypertext*.

The name hypertext means "nonsequential writing". It was coined by Theodore Nelson about two and a half decades ago, the concept of which was envisioned by Vannevar Bush, President Roosevelt's science advisor and overseer of all wartime research, in 1945. Recently, due to the advancement of computer technology, it has become more popularly used in the artificial intelligence and expert system areas. At its most basic level, hypertext is a database management system (DBMS) that allows the user to connect screens of information using associative links. At its most sophisticated level, hypertext is a software environment for collaborative work, communication, and knowledge acquisition. Hypertext products mimic the brain's ability to store and retrieve information by referential links for quick and intuitive access (Fiderio, 1988).

KnowledgePro

The software chosen for this project was *KnowledgePro* developed by Knowledge Garden, Inc. What makes KnowledgePro uniquely appropriate in this application is that it is a marriage of hypertext and expert system technologies. It is a development environment, a programming language, as well as an information-management tool (Shafer, 1988). It is described by Dan Rasmus (1989) as "a knowledge-based systems development environment that incorporates rules, graphics, hypertext, and database access."

In expert system terms, KnowledgePro uses production rules with an inference-engine usually available in an expert system shell. However, its interaction of hypertext and expert systems brings some unique advantages to this application in knowledge representation. On one hand, hypertext give users the flexibility to choose any path through the knowledge base, to explore in depth the areas of interest and skipping others. On the other hand, the expert system tends to steer the users down a path that is determined by their responses to a set of questions preset by the developer. By combining the features of both kinds of systems, KnowledgePro makes it possible for two way communication to take place. The developer can present the users with information and guidance in a way that may be most helpful, while the users can arbitrarily go off to explore or learn more about arbitrary pieces of knowledge along the way (Shafer, 1988).

These unique features of KnowledgePro are very appropriate for the presentation of knowledge such as those extracted from change orders. The design engineers can be guided through the change order summaries in the areas relevant to their projects, and also get additional explanation via hypertext whenever needed. These additional information can be in the form of graphic displays since the software is compatible with external programs such as PC Paintbrush, Lotus 123, and dBase III (Thompson and Thompson, 1988).

HIGHWAY CONSTRUCTABILITY IMPROVEMENT SYSTEM (HCIS)

To develop the system structure of the prototype Highway Constructability Improvement System (HCIS), the relationship among the different constructability improvement ideas was established. The system structure is similar to that of a semantic net, with general nodes (e.g., roads, traffic, earthwork, etc.) branching off into a hierarchy of increasingly more specific nodes (e.g., road shoulders, signals, excavation, etc.). These nodes are linked by hypertext.

There are three major options available to retrieve a change order, as shown in Figure 5.1, 1) by the work items; 2) by the reasons for the change order; and 3) by the contract and change order number. The first option allows design engineers to choose the facet of highway construction relevant to their project and be guided through the system. The main areas of construction included in this system are roads, traffic, structures, earthwork, and drainage. While all aspects of highway construction are not included, the categories in the system represent the areas where problems have been frequently encountered in the past as indicated by the large quantity of related change orders.

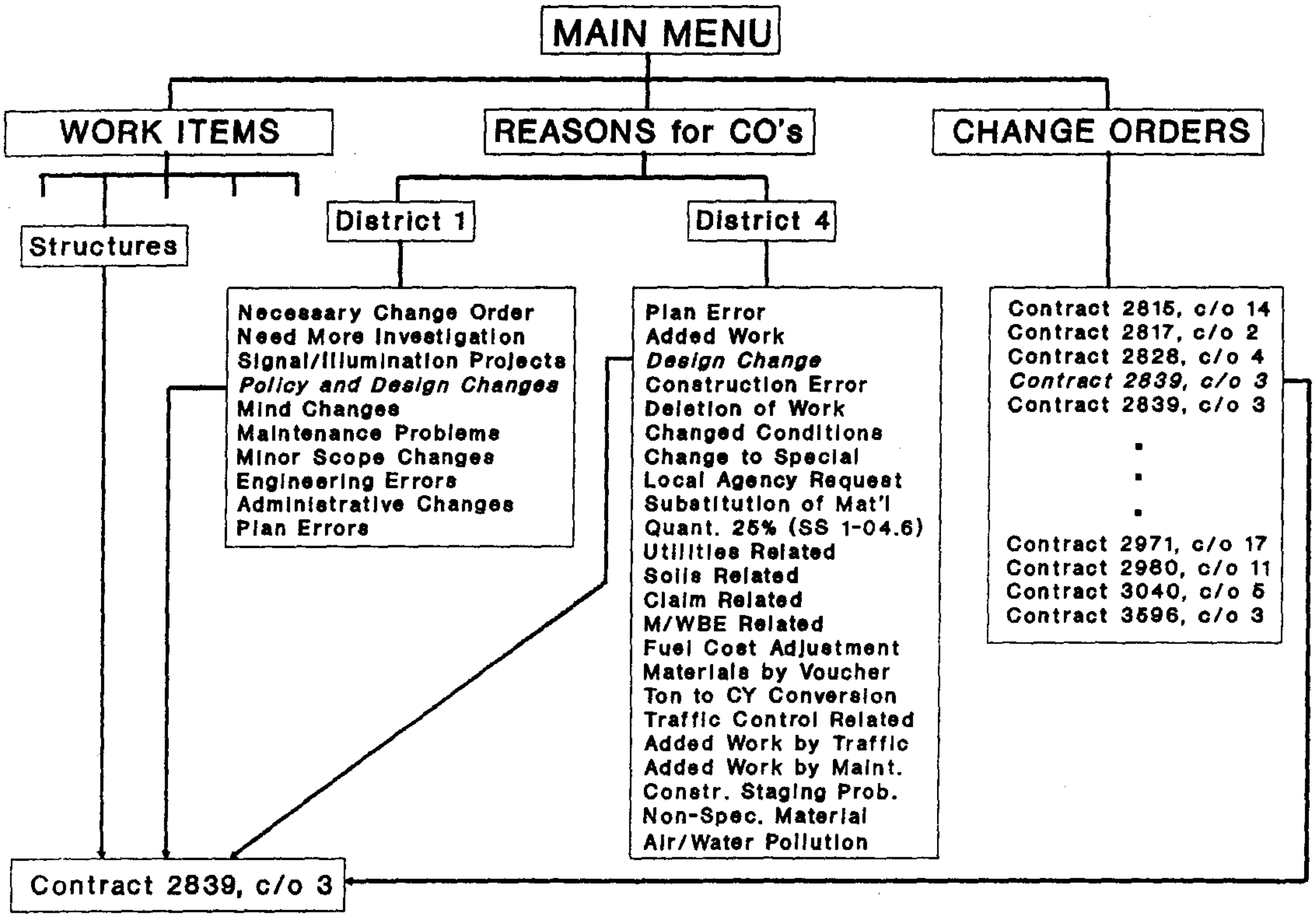

Figure 5.1 Main Options for Retrieving Change Orders

The second option is based upon the change order review procedures developed by the Districts, more specifically Districts 1 and 4. Thus, this is a good way of comparing the different District procedures and remaining aware of the activities in other parts of the state. The review procedures involve the classification of change orders into predetermined categories best describing the reasons of their necessity. The users first choose the District and then the reason category to be viewed. They then can recall statistical information derived from the actual reviews or possibly follow another path leading to a change order resulting from the selected reason. For cases in which there are more than one change order associated with a category, a list of these change orders will be displayed for the users' selection. In other cases, no change orders for the specific categories are included. An example would be "necessary change orders" since these are change orders which could not have reasonably been avoided. Therefore, they are not helpful to design engineers in improving plans to avoid possible construction problems.

The third option is the quickest method to view a change order. With this option, a collation of all the change orders included into the HCIS system is listed for the user's selection. No other information regarding the change order, such as topic or reason, is included in the display menu. Thus, if a particular contract or change order is desired, or if the user simply wants to scan some of the change orders available, they can be directly displayed without traversing through the necessary paths.

Figure 5.2 shows a simplified schematic diagram of the HCIS structure regarding work items. The general structure of the program is representative of a rule-based decision tree where each final, terminating node can be reached by only one path. The solid bold lines indicate the primary tree structure (i.e. the major categories branching into the subcategories until eventually reaching a change order). However, in the HCIS, certain branches do intersect with one another

