/////// Mn/DOT DETOUR COST \\\\\\\
\\\\\\\ ANALYSIS PROGRAM ///////

DEFLECTION ANALYSIS PROCEDURES

Roadway Life Capacity

Roadway life capacity is defined as the number of equivalent standard axle loads that a particular pavement can accommodate during its functional lifetime.

The AASHO Road Test results yielded a correlation of spring deflection to functional roadway life. Investigation 183 found this AASHO correlation to be applicable to Minnesota pavements. At the present, this equation is used to predict pavement life.

$$\mathbf{Log(ESALs) = 11.06 - 3.25 \times Log(BBS)}$$

where BBS = Spring Benkleman Beam Deflection in mils.
BBS is obtained from the output of the TONN program.

Pavement life can also be computed using the 1986 AASHTO Design Equation (1.2.1).

$$\mathbf{Log(ESALs) = Z_r \times S_o + 9.36 \times Log(SN+1) - 0.20 + \frac{Log\left[\frac{P_o - P_t}{4.2 - 1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times Log(M_r) + 8.07}$$

where Z_r = Standard normal deviate = -1.037 from Part I, Table 4.1 for 85% reliability.

S_o = Combined standard error of the traffic prediction and performance prediction.
= 0.45 as suggested in Part II, Sec. 2.1.3

SN = Structural number = a_1 x D_1 + a_2 x D_2 + ...

where: a_i = layer coefficient
D_i = layer thickness

from Part I, sec. 1.2 average layer coefficient values suggested:
asphalt: 0.44
sandy gravel: 0.11

P_o = Initial design serviceability index = 4.2

P_t = Design terminal serviceability index = 2.5

M_r = Subgrade Resilient modulus

The Subgrade Resilient modulus can be obtained from:

1. Any back-calculation procedure such as ELMOD; MODULUS; EVERCALC

2. As outlined in Part III, Sec. 5.2.3;

3. Utilizing the Boussinesq equation for deflections away from the load.
(see attached graph)

4. From the relation:

$$\mathbf{M_r = \frac{Rvalue^{0.78125} - 0.41}{0.873}}$$

Design Life

The design capacity of a pavement is calculated as outlined in Section 7-5.03.01 of the Mn/DOT Road Design Manual.

$$\textbf{Present Daily N18} = \sum\left[\frac{\textbf{ADT}}{\textbf{2}} \times \begin{pmatrix}\textbf{Assumed Distribution Factor}\\ \textbf{by Vehicle Type}\\ \textbf{(Tab 7-5.03B)}\end{pmatrix} \times \begin{pmatrix}\textbf{Average N18 Factor}\\ \textbf{by Vehicle Type}\\ \textbf{(Tab 7-5.03D)}\end{pmatrix}\right]$$

$$\textbf{One-way Design ESALS} = \textbf{365} \times \textbf{Present Daily N18} \times \begin{pmatrix}\textbf{Time-Growth Factor}\\ \textbf{(Tab 7-5.03E)}\end{pmatrix}$$

where, for expediency, the ADT is the 2-way ADT as taken off a current county traffic flow map. The Present Daily N18 is calculated following the procedure outlined in Table 7-5.03F. The time-growth factor is obtained from Table 7-5.03E assuming an annual growth factor in present daily N18 of 3.5% and a design period of 20 years, as suggested in Section 7-5.03.01.

Overlay Design

The present Mn/DOT overlay design procedure utilizes the assumption that, an inch of bituminous overlay will result in an average reduction of 11% in the deflection of a pavement (INV 630). The overlay design procedure uses this to reduce the allowable benkleman beam deflection to give the road a desired load rating.

This procedure can be modified, so that an overlay could be designed, that when added to the original structure would give a Spring Benkleman Beam Deflection that would be the same as that of a pavement that would have a Design Life equal to the original design traffic plus that of the added detour traffic.

$$\textbf{Log}(\textbf{BBS}) = \frac{\textbf{11.06} - \textbf{Log}(\textbf{ESALs})}{\textbf{3.25}}$$

$$\textbf{Log}(\textbf{BBS}^*) = \frac{\textbf{11.06} - \textbf{Log}(\textbf{ESALs}^*)}{\textbf{3.25}}$$

where, ESALs = Roadway Life or Design Life
ESALs* = Roadway Life + Detour Traffic

$$\textbf{BBS} = \textbf{10}^{\left(\frac{11.06 - Log(ESALs)}{3.25}\right)}$$

$$\textbf{BBS}^* = \textbf{10}^{\left(\frac{11.06 - Log(ESALs^*)}{3.25}\right)}$$

