appearance of RVs that provide extremely poor performance, since passenger vehicles capable of providing current minimum performance levels will remain available to RV owners.

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Headway-Distribution Models for Two-Lane Rural Highways

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The distribution of vehicle headways on two-lane, two-way roadways has been the subject of continuing research for a number of years. The growing interest in headway-generation models is related to the increased application of simulation techniques to describe traffic-flow patterns through the use of digital computers. A headway-distribution model developed for varying traffic-volume conditions (80-630 vehicles/h/lane) is described. The model was developed as part of a research project on the feasibility of using simulation techniques for depicting traffic flow on two-lane highways. A total of 18 sets of headway data (2 sets for each site) were collected from nine sites in North Carolina. The process of model development consisted of testing the field data by using a number of existing simple models and progressing with increasing degrees of complexity until an acceptable match between the field data and the model output was obtained. The study showed that none of the existing models (the Negative Exponential, Pearson Type III, and Schuhl models) provided satisfactory results for the wide range of traffic volumes tested. A modified form of the Schuhl model, incorporating parameters developed from the North Carolina data, provided the most reasonable approximation of the arrival patterns noted in the field. Parameters developed in the study are presented, along with a nomograph that can be used by traffic researchers to describe the time spacing between successive arrivals of vehicles on two-lane highways.

The distribution of vehicle headways, or the time spacing between successive arrivals of vehicles on two-lane roadways, has been a subject of continuing research for a number of years. Several past studies have attempted to describe mathematically the distribution of vehicle headways in two-lane traffic streams. The growing interest in headway-generation models is related to the increased application of simulation techniques to describe traffic-flow patterns through the use of digital computers. The development of a headway-prediction model as an appropriate descriptor of the input traffic stream is considered a mandatory requirement of any such simulation model. The importance of the headway generator, as a part of the simulation program, derives from the fact that the distribution of vehicle headways constitutes the single most important characteristic of traffic-flow patterns on two-lane roadways. The ability to accurately predict the arrival patterns of vehicle traffic by use of a headway-distribution model is thus the primary prerequisite for such a simulation model.

Drew (1), in his book on traffic-flow theory and control, discusses the theoretical concepts and practical implications of the mathematical models developed by various researchers to predict vehicle headways. Although the development of most of these models dates back to original work by Schuhl (2) and Adams (3), these concepts have been successfully applied to actual traffic data on two-lane and multilane facilities by a number of researchers in the United States (4-8). In their 1976 Transportation Research Board monograph on traffic-flow theory, Gerlough and Huber (9) provide an extensive discussion of various headway models developed by different researchers.

As part of a larger research effort conducted at North Carolina State University from 1969 to 1973, a headway-distribution model was developed and calibrated by using data collected from two-lane roadways in North Carolina. A number of original headway models were reviewed and tested by using field data. The result was the development of a headway model, based on North Carolina data, that was then incorporated as part of a program designed to predict an input queue of vehicles for a larger simulation program.

BACKGROUND OF THE RESEARCH

The basic purpose of the research study from which this paper originates was to test the feasibility of using simulation techniques to evaluate the effects on traffic of selective and systematic removal of no-passing barriers from two-lane rural roadway sections under varying geometric and traffic conditions (10). The study was conducted as part of a cooperative highway research program and was sponsored by the North Carolina Department of Transportation and Highway Safety in cooperation with the U.S. Department of Transportation. The simulation model developed in this study is capable of duplicating traffic-flow characteristics, including passing maneuvers on two-lane rural roadways. A major component of this simulation model is a "speed-headway" program that was developed for the purpose of predicting individual vehicle speeds and headways to be used as input in the simulated roadway section. This program, as developed, is capable of generating headways on a lane-by-lane basis according to the traffic volume and directional distribution specified. The input queue generated by the speed-headway program provides an ordered list of vehicles to be simulated along with assigned speeds and headways in accordance with the specified input parameters. The specification of these parameters was a part of the overall process of model calibration.