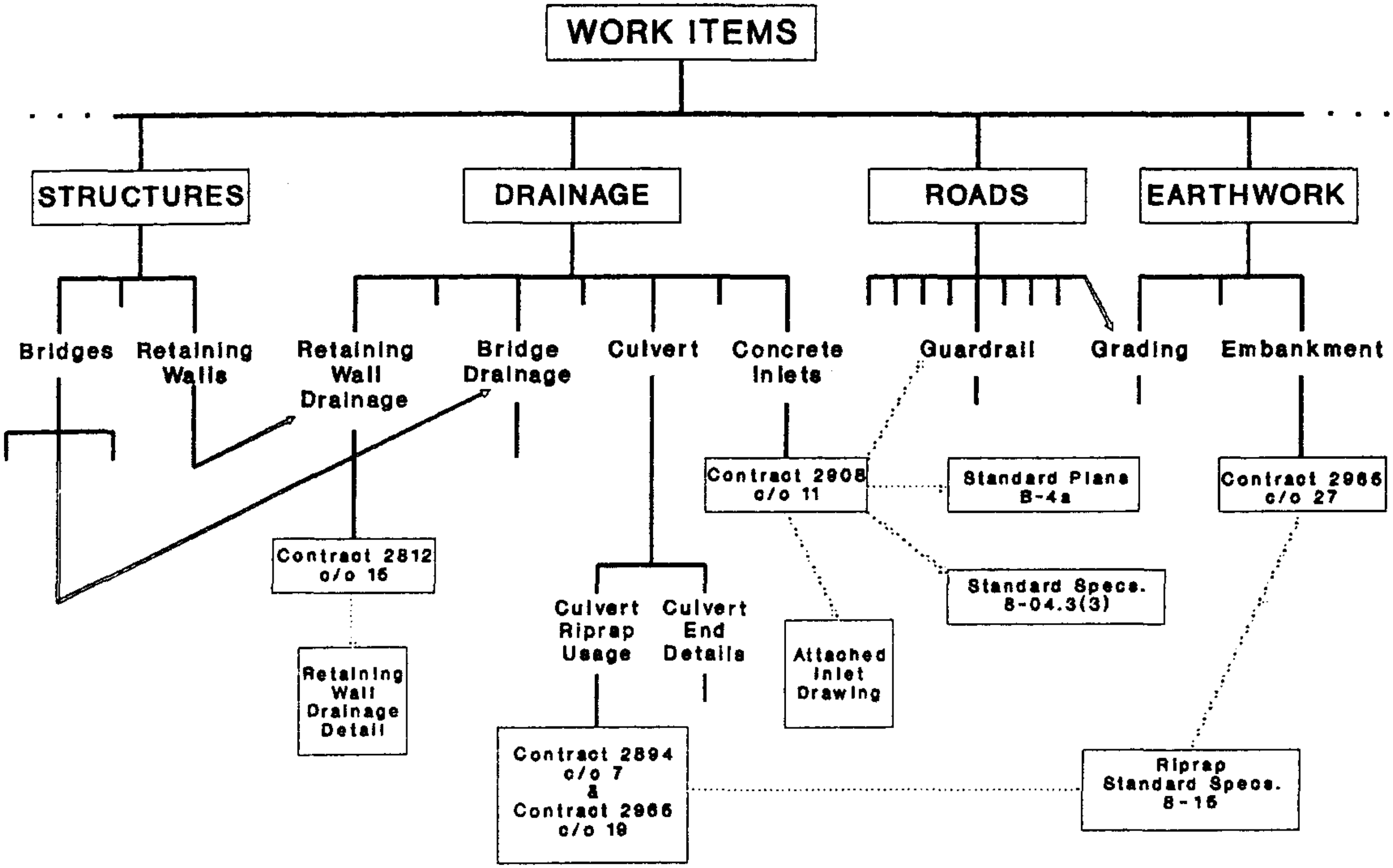

Figure 5.2 Schematic Diagram of the HCIS Structure Regarding Work Items

making it possible to reach some nodes through different paths, thus taking on the characteristics of a network. These secondary paths are indicated by the hollow arrows. Finally, the dotted lines represent the hypertexted link from the change orders to the additional explanatory screen of information.

For example, Contract 2908, change order 11, within the Drainage tree, references the guardrail category within the Roads tree. This change order also contains three additional hypertext links, one to the WSDOT Standard Specifications, one to the Standard Plans, and the final to a drawing specifically associated with the change order. The third link also references an additional summary, namely the Standard Specification explanation of riprap which can also be recalled by two other sources. This demonstrates the interrelationship among the many facets encountered in a construction project.

Since the summaries of the change orders refer to various sections of the Standard Specifications and the Standard Plans of the WSDOT, the AASHTO standards, and the ASTM standards, relevant parts of these sections are extracted and incorporated into the system along with definitions of specific terminology and technical jargon. They are linked to the change order summaries by hypertext, with either explanatory summaries or graphic illustrations, so that the design engineer can access these references efficiently to get a good understanding of the context of the change order summaries.

Therefore the HCIS itself is a complete system for design engineers to get constructability improvement ideas for highway construction projects. Unless detailed standards and specifications are needed, the user does not have to refer to other sources for reference in order to understand these constructability improvement ideas. A listing of the HCIS program is shown in Appendix A.

DEMONSTRATION OF THE HCIS

A sample run of the HCIS is explained below and shown in Figures 5.3 to 5.13. This example demonstrates the use of hypertext to link up different interrelated information such as, change order summaries, technical jargon explanations, WSDOT Standard Specifications and Standard Plans, and specific drawings related to the change order. The hypertext, which shows up as highlighted words in the program, are shown as **underscored-bold** on the screen samples of the demonstration in this paper (Lee, et. al., 1990).

After showing an introduction screen listing the functions of the system, the system proceeds directly to the main menu that contains the three options for accessing change orders (Figure 5.3). Supposing that the work items option is chosen, another menu containing the major categories of highway construction is then presented (Figure 5.4).

If a design engineer designing the various elements of a highway wants to check for constructability improvement ideas regarding the drainage systems of that roadway, the designer would choose the drainage structure hypertext. This choice would lead to a screen with more specific areas of drainage systems in highway construction. One of these areas, also in hypertext, will eventually link to a specific change order which deals with the installation of concrete inlets (Figure 5.5). In this change order summary, the reason for such a change to be needed is given so that the design engineer can compare whether such a need is relevant to the particular project. It tells the engineer that in low lying sections of a roadway, at regions where winter snow conditions exist, care should be taken to ensure that proper drainage is provided along the guard rails, such as using concrete inlets. The section numbers of the WSDOT Standard Specifications and Standard Plans are in hypertext. They can be accessed by the click of a button. The hypertext "Section 8-04.3(3)" is linked to the screen shown in Figure 5.6, and the hypertext "Standard Plan B-4a" is linked to the graphics screen shown in Figure 5.7.

Since there is a specific drawing attached to the change order, it is also included in the system and linked by hypertext, as shown in Figure 5.8. The power of hypertext is not limited to linking text-to-text and text-to-graphics, it can also link keywords on a graphics screen to a text screen with the explanation of the word. An example is shown with the keyword "RIPRAP" on Figure 5.8 being linked to the text screen shown in Figure 5.9.

The system gives the user the ability to get back to the previous node from any node of the network. As can be seen in Figures 5.5, 5.6, and 5.9, the user can also get back to the main menu from any point of the network, by clicking the hypertext "Main Menu."

Moreover, since the hypertext links are formed in a nonlinear network, the user may get to the same information from different routes. For example, the screen shown in Figure 5.6 can be obtained from hypertext keys "inlets," "metal inlets," "concrete inlets," as well as Standard Specification "Section 8-04.3(3)." This not only eliminates the duplication of information, but also prompts the design engineer of the interrelationship of the different highway construction aspects.

Furthermore, the hypertext can bring the design engineer to any point on the network as needed. For example, while looking at the "concrete inlet" change order summary, the designer is reminded of the guard rails that are required in the project, by the hypertexted word "guard rail." By "clicking" this hypertext, the system will bring the engineer to a description of different types of guard rails. Realizing that the project at hand has Type I guard rails, the design engineer continues to pursue the hypertext links which finally leads to a change order summary as shown in Figure 5.10 describing the constructability problem with Type I guard rails. When a structure, such as a retaining wall is too close to the pavement, it is impossible to install the standard Type I guard rails. The configuration of guard rails have to be modified. In the case of this change order, a modified guard rail which consists of a thrie-beam element and a W-beam element attached directly to the post without a block is used. Of course, in conjunction with this change order, the necessary Standard Plans (Figure 5.11) and specific drawings (Figures 5.12 and 5.13) are linked by hypertext as shown.

The three ways of accessing information are either by the work topic which accesses the type of areas in which constructability improvements are made, by the reasons for the change orders defined by some of the change order review categories developed in different WSDOT districts, or directly through the contract and change order number.

* <u>**Work Items**</u>

* <u>**Review Categories**</u>

* <u>**Contract Search**</u>

In order to proceed further for constructability improvement ideas regarding the above aspects, press **F3** (or use the mouse) to move the cursor to choose the topic, and **F4** to view the information.

To return to the previous screen anytime, press **Space**.

Figure 5.3 HCIS Main Menu.

The different aspects of highway construction considered in this program for constructability improvement include:

* **Roads,**

* **Bridges,**

* **Traffic Signals,**

* **Drainage Structures** and Water Distribution,

* **Earthwork,** and

* **Construction Safety**.

Press Space to return to the Main Menu.

Figure 5.4 Work Item Main Menu.

Install Concrete Inlets and 8" diameter Drain Pipe at locations staked by the Engineer. Materials and construction shall be in accordance with Standard Specifications, **Section 8-04.3(3)**, **Standard Plan B-4a**, and with the **attached drawing**.

Purpose of change is to improve drainage of low spots during winter snow conditions. The ridge of snow under the **guard rail** and along the shoulders prevents the water from draining off of the roadway, this creates a ponding situation which freezes when the temperature drops.

Ref: Contract 2908 Change Order No. 11

Return to **Main Menu**

Figure 5.5 Change Order Summary Sample.

WSDOT Standard Specifications
Section 8-04.3(3) Inlets

Inlets shall be securely connected to the gutter and to the **spillway** forming a water tight connection.

Concrete inlets shall be constructed in accordance with the Standard Plan and may be precast or cast in place. Concrete shall conform to the requirements of **Section 6-02**.

Metal inlets shall be constructed in accordance with the Standard Plan.

Return to **Main Menu**

Figure 5.6 Standard Specifications.

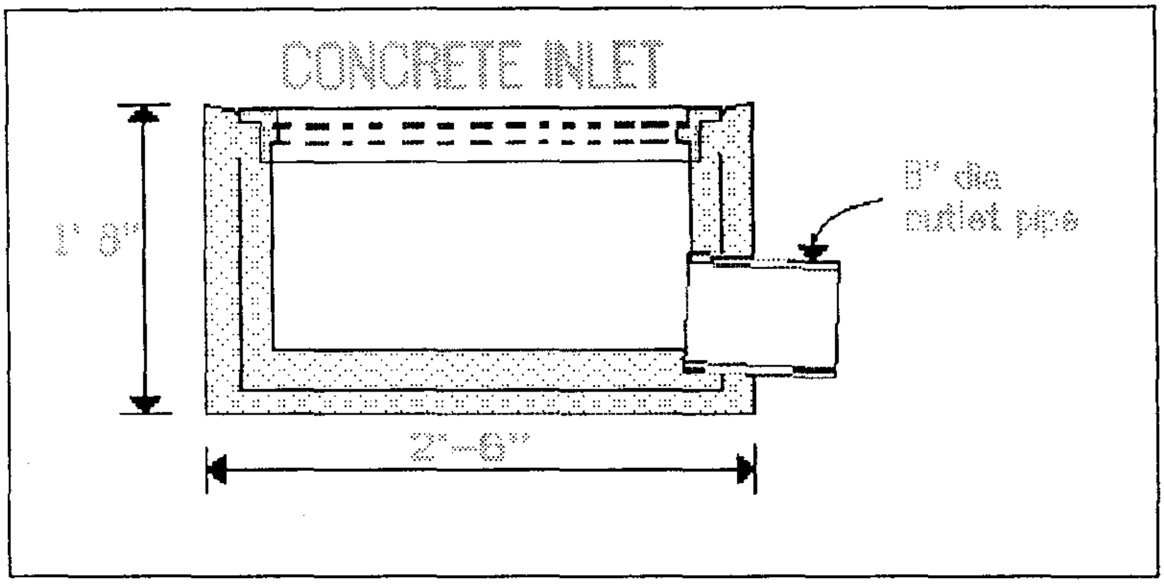

Figure 5.7 Standard Plans.

