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PROCEDURE FOR DESIGN OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

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ABSTRACT: Instructions are given for determination of traffic loading (total traffic flow, commercial volume, and conversion of flow to equivalent 18-kip single axles), pavement thickness required to carry traffic during design life, and steel quantities for continuous reinforcement. A method is also outlined for estimating total vehicles traveling over a pavement for a given number of years.

KEY WORDS: continuous reinforcement, continuously reinforced concrete pavements, concrete pavement design, design criteria, design volume, commercial traffic, traffic capacity, traffic composition, traffic forecasting, traffic volume, serviceability index.

PROCEDURE FOR DESIGN OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

This report presents a procedure for design of continuously reinforced concrète pavement, incorporating the following steps:

1. Determination of traffic loading.

   a. Estimate of total traffic flow.

   b. Estimate of commercial vehicle volume.

   c. Conversion of traffic flow to equivalent 18-kip single axles.

2. Determination of pavement thickness required to carry traffic during design life.

3. Determination of reinforcing steel quantities.

The AASHO Road Test pavement performance equations are used both for converting mixed traffic flow to equivalent 18-kip single axles and for determining pavement thickness. Intrinsic in the AASHO Road Test equations is the concept of the serviceability index to indicate pavement condition. The serviceability index ranges from 0 to 5, with 5 considered to represent perfect pavement.

Because the AASHO Road Test spanned a period of only two years, it has been shown that its results must be modified by a "time factor," when used to predict performance of conventional highways with significantly longer life spans. In most cases, a conventionally jointed pavement slab deteriorates considerably faster than predicted by AASHO Road Test results. For example, Chastain (1) showed that as a function of traffic loading, conventionally jointed 10-in. thick rigid pavement slabs in Illinois deteriorated at the approximate rate predicted by AASHO methods for pavements 6 to 7 in. thick. However, Chastain further indicated that continuously reinforced pavement performed better than conventional

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(1) Chastain, W. E., Sr., "Concepts for Application of the Road Test Formulas in the Structural Design of Pavements." HRB Special Report 73 (1962), pp. 299-313.

pavement of equal thickness, and should perform more nearly as predicted by the AASHO Road Test results. This is the basis upon which the following design procedure is predicated.

Determination of Traffic Loadings

Estimates of the following values must first be obtained:

a. Initial average daily traffic (ADT) or estimated design ADT at a given future date.

b. Annual rate of traffic growth.

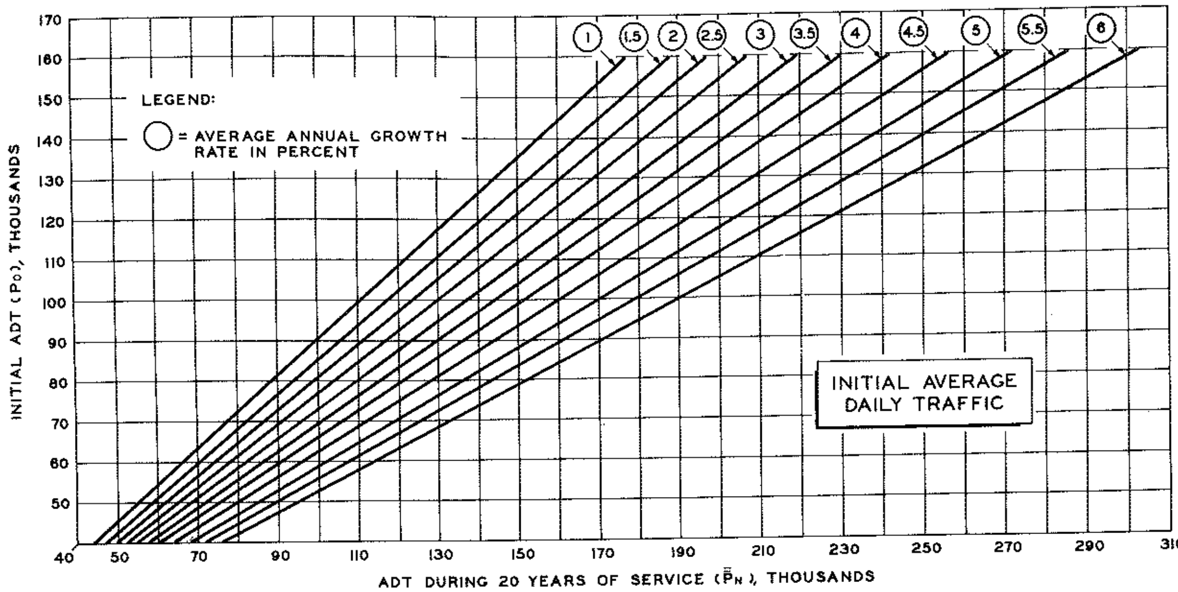
c. Proportion of commercial vehicles in the traffic stream.