The development and application of the overall simulation model have been reported elsewhere (11, 12). These publications did not, however, clarify the development of the headway-distribution model, which is an integral component of the speed-headway program. The purpose of this paper is to explain the development of the headway-distribution model and its importance in the complete model. The necessary data base was formed by collecting headway data from nine sites in North Carolina for different volume and traffic-mix conditions. These data were then used to test the ability of some of the existing headway models to adequately describe the observed arrival patterns. Initial efforts were directed toward the use of existing headway models to fit the observed data. Later, it was evident that, in order to reasonably predict the arrival of vehicles on two-lane sections, it would be necessary to develop an appropriate model with North Carolina data. The results of tests of the field data with the existing headway models and the development of the North Carolina model are described in this paper.

SIMPLE VERSUS COMPLEX MODELS

It has been pointed out in the literature that the selection of a suitable headway model represents a compromise between economic considerations and the faithfulness of the model (9). Both simple and complex models were considered in this study. Simple models, by definition, are computationally straightforward and require the development of a minimum number of parameters and a limited data base. Complex models, on the other hand, require a number of intricate mathematical manipulations. This necessitates a large data base because of the number of parameters that must be developed. Finally, the designation of a model as simple or complex must be somewhat arbitrary, since a fine line of demarcation between the two types does not exist.

The theory of error propagation in models suggests that there are essentially two types of error in model development--namely, measurement errors and specification errors (13). Measurement errors arise from inaccuracies in assessing magnitude--in this case, inaccuracies relative to the collection, recording, and transferral of the field data. Specification errors, on the other hand, are the result of misunderstanding or purposeful simplification of the relation between the variables in the model. In the present context, the description of an exponential relation by a simple linear formulation would constitute a typical specification error. Most models are characterized by both types of errors.

Although simple models can be criticized as being too simplistic in nature to consider the intricate relations between variables, they are preferred by researchers when the data base is poor. The reason cited is that the reduction in specification error resulting from the introduction of additional complexities is likely to be eroded by the effect of significant measurement errors (for a poor data base). Complex models are preferred when the data base is highly reliable. Coupled with increasing model complexity is an increase in the model's ability to explain the correlation between the dependent variables and the independent variables (13). In such cases (assuming that the data base is good), the reduction in specification errors with increasing complexity is likely to outweigh the increase in measurement errors.

In this study, the process of model development consisted of testing the data by starting with simple models and progressing to increasing degrees of complexity. Sufficient care was exercised during the collection and reduction of field data to minimize the effect of measurement errors so as to allow the testing of complex models. It was necessary to use complex models because the success of the overall two-lane simulation program, which involves passing maneuvers, depended largely on the ability of the headway model to realistically predict the successive arrival of vehicles at a specified point on the roadway. In this context, the following comment should be noted (9, p. 31):

> As in many engineering selection processes, selection of a suitable headway distribution represents a compromise between economic considerations and faithfulness of the model. Greater faithfulness is often obtained by using a model with a greater number of parameters; such a model, on the other hand, results in a more complex computational procedure. In some cases the intended use of the model can help in the selection procedure . . . . if the objective is simply the computation of delays, the simplest

(i.e., the negative exponential) distribution should be used. If, however, the objective is the determination of gaps for, say, crossing purposes, a more faithful distribution may be needed.

FIELD DATA COLLECTION

Nine two-lane primary rural highway sections in North Carolina were studied, and traffic, geometric, and operational data were collected. The critical data given in Table 1 indicate that the range of lane volumes, covered in a total of 18 sets of field data (nine sites, each with two directions), is between 80 and 632 vehicles/h/lane and that approximately 50 percent of the data sets (8 out of 18) lie within a range of 100-150 vehicles/h/lane. The directional distribution of volume in most cases was generally balanced, lying between 50:50 and 40:60 (except for site 7, where lane 1 had a considerably higher volume than the other lane). The unbalanced distribution of traffic at this site was the result of a number of traffic generators (industrial developments) immediately upstream of the site, and the fact that the data collection period coincided with the period of peak traffic outflow from these generators. The skewed nature of the distribution of the traffic volume and the resulting large variance (exhibited by the "outliers", such as 632 vehicles/h/lane) were considered to provide a wide spectrum of traffic flow ranging from "random" (light-volume) to "nonrandom" (medium to medium-heavy) conditions. The need to develop a single headway model to appropriately describe traffic flow covering this wide volume range presented a special challenge to this research. As later discussion will show, most existing headway models provided a decent fit to the field data under random conditions, but incorporating a mix of random and nonrandom flow characteristics into a single model proved to be a particularly difficult task.