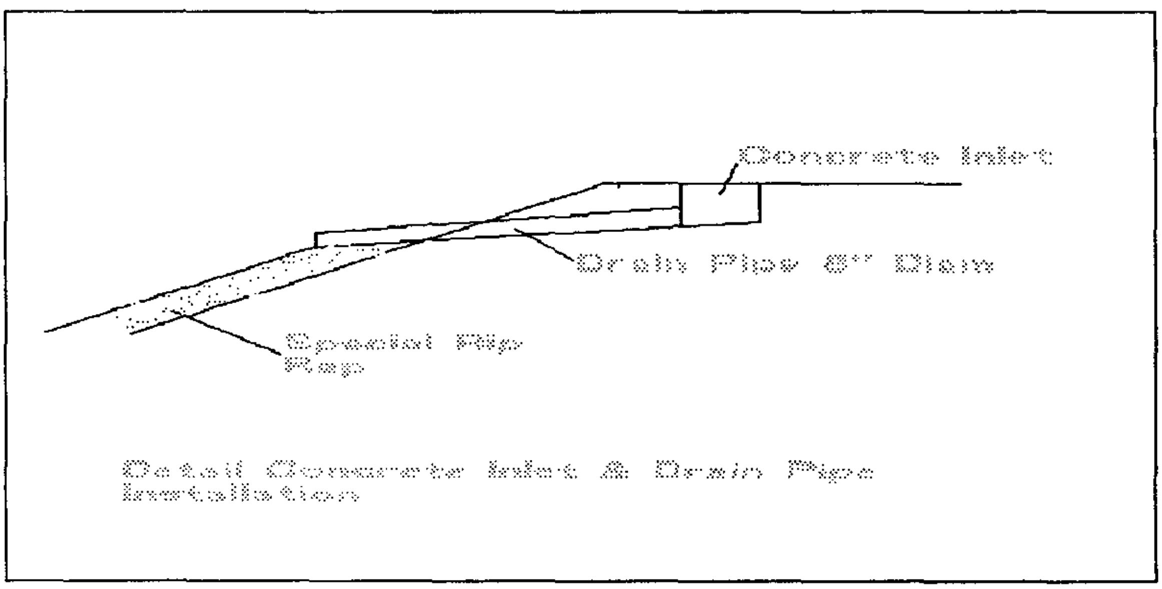

Figure 5.8 Specific Drawings Associated with the Change Order.

WSDOT Standard Specifications
Section 8-15 RIPRAP

Section 8-15.3(1) Excavation of Riprap
Section 8-15.3(2) **Loose Riprap**
Section 8-15.3(3) **Hand Placed Riprap**
Section 8-15.3(4) **Sack Riprap**
Section 8-15.3(5) **Concrete Slab Riprap**
Section 8-15.3(6) **Quarry Spalls**
Section 8-15.3(7) **Filter Blanket**

Return to **Main Menu**

Figure 5.9 Keywords Explanation.

Furnish and install "**Modified Beam Guard Rail**" in lieu of the "**Beam Guard Rail Type I**". Modified Beam Guard Rail will consist of **thrie beam rail** elements and W beam rail elements mounted on posts without blocks. All work should be per **Section 8-11** of the Standard Specifications, and **attached drawings**. Measurement will be in Linear foot.

This change is required because an existing retaining wall is located too closed to the edge of pavement to place Type I Beam Guard Rail. The guard rail posts would hit the retaining wall.

Ref: Contract 2980 Change Order No. 11

Return to **Main Menu**

Figure 5.10 Change Order Summary for Modified Beam Guard Rails.

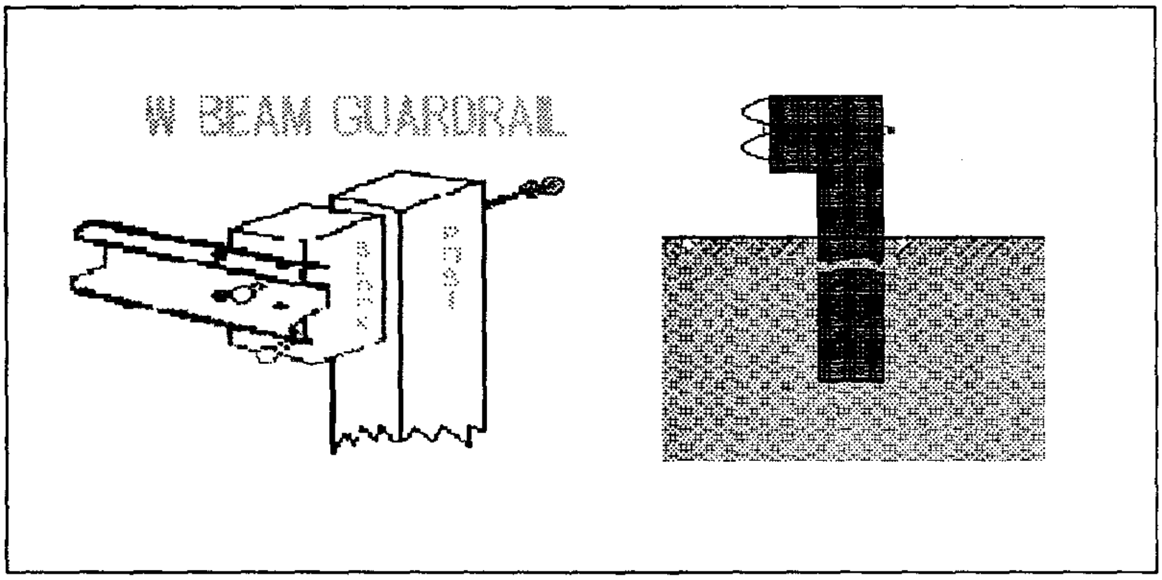

Figure 5.11 Standard Plan (Type I Guard Rail).

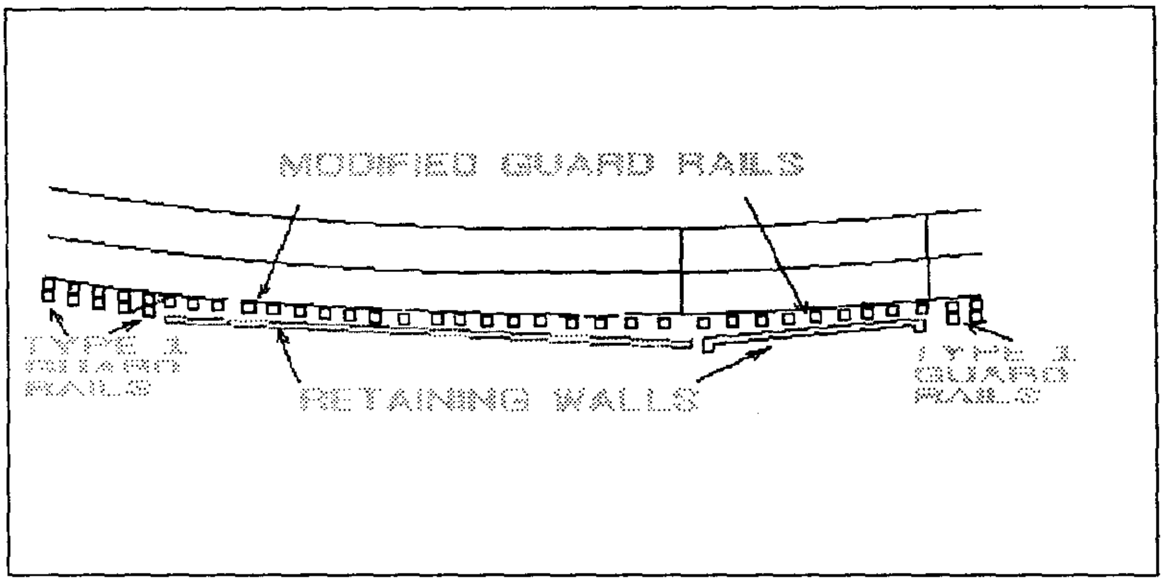

Figure 5.12 Specific Drawings Associated with the Change Order.

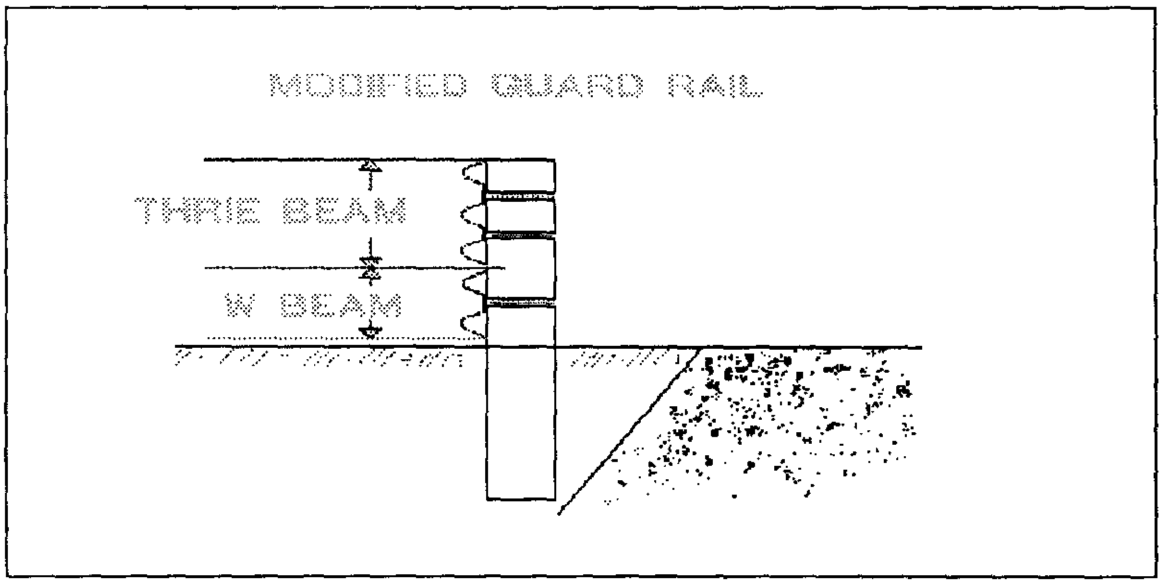

Figure 5.13 Modified Guard Rails.