d. Commercial vehicle type distribution.

Although geometric design of the roadway facility is based on the estimated traffic volume after a given number of service years, the mean ADT throughout the pavement's service life is a more realistic figure for use in computing the actual number of repetitions of wheel loading to which the pavement will be subjected. Given ADT for the initial year or a certain future year, and the estimated traffic growth rate, which is assumed to be a constant during this period, the mean ADT for pavement design purposes can be determined from Figure 1. Derivation of the equations upon which the Figure 1 curves are based is given in the Appendix. It is presumed that a design life of 20 years is reasonable and these graphs are based on that period. By entering the ordinate of either Figure 1 graph with the initial or 20-year ADT (whichever is given), and by using the curve corresponding to the appropriate growth factor, the mean ADT over the 20-year pavement life can be obtained directly.

After this 20-year ADT is known, it is divided by 2 to determine the traffic traveling in each direction and then Figure 2 is used to estimate the percentage of commercial vehicles in the right lane. By using the foregoing information, together with the estimate of the proportion of commercial vehicles in the total traffic stream, the number of commercial vehicles in the right lane can be determined.

After the total number of commercial vehicles in the right lane is known, their axle load distributions must be estimated. Michigan studies have suggested that most rural trunkline commercial traffic can be grouped into three general patterns: light, medium, and heavy. The medium