This would be the deflection of the structure needed to accommodate the addition of the detour traffic

$$\frac{\textbf{BBS}^*}{\textbf{BBS}} = \textbf{10}^{\left[\frac{Log(ESALs) - Log(ESALs^*)}{3.25}\right]}$$

This then represents the ratio of the deflection of the new structure to that of the original structure

$$= \textbf{10}^{\left[\frac{Log\left[\frac{ESALs}{ESALs^*}\right]}{3.25}\right]}$$

$$= \left[\frac{\textbf{ESALs}}{\textbf{ESALs}^*}\right]^{\left(\frac{1}{3.25}\right)}$$

Assuming an inch of bituminous overlay will yield an 11% reduction in the measured BBS, we can calculate the required overlay thickness to give the equivalent reduction necessary to accommodate the added detour traffic.

$$\frac{\mathbf{BBS}^*}{\mathbf{BBS}} = (\mathbf{1} - \mathbf{n})^{\mathbf{x}}$$

$$\left(\frac{1}{3.25}\right) \times \mathrm{Log}\left[\frac{\mathrm{ESALs}}{\mathrm{ESALs}^*}\right] = x \times \mathrm{Log}(1 - n)$$

$$\left[\frac{\mathrm{ESALs}}{\mathrm{ESALs}^*}\right]^{\left(\frac{1}{3.25}\right)} = (1 - n)^x$$

$$x = \frac{\mathrm{Log}\left[\frac{\mathrm{ESALs}}{\mathrm{ESALs}^*}\right]}{3.25 \times \mathrm{Log}(1 - n)}$$

where x = the equivalent overlay in inches
n = the reduction per inch, in this case, .11

Similarly, the overlay design procedure in the 1986 AASHTO Design Guide can be utilized to design an overlay to accommodate the detour traffic. Equation 1.2.1 is used as shown below:

$$\mathrm{Log}(\mathrm{ESALs}^*) = Z_r \times S_o + 9.36 \times \mathrm{Log}(SN_{ol} + 1) - 0.20 + \frac{\mathrm{Log}\left[\frac{P_o - P_t}{4.2 - 1.5}\right]}{0.40 + \frac{1094}{(SN_{ol} + 1)^{5.19}}} + 2.32 \times \mathrm{Log}(M_r) + 8.07$$

where SN_{ol} = Structural number of the overlaid pavement.
= a_{ol} x T_{ol} + Frl x SN

where a_{ol} = layer coefficient of overlay
T_{ol} = overlay thickness
Frl = remaining life factor

From Part III, Figure 5.17, assuming 80% consumption of the existing and the overlaid pavement, Frl = 0.57

This equation can then be solved through iteration for T_{ol}, yielding an overlay that will accommodate the additional detour traffic.

DETOUR ANALYSIS

Equivalent Overlay

If it can be assumed that additional structure will yield additional life, then an overlay can be designed such that a particular pavement will have a predicted capacity that will accommodate the original design traffic plus that imposed upon it by a detour.

Excess ESALS

Utilizing minimum design standards a structure may have a capacity beyond that of the traffic for which it was designed. To compensate for this, the concept of excess esals is proposed.

The capacity of the roadway is determined by the AASHTO 1986 or AASHO design equations.

The predicted traffic for which the actual roadway was designed is given a safety factor of 2, to account for errors of traffic prediction.

The excess esals are then the difference in the determined capacity and the traffic for which the roadway was designed.

Excess ESALs = Capacity ESALs - 2 * Design ESALs

Case 1. Excess ESALs < 0
consider alternatives if Excess ESALs << 0;
also consider Overlay ESALs = Detour ESALs
if Excess ESALs ~ 0.

Case 2. Excess ESALs = 0

Overlay ESALs = Detour ESALs

Case 3. Excess ESALs > 0

a. Excess ESALs < Detour ESALs

Overlay ESALs = Detour ESALs - Excess ESALS

b. Excess ESALs = Detour ESALs

Overlay ESALs = 0
: no payment

c. Excess ESALS > Detour ESALs

Overlay ESALs = 0
: no payment

The overlay is designed for overlay ESALs and payment, in any case, is the cost of the computed overlay.