FUTURE IMPROVEMENTS

The HCIS system developed through this project is a prototype with a limited data base. In the future, more information should be added and other information should be modified to maintain current design standards and specifications. In addition, other modifications may be made to the program to increase the run-time efficiency of the system. For example, many of the list manipulation commands cause a delay in the program execution which will only increase as more information is added. Thus changes may possibly be made to these routines to decrease the list manipulation time.

Also, currently, the majority of the information is contained directly in the main program. In the future, however, much of this information, especially the excerpts from the Standard Specifications, should be transferred to external files that are accessed from within the main program. The major reason for this is to reduce the size of the compiled knowledge base. The textual information is not important to the execution of the system and only serves to consume memory and slow down the system. Additionally, by maintaining the Standard Specifications in a separate file, changes such as updating the information can be made without manipulating the KnowledgePro program.

CHAPTER SIX

MODEL CONSTRUCTABILITY REVIEW PROCESS

By examining the districts' procedures and the collected constructability improvement ideas, a model constructability review process is proposed. By incorporating aspects from all of the districts studied, it provides a more uniform procedure which can be applicable to all the districts. The review process consists of two major parts: the pre-construction review and the post-construction review.

PRE-CONSTRUCTION REVIEW

The pre-construction or design review will incorporate the PS & E and design reviews currently being used. However, a list of items which have commonly caused problems in the past will also be included to prevent them from being overlooked, similar to a check list verification. As shown in the change order study, many of these items fall under common categories. However, all of the categories may not always be applicable to each project. Therefore, different check lists were developed for each major category and only those which do apply need to be used.

As shown in Figure 6.1, the cover page describes the overall project characteristic such as the project's title, description, purpose, and principles items of work. The following pages then contain the individual work item information such as drainage (Figure 6.2) and roadways.

For convenience and simplicity, the majority of the information is in the form of a check list. Thus, those items that are relevant to the project can be checked with additional comments added where needed and those that are not can be ignored. The complete sample review form is shown in Appendix B

MODEL CONSTRUCTABILITY REVIEW PROCESS For the Pre-Construction Review

PROJECT TITLE
PROJECT TYPE
Project limits:
Contract Number:
Initial time allowed for completion:
Project Designer:
Project Description:
Purpose of Project:
Principal Items of Work:
Other Projects in Vicinity:
Existing Conditions:
Alternatives were considered: [ ] Yes [ ] No
Analysis of Contributing Circumstances:
Analysis of Accident Types:
Analysis of Other Factors:
Summary Analysis:

Figure 6.1 Pre-Construction Review Cover Page

DRAINAGE

Existing drainage facilities consist of:

[ ] Roadside Ditches
[ ] Inlets/Catch Basins
[ ] Underdrains
[ ] Other ________
[ ] Cross-Culverts
[ ] Storm Sewer
[ ] Approach Culverts
[ ] Longitudinal Culverts

Proposed work:

[ ] No updates are required.
[ ] Culverts extensions will be installed where necessary.
[ ] Beveled ends will be installed where required.
[ ] Riprap will be installed where required.
[ ] Other work:

Check List:

[ ] Concrete inlets and drain pipes installed at locations of low spots along the roadway.

[ ] Proper drainage provided on top of retaining wall.

[ ] Riprap needed to prevent scouring and siltation inside the culvert structure.

[ ] Riprap needed to prevent erosion of the roadway sideslopes around the culvert, especially when sideslope erosion is a problem.

Recommendations:

Figure 6.2 Pre-Construction Review Form for Drainage

POST-CONSTRUCTION REVIEW

A post-construction review will provide a comparison of the original conditions and proposed work to the final conditions and actual work. Thus, the circumstances resulting in the discrepancies can be identified and the appropriate actions needed to prevent reoccurrence can be determined. The information acquired for each review can then be used to help improve future plans.

The project quality is viewed from two different perspectives: by the individual contractors and by the individual work items. For the contractor portion of the review, a form for each contractor involved in the project is completed. As shown in Figure 6.3, this includes the statistical information such as the award date, completion date, initial cost, final cost, and reasons for any differences.

The next part will be a change order review, similar to those procedures currently used statewide. A standard file (Figure 6.4) will be completed for each change order. A check list of the reasons for change orders is included for ease of classification. The categories are based upon the ones established in District 1; however, similar to District 4, the "Need More Investigation" and "Administrative Changes" categories are divided into more specific reasons. For example, since quantity estimation is a common problem and makes up a large percentage of the "Administrative Changes," it is listed separately to be analyzed individually.

CONTRACTORS
Contract Number:
Title/Description
Contractor Name:
Sub-Program:
Award Date / Completion Date:
Initial time allowed for completion:
Time extensions granted (if any): Time/reason:
Award Amount
Final Cost: **Reasons for overrun/underrun:**
Project Quality:

Figure 6.3 Post-Construction Review Form for Contractors

Change Orders Involved

Contract / Change Order Number:

Contractor Name:

Description of Problem:

Proposed by [ ] Contractor
[ ] DOT
[ ] Other

Approved by [ ] District
[ ] Headquarters

Classification Category:
[ ] 1. Necessary Change Order
[ ] 2. Need More Investigation
[ ] 3. Utility Related
[ ] 4. Signal/Illumination Related
[ ] 5. Policy & Design Changes
[ ] 6. Mind Changes
[ ] 7. Maintenance Problems
[ ] 8. Funding/Local Agency Request
[ ] 9. Engineering Errors
[ ] 10. Administrative Changes
[ ] 11. Quantity Estimation Errors
[ ] 12. Claim Related
[ ] 13. Plan Errors

Resolution of Problem:

Change in working days:

Net dollar change:

Useful for HCIS: [ ] Yes [ ] No

Figure 6.4 Post-Construction Review Change Order File

From the accumulated data, an analysis of the number of change orders, classification categories, and dollar amount can be made. The change orders can be organized by contract, contractor, type of problem classification category to see if any patterns emerge. The work item portion of the review will be very similar to the pre-construction review, mainly in the form of a checklist with boxes for the proposed work and the actual work. Thus, those work items that were completed can be checked and compared to the originally intended work. In addition, a list of the associated change orders is included to indicate any troubled areas with regard to the work item. The list of change orders for both the contract and the work items can be compared and analyzed. Thus, the interaction of conditions which have a tendency to create problems can also be determined.

RESULTS OF THE MODEL CONSTRUCTABILITY REVIEW PROCESS

There are a number of results anticipated from the adoption or use of the model constructability review process. The most significant is a standardization of the pre- and post-construction review processes which should reduce the reoccurrence of the same problems and improve the quality of the final product. Also, the review form concentrates on a checklist format, instead of verbose comments, for greater simplicity and efficiency. The use of modular forms for the individual work items is convenient in that only the forms necessary for the particular project need to be included. The accumulation and storage of historical data allows statistical analyses to be conducted with ease.

The model constructability review process is composed of a number of checklists. There is already too much paper involved for each project in the WSDOT Design and Construction offices. There are not enough people to efficiently take care of the existing paper work, let alone new paper. However, this new paper should replace the greater amount of existing paper work, resulting in lesser amount of overall paper work.

ACKNOWLEDGMENTS

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REFERENCES

Aye, R. D. (1989). "Change Order Review - I-90 (Administration Review Committee)." Intra-Departmental Communication, Mar. 22, 1989.

Berentson, D. (1985). "Construction Administration Review." Intra-Departmental Communication, Mar. 20, 1985.

Blanchard, F. P. (1981). "I-205 Columbia River Bridge: Design and Construction." Transportation Engineering Journal, ASCE, 107(6), 625-633.

Bockstruck, R. E., (1988). "Professional Excellence Committee (Administrative Review Board) Meeting on December 12, 1988." Intra-Departmental Communication, Dec. 22, 1988.

"Can Your Design Be Built?" (1986). Civil Engineering, ASCE, March, 49-51.

"Constructability (A Primer)". (1986). The Construction Industry Institute. Publication 3-1. University of Texas, Austin, Texas.

Constructability Concepts File. (1987). The Construction Industry Institute. Publication 3-3. University of Texas, Austin, Texas.

"A Demonstration of the Constructability of a Precast Concrete Stay-in-Place Forming System for Lock Wall Rehabilitation." (1987). Technical Report REMR-CS-14, U. S. Army Corps of Engineers.

Eldin, N. N. (1988). "Constructability Improvement of Project Designs." Journal of Construction Engineering and Management, ASCE, 114(4), 631-640.

Fiderio, J. (1988). "A Grand Vision." BYTE, October, 237-244.

Ferguson, E. W., (1985). "District 4 Change Orders Four Year Review (1980-1983), M.B.O. Assignment." Intra-Departmental Communication, Jan. 10, 1985.

Gee, A. F. (1989). "Constructability of Bridges -- A Construction Engineer's View." Concrete International: Design and Construction, May, 48-52.

Glaze, D. K., (1984). "Administrative Review Board Meeting." Intra-Departmental Communication, Aug. 8, 1984.

"Guidelines for Implementing a Constructability Program." (1987). The Construction Industry Institute. Publication 3-2. University of Texas, Austin, Texas.

Highlands, K. L., and Hoffman, G. L. (1988). "Subbase Permeability and Pavement Performance." In Transportation Research Record 1159, TRB, National Research Council, Washington, D.C., 7-20.

Hugo, F., O'Conner, J. T., and Ward, W. V. (1989). "Highway Constructability Guide." Research Project 3-6-88-1149, University of Texas, Austin, Texas.

Korf, V.W. (1984). "Review Procedure for Pre-Contract and Contract Engineering Activities." Intra-Departmental Communication, May 21, 1984.

Lee, H., Wong, M. K. H., Clover, P. A., and Anderson, K. W. (1990). "Development of Hypertext - Linked Highway Construction Improvement System." Transportation Research Board, 70th Annual Meeting, TRB, Washington, D. C.

Lin, T. Y. (1984). "Creativity and Constructability in Structural Engineering." Civil Engineering for Practicing and Design Engineers, (3)9, Sept, 907-930.

Michal, J. J., (April 20, 1990). "Design Engineering Workstation (DEWS) Engineering Systems Plan." Washington State Department of Transportation, Olympia, WA.

O'Connor, J. T. (1985). "Impacts of Constructability Improvement." Journal of Construction Engineering and Management, ASCE, 111(4), 404-410.

O'Connor, J. T., Larimore, M. A., and Tucker, R. L. (1986). "Collecting Constructability Improvement Ideas." Journal of Construction Engineering and Management, ASCE, 112(4), 463-475.