DEVELOPMENT OF A HEADWAY MODEL

A total of six headway-distribution models were tested by using the field data noted above. Constants (parameters) were estimated for each model by using the lane input field data. Then the model was used to generate a headway distribution that was statistically compared with the actual input headway observed and recorded in the field. This procedure was carried out for each model on all of the test sites until some conclusions could be made about each model's accuracy in generating headway distributions comparable to those that had been measured in the field. A form of the Schuhl model (2) was finally selected as providing the best fit over the range of volumes studied. The results of tests of the field data with a total of six headway-distribution models are presented below.

Testing with Individual Models

During the earlier phase of this research, an effort was made to fit the Erlang distribution to the first four sets of data collected. This model was dropped from consideration later during the research because initial testing did not provide an acceptable statistical match between the field data and the model output. Extensive testing was then conducted with three other models--namely, the Negative Exponential, Pearson Type III, and Schuhl models (see Figure 1). Of these three, the first two are considered simple models in that they require the use of one or two parameters only. The Schuhl model, on the other hand, is considered complex in that it requires the use of at least five parameters. The parameters developed by Grecco and Sword (7) with data collected from a two-lane section of US-52 in Lafayette, Indiana, during 1968 were used for the Schuhl model.

The choice of these three models for testing purposes was based on the premise that the model to be developed in this study should be capable of representing both random and nonrandom traffic flow, in light of the high variance associated with the traffic volume from the nine sites. It has been shown by a number of researchers that the distribution of the Negative Exponential model generally provides a good fit for traffic data under

Table 1. Critical field data collected for nine North Carolina study sites.

Site No.	Location	Equivalent Flow Rate (vehicles/h) Lane 1	Equivalent Flow Rate (vehicles/h) Lane 2	Trucks in Traffic Stream (%)	Posted Speed Limit (miles/h)
1	US-1; north station is just south of interchange with NC-55	90	117	13	60
2	US-1; north station is just south of site 1	80	98	19	60
3	US-64; east station is 13.7 miles west of junction with US-1	111	115	15	60
4	US-15, 501; south station is 3 miles north of Creedmoor	305	381	17	55
5	US-15, 501; south station is 3 miles north of Pittsboro	125	165	11	55
6	NC-54; east station is 1 mile west of Morrisville	143	122	8	55
7	NC-54; east station is 1 mile west of Morrisville	632	129	2	55
8	US-64; west station is 1.43 miles west of I-40 interchange	271	235	21	55
9	US-301; north station is 1.95 miles south of end of I-75	300	341	15	55

Figure 1. Headway-distribution models tested.