STEPS TO CALCULATE EQUIVALENT OVERLAY INCOME

1. CONVERT FWD READINGS TO BBs
   (1.05 * FWD @ 9 KIPS + 5.15)

2. CONVERT BBs TO BB80s
   TABLE 1, INV. 603

3. COMPUTE STANDARD DEVIATION (BBs) FOR SEGMENT

4. ADD TWO (BBs) S.D.s TO BB80

5. MAKE SEASONAL CORRECTION TO GET BBSPRING
   TABLE 2 REVISED, INV. 603

6. CALCULATE DAILY ESALs FOR STATE AND COUNTY
   ROADS USING DAILY ADT AND THE CONVERSION FACTOR
   STATE 0.0529324   COUNTY 0.0214228

7. CALCULATE CAPACITY ESALs FROM AASHO EQUATION
   LOG(ESALs) = 11.06 - 3.25 * LOG(BBS)

8. USE DAILY COUNTY ESALs TO CALCULATE DESIGN ESALs
   DESIGN ESALs = DAILY ESALS * 365 * TIME-GROWTH FACTOR

9. DETOUR ESALs = DAILY STATE ESALs * DAYS DETOURED

10. CALCULATE EXCESS ESALs

    EXCESS ESALs = CAPACITY ESALs - 2 * DESIGN ESALs

11. CALCULATE OVERLAY ESALs

12. CALCULATE OVERLAY COST USING 11% REDUCTION
    IN DEFLECTION PER INCH OF OVERLAY (INV. 630)
    AND $20,000 PER INCH PER MILE OF OVERLAY

7-5.0 FLEXIBLE PAVEMENT DESIGN

7-5.03.01 Sigma N-18 Values

The Sigma N-18 value is a convenient identification of the cumulative damage effect of heavy vehicles during the design life of a flexible pavement. Based upon equivalency factors developed during the AASHO Road Test, the damage effect (vertical deflections) of various vehicle types as generated by Mn/DOT Investigation 183 can be equated to that generated by one passage of a standard 18,000-pound single axle load. Identification numbers and descriptions of vehicle types are given in Table 7-5.03A.

The Steps which are taken in determining the Sigma N-18 value are given below. Normally these steps are taken to determine the Sigma N-18 values when specific project traffic data is not available.

1. Convert 2-direction AADT to design-lane volume by multiplying an approach factor of 0.50 for 2-lane and 4-lane pavements.

2. Determine volume of structurally significant HCADT in the design lane by applying Vehicle Type Distribution Factors (Tab 7-5.03B) to he design-lane AADT.

3. If the traffic counts require adjustment because of seasonal variation in traffic, Table 7-5.03C should be used to adjust the values for the 16-hour class by vehicle type. This will give the seasonal adjusted volume.

4. Determine the present daily total damage effect by multiplying the daily total of each type for HCADT vehicle by an average Sigma N-18 factor for that type (Table 7-5.03D) and summarizing. Note that the average damage factor varies with the type and location of the road. These values have been derived from relationships developed during the AASHO Road Test to equate the axle load measured during periodic truck weighing programs to equivalent 18,000-pound single axle loads.

5. The present daily design-lane Sigma N-18 total is converted to Sigma N-18 for the design period by using a Time Growth Factor from Table 7-5.03E. This table consists of annual growth factors for the present daily N-18. Along with the growth factors is a list of the cumulative effect of the growth factors over design periods of 10 and 20 years. These are referred to as time-growth factors. The last column in the table gives 20-year traffic projection factors that are the equivalent of the annual growth factors given in the first column. When designing a CSAH or MSAS, the established traffic projection factor should be used for determining the annual growth factor. See State Aid Manual 5-892.810, Figure A for listing of traffic projection factors. The suggested annual increase in daily N-18 is 3.5 per cent for municipal streets as well as Rural and Metro Trunk Highways. This is approximately equivalent to doubling the present ADT for a 20-year design period.
   The design-lane Sigma N-18 or N-20 is estimated by multiplying the Sigma N-18 value by the selected time growth factor, and then by the number of days in the year (365).
   For the design of full-depth asphalt pavement the N-20 value is used. The N-20 is determined by multiplying the Sigma N-18 value by a factor of 1.04 through 1.08 depending upon specific site conditions. These conditions are determined by the Bituminous Pavement Engineer who selects the appropriate factor.

