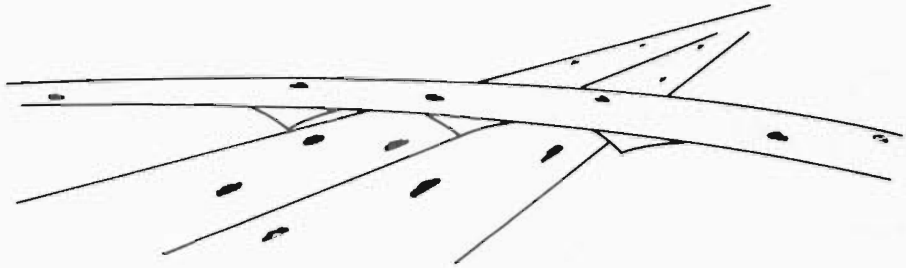

DEPARTMENTAL RESEARCH

Report Number: **S S—5.1**

A NEW TECHNIQUE FOR CAPACITY ANALYSIS OF RURAL TWO-LANE HIGHWAYS

TEXAS HIGHWAY DEPARTMENT

A NEW TECHNIQUE FOR CAPACITY ANALYSIS OF RURAL TWO-LANE HIGHWAYS

by

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RESEARCH REPORT SS 5.1

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A NEW TECHNIQUE FOR CAPACITY ANALYSIS OF
RURAL TWO-LANE HIGHWAYS

The purpose of this paper is to discuss a new method of analysis of rural two-lane highways to determine priorities for reconstruction. The procedure to be described not only points out the level of capacity at which any highway is operating but brings to attention the restrictive factors which tend to lower the capacity rating.

Rural two-lane highways serve the bulk of Texas' motoring public. Many of these are grossly underdesigned to carry their present traffic loads. One of our rural East Texas highways, for example, has had a traffic increase of near 50% in the past 10 years. I am <u>not</u> certain that this rate of increase <u>will</u> continue in the future. The only thing I <u>am</u> certain of is that traffic will continue to increase at some rate, this depending upon several contributing factors; some of these being: a continued increase in our population, a continued growth in our economy, a continued increase in our leisure time and a continued need for family mobility.

On the other side of the picture, however, there are many deterrents which will affect a continuing growth in traffic volumes. You hear from these from every level of our society -- ecologists, environmentalists, mass transportation advocates, etc. <u>Anti</u>-highway sentiment has been growing stronger each year. New highways on new locations may someday be a thing of the past. This is not surprising and, really, not even discouraging, for in the past 70 years our street and road system has only increased from 3 million miles to 3.7 million miles and the biggest part of this increase has been in expanding our nations suburban street system. My interpretation of this is that our rural highway system has not changed much since 1900 except in character. The trails or dirt roads are now paved two-lane highways. Someone back down the line has had to make the decisions to improve these dirt roads. These decisions were based on a need of the travelling public. This, then, is basically the problem we are faced with today if money is available for right of way and construction.

If the anti-highway deterrants succeed in curtailing the construction of new freeway systems, then this money must be spent to improve our existing system. This leads us to the question -- Where do we begin?

There is a statement in the Highway Design Manual which reads, "The volume of traffic served by a facility, either known or predicted, is the basis for determining what improvements, if any, are required." This, no doubt, is the single most important factor that must be considered in planning highway improvements. Other factors we have always <u>used</u> in planning a highway project include: accident data, surface and roadway structural conditions and, many times, the availability of right of way. <u>All</u> of these are important; -- any <u>one</u> of these factors: traffic volume, accidents, structural failure or right of way availability may be of sufficient importance to pre-empt an analytical system of programming highway improvements.

This discussion will assume that these things will and should happen. However, we should have a basic plan. We ought to know ahead of time where our most underdesigned highways are. We ought to be systematically eliminating these problems from our system as money becomes available.

We should begin with those rural two-lane highways that can be rated as being the most seriously underdesigned based on the amount of traffic using them. A technique, which will be discussed in this paper, has been devised to rate a rural two-lane highway using methods, tables and equations from the 1965 edition of The Highway Capacity Manual and from the Texas Highway Department Design Manual.

For want of a better term I've called this technique "capacity analysis." And this technique basically is this: when the design of a highway, including all its existing good and bad features, is related to its average daily traffic it is possible to determine the percentage of a desirable capacity at which that highway is operating. Percentage of desirable capacity, then, is the criteria we have used for rating a highway or section of a highway as to its priority for reconstruction.

At this point it might be useful to define several terms -- or rather give you my interpretation of them with relation to their use in this paper.

Capacity: This is the maximum number of vehicles that can reasonably be expected to pass over a given section of a lane or a roadway in one direction, or in both directions for a two-lane highway, during a given time period under prevailing roadway and traffic conditions. Capacity, then, is a variable sort of thing. One cannot say a two-lane highway may be expected to carry 1400 vehicles per hour or any other assigned figure without first examining the prevailing conditions.