O'Connor, J. T., and Tucker, R. L. (1986). "Industrial Project Constructability Improvement." Journal of Construction Engineering and Management, ASCE, 112(1), 69-82.

O'Connor, J. T., Rusch, S. E., and Schultz, M. J. (1987). "Constructability Concepts for Engineering and Procurement." Journal of Construction Engineering and Management, ASCE, 113(2), 235-248.

O'Connor, J. T., and Davis, V. S. (1988). "Constructability Improvement During Field Operations." Journal of Construction Engineering and Management, ASCE, 114(4), 548-564.

Pearson, R. I. (1989). "Washington State's Mammoth I-90 Project." Concrete International: Design and Construction, February, 23-53.

Proctor and Gamble Company (1976). "Building and Construction Technology Bulletin." Proctor and Gamble Company, Cincinnati, Ohio.

Proctor and Gamble Company (1977). "Constructability--It Works." Proctor and Gamble Company, Cincinnati, Ohio.

Putas, G. (1990) "Stages of Review on a Construction Project." District 6 Memorandum, October 31, 1990.

Ramsey, T. S. (1984). "Quality Control -- A Necessity, Not An Option." Journal of Construction Engineering and Management, ASCE, 110(4), 513-517.

Rasmus, D. (1989). "KnowledgePro -- A Complete Applications Development Environment." PC AI,(3)5, September/October, 47-57.

Shafer, D. (ed) (1988). "Hypertext and AI Merge." Intelligent Systems Analyst, (1)9.

Smith, G. E. (1988). "Change Order Review (District Administrative Review Board Committee)." Intra-Departmental Communication, May 12, 1988.

Smith, G. E., (1989). "Change Order Review (District Administrative Review Board)." Intra-Departmental Communication, Aug. 7, 1989.

Smith, G. E., (1990). "Change Order Review (District Administrative Review Board)." Intra-Departmental Communication, June 12, 1990.

"Structural Engineering Research Needs." (1979). Civil Engineering, ASCE, 49(12), Dec, 61-65.

Tatum, C. B. (1987). "Improving Constructability during Conceptual Planning." Journal of Construction Engineering and Management, ASCE, 113(2), 191-207.

Thompson, B., and Thompson, B. (1988). KnowledgePro User Manual. Knowledge Garden, Inc.

Wallace, M. (1987). Redesign Improves Constructability: Attention to details Enhances Appearance. Concrete Construction, (32)4, April, 357-364.

