Course Project For IE 385

Pavement Rehabilitation Scheduling Problem

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Pavement Rehabilitation Scheduling Problem

As a requirement for getting an additional 1/4 unit credit for IE 385, this topic was chosen to solve a real pavement rehabilitation scheduling problem by using the integer programming technique. This problem was solved by LINDO on IBM Mainframe (VM/CMS) with the assistance of my officemate Dr. Ala Mohseni.

1.0 Problem Description

A transportation engineer has a new assignment to make a pavement rehabilitation scheduling for all inter-state highways in District 5 for the next 5 budget years period. There are 121 pavement sections totally. All these pavement were evaluated by a Pavement Network Management Program (ILLINET - Version 2.0) in advance in order to get their predicted future conditions which include: 1) years when the pavement should be rehabilitated with a maximum delay of 2 years allowed, 2) estimated pavement life after rehabilitation, 3) estimated cost for performing rehabilitation. Out of many rehabilitation alternatives, only 3-inch Asphalt Concrete (AC) overlay was considered in this project. All data needed for this analysis is shown in Table 1. The objective of this analysis is to maximize the total added vehicle-mile traveled (VMT), which is defined as the product of average daily traffic (ADT), section length, and predicted pavement life, under a yearly budget of 7.5 millions for 5 years.

2.0 Formulate as a Binary Integer Programming (BIP) Model

2.1 Possible Objective Functions

There are several ways to define the benefit of rehabilitation such as optimizing : 1) the average pavement condition, 2) the average remaining life of the pavement, 3) the total added vehicle-mile traveled (VMT), etc..

In this report, we only consider the last one as our objective function such that most of the public users will be benefitted.

2.2 Possible Constraints

Not all the pavements which need rehabilitation will receive funding. Several yearly budget constraints or a single overall 5-year budget constraint could result in different answers. In case of budget limitation, a pavement which needs rehabilitation will be delayed for certain years. For some sections, it may not be feasible to use a 3-inch overlay as the only rehabilitation strategy.

Under this analysis, we use a yearly budget constraint of 7.5 millions for 5 years analysis period. A pavement section which needs rehabilitation at year i, could be rehabilitated before year i+2 after which the pavement will deteriorate to an un-rehabilitated condition and will not be considered. In addition, a pavement section could receive rehabilitation only once.

2.3 Possible Decision Variables

The decision variables are defined as binary variables where 0 treated as not

selected, and 1 treated as selected. There are totally 202 decision variables in this model. The notations are as follows:

Decision Variables = P_iS_{jk}

Where:

i := Pavement section number, i=1..121

j := Selected rehabilitation strategy, j=0 (for no rehabilitation) or j=3 (for 3-inch AC overlay)

k := Year at which the rehabilitation will be performed, k=1..5

2.4 BIP Model For Analysis

MAX 398.7998 P1S31 + 362.59985 P1S32 + 362.59985 P1S33
+ 505 P2S32 + 505 P2S33 + 454.5 P2S34 + 907.09985 P5S31
+ 907.09985 P5S32 + 831.5 P5S33 + 459.5 P7S31 + 459.5 P7S32
+ 459.5 P7S33 + 414.2998 P9S35 + 707.3999 P14S35
+ 249.89999 P18S31 + 222.2 P18S32 + 222.2 P18S33
+ 569.5 P19S31 + 506.2998 P19S32 + 506.2998 P19S33
+ 398.7998 P21S31 + 362.59985 P21S32 + 362.59985 P21S33
+ 555.5 P22S31 + 505 P22S32 + 505 P22S33 + 459.5 P27S32
+ 459.5 P27S33 + 408.5 P27S34 + 670.09985 P32S33
+ 609.19995 P32S34 + 609.19995 P32S35 + 529.19995 P33S35
+ 622.5 P34S31 + 622.5 P34S32 + 622.5 P34S33 + 141.5 P35S35
+ 506.2998 P40S35 + 537.5 P41S31 + 537.5 P41S32
+ 477.69995 P41S33 + 55.89999 P46S34 + 48 P46S35
+ 359.59985 P48S31 + 359.59985 P48S32 + 359.59985 P48S33
+ 532.3999 P53S35 + 198.7 P60S35 + 156.29999 P62S35
+ 532.3999 P66S35 + 597.5 P85S35 + 470.3999 P88S31
+ 470.3999 P88S32 + 470.3999 P88S33 + 276.59985 P94S34
+ 276.59985 P94S35 + 294.8999 P95S35 + 231.29999 P97S33
+ 231.29999 P97S34 + 205.59999 P97S35 + 919.69995 P98S31
+ 817.5 P98S32 + 817.5 P98S33 + 1249.09985 P99S33
+ 1249.09985 P99S34 + 1249.09985 P99S35 + 291 P105S33
+ 291 P105S34 + 291 P105S35 + 472.69995 P106S32
+ 420.19995 P106S33 + 420.19995 P106S34 + 919.69995 P113S31
+ 817.5 P113S32 + 817.5 P113S33 + 1249.09985 P114S34