Prevailing Conditions: Are of 3 types. The first is related to the physical characteristics of the roadway. This includes the surface conditions, roadway width, lateral clearance from obstructions and any other condition which may be physically altered to improve the highway. Another prevailing condition is the nature of the traffic on the roadway. Conditions in this second group change from one hour to the next. These include, for example, the percentage of trucks to passenger vehicles, the types of drivers that make up the traffic stream, and the average speed of the traffic stream. The last are the ambient conditions, which are present at all times. These relate primarily to the weather and the time of day.

Another term with which most of us are only vaguely familiar is Level of Service. This term broadly describes or rates the operating condition of a roadway at any given time under conditions prevailing at that time. It is a qualitative measure of the effect of a number of factors on the traffic stream. These include speed, travel time, traffic interruptions, freedom to maneuver, safety, driving comfort, convenience and operating costs. From the viewpoint of the driver low volumes provide higher levels of service and high volumes provide low levels. The level of service, then, varies inversely as some function of the traffic density. This is particularly true if we are rating an existing highway, because roadway conditions are fixed and the character of the traffic stream is the variable.

The Highway Capacity Manual describes 6 levels of service:

Level of Service A (Free Flow): There is very little restriction on maneuvering or operating speed. (60 miles per hour or higher).

Level of Service B (Stable Flow): Operating speeds are restricted somewhat (50 miles per hour or higher). Most drivers are affected, though not unreasonably, by other vehicles in the traffic stream.

Level of Service C (Lower Range of Stable Flow): Operating speeds and maneuverability are directly affected by the total volume of traffic. The average traffic speed will not be below 40 miles per hour at this level.

Level of Service D (Approaching Unstable Flow): Operating speeds in this range fall to 35 miles per hour. 1700 vehicles per hour may be maintained for brief periods of time without a high probability of breakdown in flow.

Level of Service E (Unstable Flow): Operating speeds in the neighborhood of 30 miles per hour but may vary considerably. Volumes under ideal conditions may reach 2000 vehicles per hour which is the theoretical capacity.

There is a forced flow level below this, which is called Level F, but volumes are below capacity and operating speeds average below 30 miles per hour.

As mentioned in describing Level of Service E, the theoretical capacity of a single lane of a multi-laned highway is 2000 vehicles per hour. This is also true for a two-lane, two-way highway because passing maneuvers must be performed in the lane normally used for oncoming traffic. With traffic traveling in both directions, slower moving vehicles create gaps between vehicles that can be filled only by passing maneuvers. These same gaps may be used for passing maneuvers for oncoming traffic in the opposing lane. Traffic, then, on two-lane highways during heavy volume conditions oscillates between the formation of queues with gaps between them and the continuous use of these gaps for passing maneuvers. Studies have shown that this type of operation limits the flow to a maximum of 1000 vehicles per hour in each direction or at the other extreme to some figure approaching 2000 vehicles per hour in one direction leaving the other lane free for passing maneuvers.

The capacity of a two-lane rural highway, therefore, is also 2000 vehicles per hour total regardless of distribution by direction.

The foregoing discussion of Capacity and Level of Service has been with the assumption that highways operate under ideal conditions. However, there are many factors associated with a normal highway which will make it less than ideal. Through research these factors have been assigned numerical values and can be used to reduce a highway's theoretical operating capacity directly proportional to its restrictive conditions.

Roadway conditions for which reduction factors have been derived include lane width, lateral clearance, roadway grades, average traffic speeds, and percentage of no-passing areas. The effect of restrictions due to lane width and lateral clearance has been combined into one table. This table covers a range of lane widths from 9 to 12 feet and a range of lateral clearances from 0 to 6 feet.

At this point one should take into consideration that adequate shoulders of paved materials (4 feet or more) increase the effective width of an adjacent traffic lane by 1 foot.

The general terrain through which a highway runs also affects its capacity. This is true more so with trucks than with passenger cars and, therefore, a reduction factor has been derived which may be applied to reduce the theoretical capacity of a highway in relation to its percentage of truck traffic and also in relation to the type of terrain through which it travels.

The Highway Design Manual states that a Level of Service "C" is recommended as the lowest level that should be used for design although <u>higher</u> levels are preferred. The Capacity Manual states that the lower limit of Level "B" or possibly the upper limit of Level "C" is used <u>generally</u> in the design of rural highways. For the purpose of uniformity and also in an effort to obtain results that seemed reasonable a Level of Service "C" was chosen as a basis for this report.

Either "B" or "C" can be used as long as it is used uniformly.