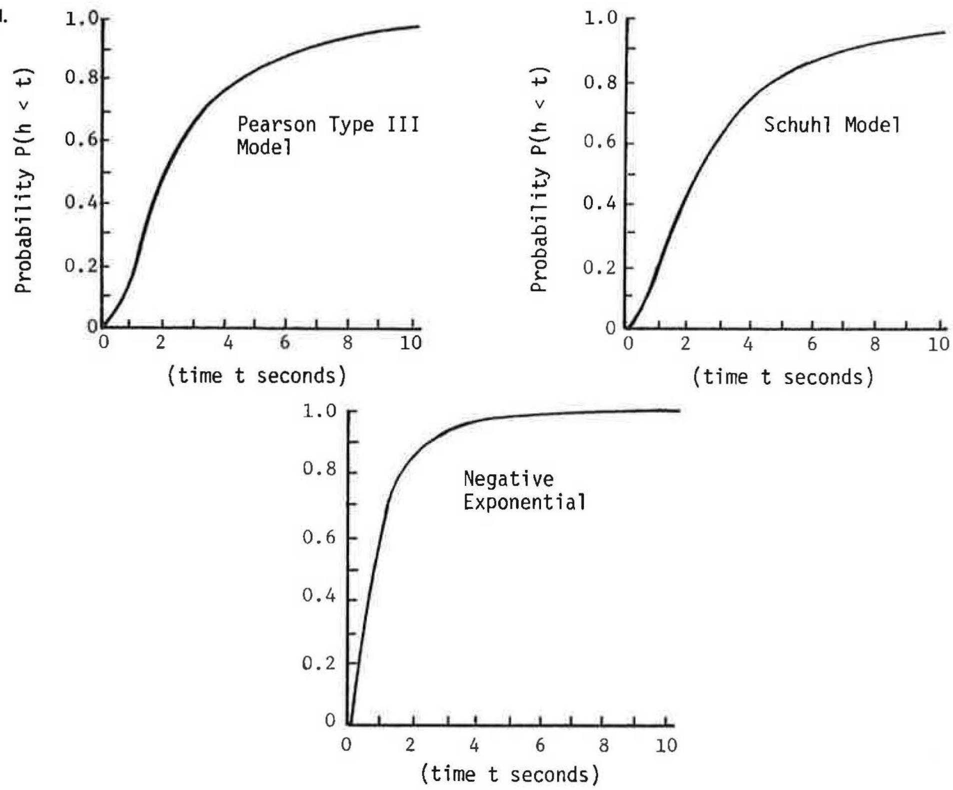


Table 2. Probability distribution models used to generate simulation headways for comparison with headways measured in the field.

	Goodness of Fit over Range of Lane Volumes Tested[a] (s)			Lane Volume That Gives Best Single Fit for Each Model			
Model Category	Underprediction	Good Fit	Overprediction	Vehicles per Hour	χ^2	df	χ^2 0.05
Original							
Negative Exponential	5-30	1-5 and 30-50	>50	143	13.02	11	19.70
Pearson Type III	5-50	1-5 and 50-80	>80	143	14.31	11	19.70
Schuhl (Grecco parameter)	5-30	1-5 and 50-120	30-50	166	6.59	12	21.00
Combined							
Schuhl and Pearson Type III	5-30	1-5 and 30-50	>50	122	9.87	9	16.90
Schuhl and Negative Exponential	5-50	1-5 and 50-80	>80	166	9.20	13	22.40
Modified individual							
Schuhl (North Carolina parameter)		1-150		166	9.84	14	23.70

[a]80-632 vehicles/h.

light-volume conditions (random). The Pearson Type III and Schuhl models, on the other hand, are both capable of incorporating a combination of random and nonrandom flow through the use of appropriate parameters.

Columns 2-4 in Table 2 give generalized observations concerning the fit of specific models to the 18 different headway distributions. The well-known nonparametric test called the "chi-square" test was used to check the goodness of fit of the model data with the field data. The null hypothesis tested during this analysis was that there is no significant difference in the observed and predicted headway distributions. The number of observations falling into prespecified headway groups was compared between the two sources (field and model) by using the chi-square computational procedure. Where the number of observations in a given cell was less than 5, these were combined with the observations in the next cell.

It is apparent from the results presented in Table 2 that the individual models used underpredict short headways and overpredict longer headways. Columns 5-8 indicate the traffic-lane volume that gives the best single fit for that model and the associated chi-square value. These last four columns clearly show that in all of the models listed the best fit was obtained for low-volume conditions where arrival patterns were generally random in nature.

Testing with Combined Models

An effort was made to combine two headway models into a composite and a more complex one, assuming that the total area under the probability distribution curve was unity. A computer program was developed to carry out the necessary mathematical manipulation. Headways up to 5 s were described by the Schuhl model, and those greater than 5 s were described by one of the other two models. The Schuhl model was selected to estimate shorter headways within the combined model because our experience indicated that this model was capable of predicting such short headways. Columns 5-8 of Table 2 give the results of fitting the two combined models, Schuhl and Pearson Type III and Schuhl and Negative Exponential, on the field data. The results indicate that this effort was not very successful. Column 2 of Table 2 indicates that the underprediction of short headways is a problem with the combined models as well.