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    + 1249.09985 P114S35 + 291 P120S35 + 472.69995 P121S32
    + 420.19995 P121S33 + 420.19995 P121S34
SUBJECT TO
     2)  P1S31 + P1S32 + P1S33 + P1S01 =    1
     3)  P2S32 + P2S33 + P2S34 + P2S02 =    1
     4)  P3S05 =    1
     5)  P4S05 =    1
     6)  P5S31 + P5S32 + P5S33 + P5S01 =    1
     7)  P6S05 =    1
     8)  P7S31 + P7S32 + P7S33 + P7S01 =    1
     9)  P8S05 =    1
    10)  P9S35 + P9S05 =    1
    11)  P10S05 =    1
    12)  P11S05 =    1
    13)  P12S05 =    1
    14)  P13S05 =    1
    15)  P14S35 + P14S05 =    1
    16)  P15S05 =    1
    17)  P16S05 =    1
    18)  P17S05 =    1
    19)  P18S31 + P18S32 + P18S33 + P18S01 =    1
    20)  P19S31 + P19S32 + P19S33 + P19S01 =    1
    21)  P20S05 =    1
    22)  P21S31 + P21S32 + P21S33 + P21S01 =    1
    23)  P22S31 + P22S32 + P22S33 + P22S01 =    1
    24)  P23S05 =    1
    25)  P24S05 =    1
    26)  P25S05 =    1
    27)  P26S05 =    1
    28)  P27S32 + P27S33 + P27S34 + P27S02 =    1
    29)  P28S05 =    1
    30)  P29S05 =    1
    31)  P30S05 =    1
    32)  P31S05 =    1
    33)  P32S33 + P32S34 + P32S35 + P32S03 =    1
    34)  P33S35 + P33S05 =    1
    35)  P34S31 + P34S32 + P34S33 + P34S01 =    1
    36)  P35S35 + P35S05 =    1
    37)  P36S05 =    1
    38)  P37S05 =    1
    39)  P38S05 =    1
    40)  P39S05 =    1
    41)  P40S35 + P40S05 =    1
    42)  P41S31 + P41S32 + P41S33 + P41S01 =    1
    43)  P42S05 =    1
    44)  P43S05 =    1
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91) P90S05 = 1
92) P91S05 = 1
93) P92S05 = 1
94) P93S05 = 1
95) P94S34 + P94S35 + P94S04 = 1
96) P95S35 + P95S05 = 1
97) P96S05 = 1
98) P97S33 + P97S34 + P97S35 + P97S03 = 1
99) P98S31 + P98S32 + P98S33 + P98S01 = 1
100) P99S33 + P99S34 + P99S35 + P99S03 = 1
101) P100S05 = 1
102) P101S05 = 1
103) P102S05 = 1
104) P103S05 = 1
105) P104S05 = 1
106) P105S33 + P105S34 + P105S35 + P105S03 = 1
107) P106S32 + P106S33 + P106S34 + P106S02 = 1
108) P107S05 = 1
109) P108S05 = 1
110) P109S05 = 1
111) P110S05 = 1
112) P111S05 = 1
113) P112S05 = 1
114) P113S31 + P113S32 + P113S33 + P113S01 = 1
115) P114S34 + P114S35 + P114S04 = 1
116) P115S05 = 1
117) P116S05 = 1
118) P117S05 = 1
119) P118S05 = 1
120) P119S05 = 1
121) P120S35 + P120S05 = 1
122) P121S32 + P121S33 + P121S34 + P121S02 = 1
123) 1002 P1S31 + 1873 P5S31 + 1119 P7S31 + 737 P18S31
+ 1296 P19S31 + 1863 P21S31 + 1545 P22S31 + 992 P34S31
+ 1284 P41S31 + 3434 P48S31 + 1194 P88S31 + 1395 P98S31
+ 1278 P113S31 <= 7500
124) 1089 P1S32 + 1452 P2S32 + 2000 P5S32 + 1197 P7S32
+ 794 P18S32 + 1436 P19S32 + 1994 P21S32 + 1688 P22S32
+ 1065 P27S32 + 1062 P34S32 + 1400 P41S32 + 3683 P48S32
+ 1300 P88S32 + 1576 P98S32 + 1619 P106S32 + 1454 P113S32
+ 1537 P121S32 <= 7500
125) 1183 P1S33 + 1593 P2S33 + 2134 P5S33 + 1326 P7S33
+ 855 P18S33 + 1534 P19S33 + 2143 P21S33 + 1841 P22S33
+ 1165 P27S33 + 1328 P32S33 + 1137 P34S33 + 1524 P41S33
+ 3948 P48S33 + 1414 P88S33 + 452 P97S33 + 1772 P98S33
+ 1984 P99S33 + 1319 P105S33 + 1829 P106S33 + 1643 P113S33