APPENDIX A

HCIS KnowledgePro Prgram Skeleton

Note: To reduce the length of the program listing, the text from the change order topics, standard specification, etc. (excluding hypertext section) have been deleted. For more information regarding the change order summaries, see section 4.4.3.

```
(* CONSTRUCTABILITY IMPROVEMENT FOR HIGHWAY PROJECTS *)
(* --- Demo Program for Constructability Vers.3 ---  *)
(*     Focus :  Design Engineer                      *)


do (introduction_page).

load ('picture.hkb').

topic introduction_page.
say ('').
end. (* introduction page *)

do ('set up').
do ('main menu').


topic 'set up'.
write (con:,'#e
     Please wait while setting up ').


(* --- Change orders included in the system --- *)

contract is
  ['Contract 2809, c/o 3', ... , 'Contract 3596, c/o 3',
   'Main Menu'].


(* --- Topic names for change orders --- *)

contract_topic is
  ['guard rail post design', ...
  ,'pavement overlay preparation','Main Menu'].


(* --- District 1 - Change order classification --- *)

d1_0 is [].
d1_1 is ['Contract 2828, c/o 4','Contract 2947, c/o 14',
         'Contract 3040, c/o 5'].
      .
      .
      .
d1_9 is [].
```

```
(* --- District 4 - change order classification --- *)
d4_1  is [].
     .
     .
     .
d4_22 is ['Contract 2866, c/o 18','Contract 2867, c/o 12'].
d4_23 is [].

end. (* set up *)


topic 'main menu'.
say('
         * #mWork Topics#m

         * #mReview Categories#m

         * #mContract Search#m
').
end.  (* main menu*)


topic 'Review Categories'.
say ('
         * #mDistrict 1#m

         * #mDistrict 4#m
').
end. (* Review Categories *)


topic 'District 1'.
dlist is ['0.  Necessary change orders',
           '1.  Need more investigation',
           '2.  Signal and illumination projects',
           '3.  Policy and design changes',
           '4.  Mind changes',
           '5.  Maintenance problems',
           '6.  Minor scope changes',
           '7.  Engineering errors',
           '8.  Administrative changes',
           '9.  Plan errors',
           'Exit'].
ask('                        #flightcyan --- DISTRICT 1 Change
Order Review ---#d

     The Change Order Review Committee of the District
Administrative Review
     Board developed 10 categories into which to sort the
change orders
     studied during its annual review.  The categories are
as follows:
```

```
     Use #fyellow cursor keys#d to
     select the desired categories
     then press #fyellow Enter#d.#x40#y4',
     district,?dlist).

numsub is where(?dlist,?district).
if ?district <> Exit then do(?district)
                     else do('Review Categories').

(* Note: End of District 1 topic after example secton *)


topic '0.  Necessary change order'.
catlist is ?d1_0.
stat_no =''.
say('
     Necessary change order

         * #mStatistics#m').
end.  (* 0. Necessary change order *)


topic '1. Need more investigation'.

catlist is d1_1.
stat_no = ''.
say('
     Need more investigation
         * #mStatistics#m

         * #mExamples#m').
end. (* 1. Need more investigation *)


topic '2.  Signal and illumination projects'.
catlist is ?d1_2.
stat_no = ''.
say('
     Need more information - signal and illumination
projects.

         * #mStatistics#m

         * #mAssociated Change Orders#m').
end.  (* 2. Need more information *)


topic '3.  Policy and design changes'.
catlist is ?d1_3.
stat_no = ''.
say('
     Policy and design changes

         * #mStatistics#m
```

```
          * #mAssociated Change Orders#m').
end.  (* 3. Policy and design changes *)


topic '4.  Mind changes'.
catlist is ?d1_4.
stat_no = ''.
say('
     Mind changes

          * #mStatistics#m

          * #mAssociated Change Orders#m').
end.  (* 4. Mind changes *)


topic '5.  Maintenance problems'.
catlist is ?d1_5.
stat_no = ''.
say('
     Maintenance problems

          * #mStatistics#m

          * #mAssociated Change Orders#m').
end.  (* 5. Maintenance problems *)


topic '6.  Minor scope changes'.
catlist is ?d1_6.
stat_no = ''.
say ('
      Minor scope changes

          * #mStatistics#m

          * #mAssociated Change Orders#m').
end.  (* 6. Minor scope changes *)


topic '7.  Engineering errors'.
catlist is ?d1_7.
stat_no = ''.
say('
     Engineerings errors

          * #mStatistics#m

          * #mAssociated Change Orders#m').
end.  (* 7. Engineering errors *)


topic '8.  Administrative changes'.
```

```
catlist is ?d1_8.
stat_no = ''.
say('
     Administrative changes

         * #mStatistics#m

         * #mAssociated Change Orders#m').
end.  (* 8. Administrative changes *)


topic '9.  Plan errors'.
catlist is ?d1_9.
stat_no = ''.
say('
     Plan errors

        * #mStatistics#m

        * #mAssociated Change Orders#m').
end.  (* 9. Plan errors *)


topic 'statistics'.
say('  CHANGE ORDERS - 1987 to 1989 Comparison
  (From the District 1 Change Order Review)

  #flightgreen Category #s',?district1,#l,
'

                  #dNumber of                     Dollar
Values
                Change Orders   Total               ($000)
Total
                ------------------------------------------
----------- ',
?stat_no,'

                         Press  #fyellow Space #d to
continue.').
end.  (* statistics *)


topic 'Associated Change Orders'.
  if last(?catlist) <> Exit then catlist gets [Exit].

  ask([' Examples of change orders according to the
District 1 categories
  for category #s',?district,'#l'],CO_num,?catlist).

  contract_name is
element(?contract_topic,where(?contract,?CO_num)).
  if co_num <> Exit then do(?contract_name).
  if co_num <> Exit then do(?'Associated Change Orders').
```

```
end. (* Associated Change Orders *)

end. (* District 1 *)


topic 'District 4'.
dlist is [' 1. Plan Error',' 2. Added Work',' 3. Design
Change',
  ' 4. Construction Error',' 5. Deletion of Work',' 6.
Changed Conditions',
  ' 7. Change to Special',' 8. Local Agency Request',
  ' 9. Substitution of Materials','10. Quant. >25% (SS 1-
04.6)',
  '11. Utilities Related','12. Soils Related','13. Claim
Related',
  '14. M/WBE Related','15. Fuel Cost Adjustment','16.
Materials by Voucher',
  '17. Ton to CY Conversion','18. Traffic Control Related',
  '19. Added Work by Traffic','20. Added Work by
Maintenance',
  '21. Construction Staging Problem','22. Non-Specification
Material',
  '23. Air/Water Pollution','Exit'].
ask ('
                  #flightcyan --- DISTRICT 4  Change Order
Review ---#d

  The change order review study assigns each change order to
one of the
  following categories.

  Use the #fyellow cursor keys#d to
  select the desired category
  then press #fyellow Enter#d.#x40#y3',district,?dlist).

if ?district <> Exit then do(subdist4)
                     else do('Review Categories').

   topic subdist4.
   numsub is where(?dlist,?district).
   if ?numsub = 10 then say (#y2,?district,'

   Available options are

      * Standard Specifications #mSection 1-04.6#m

      * #mStatistics#m

      * #mAssociated change orders#m


   Return to #mMain Menu#m.').
```

```
   if ?numsub <> 10 then say (#y2,?district,'

   Available options are

      * #mStatistics#m

      * #mAssociated change orders#m


   Return to #mMain Menu#m.').
   end. (* subdist4 *)

   topic Statistics.
   statlist is [''].  (* includes information from App. G *)

   numlist is where(?dlist,?district).
   select is concat(#fyellow,' ',
element(?statlist,?numlist),#d).
   newlist is replace_elements(?statlist,?numlist,?select).

   say ('',?newlist).
   end. (* Statistics *)

  topic 'Associated change orders'.
  if numsub = 1 then catlist is d4_1.
     .
     .
     .
  if numsub = 23 then catlist is d4_23.

  if last(?catlist) <> Exit then catlist gets [Exit].
  ask(['  Examples of change orders according to the
District 4 categories
  for category #s',?district,'#l'],CO_num,?catlist).

  contract_name is
element(?contract_topic,where(?contract,?CO_num)).
  if co_num <> Exit then do(?contract_name)
  if co_num <> Exit then do(?'Associated change orders').


   end. (* Associated change orders *)

end.  (* District 4 *)


topic 'Contract Search'.
ask ('
                       #flightcyan --- CHANGE ORDER LIST ---
#d
```

```
  Select the Contract/Change Order
  by using the #fyellow cursor keys#d
  to move up or down and then press
  #fyellow Enter#d.#x55#y0',CO_num,?Contract).

contract_name is
element(?contract_topic,where(?contract,?CO_num)).
do(?contract_name).
do('Contract Search').
end.  (* Contract Search *)


topic 'Work Topics'.
say('
         * #mRoads#m,
         * #mStructures#m,
         * #mTraffic signals#m,
         * #mDrainage Structures#m and Water Distribution,
         * #mEarthwork#m, and
         * #mConstruction Safety#m').
end. (* Topic Menu *)


topic roads.
say('
     * #mpavement#m                          * #mresurfacing#m
     * #mshoulder#m
     * #mguard rail#m
     * #mconcrete barriers#m
     * #mpavement markings#m
     * #msidewalks, curbs, and gutters#m
     * #mgrading#m
     * #mgroundwater problems#m').
end. (* roads *)


topic pavement.
say('
         #masphalt#m
         #mconcrete#m').
end. (* pavement *)


topic asphalt.
say('
         * #mtack coat#m application, and
         * #mtypes of asphalt#m.').
end. (* asphalt *)


topic 'resurfacing'.
say('
         * #mpavement overlay preparation#m').
end.  (*resurfacing*)
```

```
topic 'guard rail'.
say('
         * #mguard rail applications#m
         * #mguard rail post design#m').
end. (*guard rail*)

topic guardrail.
do ('guard rail').
end. (* guardrail *)


topic 'concrete barriers'.
say('
         * #mMedian Barrier#m
         * #mSingle Faced Barriers#m').
end.  (*concrete barriers*)


topic 'structures'.
say('
         * #mBridges#m
         * #mRetaining Walls#m
         * #mExpansion Joints#m').
end. (* structures *)


topic 'bridges'.
say('
         * #mBridge Drainage#m
         * #mPrestressed Girders#m
         * #mBridge Replacement#m
').
end.  (* bridges *)


topic 'drainage structures'.
say('
         * #mconcrete inlet#m
         * #mcatch basins#m
         * #mirrigation systems#m
         * #mculverts#m
         * #munderdrain pipes#m
         * #mbridge drainage#m
         * #mretaining wall drainage#m
').
end. (* drainage structures *)


topic 'culverts'.
say('
         *  #mculvert end details#m
         *  #mculvert riprap usage#m
```

```
').
end.  (*culverts*)


topic 'groundwater problems'.
say('
         * #martesian water#m').
end.  (*groundwater problems*)


topic 'retaining walls'.
say('
         * #mretaining wall drainage#m').
end.  (*retaining walls*)


topic earthwork.
say('
         * #mexcavation#m
         * #mEmbankment#m
         * #mgrading#m').
 end. (* earthwork *)


topic 'traffic signals'.
say('
        * #msignal controller location#m
        * #mintersection expansion#m
        * #mtraffic signs#m
        * #mtraffic illumination#m').
end.  (*traffic signals*)


topic 'intersection expansion'.
say('
         * #madditional vehicle detection devices#m
').
end.  (*intersection expansion*)


topic 'sidewalks, curbs, and gutters'.
say('
        * #msidewalk construction#m
        * #mbusiness area curbs#m
').
end.  (*sidewalks, curbs, and gutters*)


(* ---------------------------------------------------- *)
(* -- Change Order Summaries and Associated Hypertext -- *)
(* ---------------------------------------------------- *)

topic 'construction safety'.
```

```
say(' ').
end. (* construction safety *)


topic 'artesian water'.
say('#martesian springs#m').
end.  (*artesian water*)


topic 'artesian springs'.
say('').
end.  (*artesian springs*)


topic 'artesian spring graphic'.
say('').
end. (*artesian spring grahpic*)


topic 'median barrier'.
say('#mmedian barrier footing detail#m').
end. (*median barrier*)

topic 'median barrier footing detail'.
say('').
end.  (*median barrier footing detail*)


topic 'retaining wall drainage'.
say('#mretaining wall drainage detail#m').
end. (*retaining wall drainage*)


topic 'retaining wall drainage detail'.
say('').
end.  (*retaining wall drainage detail*)


topic 'pavement overlay preparation'.
say('').
end. (*pavement overlay preparation*)


topic 'business area curbs'.
say('').
end.  (*business area curbs*)


topic 'signal controller location'.
say('').
end.  (*signal controller location*)


topic 'additional vehicle detection devices'.
```

```
say('').
end.  (*additional vehicle detection loops devices*)


topic 'expansion joints'.
say('#mA-9-73 paint#m').
end.  (*expansion joints*)


topic 'A-9-73 paint'.
say('').
end.  (*A-9-73 paint*)


topic 'culvert riprap usage'.
say('#mRipRap#m').
end.  (*culvert riprap usage*)


topic 'Embankment'.
say('#mriprap#m').
end.  (*embankment*)


topic 'Bridge Replacement'.
say('').
end.  (*bridge replacement*)


topic 'grading'.
say('').
end. (*grading*)


topic 'culvert end details'.
say ('').
end. (*culverts*)


topic 'Bridge Drainage'.
say('').
end. (*bridge drainage*)


topic 'sidewalk construction'.
say('').
end. (*sidewalk construction*)


topic 'prestressed girders'.
say('#msec. 9-19#m').
end. (*prestressed girders*)
```

```
topic shoulder.
say ('').
end. (* shoulder *)


topic 'catch basins'.
say ('').
end. (* catch basins *)


topic 'irrigation systems'.
say ('#mPVC plastic pipe#m').