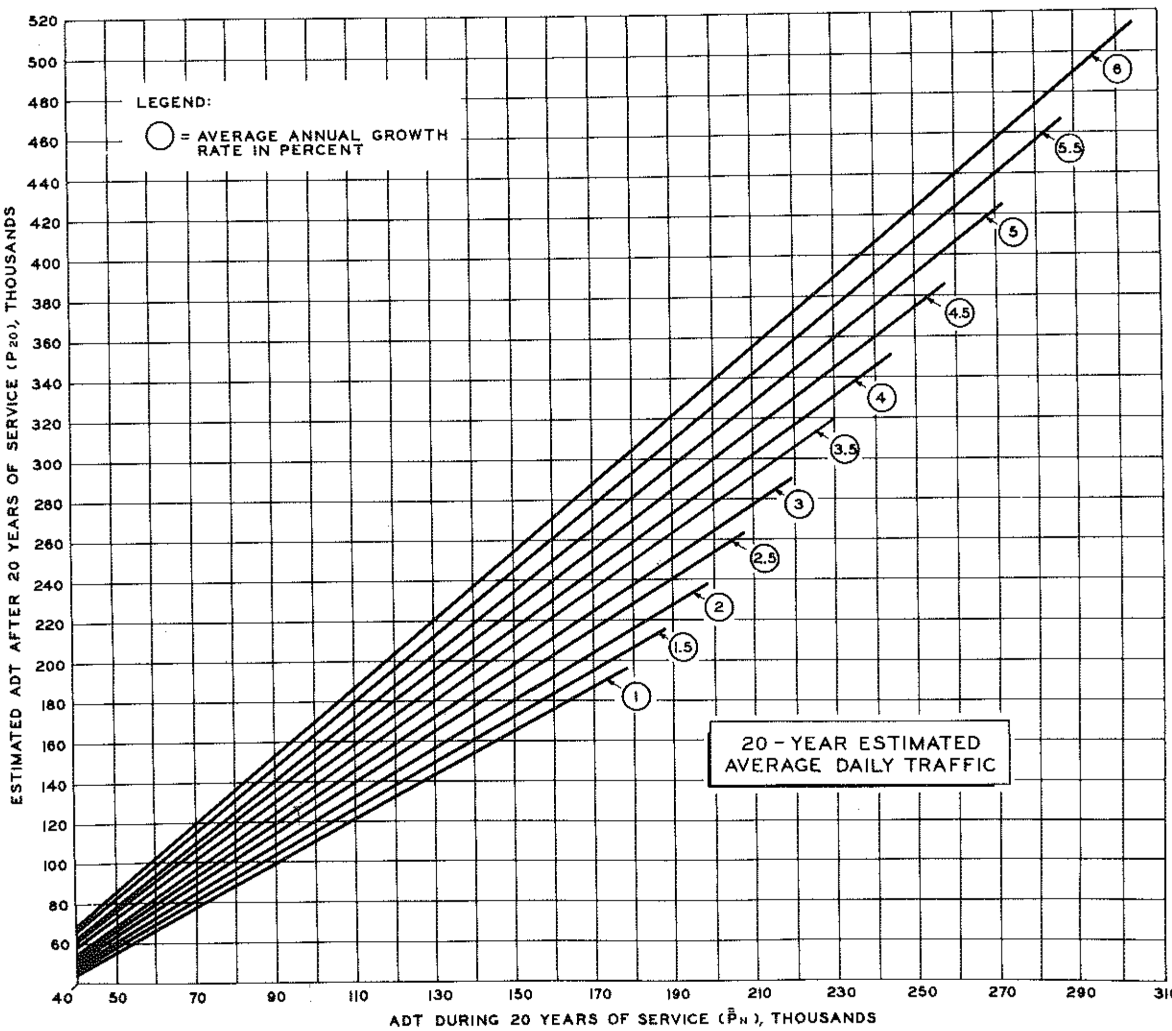


Figure 1. Charts for determining average ADT for a 20-year period.

commercial traffic patterns are common to many interstate highways in the lower part of the State and the heavy commercial traffic pattern applies only to those highways carrying high densities of industrial traffic, such as I 75 between Detroit and Toledo. Table 1 shows the approximate commercial traffic type distributions, together with the average number of equivalent 18-kip single axles for each type. This conversion to equivalent 18-kip single axles was made using results of the AASHO Road Test.

