Table of Contents

1. Introduction

This document has been prepared by Deighton Associates Limited (Deighton) and is the final report for project SD98-05: Pavement Management Segment Consolidation. This report will present the results of the study that lead to the enhanced feature in dTIMS that is known as Automatic Programme Development (APD).

For specifics on the functionality and capabilities of the APD feature of dTIMS 6.1, the reader is directed to dTIMS 6.1 Reference Manual – April, 1998. Particularly; Chapter 3, pages 87 – 95, Chapter 4, pages 182 – 189 and Chapter 4, pages 201 – 205.

1.1 Project History

This research project was initiated in 1997 when the South Dakota Department of Transportation (SDDOT) issued a Research Project Statement (RPS). The RPS stated the following in the form of a Problem Description.

> *SDDOT uses Deighton Associates Limited software, dTIMS, to analyze life-cycle costs for various rehabilitation strategies on each segment of road in its network. To use dTIMS, SDDOT divides its road network into "homogeneous" segments. Homogeneous means that the source data describing the attributes of a segment are the same throughout the segment's entire length. Unfortunately, dTIMS makes the "optimal" strategy selection for each segment independent of the segment's location, length, or adjacent segment status.*
>
> *For instance, dTIMS might recommend a particular repair strategy for one segment, a different strategy for the next and a third strategy for the next, But each of these three segments may not be of sufficient length to be a stand alone project or it might be more cost effective to do one project at one time instead of spreading projects over more years. To combine these segments requires Planning and Programming staff to manually combine segments so that viable construction projects can be proposed.*
>
> *Research is needed to define rules for consolidating segments and to automate those methods in the dTIMS software.*

Deighton responded to the RPS and based on their proposal was awarded a contract on November 25th, 1997. The software, complete with users guides and an integrated Help system, was delivered to SDDOT on April 30, 1998. All tasks are complete with the submission of this report.

2. Background Summary

Dividing roads into "homogeneous" segments has been a major problem for all areas of highway engineering. Yet, there is little or no work done in this area guiding us to a proper theoretical solution to a tough practical problem. Some specific work has been done, but no purely theoretical work. For example, Appendix J in the AASHTO Design of Pavement Structures manual is devoted to describing "a powerful analytical method for delineating statistically homogeneous units from pavement response measurements." This powerful analytical method, however, presupposes that project lengths are already known; how unfortunate.

dROAD has a function called "automatic sectioning" whose purpose is to produce homogeneous sections. This function, however, is not based on rigorous theory. Rather, it is based on brute force. The reason for this is the lack of direction from the literature. This too, by the way, is why the construction project development problem has stayed on the shelf at Deighton for so long.

One of the biggest problems this research project will encounter is how to aggregate data from small sections to bigger sections. Issues such as the following will require careful study, for example:

1. First, assume that dTIMS has been set up to produce a list of feasible strategies for each segment. Second, assume that the recommended strategy for segment one is not even in the list for segment two. Will this new procedure generate the strategy for segment two so that it can analyze the effect of joining segment one and segment two into construction projects? If not, why? If so, why wasn't dTIMS set up to have the strategy generated for the section segment in the first place?

2. Presumably, when two smaller segments are joined into a larger construction project the cost for the same strategy is not simply the sum of the costs for two individual strategies. (Consider the savings in mobilization costs as an example of why this may happen.) If this is true, then the optimization analysis to initially select the two individual strategies was not using the same information as we are ending up with. Does this mean we are moving away from the optimal solution? Or, is the amount of movement so small it's

not significant? Or, do we change the original cost to remove the mobilization factor out of the original cost equations and just add it in later?

3. Using a similar line of thought, when two identical strategies are added for two adjacent segments, are the benefits additive?

4. If a one mile-long ‘oddball’ segment exists between two fifteen mile segments which have the same recommended strategy, should the oddball be ‘thrown in’ and the two segments joined together? What if the two segments were each one mile and the oddball was fifteen miles? If you answered “Yes” to the first and “No” to the second, where is the dividing line?