Calibration of Schuhl Model with North Carolina Data

A decision was made to develop parameters for the Schuhl model by using North Carolina data. The decision to adopt the Schuhl model for this study was based on the finding that, as an individual model, the Schuhl model provided the best fit for North Carolina field data, although the question of underprediction or overprediction remained. The choice of this complex model (which requires the use of at least five parameters) was considerably affected by the fact that the simple models tested earlier were incapable of incorporating the mixed random and nonrandom aspects of traffic flow. The principle of least squares was applied in developing the revised model parameters; the field data were tested by conducting an orderly and successive revision of the model parameters until the squared differences between the observed and expected frequencies were minimized.

The Schuhl model (here called the modified Schuhl model) was ultimately selected as the model that provided the best overall fit for the headway distributions surveyed. Table 3 gives the results of the chi-square test in which the headway distributions generated by the Schuhl model were compared with those recorded in the field; as indicated earlier, the hypothesis tested was that there is no difference between the field and the model-generated headway distributions. Table 3 indicates that this hypothesis was rejected in three cases (two lanes at site 9) for the 1 percent level of significance. Each of these three cases had an inordinate number of short headways in the 1- to 5-s range. The acceptance of the null hypothesis (implying "no difference" between the model output and the observed data) in a total of 15 out of 18 cases clearly demonstrated the capability of the model to reasonably duplicate headway patterns observed in the field. It was evident from the testing that underprediction of short headways is a problem with most of the models and that neither the combination of the two models nor the development of new parameters for the Schuhl model resolved the problem satisfactorily. The modified Schuhl model was used to generate a headway distribution for providing a fixed input queue of vehicles to the simulation model.

Table 3. Field versus model-generated headway distributions.

Site No.	$\chi^2_{calculated}$ Value for Comparing Field and Simulated Headway Distributions: Lane 1	Lane 2	χ^2 0.01 (df = 14)	Outcome of Testing[a]
1	26.10	28.42	29.10	Accept H_0
2	26.95	14.51	29.10	Accept H_0
3	25.91	8.60	29.10	Accept H_0
4	22.49	22.82	29.10	Accept H_0
5	16.95	9.84	29.10	Accept H_0
6	32.06	20.40	29.10	Reject H_0 (lane 1) Accept H_0 (lane 2)
7	10.30	24.45	29.10	Accept H_0
8	17.65	22.93	29.10	Accept H_0
9	42.68	39.88	29.10	Reject H_0

[a] H_0 = no difference between field data and simulation data.

The general form of the Schuhl model is as follows:

$$P(h \geq t) = \gamma e^{-(t-\epsilon)/t_1} + (1-\gamma) e^{-t/t_2} \quad (1)$$

where

$P(h \geq t)$ = probability of a headway equal to or greater than time t;
γ = ratio of vehicles in the restrained group to all vehicles = C x (lane volume/100), where C is a constant;
ϵ = minimum headway for vehicles in the restrained group (s);
t_1 = parameter that is a function of the average headway of the restrained group (s);
t_2 = parameter that is a function of the average headway of the unrestrained group (s) = a - b x (lane volume/100), where a and b are constants; and
e = base of Naperian logarithms.

The Schuhl model was calibrated by using the following values, based on North Carolina field data: $\bar{t}_1 = 1.996$, $\bar{t}_2 = 37.78 - (4.544V/100)$, and γ = 0.2693 + (0.056 16V/100), where V = lane volume per hour and ϵ = 1 s.

Efforts to fit the Schuhl model for single-lane traffic flow were originally reported by Grecco and Sword in 1968 on their study of US-52 in Lafayette, Indiana, where data were collected for each lane of the two-lane portion of that facility (7). Grecco and Sword recognized that Schuhl had attempted to divide the set of all vehicle spacings into two subsets, that of restrained and unrestrained groups (2, p. 61):

> Before proceeding further it must be observed that the first set spacing might apply to retarded vehicles which are prevented from passing by opposing traffic and the second set to free-moving vehicles which are able to pass at will.

According to Grecco and Sword (7, p. 36),

> By definition the restrained group is composed of those drivers who are traveling at or below their desired speed but are resigned to traveling in a platoon. The unrestrained group includes those drivers, not in a platoon, traveling at their desired speed and those drivers traveling below their desired speed in the platoon who are attempting or desiring to pass.

