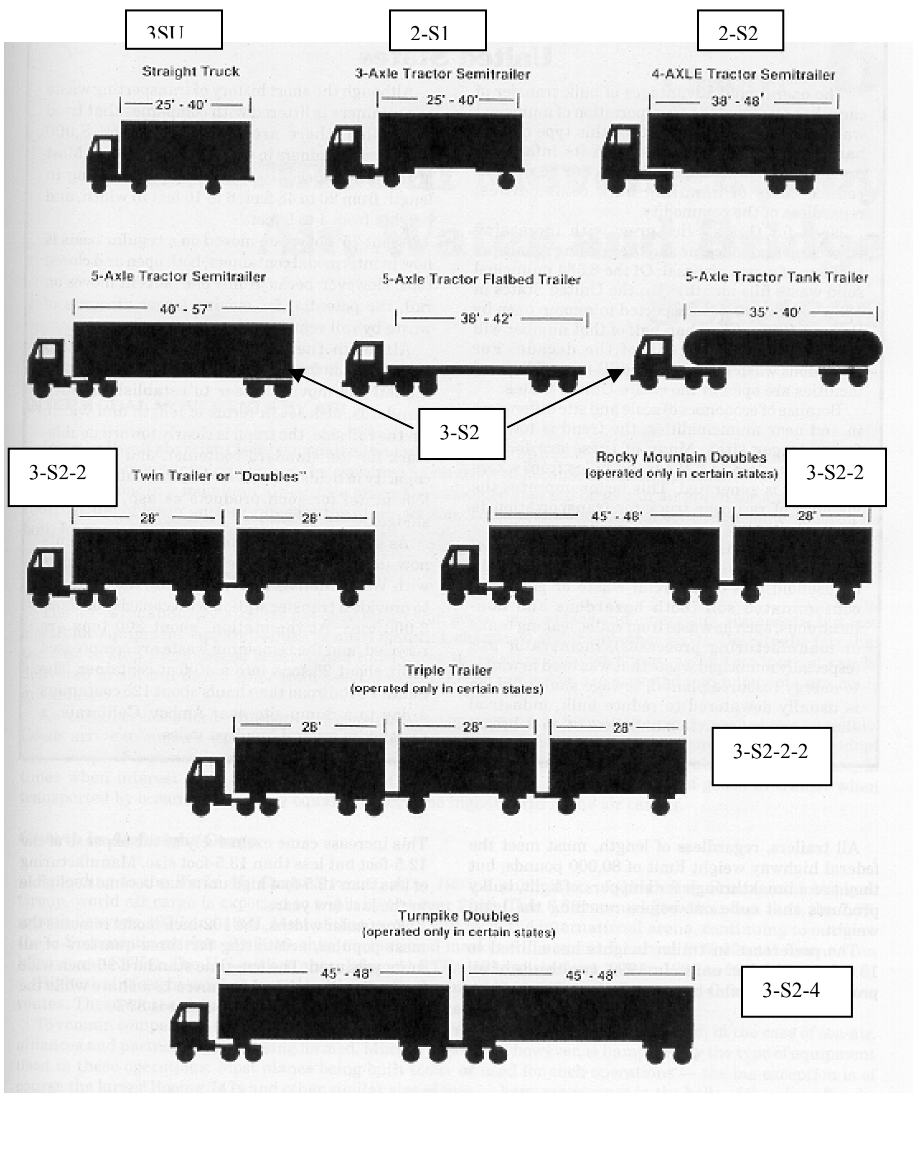
Table 9.3 Truck Identifiers

Designation	Truck Description	Common Name
2A	single truck with two axles and four tires	Pick-up
2D	heavy single unit truck with two axles and 6 tires	small delivery van
3SU	heavy single unit truck with three axles	delivery van/dump truck
4SU	heavy single unit truck with 4 axles	dump truck
2-S1	heavy tractor-semitrailer truck with three axles	semi
2-S2	heavy tractor-semitrailer truck with four axles	semi
3-S2	heavy tractor-semitrailer truck with five axles	semi (18-wheeler)
2-S1-2	heavy tractor-semitrailer-trailer with five axles	double bottom
3-S2-4	heavy tractor-semitrailer-trailer with 9 axles	turnpike double

Source: States of Wisconsin and New Jersey DOTs (website)

Figure 9.9 Axle Configurations for Trucks



Source: ENO Intermodal Freight Study 1994

Example 9.3

Consider a classification site with daily traffic level of 300 trucks -- 100 2-S1 and 200 3-S2 trucks. Estimate the ESALs using Equation 9.4.