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    + 1743 P121S33 <=   7500
    126)   1745 P2S34 + 1271 P27S34 + 1448 P32S34 + 210 P46S34
    + 730 P94S34 + 508 P97S34 + 2083 P99S34 + 1515 P105S34
    + 2071 P106S34 + 2083 P114S34 + 1980 P121S34 <=   7500
    127)   1218 P9S35 + 1634 P14S35 + 1605 P32S35 + 1346 P33S35
    + 347 P35S35 + 1547 P40S35 + 257 P46S35 + 1687 P53S35
    + 1078 P60S35 + 540 P62S35 + 1687 P66S35 + 1787 P85S35
    + 767 P94S35 + 1369 P95S35 + 568 P97S35 + 2187 P99S35
    + 1741 P105S35 + 2187 P114S35 + 1632 P120S35 <=   7500
END
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3.0 Uncertainty Of Data

As a very important part of Expert System For Pavement Network Management, this rehabilitation scheduling problem involves lots of uncertainties. The future remaining life of original pavement or rehabilitated pavement was estimated from a prediction model which involves many pavement design and performance parameters and may results in as much as 50% of uncertainty. The estimated rehabilitation cost and the average daily traffic (ADT) may change year by year, though we keep these data at the current level for all 5-year analysis period to avoid introducing other uncertain factors. Thus, the objective function, total added VMT, may also carry 50% of uncertainty.

4.0 Discussion Of Results

4.1 BIP Model With Separate Yearly Budget Constraints

Generally speaking, each District may have their yearly budget constraints different. In this analysis, however, we assume that there is no yearly budget difference in this 5-year analysis period. Using LINDO under IBM mainframe (VM/CMS), we

solve the BIP model discussed above 5 times by alternating the right hand side values of rows 123-127 with 1500, 3500, 5500, 7500, 9500.

A summary table of these 5 runs is shown below. Two out of five runs have not reached the optimum solution yet, though additional 1,000,000 iterations were added for each run. A sub-optimum solution was shown in this table when we still have not reached the overall optimum solution. The maximum absolute errors are less than 5% which suggest that the sub-optimum solutions are still fairly good solutions.

Separate Yearly Budgets, M$	LP Optimum, Million VMT	Bound On Optimum, Million VMT	Optimum Found	Maximum Absolute Error, %
1.5 * 5 years	3.500	---	Yes	---
3.5 * 5 years	8.720	---	Yes	---
5.5 * 5 years	12.207	12.722	No	4.05
7.5 * 5 years	14.878	15.474	No	3.85
9.5 * 5 years	16.665	---	Yes	---

Table 2 provides a detailed comparison of: 1) which pavement section was selected for rehabilitation (3-inch AC overlay) at which year, 2) the cost associated with the rehabilitation under these 5 different budget conditions. For example, pavement section 32, at year 3, with a cost of 1.328 millions was selected when the yearly budgets are equal to 1.5 millions. The total costs among this analysis period are also provided at the end of this Table.