After assuming a Level of Service "C" the next step to be performed is to make physical surveys of the highways to be studied. The highways should be broken down into sections with physical features as nearly uniform as possible. These sections should also contain as nearly as possible uniform average highway speeds and a uniform terrain. Each section should be homogeneous.

Once the sections have been chosen field measurements should be taken to determine lane widths, lateral clearances, average highway speeds and lengths of "no-passing" zones. Much of this information may be obtained from Highway Department Logs. The percentage of "no-passing" zones with respect to the total section lengths should be found by actually measuring the lengths of the yellow "no-passing" stripes and relating that to the total section length. Average highway speeds may be actually measured by radar units and in this technique are the average, <u>not</u> the 85 percentile speed.

In addition to these measurements, the percentage of truck traffic and the Average Daily Traffic for each of these sections need to be obtained. This information can be furnished by D-10 along with a factor which provides the ratio of the Design Hourly Volume to the Average Daily Traffic.

The Capacity Equation

$$\text{Capacity} = 2000\ (v/c)\ W_C\ T_C$$

is the basic equation used in determining the theoretical capacity of any highway subject to whatever limitations or restrictions that may be part of its existing features.

A definition of the various terms used in this equation are as follows:

2000 is the theoretical capacity of a two-lane highway.

(v/c) is the Service Volume/Capacity Ratio. This may be obtained from Table 3. Using factors resulting from field measurements such as percentage of passing sight distance and average highway speeds and by interpolation a restrictive factor relating to Level of Service "C" may be obtained.

W_C is the adjustment factor relating to lane width and lateral clearance. Using field measurements and applying them to information in Table 1 the capacity reduction factor relating to these restrictions may be obtained.

T_C is the truck reduction factor. Data from D-10 and from field observations applied to Table 2 will furnish this reduction factor.

When this information is applied to the capacity equation a Level of Service "C" theoretical existing capacity in vehicles per hour may be obtained. The next procedure is to compare this figure with the existing volumes of traffic now using the highway under consideration. To do so requires that the capacity calculation be converted from vehicles per hour to vehicles per day. To do this a Design Hourly Volume Factor (30th Highest Hour) may be obtained from D-10 for any section of highway. The theoretical capacity divided by the DHV factor will convert the units to vehicles per day which is in a form comparable to figures furnished by D-10 on highway traffic maps.

The following pages are tables and samples of forms used in making a capacity analysis.

TABLE 10.8—COMBINED EFFECT OF LANE WIDTH AND RESTRICTED LATERAL CLEARANCE ON CAPACITY AND SERVICE VOLUMES OF TWO-LANE HIGHWAYS WITH UNINTERRUPTED FLOW

DISTANCE FROM TRAFFIC LANE EDGE TO OBSTRUCTION (FT)	ADJUSTMENT FACTORS W_L AND W_c FOR LATERAL CLEARANCE AND LANE WIDTH[a]															
	OBSTRUCTION ON ONE SIDE ONLY[b]								OBSTRUCTIONS ON BOTH SIDES[b]							
	12-FT LANES		11-FT LANES		10-FT LANES		9-FT LANES		12-FT LANES		11-FT LANES		10-FT LANES		9-FT LANES	
	LEVEL B	LEVEL E[c]	LEVEL B	LEVEL E[c]	LEVEL B	LEVEL E[c]	LEVEL B	LEVEL E[c]	LEVEL B	LEVEL E[c]	LEVEL B	LEVEL E[c]	LEVEL B	LEVEL E[c]	LEVEL B	LEVEL E[c]
6	1.00	1.00	0.86	0.88	0.77	0.81	0.70	0.76	1.00	1.00	0.86	0.88	0.77	0.81	0.70	0.76
4	0.96	0.97	0.83	0.85	0.74	0.79	0.68	0.74	0.92	0.94	0.79	0.83	0.71	0.76	0.65	0.71
2	0.91	0.93	0.78	0.81	0.70	0.75	0.64	0.70	0.81	0.85	0.70	0.75	0.63	0.69	0.57	0.65
0	0.85	0.88	0.73	0.77	0.66	0.71	0.60	0.66	0.70	0.76	0.60	0.67	0.54	0.62	0.49	0.58

[a] Adjustment W_c given for level E, capacity, and W_L for level B; interpolate for others.
[b] Includes allowance for opposing traffic.
[c] Capacity.