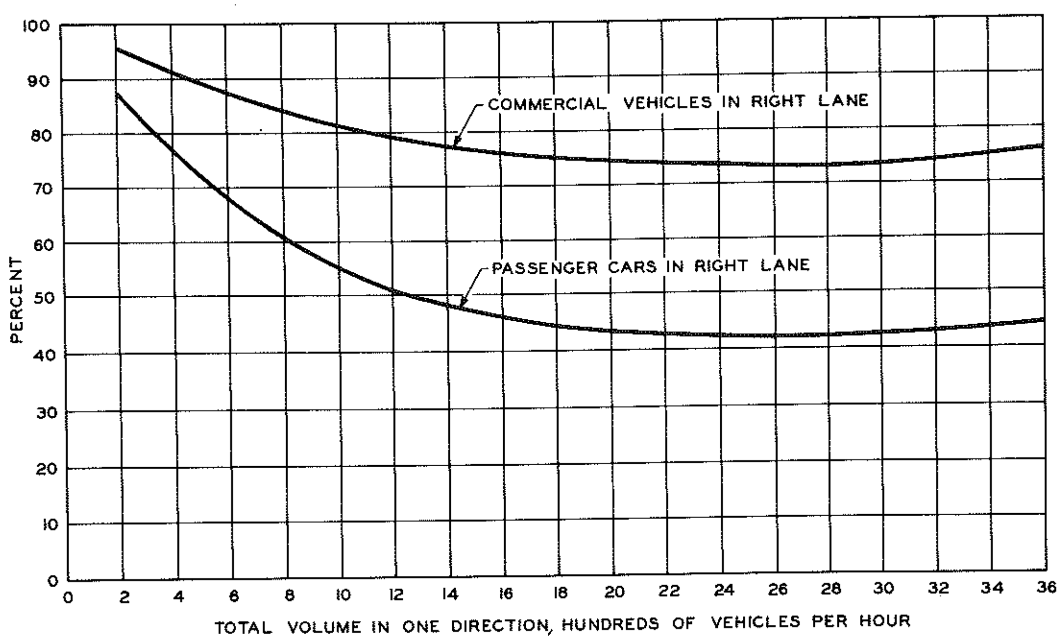


Figure 2. Percentage of vehicles using right-hand lane of a four-lane divided highway (from Asriel Taragin's "Lateral Placement of Trucks on Two-Lane and Four-Lane Divided Highways," Public Roads, Vol. 30, No. 3, August 1958, pp. 71-5).

Table 1 also lists total equivalent 18-kip single axles per 100 commercial vehicles for each of the three classes of trunkline. These data in combination with the information already discussed can be used to estimate the daily number of equivalent 18-kip single axles for commercial traffic in the right or critical lane. Auto traffic can be considered by first using Figure 2 when applicable to approximate the proportion of automobiles in the right lane, and then converting to equivalent 18-kip single axles by multiplying the number of vehicles in that lane by the appropriate AASHO equivalence factor. For average auto weights (4,000 lb) this factor is 0.0004 or 0.4 equivalent 18-kip single axle per 1,000 automobiles. In most cases, automobile traffic has an insignificant effect on pavement thickness design.