The specific answers to the above questions are not important. What is important, though, is the number of possible questions that must be answered when performing a function such as that being proposed here. We must be sure that we ask as many of these questions before the software code is modified so that the design can be complete. Deighton’s law of code bloat says “the number of lines of code is inversely proportional to the amount of forethought that goes into a design.”

For this reason, at the last Deighton user meeting an informal group of people was assembled to form the “hop scotch user group.” The mandate of the group was to contribute to this forethought. We think that getting comments from this group will benefit the project.

If we assume the first project deliverable is a report describing our understanding of the parameters, the second deliverable will be a new version of dTIMS. The new version will have three software functions not currently available in dTIMS. These are:

1. A window which accepts the user’s parameters regarding how the construction project generation analysis will act. This screen will get such things as the minimum and maximum project lengths.

2. A function (presumably initiated from a “Execute” button on the above window) which uses the Road, From, and To fields in the DT2699 file to automatically generate construction projects.

3. A window that allows for manual override of the construction projects. This window will use a strip map interface which shows the analysis segments along each road with their optimal strategies. It also shows the resulting construction projects with their strategies. This function will allow the user to adjust the length and strategy for each construction project interactively.

2.1 Project Objectives

This project has three research objectives. They are listed in the following with a short discussion that is intended to communicate the perception of our understanding of the objectives. A more detailed discussion for each objective can be found in later sections of this proposal.

Objective One: To develop a set of user definable parameters, or a mechanism to handle 'open-ended' parameters which will determine how dTIMS will generate construction projects from the analysis segments and its corresponding list of recommended strategies.

> One of the most predominant considerations when making construction projects is *minimum length*. For instance, it is impractical to initiate a 500 foot long construction project in the middle of nowhere. Therefore, anyone can say with certainty that one of the parameters will be minimum length. However, can anyone say that the minimum length parameter is the same for construction projects in urban areas? How about treatment type or funding category? Issues such as this must be identified and clearly understood.
>
> Other parameters are not quite as certain as minimum length. The project must either develop an exhaustive list of prioritized parameters; or it must develop a mechanism to accommodate 'open-ended' parameters. An 'open-ended' parameter is user specified. Without them the next objective will be difficult to satisfy.

Objective Two: To develop procedures that use the above parameters to automatically generate a set of viable construction projects.

This objective prompts the development of a function in dTIMS that can use the parameters to go through the list of analysis segments and test various combinations of them to see which best meets the criteria for a construction project. Building this function will not be trivial. It will possibly have to have a recursive component that keeps calling itself until all criteria are satisfied. Although it is premature to design the function here, we do not want to trivialize the effort required here.

One of the difficulties in demonstrating that this objective has been satisfied is getting a consistent, reproducible definition of viable construction project. The word viable was used here to distinguish the resulting construction project from “optimum.” To get the “optimum” construction projects would require a totally different project going in a totally different direction. The basic idea is to produce a set of construction projects that are reasonably close to those that are currently produced by hand using dTIMS’ output.

Objective Three: To provide functions in dTIMS which will allow a user to (a) enter the parameters of objective one, (b) perform the analysis of objective two, (c) interactively review and adjust the construction projects which result from the previous function on a strip map, and (d) print and export the results.

Finally, the project must produce results that are actually implemented in dTIMS. After all the symptom we are trying to reduce is the tremendous (impractical) amount of time it currently takes SDDOT staff to sit down and rationalize reasonable construction projects by manually combining adjacent road segments. This objective is aimed at ensuring this symptom is corrected.

The interface will ‘borrow’ the strip map technology already in use in dROAD version 6. The word borrow is used because the objects in dROAD 6 are not directly transferable to dTIMS 6 for various reasons. The technology will have to be custom written for dTIMS.