(From Highway Capacity Manual)

Table 1

Reduction Factors for Lane Width and Restricted Lateral Clearance

Table 2
Truck Reduction Factors

TABLE 10.9b—AVERAGE GENERALIZED ADJUSTMENT FACTORS FOR TRUCKS[b] ON TWO-LANE HIGHWAYS, OVER EXTENDED SECTION LENGTHS

PERCENTAGE OF TRUCKS, P_T	TRUCK ADJUSTMENT FACTOR, T								
	LEVEL TERRAIN			ROLLING TERRAIN			MOUNTAINOUS TERRAIN		
	LEVEL OF SERVICE A	LEVELS OF SERVICE B AND C	LEVELS OF SERVICE D AND E[c]	LEVEL OF SERVICE A	LEVELS OF SERVICE B AND C	LEVELS OF SERVICE D AND E[c]	LEVEL OF SERVICE A	LEVELS OF SERVICE B AND C	LEVELS OF SERVICE D AND E[c]
1	0.98	0.99	0.99	0.97	0.96	0.96	0.94	0.92	0.90
2	0.96	0.97	0.98	0.94	0.93	0.93	0.89	0.85	0.82
3	0.94	0.96	0.97	0.92	0.89	0.89	0.85	0.79	0.75
4	0.93	0.95	0.96	0.89	0.86	0.86	0.81	0.74	0.69
5	0.91	0.93	0.95	0.87	0.83	0.83	0.77	0.69	0.65
6	0.89	0.92	0.94	0.85	0.81	0.81	0.74	0.65	0.60
7	0.88	0.91	0.93	0.83	0.78	0.78	0.70	0.61	0.57
8	0.86	0.90	0.93	0.81	0.76	0.76	0.68	0.58	0.53
9	0.85	0.89	0.92	0.79	0.74	0.74	0.65	0.55	0.50
10	0.83	0.87	0.91	0.77	0.71	0.71	0.63	0.53	0.48
12	0.81	0.85	0.89	0.74	0.68	0.68	0.58	0.48	0.43
14	0.78	0.83	0.88	0.70	0.64	0.64	0.54	0.44	0.39
16	0.76	0.81	0.86	0.68	0.61	0.61	0.51	0.41	0.36
18	0.74	0.80	0.85	0.65	0.58	0.58	0.48	0.38	0.34
20	0.71	0.77	0.83	0.63	0.56	0.56	0.45	0.36	0.31

[b] Not applicable to buses where they are given separate specific consideration; use instead Table 10.9a in conjunction with Table 10.12.
[c] Capacity.

(From Highway Capacity Manual)

Table 3

Volume/ Capacity Ratios

TABLE 10.7—LEVELS OF SERVICE AND MAXIMUM SERVICE VOLUMES ON TWO-LANE HIGHWAYS UNDER UNINTERRUPTED FLOW CONDITIONS
(NORMALLY REPRESENTATIVE OF RURAL OPERATION)

LEVEL OF SERVICE	TRAFFIC FLOW CONDITIONS: DESCRIPTION	TRAFFIC FLOW CONDITIONS: OPERATING SPEED[a] (MPH)	PASSING SIGHT DISTANCE >1,500 FT (%)	SERVICE VOLUME/CAPACITY (v/c) RATIO: BASIC LIMITING VALUE[a] FOR AHS OF 70 MPH	WORKING VALUE FOR RESTRICTED AVERAGE HIGHWAY SPEED[b] OF 60 MPH	50 MPH	45 MPH	40 MPH	35 MPH	MAXIMUM SERVICE VOLUME UNDER IDEAL CONDITIONS, INCLUDING 70-MPH AHS (PASSENGER CARS, TOTAL, BOTH DIRECTIONS, PER HOUR)
A	Free flow	≥60	100	≤ 0.20	—	—	—	—	—	400
			80	0.18	—	—	—	—	—	
			60	0.15	—	—	—	—	—	
			40	0.12	—	—	—	—	—	
			20	0.08	—	—	—	—	—	
			0	0.04	—	—	—	—	—	
B	Stable flow (upper speed range)	≥50	100	≤ 0.45	≤ 0.40	—	—	—	—	900
			80	0.42	0.35	—	—	—	—	
			60	0.38	0.30	—	—	—	—	
			40	0.34	0.24	—	—	—	—	
			20	0.30	0.18	—	—	—	—	
			0	0.24	0.12	—	—	—	—	
C	Stable flow	≥40	100	≤ 0.70	≤ 0.66	≤ 0.56	≤ 0.51	—	—	1400
			80	0.68	0.61	0.53	0.46	—	—	
			60	0.65	0.56	0.47	0.41	—	—	
			40	0.62	0.51	0.38	0.32	—	—	
			20	0.59	0.45	0.28	0.22	—	—	
			0	0.54	0.38	0.18	0.12	—	—	

(From Highway Capacity Manual)

RADAR MOTOR VEHICLE SPEED
Field Tally Sheet

EXHIBIT 1

Date 10-16-69 County Tyler Highway US 69 Location 05 Mi/ North of Tyler Hardie Co. Line