end. (* irrigation systems *)


topic 'excavation'.
say ('#mSection 2-03.3(11)#m').
end. (* earthwork excavation *)


topic 'traffic signs'.
say ('#msign bridges#m #msign mounting details#m').
end. (* traffic signs *)


topic 'traffic illumination'.
say ('#mjunction box#m').
end. (* traffic illumination *)


topic 'underdrain pipes'.
say('#mgravel borrow#m #mfilter cloth#m').
end. (*underdrain pipes*)


topic 'single faced barriers'.
say ('').
end. (* single faced barriers *)


topic 'tack coat'.
say ('#mClass D#m #mClass G#m').
end.  (* tack coat *)


topic 'types of asphalt'.
say ('#mClass B#m #mSection 5-04.3(10)B#m').
end. (* types of asphalt *)


topic 'pavement markings'.
say('#mSec 8-09.3(1),(2),(3)#m').
end.  (*pavement markings*)
```

```
topic concrete.
say ('').
end. (* concrete *)


topic 'guard rail applications'.
say ('#mModified Beam Guard Rail#m
  #mBeam Guard Rail Type I#m" #mthrie beam rail#m
  #mW beam rail#m #mSection 8-11#m
  #mattached rail drawings#m.  ').
end. (* guard rail applications*)


topic 'guard rail post design'.
say('').
end.  (*guard rail post design*)


topic 'concrete inlet'.
say ('#mSection 8-04.3(3)#m #mStandard Plan B-4a#m
 #mattached inlet drawing#m #mguard rail#m
').
end. (* concrete inlet *)


topic 'attached inlet drawing'.
select is element (picture ('cinlet.pcx',1,8,N,
[['special riprap',T,186,220],
 ['special riprap',T,80,200]]),2).

if ?select <> ''
then do (?select) and
     do ('attached inlet drawing').

topic 'special riprap'.
do ('riprap').
end.

end. (*attached inlet drawing*)


topic 'Modified Beam Guard Rail'.
picture ('thrie.pcx').
end. (* Modified Beam Guard Rail *)


topic 'Beam Guard Rail Type I'.
picture ('gomar.pcx').
end. (* Beam Guard Rail Type I *)


topic 'thrie beam rail'.
picture ('thrie.pcx').
```

```
end. (* thrie beam rail *)


topic 'W beam rail'.
do ('Beam Guard Rail Type I').
end. (* W beam rail *)

topic 'attached rail drawings'.
   select is element (picture ('modified.pcx',1,8,N,
    [['thrie',G,252,82],
     ['thrie',G,129,140],
     ['thrie',G,377,142],
     ['gomar',G,474,177],
     ['gomar',G,47,173]]),2).

   if ?select <> ''
   then do (?select) and
        do ('attached rail drawing').

   topic thrie.
   picture ('thrie.pcx').
   end.

   topic gomar.
   picture ('gomar.pcx').
   end.

end. (* attached rail drawings *)


topic 'Standard Plan B-4a'.
picture ('concrete.pcx').
end. (* Standard Plan B-4a *)


topic 'sign bridges'.
say('').
end. (* sign briges *)


topic 'sign mounting details'.
say('').
end. (* sign mounting details *)


topic 'filter cloth'.
say('').
end. (*filter cloth*)
```

```
(* ---------------------------------------- *)
(* -------- STANDARD SPECIFICATIONS -------- *)
(* ---------------------------------------- *)

topic 'Section 1-04.6'.
ss is read ('SS1-04-6.txt').
say (?ss).
close ('SS1-04-6.txt').
end. (* Section 1-04.6 *)


topic 'Section 2-03.3(11)'.  (* Slides *)
say ('').
end.  (* Section 2-03.3(11)  <Slides> *)


topic 'Section 5-04.3(10)B'.
say ('').
end. (* Section 5-04.3(10)B *)


topic 'Section 6-02'.  (* Concrete Structures *)
say ('
         #mSection 6-02.1#m  Description
         #mSection 6-02.2#m  Materials
         #mSection 6-02.3#m  Construction Requirements
         #mSection 6-02.4#m  Measurement
         #mSection 6-02.5#m  Payment').
end.  (* Section 6-02  <Concrete Structures> *)


topic 'Section 6-02.1'.  (* Description *)
say ('').
end.  (* Section 6-02.1  <Description> *)


topic 'Section 6-02.2'.  (* Materials *)
say ('').
end.  (* Section 6-02.2  <Materials> *)


topic 'Section 6-02.3'.  (* Construction Requirements *)
say ('
 #mSection 6-02.3(1)#m   Classification of Structural
Concrete
 #mSection 6-02.3(2)#m   Proportioning Materials
 #mSection 6-02.3(3)#m   Admixtures
 #mSection 6-02.3(4)#m   Mixing Concrete
 Section 6-02.3(5)   Consistency
 #mSection 6-02.3(6)#m   Placing Concrete
 Section 6-02.3(7)   Concrete Exposed to Sea Water
 Section 6-02.3(8)   Concrete Exposed to Alkaline Soils or
Water
 Section 6-02.3(9)   Vibration of Concrete
```

```
 Section 6-02.3(10)  Roadway Slabs
 #mSection 6-02.3(11)#m  Curing Concrete
 Section 6-02.3(12)  Construction Joints
 Section 6-02.3(13)  Expansion Joints
 #mSection 6-02.3(14)#m  Finishing Concrete Structures
 #mSection 6-02.3(15)#m  Date Numerals
 #mSection 6-02.3(16)#m  Plans for Falsework and Forms
 #mSection 6-02.3(17)#m  Falsework and Forms
 Section 6-02.3(18)  Placing Anchor Bolts
 #mSection 6-02.3(19)#m  Elastomeric Bearing Pads
 #mSection 6-02.3(20)#m  Steel Expansion Bearings
 Section 6-02.3(21)  Drainage of Box Girder Cells
 Section 6-02.3(22)  Drainage of Substructure
 Section 6-02.3(23)  Opening to Traffic
 #mSection 6-02.3(24)#m  Reinforcement
 #mSection 6-02.3(25)#m  Prestressed Concrete Girders
 #mSection 6-02.3(26)#m  Girder Deflection
 #mSection 6-02.3(27)#m  Concrete for Precase Units').
end. (* Section 6-02.3  <Construction Requirements> *)


topic 'Section 6-02.3(1)'.  (* Classification of Structural
Concrete *)
say ('').
end.  (* Section 6-02.3(1)  <Classification of Structural
Concrete> *)

topic 'Class AX'.
do ('Section 6-02.3(1)').
end.  (* Class AX *)


topic 'Section 6-02.3(2)'.  (* Proportioning Materials *)
say ('').
end.  (* Section 6-02.3(2)  <Proportioning Materials> *)


topic 'Section 6-02.3(3)'.  (* Admixtures*)
say ('').
end.  (* Section 6-02.3(3)  <Admixtures> *)


topic 'Section 6-02.3(4)'.  (* Mixing Concrete *)
say ('').
end.  (* Section 6-02.3(4)  <Mixing Concrete> *)


topic 'Section 6-02.3(6)'.  (* Placing Concrete *)
say ('').
end. (* Section 6-02.3(6)  <Placing Concrete> *)


topic 'Section 6-02.3(11)'. (* Curing Concrete *)
say ('').
```

```
end. (* Section 6-02.3(11)  <Curing Concrete> *)


topic 'Section 6-02.3(14)'.  (* Finishing Concrete
Structures *)
say ('').
end.  (*Section 6-02.3(14) <Finishing Concrete Structures>*)


topic 'Section 6-02.3(15)'.  (* Date Numerals *)
say ('').
end. (* Section 6-02.3(15)  <Date Numerals> *)


topic 'Section 6-02.3(16)'.  (* Plans for Falsework and
Forms *)
say ('').
end.  (* Section 6-02.3(16)  <Plans for Falsework and Forms>
*)


topic 'Section 6-02.3(17)'.  (* Falsework and Forms *)
say ('').
end.  (* Section 6-02.3(17)  <Falsework and Forms> *)


topic 'Section 6-02.3(19)'.  (* Elastomeric Bearing Pads *)
say ('').
end. (* Section 6-02.3(19)  <Elastomeric Bearing Pads> *)


topic 'Section 6-02.3(20)'.  (* Steel Expansion Bearings *)
say ('#mSection 6-03.3(36)#m').
end.  (* Section 6-02.3(20)  <Steel Expansion Bearings> *)


topic 'Section 6-02.3(24)'.  (* Reinforcement *)
say ('').
end. (* Section 6-02.3(24)  <Reinforcement> *)


topic 'Section 6-02.3(25)'.  (* Prestressed Concrete Girders
*)
say ('').
end. (* Section 6-02.3(25)  <Prestressed Concrete Girders>
*)


topic 'Section 6-02.3(26)'.  (* Cast-in-Place Prestressed
Concrete *)
say ('#mClass AX#m').
end. (* Section 6-02.3(26)  <Cast-in-Place Prestressed
Concrete *)
```

```
topic 'Section 6-02.3(27)'.  (* Concrete for Precast Units
*)
say('').
end.  (* Section 6-02.3(27)  <Concrete for Precast Units> *)


topic 'Section 6-02.4'.  (* Measurement *)
say ('').
end.  (* Section 6-02.4  <Measurement>  *)


topic 'Section 6-02.5'.  (* Payment *)
say ('').
end.  (* Section 6-02.5  <Payment>  *)


topic 'Section 6-03.3(7)'.  (* Shop Plans *)
say ('#mSection 1-05.3#m').
end.  (* Section 6-03.3(8)  <Shop Plans> *)


topic 'Section 6-03.3(25)'.  (* Welding and Repair Welding
*)
say ('#mSection 6-03.3(7)#m').
end.  (* Section 6-03.3(25)  <Welding and Repair Welding> *)


topic 'Section 6-03.3(26)'.  (* Screw Threads *)
say ('').
end.  (* Section 6-03.3(26)  <Screw Threads> *)


topic 'Section 8-11'.
say ('
         #mSection 8-11.1#m  Description
         #mSection 8-11.2#m  Materials
         #mSection 8-11.3#m  Construction Requirements
         #mSection 8-11.4#m  Measurement
         #mSection 8-11.5#m  Payment
').
end. (* Section 8-11 *)


topic 'Inlet'.
say ('
     WSDOT Standard Specifications
     Section 8-04.3(3)  Inlets

 #mspillway#m #mSection 6-02#m').
end. (* Section 8-04.3(3) *)

topic 'Section 8-04.3(3)'.
do ('inlet').
```

```
end. (* Section 8-04.3(3) *)

topic 'metal inlet'.
do ('Inlet').
end. (* metal inlet *)


topic 'Sec 8-09.3(1),(2),(3)'.
say('').
end.  (*Sec 8-09.3(1),(2),(3)*)


topic 'riprap'.
say ('         Section 8-15.3(1)  Excavation of Riprap
         Section 8-15.3(2)  #mLoose Riprap#m
         Section 8-15.3(3)  #mHand Placed Riprap#m
         Section 8-15.3(4)  #mSack Riprap#m
         Section 8-15.3(5)  #mConcrete Slab Riprap#m
         Section 8-15.3(6)  #mQuarry Spalls#m
         Section 8-15.3(7)  #mFilter Blanket#m
').
end. (* riprap *)


topic 'Section 8-11.1'.  (* Descriptions *)
say ('').
end. (* Section 8-11.1 <Descriptions> *)


topic 'Section 8-11.2'.  (* Materials *)
say ('
             Rail Element ........... #mSection 9-16.3(1)#m
             Posts and Blocks ....... #mSection 9-16.3(2)#m
             Galvanizing ............ #mSection 9-16.3(3)#m
             Hardware ............... #mSection 9-16.3(4)#m
             Anchors ................ #mSection 9-16.3(5)#m
 Weathering Steel Beam Guardrail .... #mSection 9-16.8#m
').
end. (* Section 8-11.2  <Materials> *)


topic 'Section 8-11.3'.  (* Construction Requirements *)
say ('           #mSection 8-11.3(1)A#m  Erection of Posts
           Section 8-11.3(1)B  Vacant
           #mSection 8-11.3(1)C#m  Erection of Rail
           #mSection 8-11.3(1)D#m  Anchor Installation
           #mSection 8-11.3(1)E#m  Plans
         #mSection 8-11.3(2)#m  Guardrail Construction
Exposed to Traffic
         #mSection 8-11.3(3)#m  Access Control Gates
         #mSection 8-11.3(4)#m  Removing Guard Rail
         #mSection 8-11.3(5)#m  Raising Guardrail').
end. (* Section 8-11.2  <Construction Requirements> *)
```

```
topic 'Section 8-11.3(1)A'.  (* Erection of Posts *)
say ('').
end. (* Section 8-11.3(1)A  <Erection of Posts> *)


topic 'Section 8-11.3(1)C'.  (* Erection of Rail *)
say ('#mweathering steel beam guardrail#m').
end. (* Section 8-11.3(1)C  <Erection of Rail> *)


topic 'Section 8-11.3(1)D'.  (* Anchor Installation *)
say ('').
end. (* Section 8-11.3(1)D  <Anchor Installation>  *)


topic 'Section 8-11.3(1)E'.  (* Plans *)
say ('').
end. (* Section 8-11.3(1)E  <Plans> *)


topic 'Section 8-11.3(2)'.  (* Guardrail Constr. Exposed to
Traffic *)
say('').
end.  (* Section 8-11.3(2)  <Guardrail Const. Exposed to
Traffic> *)


topic 'Section 8-11.3(3)'.  (* Access Control Gates *)
say ('').
end. (* Section 8-11.3(3)  <Access Control Gates> *)


topic 'Section 8-11.3(4)'.  (* Removing Guard Rail *)
say ('').
end.  (* Section 8-11.3(4)  <Removing Guard Rail> *)


topic 'Section 8-11.3(5)'.  (* Raising Guardrail *)
say ('').
end.  (* Section 8-11.3(5)  <Raising Guardrail> *)


topic 'Section 8-11.4'.  (* Measurement *)
say ('').
end. (* Section 8-11.4  <Measurement>  *)


topic 'Section 8-11.5'.  (* Payment *)
say ('').
end.  (* Section 8-11.5  <Payment> *)


topic 'PVC plastic pipe'.
```

```
say ('#mductile iron pipe#m').
end. (* PVC plastic pipe *)


topic 'Section 9-16.3(1)'.  (* Rail Element *)
say ('').
end. (* Section 9-16.3(1)  <Rail Element> *)


topic 'Section 9-16.3(2)'.  (* Posts and Blocks *)
say ('').
end. (* Section 9-16.3(2)  <Posts and Blocks> *)


topic 'Section 9-16.3(3)'.  (* Galvanizing *)
say ('').
end. (* Section 9-16.3(3)  <Galvanizing> *)


topic 'Section 9-16.3(4)'.  (* Hardware *)
say ('').
end. (* Section 9-16.3(4)  <Hardware> *)


topic 'Section 9-16.3(5)'.  (* Anchors *)
say ('#mSection 6-03.3(25)#m #mSection 9-16.3(3)#m
      #mSection 6-02.3#m').
end. (* Section 9-16.3(5)  <Anchors> *)


topic 'Section 9-16.8'.  (*Weathering Steel Beam Guardrail*)
say ('').
end.  (* Section 9-16.8 <Weathering Steel Beam Guardrail> *)

topic 'weathering steel beam guardrail'.
do ('Section 9-16.8').
end.  (* weathering steel beam guardrail *)


topic 'junction box'.  (* SS 9-29.2 *)
say ('').
end. (* junction box *)


topic 'ductile iron pipe'. (* SS 9-30.2(11) *)
say ('').
end. (* Ductile Iron Pipe *)


topic 'spillway'.
say ('').
end. (* spillway *)

topic ''.
```

```
say ('').
end. (* Class B *)

topic 'Class D'.
say ('').
end. (* Class D *)

topic 'Class G'.
say ('').
end. (* Class G *)


topic 'Sec 9-03.14'.
do ('gravel borrow').
end. (*Sec 9-03.14*)

topic 'gravel borrow'.
say('#mSand Equivalent#m').
end. (*gravel borrow*)


topic 'sec. 9-19'.
say('#mSec. 9-03.1#m #mSec. 9-25.1#m #mSec. 9-01#m
     #mSec. 9-23.7#m #mSec. 9-07#m.').
end. (*9-19*)


topic 'Sec. 9-01'.
say('
         * #mSec. 9-01.1#m    Types of Cement
         * #mSec. 9-01.2#m    Specifications
         * #mSec. 9-01.3#m    Tests and Acceptance
         * #mSec. 9-01.4#m    Storage on the Work Site').
end. (*Sec. 9-01*)


topic 'Sec. 9-01.1'.
say('').
end. (*Sec. 9-01.1*)


topic 'Sec. 9-01.2'.
say('').
end.  (*Sec. 9-01.2*)


topic 'Sec. 9-01.3'.
say('').
end.  (*Sec. 9-01.3*)


topic 'Sec. 9-01.4'.
say('').
end.  (*Sec. 9-01.4*)
```

```
topic 'Sec. 9-23.7'.
say('').
end.  (*Sec. 9-23.7*)


topic 'Sec. 9-25.1'.
say('').
end.  (*Sec. 9-25.1*)


topic 'Sec. 9-03.1'.
say('').
end. (*Sec. 9-03.1*)


topic 'Sec. 9-07'.
say('').
end. (*Sec. 9-07*)


topic 'Sand Equivalent'.
say('').
end.  (*Sand Equivalent*)
```