TABLE 1
SUMMARY OF COMMERCIAL TRAFFIC DISTRIBUTION

Vehicle Type	Light Commercial Traffic			Medium Commercial Traffic			Heavy Commercial Traffic		
	No. Per 100 Commercial Vehicles	Total 18-Kip Equivalent Factors for Given Vehicle*	18-Kip Single Axles per 100 Commercial Vehicles	No. Per 100 Commercial Vehicles	Total 18-Kip Equivalent Factors for Given Vehicle*	18-Kip Single Axles per 100 Commercial Vehicles	No. Per 100 Commercial Vehicles	Total 18-Kip Equivalent Factors for Given Vehicle*	18-Kip Single Axles per 100 Commercial Vehicles
2	47.2	0.0016	0.08	16.5	0.0016	0.03	7.4	0.0016	0.01
2D	21.5	0.06	1.29	15.2	0.06	0.91	9.1	0.06	0.55
3	1.7	0.19	0.32	1.8	0.19	0.34	1.1	0.19	0.21
2S1	7.2	0.32	2.30	14.2	0.32	4.54	13.3	0.32	4.26
3S1	0.54	0.76	0.41	--	--	--	0.6	0.76	0.46
2S2	7.91	0.42	3.32	19.7	0.42	8.27	26.5	0.42	11.13
2S2L	0.95	0.56	0.53	2.5	0.56	1.40	3.1	0.56	1.74
3S2L	1.78	0.74	1.32	5.8	0.74	4.29	10.9	0.74	8.07
3S2	2.45	0.49	1.20	8.0	0.49	3.92	17.0	0.49	8.33
2S3L1	0.10	1.16	0.12	0.3	1.16	0.35	0.5	1.16	0.58
2S3	0.05	1.11	0.06	0.1	1.11	0.11	0.1	1.11	0.11
2S3L	0.09	1.05	0.95	0.3	1.05	0.32	0.7	1.05	0.74
2S3L2	0.06	1.71	0.10	--	--	--	0.1	1.71	0.17
2S3LL	0.07	1.02	0.07	0.2	1.02	0.20	0.4	1.02	0.41
3S3LL	--	--	--	--	--	--	--	--	--
3S3L	--	--	--	--	--	--	--	--	--
3S3L2	--	--	--	--	--	--	--	--	--
3S3	0.2	0.98	0.20	1.1	0.98	1.08	0.4	1.02	0.41
3S3L1	--	--	--	--	--	--	--	--	--
3S4	--	--	--	--	--	--	--	--	--
3S5	--	--	--	--	--	--	--	--	--
2S1-2	0.6	0.71	0.43	0.7	0.71	0.50	2.9	0.71	2.06
2S2-2	1.4	1.82	2.55	2.9	1.82	5.28	2.1	1.82	3.82
2S2-3	1.2	1.06	1.27	2.6	1.06	2.76	0.3	1.06	0.32
3S2-3	0.5	3.73	1.86	1.0	3.73	3.73	--	--	--
3S2-4	0.3	2.90	0.87	0.8	2.90	2.32	--	--	--
3S3-4	0.5	4.34	2.17	0.9	4.34	3.91	--	--	--
3S3-5	0.6	4.69	2.81	1.3	4.69	6.10	--	--	--
3S4-5	--	--	--	0.2	6.58	1.32	--	--	--
2-2	0.6	1.3	0.78	0.7	1.3	0.91	0.8	1.3	1.04
3-2	0.2	0.65	0.13	0.5	0.65	0.32	0.6	0.65	0.39
3-3	--	--	--	0.1	0.49	0.05	0.1	0.49	0.05
3-4	--	--	--	0.1	1.00	0.10	--	--	--
3-5	--	--	--	0.2	1.43	0.29	--	--	--
Bus	2.3	0.004	0.01	0.9	0.004	0.00	1.8	0.004	0.01
Totals	100.0		25.15	100.0		54.41	100.0		45.05

*Based on Bartelsmeyer, R. R. and Finney, E. A. "Use of AASHO Road Test Findings by the AASHO Committee on Highway Transport." HRB Special Report 73 (1962), pp. 415-38. Conversion factors computed using rigid pavement and terminal serviceability index of 2.5.

Determination of Pavement Thickness

When the daily number of equivalent 18-kip single axles is known, Figure 3 can be used for direct determination of the pavement thickness required. The Terminal Serviceability Index used in Figure 3 is 2.5, an average value determined during a recent nationwide survey of expressways requiring resurfacing. Given certain data concerning a construction project and its traffic, typical calculations would follow as in this sample problem:

Given Project and Traffic Data

Initial ADT: 80,000
Percent commercial: 15
Annual growth rate, percent: 2
Design service life: 20 years
Six-lane Interstate project
Medium commercial vehicle type distribution

Calculations

Average ADT over 20-year period (Fig. 1) = 99,000
ADT in each direction $= \frac{99,000}{2} = 49,500$

Daily commercial vehicles in each direction = 49,500 x 0.15 = 7,430
Total hourly volume in one direction $= \frac{49,500}{24} = 2,060$

Percent of commercial vehicles in right lane (Fig. 2) = 75
Daily total commercial vehicles in right lane = 7,430 x 0.75 = 5,570
Daily equivalent 18-kip single axles due to trucks in right lane (using "Medium Traffic" columns of Table 1) = 55.7 x 54.4 = 3,030
Autos in each direction = 49,500 - 7,430 = 42,070

Referring first to Figure 2 and then reducing the proportion indicated in the right lane because the pavement has six lanes, the percent of autos in the right lane is assumed to be 25. Thus, the number of autos in right lane = 42,070 x 0.25 = 10,500. The number of equivalent 18-kip single axles in the right lane resulting from auto traffic = 10.5 x 0.4 $\doteq$ 4.