Time: From 10:05 To 11:35 Weather Clear Surface Type Asphalt

M.P.H.	Automobiles Direction ↓ Warren	Total	Automobile Direction ↑ Village Mills	Total #6
>80			86-92	103
80				101
78		106		100
76		105		99
74		104		
72		99		97
70		96		93
68		85		87
66		79		75
64		65		70
62		53		62
60		45		49
58		35		36
56		25		28
54		16		22
52		12		18
50		8		15
48		4		7
46		2		5
44				4
42				
40		1		3
38				2
36				
34				
32				1
30				
28				
26				
24				
22				
20	106x.85 = 90.10		103x.85 = 87.55	
18				
16	69		68	
14				
12				
10	6,596✓		6,300✓	
8				
6				
4				

AHS = $\frac{12896}{209}$ = 61.7 = 62 mph

Total Cars 106✓ Total Cars 103 ✓
85% Speed 69 85% Speed 68
Remarks
12,896

Recorder [illegible]

~~4~~ ~~6~~ ~~11~~ ~~12~~ ~~13~~ 14

EXHIBIT 2

Zone #17 HIGHWAY US 69 COUNTY Hardin

YT- LENGTH	NO PASS ZONES				SURFACED SHOULDERS		6.60 – 8.58 = 1.98 3.96 TOTAL LENGTH
	LEFT		RIGHT				
	BEGIN	END	BEGIN	END	BEGIN	END	
.20	7.40	7.60					
.15	7.82	7.97					
.08	8.50	8.58					
.20			7.20	7.40			
.42			7.60	8.02			
1.05	"No Pass" Stripes						

% NP = 27%

Adequate Passing = 73%

~~#6 #12 #13~~ #15

CAPACITY COMPUTATIONS EXHIBIT 3

Highway: U.S. 69

Zone : 7

County : Tyler

Control: 200-7

Location: From: Doucette

To : Woodville

Right of Way : 100' Min.

Posted Speeds : 70/65

(A) DHV Factor (Estimate of 30th Highest Hour): 12.7 % of ADT

(B) 1968 ADT: 3720 vpd

Capacity Reduction Factors

Estimated % of Trucks = 17.2 % (Rolling) ∴Tc = .59

Pavement Width: 20' Type: ACP

Shoulder Width: 7'

Sod : X

Surfaced:

Restricted Width Strs.: 1) Big Turkey Ck: 24'W, 160'L

2)

3) ∴Wc = .64

% of Roadway with Adequate Sight Distance: 15 %

Average Highway Speed(209 Veh. Survey): 57 mph ∴v/c = .38

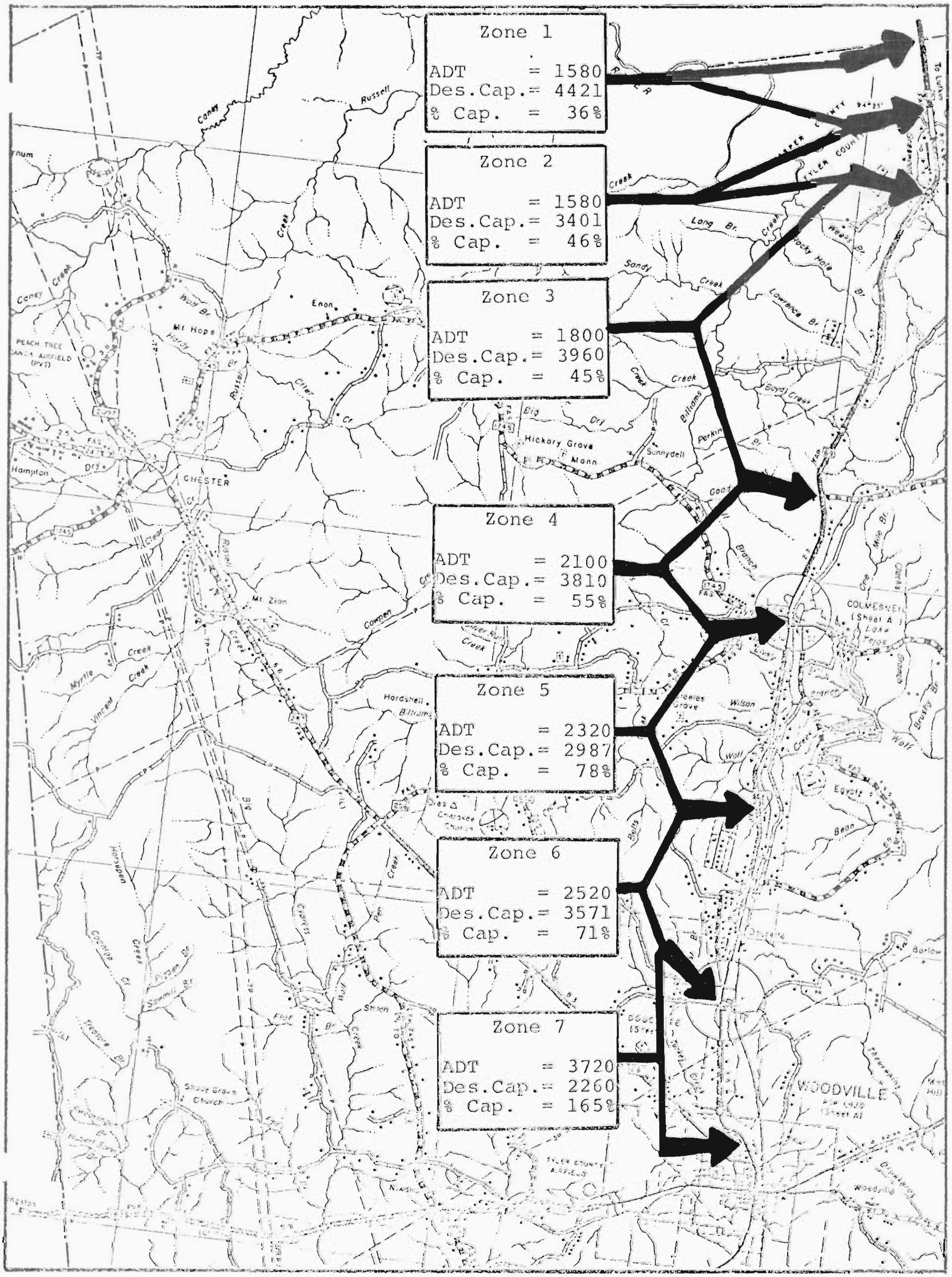
(C) Level of Service "C" Volume = 2000 Tc Wc v/c