Clearly, both Schuhl and Grecco and Sword envisioned both the restrained and unrestrained groups to be in the same traffic lane (as shown by Schuhl's words "prevented from passing by opposing traffic" and the two-lane experimental site used by Grecco and Sword). During the testing of the North

Figure 2. Probability distribution nomograph based on parameters developed by Sword and Grecco (7).

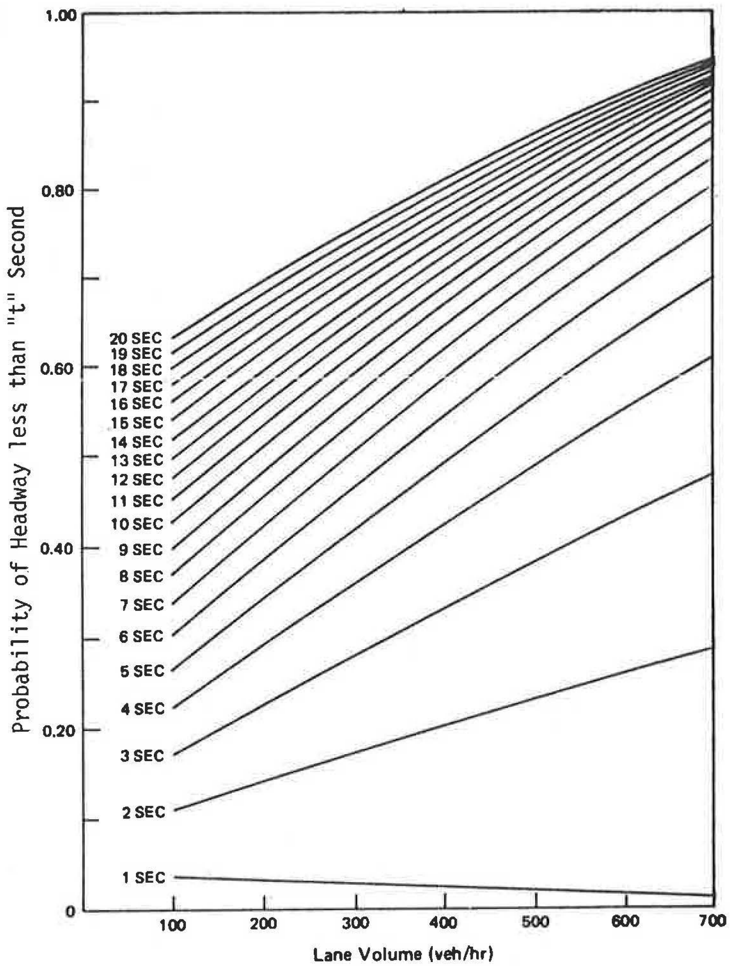
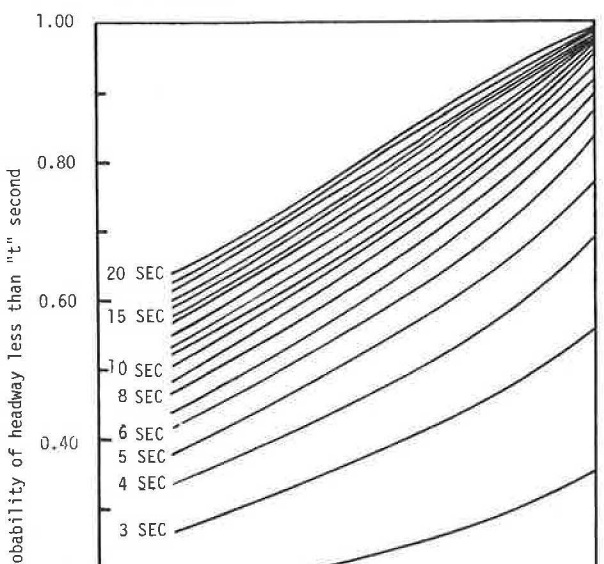


Figure 3. Probability distribution nomograph based on parameters developed in the North Carolina study.



Carolina data with the Schuhl model, we worked under similar postulations--namely, that traffic in a single lane contains two subsets (restrained and unrestrained groups) and that, at higher volume levels, the proportion of the restrained group tends to be higher. Furthermore, the parameters describing the restrained and unrestrained groups (γ, $\bar{t}_1$, and $\bar{t}_2$ in Equation 1) were developed as a part of the model-testing process.