Solution to Example 9.3

Each 2-S1 truck has 3 single axles. (See Figure 9.9.) Each 3-S2 truck has one single and two tandem axles. Collectively, the trucks at the site have (100*3) + (200*1) = 500 single axles and (200*2) = 400 tandem axles. Using Equation 9.4, the daily ESALs for the classification site would be estimated as

ESALs = (0.072*500) + (0.46*400) = 36.00 + 184.00 = 220.00.

Example 9.4

Determine the least cost pavement for the design begun above, without going to higher-grade materials. (Hint: One approach is to specify the thickness of the surface layer of Hot Mix Asphalt, then determine the thickness of the base and subbase courses in the steps above. In this solution, 4-, 6-, 8-, and 10-inch surface thicknesses will be tried. Be aware that additional excavation will be required for thicker pavement. The cost of added grading and hauling to a borrow pit will also be necessary. The extra excavation and haul costs may offset the saving from using thicker layers of less expensive material. For the cost estimates in this problem, use the values indicated in Table 9.7a.

Table 9.7a Cost of materials for Example 9.4

Material	Layer	Layer coefficient	Specific gravity	Cost /ton delivered	Cost per lane-mile per inch depth
Asphalt concrete	Top/wearing	0.36 to 0.44	2.65	$90.00	$39,352.50
Asphatic Stabilized Base	Alternate Base	0.24 to 0.26	2.40	$40.00	$15,840.00
Base -Compacted Dense Aggregate, well graded	Base	0.12 to 0.16	2.70	$13.00	$5,791.50
Course Aggregate	Subbase	0.10 to 0.11	2.30	$7.00	$2,656.50

Solution to Example 9.4

First, to provide an upper bound for the analysis, "design" what is called a *full depth asphalt* pavement. This means that only hot mix asphalt (HMA) will be used between the pavement's surface and the subgrade. Because HMA is much more expensive than base and subbase materials, a full depth asphalt pavement is expected to be a very costly design. The thickness of the full-depth asphalt pavement would be $d_{fulldepth} = \frac{SN}{a_1} = \frac{5}{0.41} = 12.2$ inches. Standard practice is to round up the computed thickness to the next one-half inch, making the full-depth asphalt design 12.5 inches thick, as shown at the bottom of the fourth column in Table 9.7b.

For a standard lane 12 feet wide and one mile long, the material cost *for each inch* thickness of HMA would be estimated as follows:

HMA volume: 5280 ft/mi * 12 ft * $\frac{1}{12}$ ft = 5280 ft^3 per mile

HMA weight: 2.65 * 62.5#/ft^3 * 5280 ft^3 = 874,500 lbs = 437.25 tons

HMA cost: 437.25 tons * $90.00/ton = $39,352.50

This cost per lane-mile per inch depth appears in Table 9.7a for Asphalt Concrete. The "costs per lane-mile per inch" for the other materials in Table9.7a can be computed and verified in a similar fashion. The cost of 12.5 inches of HMA would be $39,352.50 * 12.5 inches = $491,906.25, as shown in the last line of the "Paving Cost" column of Table 9.7b.

In Table 9.7b, the full-depth asphalt design serves as the frame of reference for excavation costs. Any other pavement design of the same strength will require more excavation, because the base and subbase layers will use greater thicknesses of cheaper, less strong materials. The hope is that the additional excavation and hauling costs will be more than offset by the cost savings from the use of cheaper materials. An alternative to 12.5 inches of HMA is 10.0 inches of HMA. In this case, use Equation 9.5 to compute the minimum thickness of base to maintain a structural number of 5.0.

$$d_2 = \frac{SN - (a_1 * d_1)}{a_2} = \frac{5.0 - (0.41*10.0)}{0.12} = \frac{5.0 - 4.1}{0.12} = \frac{0.9}{0.12} = 7.5''$$

There is no need to round up this value, because it is an exact multiple of one-half inch. This layer combination is shown in the next-to-last line of Table 9.7b.