Compared to the truck loading, the autos are therefore insignificant. Entering Figure 3 with 3,030 equivalent 18-kip axle loads per lane, the thickness of pavement to last 20 years would be about 9.7 in. Thus, use a 10-in. thick pavement.

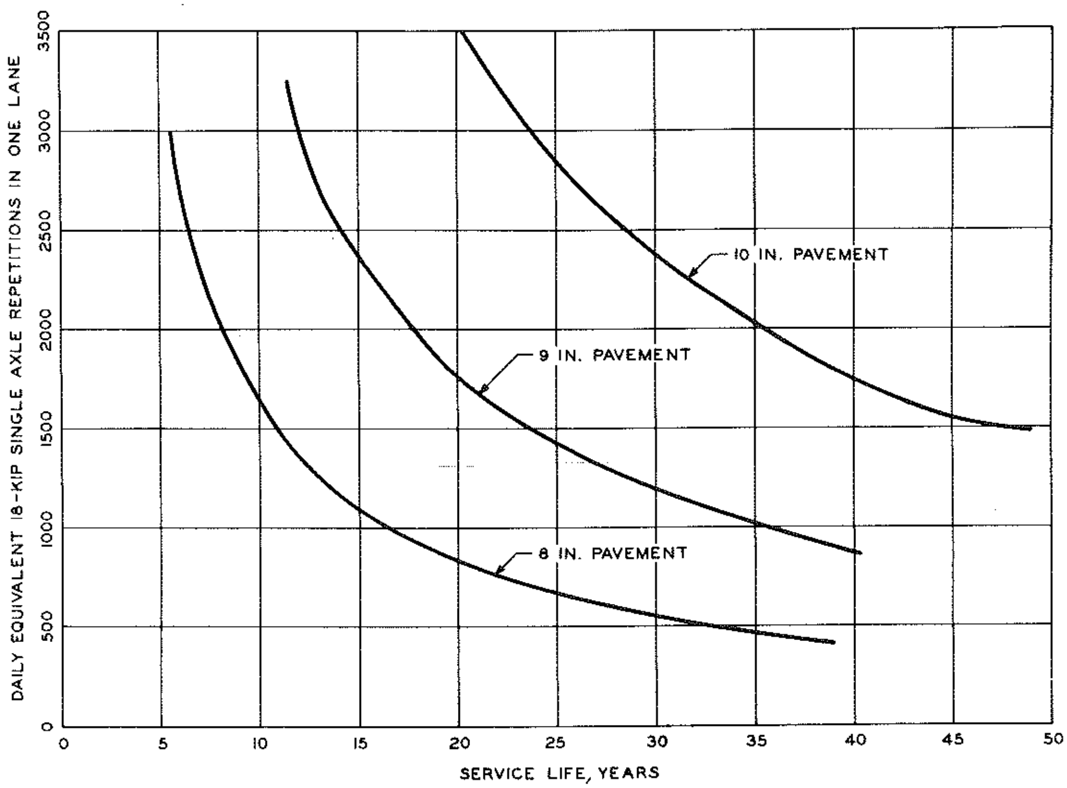


Figure 3. Traffic loading related to years of service, based on AASHO Road Test pavement performance equations, with Terminal Serviceability Index of 2.5.

Selection of Steel

If a continuously reinforced concrete pavement is to give satisfactory performance, the steel reinforcement has to maintain the adjoining surfaces at the cracks in a tight position so as to preserve the continuity of the slab to the greatest degree possible. Also, tightly closed cracks are essential in order to prevent corrosion of the steel and destruction of the continuity of the reinforcement.