APPENDIX B

Model Constructability Review Form

(Design / Pre-Construction Review)

MODEL CONSTRUCTABILITY REVIEW PROCESS
For the Pre-Construction Review

PROJECT TITLE
PROJECT TYPE
Project limits:
Contract Number:
Initial time allowed for completion:
Project Designer:
Project Description:
Purpose of Project:
Principal Items of Work:
Other Projects in Vicinity:
Existing Conditions:
Alternatives were considered: [ ] Yes [ ] No
Analysis of Contributing Circumstances:
Analysis of Accident Types:
Analysis of Other Factors:
Summary Analysis:

DRAINAGE

Existing drainage facilities consist of:

[ ] Roadside Ditches
[ ] Inlets/Catch Basins
[ ] Underdrains
[ ] Other ____________________
[ ] Cross-Culverts
[ ] Storm Sewer
[ ] Approach Culverts
[ ] Longitudinal Culverts

Proposed work:

[ ] No updates are required.
[ ] Culverts extensions will be installed where necessary.
[ ] Beveled ends will be installed where required.
[ ] Riprap will be installed where required.
[ ] Other work:

Check List:

[ ] Concrete inlets and drain pipes installed at locations of low spots along the roadway.

[ ] Proper drainage provided on top of retaining wall.

[ ] Riprap needed to prevent scouring and siltation inside the culvert structure.

[ ] Riprap needed to prevent erosion of the roadway sideslopes around the culvert, especially when sideslope erosion is a problem.

Recommendations:

TRAFFIC

Check List:

[ ] Field review against design plans for underground utilities

[ ] Signal control equipment located on the same corner of the intersection as the power source.

[ ] Vehicle detection device to be added for additional approach lane can be added into the existing actuated signalized intersection system.

[ ] Sign bridges have mounting brackets.

Comments:

STRUCTURES

Check List:

[ ] Field check to assure that the pilings from the existing bridge will not interfere with the piling from the replacement bridge.

[ ] Steel reinforcing protruding from the end of prestressed girders does not interfere with the protruding reinforcement of the wall or column on which the girder is to be placed.

Comments:

ROADWAY

Roadway Geometrics:	Existing	Proposed	Standard
Lane Width			
Shoulder Width			

Proposed work:

[ ] Intersections
[ ] Channelization
[ ] Horizontal Alignment
[ ] Vertical Alignment
[ ] Superelevation/Crown Slope
[ ] Slope - (Ditch, Fill, & Cut)
[ ] Other Work

Check List:

[ ] Thermoplastic pavement markings removed prior to Bituminous Surface Treatment (BST) or Asphalt Concrete Pavement (ACP) overlays.

[ ] Field check to determine which type of guard rail to install based upon the proximity of existing structures to the edge of pavement.

[ ] No large rocks or boulders are present within at least the top six inches of the final subgrade surface when spreading and compacting subgrade material.

Other Areas/Comments:

PEDESTRIAN AND BIKE WAYS

[ ] The existing shoulders are adequate to facilitate bicycle and pedestrian traffic.
[ ] Shoulders are being widened to facilitate bicycle and pedestrian traffic.
[ ] This project is not within a designated bike way.
[ ] Sidewalks exist within this project.
[ ] Curb cut ramps will be constructed in this project.

Comments:

UTILITIES

Control Zone Distance
Location I Objects
[ ] All Location I Objects will be relocated.
[ ] Selected Location I Objects will be relocated.
[ ] No Location I Objects will be relocated.
Location II Objects
[ ] All Location II Objects will be relocated.
[ ] Selected Location II Objects will be relocated.
[ ] No Location II Objects will be relocated.
Location III Objects
Recommendations:

PITS AND QUARRIES

[ ] Yes
[ ] No
[ ] Unknown

RIGHT-OF-WAY

Existing Width:	Design Standard Width:

Proposed:

[ ] No additional right-of-way will be required.
[ ] ________ acres of additional R/W will be required.
[ ] ________ acres required at
[ ] ________ acres required at
[ ] R/W plan revisions will be submitted.
[ ] R/W plan revisions were submitted on
[ ] Construction Permits will be required.

[ ] **This project involves railroad Right-of-Way.**

Comments:

PUBLIC TRANSFER FACILITIES

Park 'n Ride Lots:

[ ] None exist within this project.
[ ] A lot exists at ________________; it will not be overlaid. (Beyond the scope of this project)
[ ] An existing lot at __________________ will be overlaid
[ ] A lot will be constructed at

Local Public Transit Agency:

Bus Pullouts:

[ ] None exist within this project.
[ ] All existing pullouts meet current design standards and will be overlaid.
[ ] All existing pullouts will be updated to current design standards.
[ ] ________ pullouts will be constructed, based upon the recommendations of

Comments

COST ESTIMATE

	Construction	Right-of-Way	Total
Estimated Cost			
Current Program			
Original Budget			

All costs are inflated to the **Proposed Ad Date:**

The estimated construction cost includes:

Sales Tax @ _____ %   Engineering @ _____ %

This project qualifies for federal aid: [ ] Yes [ ] No

Report Prepared By:

Project Engineer ______________________.

Design Squad Leader ______________________.

Date ______________________.

MODEL CONSTRUCTABILITY REVIEW PROCESS
For the Post-Construction Review

PROJECT TITLE
PROJECT TYPE
Project limits:
Project Designer:
Project Description:
Purpose of Project:
Principal Items of Work:
Other Projects in Vicinity:
Original Conditions:
Final Conditions:
Overall Project Quality:

DRAINAGE

Original drainage facilities consisted of:

[ ] Roadside Ditches
[ ] Inlets/Catch Basins
[ ] Underdrains
[ ] Other ____________________
[ ] Cross-Culverts
[ ] Storm Sewer
[ ] Approach Culverts
[ ] Longitudinal Culverts

Present drainage facilities consist of:

[ ] Roadside Ditches
[ ] Inlets/Catch Basins
[ ] Underdrains
[ ] Other ____________________
[ ] Cross-Culverts
[ ] Storm Sewer
[ ] Approach Culverts
[ ] Longitudinal Culverts

Proposed	**Actual**	
[ ]	[ ]	No updates required.
[ ]	[ ]	Culverts extensions installed
[ ]	[ ]	Beveled ends installed
[ ]	[ ]	Riprap installed
[ ]	[ ]	Other work:

Check List:

[ ] Concrete inlets and drain pipes installed at locations of low spots along the roadway.

[ ] Proper drainage provided on top of retaining wall.

[ ] Riprap needed to prevent scouring and siltation inside the culvert structure.

[ ] Riprap needed to prevent erosion of the roadway sideslopes around the culvert, especially when sideslope erosion is a problem.

Recommendations:

Associated Change Orders:

CONTRACTORS

Contract Number:
Title/Description
Contractor Name:
Sub-Program:
Award Date / Completion Date:
Initial time allowed for completion:
Time extensions granted (if any): Time/reason:
Award Amount
Final Cost: Reasons for overrun/underrun:
Project Quality:

Change Orders Involved

Contract / Change Order Number:

Contractor Name:

Description of Problem:

Proposed by [ ] Contractor
[ ] DOT
[ ] Other

Approved by [ ] District
[ ] Headquarters

Classification Category:
[ ] 1. Necessary Change Order
[ ] 2. Need More Investigation
[ ] 3. Utility Related
[ ] 4. Signal/Illumination Related
[ ] 5. Policy & Design Changes
[ ] 6. Mind Changes
[ ] 7. Maintenance Problems
[ ] 8. Funding/Local Agency Request
[ ] 9. Engineering Errors
[ ] 10. Administrative Changes
[ ] 11. Quantity Estimation Errors
[ ] 12. Claim Related
[ ] 13. Plan Errors

Resolution of Problem:

Change in working days:

Net dollar change:

Useful for HCIS: [ ] Yes [ ] No