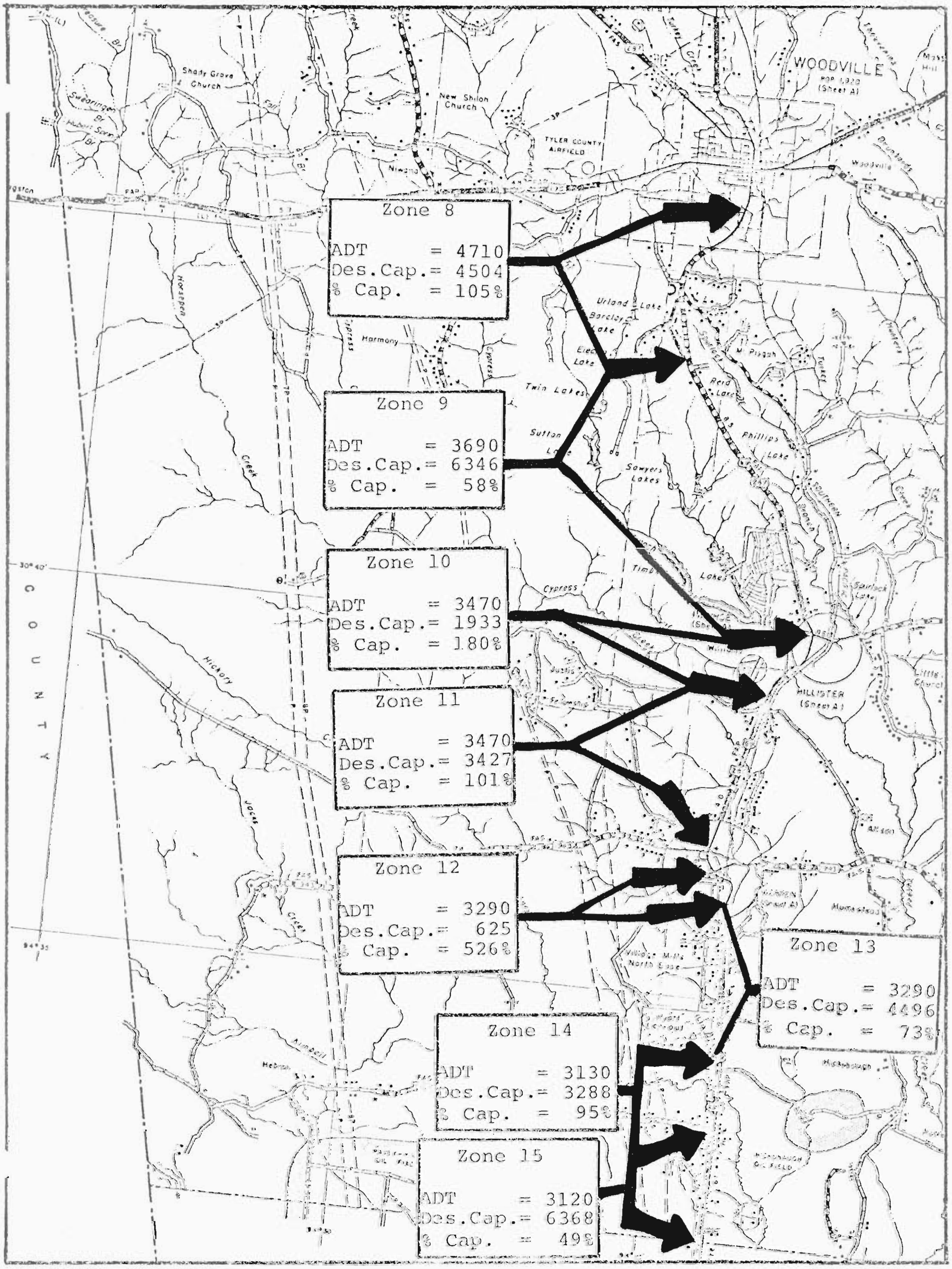
= 287 vph

(D) Existing Design Capacity = $\frac{C}{A}$ = 2260 vpd

% of Capacity Operation = $\frac{B}{D}$ = $\boxed{165\ \%}$

46 11 12 13 14 15 16


Zone 1
ADT = 1580
Des.Cap.= 4421
% Cap. = 36%
Zone 2
ADT = 1580
Des.Cap.= 3401
% Cap. = 46%
Zone 3
ADT = 1800
Des.Cap.= 3960
% Cap. = 45%
Zone 4
ADT = 2100
Des.Cap.= 3810
% Cap. = 55%
Zone 5
ADT = 2320
Des.Cap.= 2987
% Cap. = 78%
Zone 6
ADT = 2520
Des.Cap.= 3571
% Cap. = 71%
Zone 7
ADT = 3720
Des.Cap.= 2260
% Cap. = 165%
CHESTER
WOODVILLE
COLMESNEIL
Hickory Grove
Mt. Zion
Sunnydell