3. Project Tasks

The list of research tasks to be accomplished during this project is shown below. The first two tasks, A and B, are general to all Deighton projects and not specific to this project. All other tasks, 1 to11, are specific to this project. Each task is discussed.

Task A: Initiate and maintain the project in Deighton's Quality System.

Over the past several years Deighton Associates has been designing and implementing a Quality System for its off-the-shelf software. This quality system is scheduled for ISO 9001 certification in October 1997.

Before any project involving the software is initiated Deighton Staff must initiate the project in the Quality system. To do this the project manager must sit down and create a file with a number of documents in it. These documents include such things as the Project Plan, the Requirements Document, the Test Plan, just to name a few.

Each of these documents are meticulously maintained throughout the life of the software. The specific steps are described in detail in Deighton's Quality Procedures Manual.

Task B: Change project scope and work plan to incorporate the comments of SDDOT's project's technical panel.

Deighton will adjust and modify this plan to incorporate all reasonable requests and ideas from the SDDOT's technical panel.

The word reasonable is used to make it perfectly clear that Deighton has the final say on all matters dealing with the deliverables of this project. SDDOT has the right to recommend and make suggestions. However, Deighton reserves the right to refuse suggestions which may jeopardize the successful completion of this project. For instance, Deighton will refuse a request by SDDOT to include a button on the manual adjust window which will allow the user to view a video clip of the affected segments.

Preparing and submitting this document is the how this task will be accomplished. In this document Deighton has described the project, its objectives, and its scope. SDDOT has the opportunity to review this document and suggest changes. SDDOT will submit these suggestions back to Deighton who will accept/negotiate them prior to reaching any formal agreements.

Task One: Write strip map function for dTIMS.

No matter what the results of the remaining tasks are, the end product of this project must be manifested in the dTIMS software. The primary user interface for this will be a strip map function similar to the one used in dROAD 6. (See the "View|Element Locations" function in dROAD 6)

The idea is to use the dROAD 6 strip map function as a prototype for a similar function in dTIMS. The reason a new function has to be built is primarily related to the difference between data structures used in both systems; dROAD has a much more sophisticated data structure than dTIMS.

Nevertheless, building the foundation for this strip map function in dTIMS can commence immediately. Objects such as information windows and buttons will be added to this basic strip map later to accommodate any specific functions and procedures developed in subsequent tasks.

Task Two: Investigate and recommend a set of parameters to be used by dTIMS to control the automatic generation of construction projects.

This is perhaps the most difficult task of the project. During this task Deighton must solicit input from the SDDOT Technical Panel as well as other dTIMS users for the criteria dTIMS must use when making construction projects. During this task Deighton will:

- develop a questionnaire which will allow various experienced dTIMS user's to describe the criteria used to decide on construction projects;
- as a minimum the parameters will include: (a) minimum and maximum length by treatment type and grouping, (b) open-ended parameters (defined earlier), (c) a parameter to lock out joining adjacent projects of certain unamicable pavement types.
- get comments from SDDOT on the questionnaire by fax, modify it, then distribute it to SDDOT as well as other experienced dTIMS's users;
- collect the questionnaire and analyze the results;
- summarize the results in the form of a draft report which suggests a list of criteria to be used in the automated procedure;
- distribute the above report to the original participants;
- have a conference call between Deighton and SDDOT to discuss changes to the report;
- incorporate the comments into a revised report and redistribute;
- use the report as the basis for Task three and four.

Task Three: Create a window in dTIMS which allows the user to enter the required parameters and to initiate the automatic generation of construction projects.

Deighton will use the above report to create a window in the dTIMS software. This window will allow the user to set and/or edit the parameters dTIMS will use in automatically generating construction projects. This window will 'remember' the settings the user entered the last time he/she used the function. It will also be the point from which the user initiates the function which automatically generates construction projects.