The proportion of steel in the slab cross-section necessary to induce other cracks to form in the concrete, as a result of shrinkage and temperature changes, before an existing crack opens excessively is approximately given as $p = f'_t/f_s$, where f'_t is the ultimate tensile strength of the concrete, and f_s is the steel stress at which a bond slip occurs corresponding to one-half of the limiting crack opening.

For most concrete, f'_t is approximately equal to $0.08\ f'_c$, where f'_c is the 28-day cylinder compressive strength. For average maximum f'_c equal to 4,000 psi, f'_t is about 320 psi. Based on a limiting value for crack opening of 0.025 in., bond-slip data reported in "Design Considerations for Distributed Reinforcement for Crack Control" (Report of Subcommittee IV of ACI Comm. 325, Feb. 1955) indicate that steel stresses at which end slips of 0.012 in. occur for No. 5 deformed bars would be about 45,000 psi. Using these values, the minimum steel percentage would be about 320/45,000 = 0.71 percent. For 8-, 9-, and 10-in. slabs, the number and spacing of the No. 5 deformed bars required would be as follows:

Slab Thickness, in.	Bars per 12-ft Lane Width	Bar Spacing, in.*
8	27	5.5
9	30	4.8
10	33	4.4

*Based on a 2-in. edge clearance.

Since crack spacings may occur that are slightly less than twice the minimum crack spacing for which the steel stress would be limited to 45,000 psi, steel stresses at these cracks could become appreciably higher. For this reason it is recommended that all deformed bar reinforcement in continuously reinforced concrete pavement conform to ASTM Specification A 432.

APPENDIX
Development of Method for Estimating Total Vehicles Traveling Over a Pavement During a Given Number of Years

P_n = number of vehicles per year at end of any year, n

R = rate of traffic volume growth per year

P_0 = initial annual traffic volume

Thus, $P_n = P_0(1 + R)^n$.

The total number of vehicles, T_n, traveling over a pavement during n years can be approximated as follows:

$$T_n = \frac{P_0 + P_1}{2} + \frac{P_1 + P_2}{2} + \frac{P_2 + P_3}{2} + \ldots \frac{P_{n-1} + P_n}{2}$$

$$= \sum_1^{n-1} P_n + \frac{P_0 + P_n}{2} = \sum_1^{n-1} P_n + \frac{P_0}{2}\left[(1 + R)^n + 1\right]$$

Then, $$\sum_1^{n-1} P_n = P_0 + P_0 (1 + R) + P_0 (1 + R)^2 + P_0 (1 + R)^3 + \ldots P_0 (1 + R)^{n-1} - P_0$$

The first n terms of this series are therefore a geometric progression, with common ratio (1 + R).

Thus, $$\sum_1^{n-1} P_n = \frac{P_0\left[1 - (1 + R)^n\right]}{1 - (1 + R)} - P_0 = \frac{P_0}{R}\left[(1 + R)^n - 1\right] - P_0$$

Then, $$T_n = \frac{P_0}{R}\left[(1 + R)^n - 1\right] + \frac{P_0}{2}\left[(1 + R)^n + 1\right] - P_0$$

$$= \frac{P_0}{R}\left[(1 + R)^n - 1\right] + \frac{P_0}{2}\left[(1 + R)^n - 1\right]$$

$$T_n = P_0\left[(1 + R)^n - 1\right]\left[\frac{1}{R} + \frac{1}{2}\right]$$

The average number of vehicles $\bar{\bar{P}}_n$ using the pavement during n years be $\bar{\bar{P}}_n = \frac{T_n}{n}$.

Since traffic volume as used for design is normally considered in hourly or daily totals, the average hourly or daily vehicle count can be determined by dividing $\bar{\bar{P}}_n$ by the appropriate constant, i.e. 365 for daily volume and 365 x 24 for hourly volume.

Further, it can be seen from the preceeding derivation that average hourly or daily traffic volume values can be used vice annual values to determine $\bar{\bar{P}}_n$ directly in terms of hourly or daily traffic flow.