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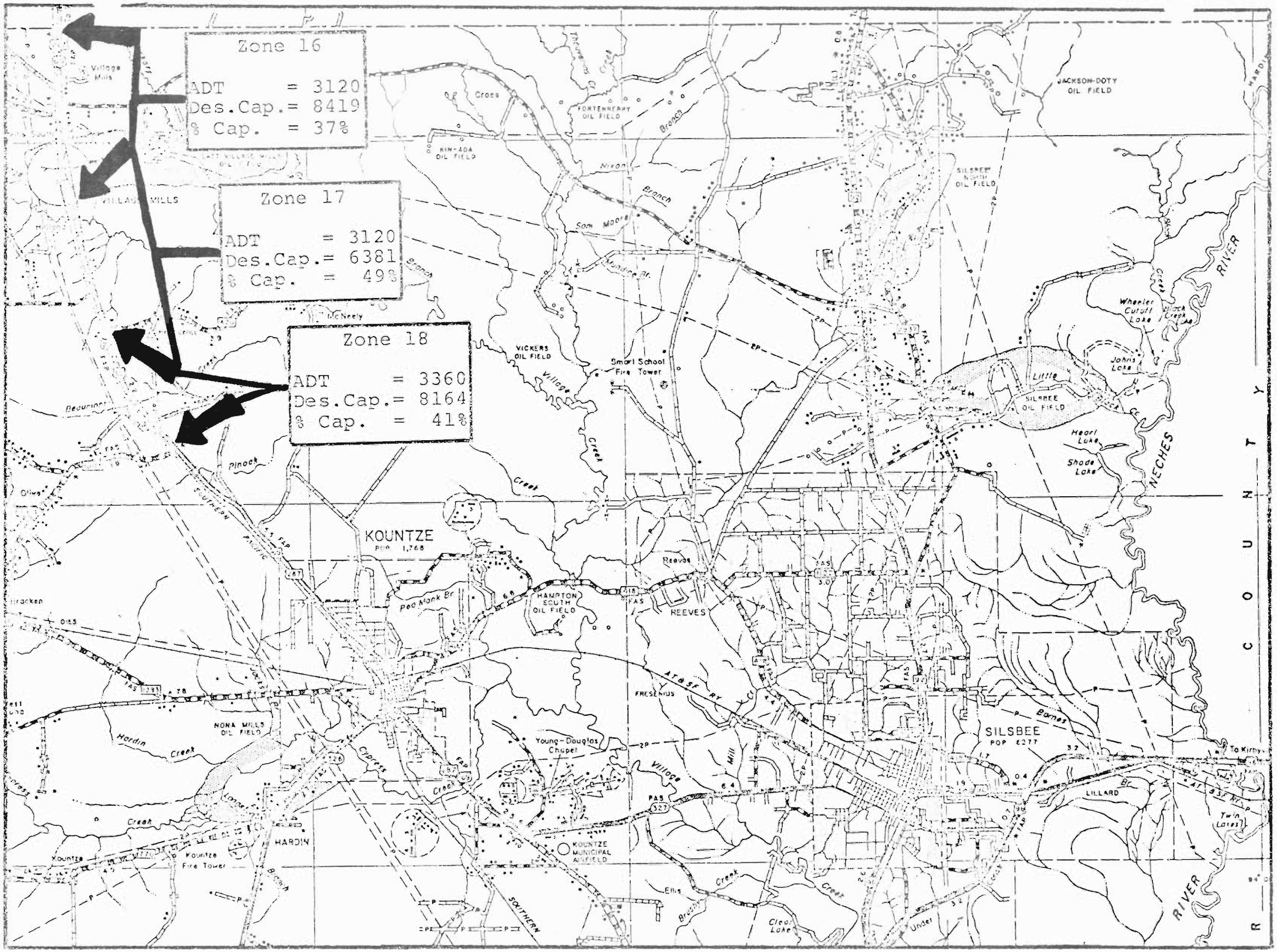