Task Four: Write a function which uses the parameters and dTIMS' list of strategies to automatically generate a 'first-cut' set of construction projects.

Deighton will write a function which uses the above parameters and the list of dTIMS' strategies to automatically generate a set of construction projects. Some initial ideas about this function are listed below (NOTE the highlighted words are specific objects in dTIMS described in the help system):

- A "construction project" will be a set of one or more analysis segments. The function will not subdivide the analysis segments into smaller pieces when forming construction projects.

- The strategy for a construction project will be the aggregation of the ***selected strategies*** for each of its analysis segment's. This means that dTIMS will simply modify the selected strategies of an existing ***Budget Scenario.***

- This function will have the ability to automatically add another strategy to an analysis segment's ***list of strategies***. This strategy will be ***generated*** in a manner similar to dTIMS' ***committed treatment***. The difference will be that this new strategy will be added to the existing list of strategies.

Task Five: Conduct a conference call with SDDOT to review progress of the overall project.

Have a conference call between Deighton and SDDOT to discuss other ideas about how this function will operate that may have developed as the project progressed.

Task Six: Use the Strip Map function as the basis of a function that allows the user to manually create and edit construction projects, and their strategies.

This task will add the information windows and buttons to the basic strip map function created in task three. The basic idea for this function will be to give dTIMS a function that will allow a user to create his own construction projects manually. The user can create them from scratch, or, can modify the projects recommended by the function developed in task six.

Task Seven: Develop a print and output function so that optimum and viable construction projects' budget information can be output to a printer or a file.

This function will include a **recalculate** button and an **undo** button which will affect the budgeting factors. It will also have a **print** and **export** button which will, among other things, print the original optimal strategy for each section along side of the construction project segment.

The reader is encouraged to have a demonstration of the "View|Element Locations" function in dROAD 6 to get an idea of how section limits can be "grabbed" with the mouse and moved along the roadway. The processes and capabilities of that function are how Deighton envisions this function operating.

Task Eight: Make necessary changes to the on-line Help system and the hard copy User Manual.

The new functions and definitions developed in this project must be incorporated into dTIMS' existing on-line help system. This task will ensure that not only is the text added, but, the context mapping is performed and linked into dTIMS.

Deighton Quality Procedures describe the processes involved in transferring the help system text into the hard copy manual for dTIMS. Deighton will follow these steps to ensure that an up-to-date hard copy manual is completed by the end of this project and a copy of this manual shall be provided to SDDOT for each license they possess.

Task Nine: Develop a test plan and test the software according to the plan to verify that the software performs its intended function.

Deighton's Quality Procedures manual also outlines the steps necessary to develop a test plan and to carry out a series of tests to verify that the software is functioning as intended. Deighton will conduct the initial tests and will rely upon a select group of existing dTIMS users including SDDOT to perform beta testing of the software components.

Task Ten: Classify faults and correct all "bugs.".

Deighton's Quality Procedures manual outlines the steps required by the vice president of R&D, the project manager and the programmer/analysts to classify all faults discovered during the testing process and correct the bugs. Deighton has procedures which track each and every fault discovered during all phases of testing.

Basically, a fault is a perception that the software did not perform according to the requirements. Faults can be (a) bugs (the software did not provide a function that was part of the requirements), (b) enhancements (mistaken belief that the software should have provided a function and the function is NOT in the requirements, but, is desirable), or (c) misconceptions (mistaken belief that the software should have provided a function and the function is NOT in the requirements and is NOT desirable). This task requires that Deighton correct all identified bugs before the software is released.

Task Eleven: Write a report presenting the results of this study and provide to SDDOT for review and comments.

Deighton will conclude this project with the delivery of a final report that will summarize the results of this study. Following a review and comment by SDDOT, Deighton will issue a final version of the report.

4. Project Summary

Throughout the course of this research project , Deighton performed all of the tasks that are described in section 1.4 of this report. The following is a brief summary of how the project was carried out.