Grecco and Sword (7) developed a nomograph for calculating the probabilities of various headways ("cumulative-percentage-less-than" curves) by using the parameters for the Schuhl model and data collected from Lafayette, Indiana. A similar nomograph was developed in the North Carolina study by using the Schuhl model parameters estimated based on nine sets of field data. These two nomographs are shown in Figures 2 and 3, respectively. The cumulative-percentage-less-than frequencies are also represented in Table 4 for various volume groups for the modified Schuhl model. It should be noted that both of these nomographs are based on the same distribution model--the Schuhl model--although the parameters used in the plots are somewhat different. The differences observed in the two cumulative distribution curves are the result of these different parameters.

DEVELOPMENT OF THE INPUT QUEUE

The preparation of the speed-headway program was carried out as part of the testing and calibration of the overall simulation model (10). A normal distribution function that is completely defined by

Table 4. Probability of headway less than t seconds as predicted by the modified Schuhl model.

Headway (s)	Probability by Lane Volume in Vehicles per Hour						
	100	200	300	400	500	600	700
1	0.0200	0.0212	0.0228	0.0252	0.0289	0.0357	0.0520
2	0.1677	0.1920	0.2172	0.2437	0.2727	0.3071	0.3571
3	0.2642	0.3029	0.3427	0.3844	0.4294	0.4814	0.5525
4	0.3295	0.3772	0.4262	0.4775	0.5327	0.5960	0.6799
5	0.3758	0.4291	0.4839	0.5413	0.6031	0.6735	0.7646
6	0.4103	0.4671	0.5257	0.5870	0.6530	0.7279	0.8223
7	0.4375	0.4966	0.5576	0.6215	0.6901	0.7676	0.8627
8	0.4600	0.5206	0.5832	0.6487	0.7190	0.7978	0.8917
9	0.4796	0.5412	0.6047	0.6713	0.7425	0.8217	0.9132
10	0.4971	0.5594	0.6236	0.6907	0.7623	0.8412	0.9294
11	0.5134	0.5760	0.6406	0.7080	0.7796	0.8576	0.9421
12	0.5286	0.5914	0.6562	0.7236	0.7950	0.8718	0.9521
13	0.5430	0.6060	0.6708	0.7380	0.8080	0.8841	0.9601
14	0.5569	0.6198	0.6845	0.7515	0.8216	0.8951	0.9666
15	0.5702	0.6330	0.6975	0.7641	0.8333	0.9049	0.9720
16	0.5830	0.6457	0.7099	0.7760	0.8442	0.9137	0.9765
17	0.5954	0.6579	0.7218	0.7872	0.8543	0.9216	0.9802
18	0.6075	0.6697	0.7331	0.7979	0.8637	0.9288	0.9833
19	0.6191	0.6810	0.7440	0.8079	0.8725	0.9353	0.9859
20	0.6304	0.6920	0.7544	0.8175	0.8807	0.9412	0.9881

its mean and its standard deviation was used to generate individual (desired) speeds for each input vehicle, given the mean and standard deviation specified by the user. The mean and standard deviation can be calculated by using relations developed as part of the process of model calibration (12).

After individual speeds have been generated, a random list of desired speeds is prepared and assigned to each vehicle to be input to the simulated roadway. The listing of headways generated by the modified Schuhl model is then paired by random assignment with the desired-speed list. The merging of these two arrays provides a sequential list of vehicles ready to be entered into the simulation routine. Each vehicle in the queue is thus assigned a desired speed, headway, and vehicle-type designation. After the vehicle moves onto the simulation roadway, the car-following rule built into the simulation model causes further adjustments to the headways to reflect the effect of the speed differential between the vehicle and the following car. This feature is discussed in more detail elsewhere (11,12).