4.2 BIP Model With A Total 5-Year Budget Constraint

1. Figure 1 indicates that a single total 5-year budget constraint results in higher added VMT, i.e. objective function, as compared to the results from 5 separate yearly budgets. This is because the former condition could distribute the limited funds more freely than the latter one. Also notice that the slope of the added VMT versus the total budgets decreases when the total budgets increase because of the optimization process.

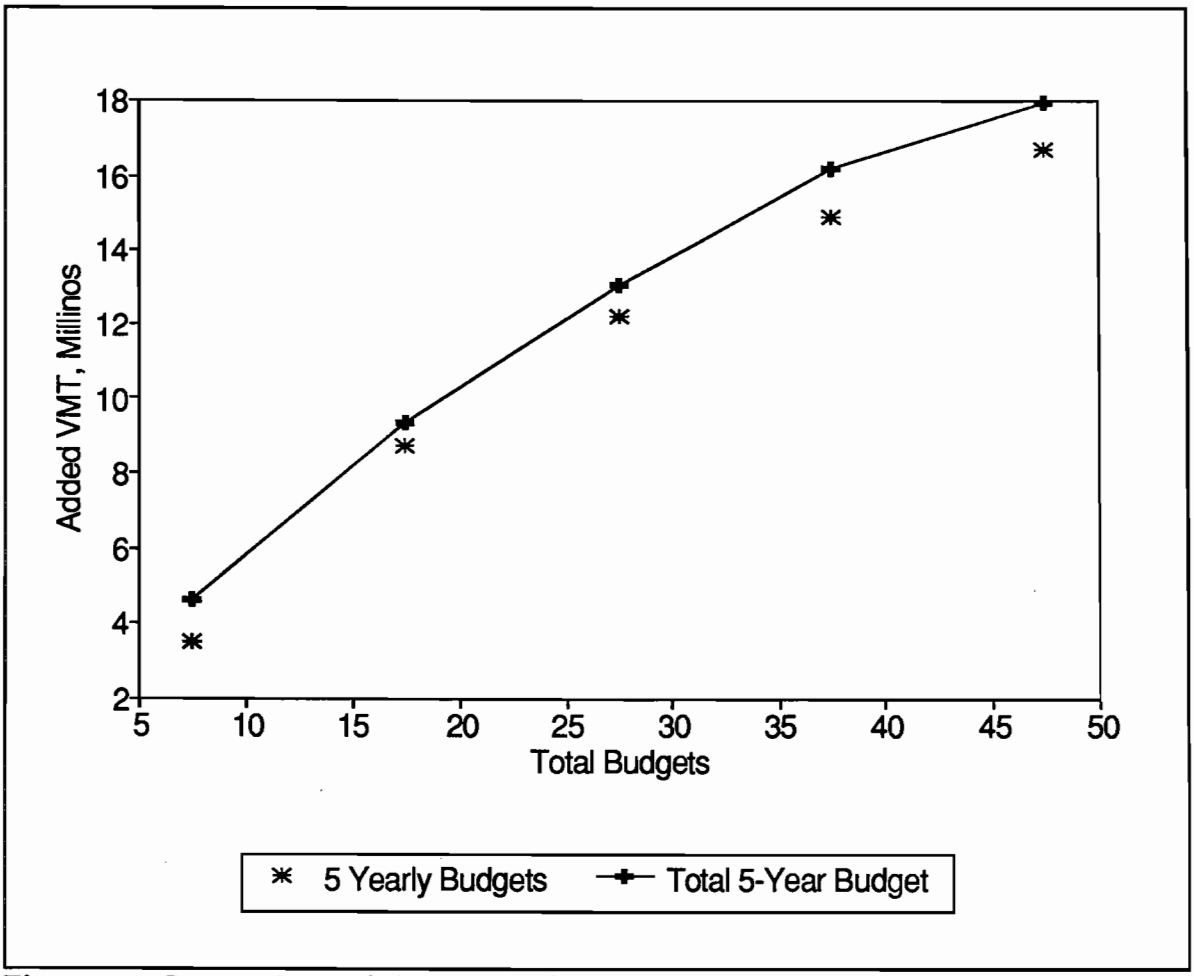

Figure 1 - Comparison of the results from Sections 4.1 and 4.2