The project began with the investigation of the parameters to be used by dTIMS to control the APD. This is Task Two of the project but was tackled first because of the need to solicit input from a number of individuals that were current dTIMS users but, not directly involved in this project. This was correctly perceived by Deighton as potentially being a time consuming process.

Task Two specifically involved the investigation and recommendation of a set of parameters to be used by dTIMS to control the automatic generation of viable construction projects.

To accomplish the objectives of Task Two, Deighton proposed the following:

- develop a questionnaire which will allow various experienced dTIMS user's to describe the criteria used to decide on construction projects;
- get comments from SDDOT on the questionnaire by fax, modify it, then distribute it to SDDOT as well as other experienced dTIMS's users;
- collect the questionnaire and analyze the results;
- summarize the results in the form of a draft report which suggests a list of criteria to be used in the automated procedure;
- distribute the above report to the original participants;
- have a conference call between Deighton and SDDOT to discuss changes to the report;
- incorporate the comments into a revised report and redistribute;
- use the report as the basis for the development of the viable projects enhancement.

The results of the survey are summarized in the dTIMS Viable Projects Questionnaire Summary. Deighton anticipated that the task at hand was going to be complicated. The questionnaire responses confirmed just that. Although Deighton never asked directly for any "secrets" that might make the job easier, none came. Therefore, the problem was investigated from several different angles and an approach developed. Which, in the absence of anything better, is a little complicated, but, will work.

While Deighton was waiting for the results of the questionnaire work began on the writing of the strip map function within dTIMS. This was the single most time consuming task in the project.

The whole idea of the strip map is to (a) draw a line diagram of a particular road showing where the elements from the inventory file occur along the road, and (b) let you compare the selected strategies for each element from a particular budget scenario with the selected strategies in another budget scenario that you manipulate to form programme projects.

The general logic required to have dTIMS perform APD was developed as part of the summary of the dTIMS user questionnaire. It was only left to determine how dTIMS would process the logic. The approach taken was to layout the logic in a flowchart and identify the decisions that needed to be made. To help dTIMS answer the questions, Deighton proposed that the user define a decision tree.

The programming of dTIMS, the second most time consuming task, included Tasks 4, 6 and 7. The results of this phase of the project can be seen in the software that was delivered to SDDOT. The new code was delivered via a patch from the Internet. Through the application of the patch their current dTIMS 6.0 was upgraded to version 6.1.

In conjunction with the software upgrade, the online Help and Reference Manual were modified to reflect the enhancements that were made to the software during this research project. This work was accomplished under Task Eight.

Prior to the delivery of the dTIMS 6.1, however, Deighton committed a significant effort towards the in-house testing to verify that the software was working as intended. This involved the development of a test plan, as outlined in Deighton's Quality Procedures manual, necessary to carry out a series of tests to verify that the software is functioning as planned.

The test plan yielded a number of faults that were documented and corrected prior to the delivery of the product.

5. Recommendations

5.1 Decision Tree Development

Following the review of the software documentation it is recommended that SDDOT commence with the development of decision tree theory that will be used to model the current programme development process in South Dakota. Any assumptions or background used in the development of the theory should be recorded in the documentation that accompanies the decision tree summary.

5.2 Further Testing

The SDDOT decision tree structure should be applied to the SDDOT network for testing the reliability of the APD. Results of the test program should be used to, not only, debug the decision tree setup but, also to give additional feedback to Deighton regarding the functionality of the software.

5.3 APD Implementation

SDDOT must develop an implementation plan that will enable the APD to be used in the development of practical construction projects from the dTIMS optimized construction programme. It may be wise, as part of the implementation plan, to check results from APD with the proramme that was produced using current procedures in a previous year.

5.4 Review and Revise

Following the generation of the first automatic programme, SDDOT should review the programme developed with the intent of evaluating the suitability of using decision trees as a foundation in the construction programme process.