Table 9.7b Pavement cost plus added excavation costs in Example 9.4

Asphalt Concrete (a=0.41)	Crushed Stone Base (well graded) (a=0.12)	Subbase crushed stone (a=0.10)	Overall Depth of Pavement	SN	Paving Cost	Added Grading @ $3/CY	Estimated Cost/mi to lay pavement	*Added Grading @ $15/CY*	***Estimated Cost/mi to lay pavement***
4"	14.0"	17"	35"	5.02	$283,652	13,200	$296,852	66,000	$349,652
6"	10"	13.5"	29.5"	5.01	$329,893	9,973	$339,866	49,867	$379,759
8"	7"	9"	24"	5.02	$379,269	6,747	$386,016	33,733	$413,002
10"	7.5"	0"	17.5"	5.00	$436,961	2,933	$439,894	14,667	$451,628
12.2"	0	0	12.5"	5.125	$491,906	0	$491,906	*0*	$439,894

The extra depth of excavation needed for the 7.5" + 10" design is (7.5+10) – 12.5 = 5.0 inches. This translates into $\frac{5.0}{12}$ ft thick * 12ft wide * 5280ft long = 26,400 ft^3 = 977.8 cubic yards. The extra cost to excavate and haul soil will differ from site to site. However, for this problem, the cost of extra excavation is set at a low value of $3.00 per cubic yard. At $3/CY, the extra cost to excavate and haul the extra soil in the new 2-layer design is $2933. The cost to place 10.0 inches of HMA at $39,352.50/inch is 10.0 * $39,352.50 = $393,525. The cost saved by reducing the HMA thickness from 12.5 inches to 10.0 inches is (12.5-10.0) * $39,352.50 = $98,381. The cost to place 7.5 inches of Base material at $5791.50/inch (see Table 9.7a) is 7.5 * $5791.50 = $43,436. The total Paving Cost becomes $393,525 + $43,436= $436,961. When the added excavation and hauling costs are included the overall cost becomes \$436,961+ \$2933 = \$439,894. Trading in a unit thickness of expensive surface material for a greater thickness of less expensive base material, even with the added excavation costs, saved money while maintaining the strength of the pavement.

The alternative in Table 9.7b that uses 8" of HMA introduces a subbase layer. The equation for finding d_2 used for the 10" HMA alternative can be repeated here for 8" of HMA:

$$d_2 = \frac{SN - (a_1 * d_1)}{a_2} = \frac{5.0 - (0.41*8.0)}{0.12} = \frac{5.0 - 3.28}{0.12} = \frac{1.72}{0.12} = 14.3" \text{ of base.}$$

Of the many possible values of d_2 that could be chosen, let is chose 7 inches. This means that the subbase layer will have to contribute the remaining 7.3 units to the overall pavement structural; number.

$$d_3 = \frac{SN - (a_1 * d_1) - (a_2 * d_2)}{a_3} = \frac{5.0 - (0.41*8.0) - (0.12*7.0)}{0.10} = \frac{5.0 - 3.28 - 0.84}{0.10} = \frac{0.88}{0.10} = 8.8" \text{ of subbase.}$$

In Table 9.7b, this is rounded to 9.0 inches. Again the tradeoff is economical – the cost continues to decline.

Using different combinations of layer thickness that preserve the overall SN=5.0 value, a variety of layer designs have been created in Table 9.7b. The total cost for each layer design is found in the right hand column of Table 9.7b. It indicates that, for the costs given, the 4" HMA +24" base + 5" subbase will be the cheapest overall. In practice, the pavement design depends on the availability (and therefore the price) of the materials. Even if, because the borrow pits are some distance away, the grading/excavation costs were \$15, the second pavement in Table 9.7b is still the cheapest. However, operational considerations, like the availability of paving equipment, might swing the construction recommendation in favor of some other design.