Table 7-5.03B

ASSUMED DISTRIBUTION FACTORS BY VEHICLE TYPE

Vehicle Type	Description	Rural Trunk Highway % of AADT	Metro % of AADT	Local Rural and CSAH % of AADT**
1	Passenger Cars	78.1	83.5	75.7
2	Panels and Pickups (under 1 Ton)	10.0	9.0	16.0
3	Single Unit - 2 axle, 4 tire	1.4	1.6	2.4
4	Single Unit - 2 axle, 6 tire	3.9	1.8	2.6
5	Single Unit - 3 axle & 4 axle	1.3	0.5	1.7
6	Tractor Semitrailer Combination - 3 axle	0.3	0.3	-
7	Tractor Semitrailer Combination - 4 axle	0.5	0.4	0.1
8	Tractor Semitrailer Combination - 5 axle	3.0	2.4	0.5
9	Tractor Semitrailer Combination - 6 axle	*	*	*
10	Trucks with Trailers and Buses	1.5	0.5	1.0

*Too few to establish at this time
**Data for local rural roads is from 1975 and 1977 County Roads Pilot Project, and these should not be used in preference to current seasonally adjusted classification counts.

Table 7-5.03C

SEASONAL ADJUSTMENT FACTORS FOR VEHICLE TYPES

For Trunk Highways and Major Arterials in the Twin City Metro Area

Time of Data Collection	Vehicle Type 1-3	4	5	6	7	8-9	10
January - April	1.44	0.93	1.34	1.03	1.06	1.18	1.33
May - August	1.03	0.91	0.91	0.95	0.87	1.01	1.20
September - December	1.17	0.83	0.88	0.96	0.93	1.04	1.01

For Trunk Highways in the Rural Area

Time of Data Collection	Vehicle Type 1-3	4	5	6	7	8-9	10
January - April	1.54	1.04	1.13	0.94	0.96	1.13	1.35
May - August	0.89	0.84	0.90	0.99	1.09	1.14	1.10
September - December	1.17	0.86	0.96	0.90	0.96	1.02	1.18

Local Rural Roads (CSAH's & County Roads in the Rural Area)

Time of Data Collection	Vehicle Type 1-3	4	5	6	7	8-9	10
December - February	1.32	1.26	1.43	1.00	0.98	1.36	0.95
March - May	1.23	0.84	0.95	0.69	1.14	1.21	0.72
June - August	1.00	0.92	0.74	1.25	0.88	0.95	1.07
September - November	1.10	0.72	0.68	0.92	0.88	0.54	0.70

The data for the Local Rural Roads is taken from the Pilot Project on County Roads conducted between 1975 and 1977.

Table 7-5.03D

AVERAGE N18 FACTORS BY VEHICLE TYPE

Vehicle Type	Description	Rural T.H. N18 Factor	Metro N18 Factor	Local Rural CSAH & Municipal N18 Factors	Range		
					Max. Legal 10-Ton	Measured	
						Max.	Min.
1	Passenger Car	0.0004	0.0004	0.0004	-	0.0008	0.0003
2	Panels and Pickups (under 1 Ton)	0.007	0.007	0.007	3.0	0.012	0.0006
3	Single Unit - 2 axle, 4 tire	0.01	0.01	0.01	3.0	0.070	0.003
4	Single Unit - 2 axle, 6 tire*	0.24	0.22	0.21	3.0	0.61	0.019
5	Single Unit - 3 axle and 4 axle****	0.41	0.57	0.45	2.61	1.40	0.015
6	Tractor Semitrailer Combination - 3 axle	0.58	0.21	0.15	2.20	2.45	0.028
7	Tractor Semitrailer Combination - 4 axle	0.53	0.41	0.30	2.62	3.91	0.060
8	Tractor Semitrailer Combination - 5 axle	0.88	0.63	0.59	2.20	4.10	0.028
9	Tractor Semitrailer Combination - 6 axle	***	***	***	-	-	-
10	Trucks with Trailers and Buses**	0.42	0.42	0.34	-	-	-

* Use 0.60 for 2 axle garbage trucks
** Use 1.25 for MTC Buses
*** Too few to establish a value at this time
**** Use 0.91 for Sugar Beet Trucks

Table 7-5.03E

TIME-GROWTH FACTORS FOR DESIGN PERIODS OF 10 OR 20 YEARS

Annual Growth Factor in Present Daily N18	DESIGN PERIOD		20 Year Projection Factor
	10 Years	20 Years	
0%	10.00	20.00	1.00
0.5%	10.23	20.98	1.10
1%	10.46	22.02	1.22
1.5%	10.70	23.12	1.35
2%	10.95	24.30	1.49
2.5%	11.20	25.54	1.64
3%	11.46	26.87	1.81
3.5%	11.73	28.28	1.99
4%	12.01	29.78	2.19
4.5%	12.29	31.37	2.41
5%	12.58	33.07	2.65
5.5%	12.88	34.87	2.92
6%	13.18	36.79	3.21