CONCLUSIONS

The following conclusions can be made as a result of the research reported in this paper:

1. For a wide range of lane volumes--80-632 vehicles/h/lane--no one of the headway models tested in this study (the Negative Exponential, Pearson Type III, and Schuhl models) provided an adequate fit to the field data with an acceptable level of statistical reliability. Simple models particularly were found to be inadequate to describe the arrival patterns for the ranges of traffic volume tested.
2. Combining two headway models into a composite model is not likely to result in any improvement in predictive capability.
3. Underprediction of shorter headways is generally a problem with most headway-distribution models within the volume ranges studied.
4. It is possible to develop specific model parameters for a modified Schuhl model to predict the distribution of headways that incorporate traffic-flow conditions with characteristics ranging from random to nonrandom. The choice of such a complex model over simple ones can be justified by its improved predictive capability.
5. Most of the models studied provided a decent fit for traffic data in light-volume conditions (i.e., approximately 150 vehicles/h/lane).

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The contents of this paper reflect our views, and we are responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the North Carolina Department of Transportation and Highway Safety or the Federal Highway Administration.

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Abridgment

Changes in Traffic Speed and Bunching Near Transition Points Between Two- and Four-Lane Rural Roads

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The results of several field experiments conducted to measure changes in traffic performance caused by transitions from two to four lanes on rural highways are reported. Vehicle speed and bunching data were recorded at a number of points upstream and downstream of a transition. A microprocessor-based recorder unit and flat metal-and-rubber detector strips were used. The results show that changes in traffic performance with position occur more rapidly on entering a four-lane road than on merging into two lanes. The effects of a change in road quality at the transition were isolated. The results are applicable to the study of rural overtaking lanes and the validation of simulation models and may also be of interest in the study of rural transition points and temporary detours.

Several field experiments were conducted as part of a simulation study of the performance of rural overtaking lanes. The aims of the experiments were (a) to provide validating data for two- and four-lane simulation models and (b) to investigate directly the changes in traffic parameters that occur in transition between two- and four-lane rural road sections (1).

The experiments were designed to measure traffic mean speed and bunching at a number of points along the road in order to determine equilibrium performance and the rate of change of this performance attributable to the transition in road type. Although the data represent only a limited range of traffic conditions at two sites, the results should be of interest in the study of rural traffic behavior, especially in relation to passing lanes, lane transitions, and temporary detours.

This paper reviews variations in mean speed and bunching with distance downstream of a four- or two-lane merge point or a two- to four-lane demerge point on a rural highway, at various flow rates. The effects of variations in road quality are also briefly discussed.

DATA COLLECTION AND REDUCTION

Field observations were made at two sites near Frankston, Australia, an outer suburban center about 40 km from Melbourne (see Figure 1). Three experiments were conducted between July and October 1978. In all, more than 30 000 vehicle observations were made over 15 h, or 50 traffic-h if each recording station is considered separately. Only Sunday traffic was recorded; this included a significant proportion of recreational traffic but few trucks.

The physical layout of each site and the positions of the stations used for recording are shown in Figure 2. It should be noted that vehicles in Australia travel on the left side of the road. The merge site involved a divided four-lane arterial road merging into a two-lane, two-way carriageway in mildly undulating terrain. The Victoria state speed limit of 100 km/h applied throughout, and curves on the two-lane road section limited overtakings. At the demerge site, a narrow two-lane road with a 90-km/h speed limit joined a newly constructed freeway with a 100-km/h speed limit.

Vehicle speed and headway data were measured by using flat metal-and-rubber detector strips in pairs, coupled to a microprocessor-based recorder unit that stored the information on cassette tape. About 6 km of two-core wire was used to connect recording stations over 2 km of road. Because of wire limitations, some stations were recorded for shorter periods of time than others. Data on opposing traffic were also collected at the merge site.

The field data were later analyzed by using 5-min sample periods to give average values of the following parameters:

V = mean speed (km/h),
F = mean percentage following ("bunching"),
Q = flow rate (vehicles/h),
$Q2$ = opposing-flow rate at the merge site (vehicles/h), and
X = position downstream of the merge or demerge point (m).

Vehicles were defined as following if their headway from the preceding vehicle was ≤ 3 s. The term "bunching" is used in this paper to refer to the mean percentage of vehicles following in bunches (F). To provide a common basis for comparison, data from two-lane, one-way road sections were artificially merged into a single stream.

DATA ANALYSIS

The aim of this analysis was to establish relations between traffic mean speed and bunching and position