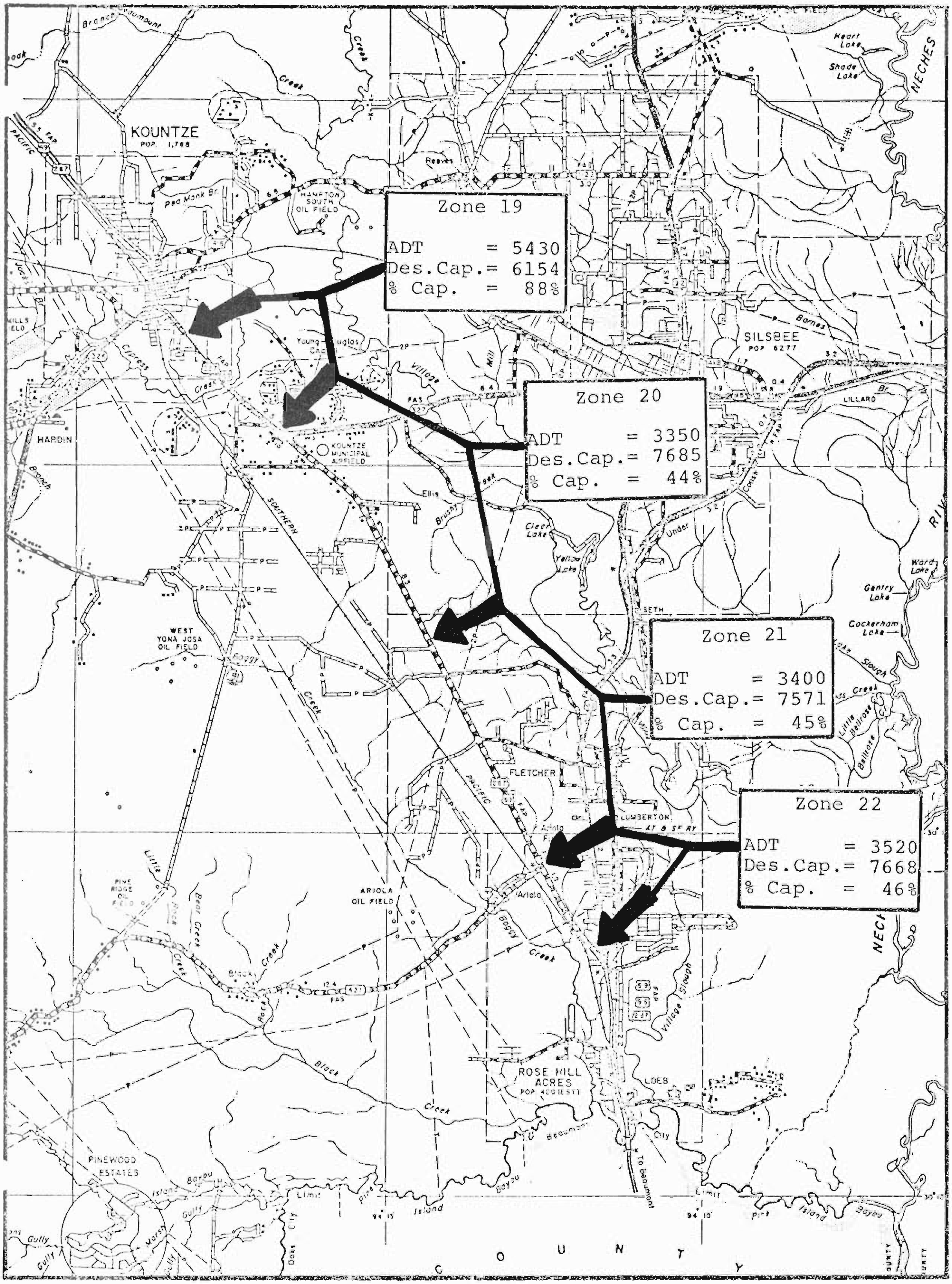

Zone 16
ADT = 3120
Des.Cap.= 8419
% Cap. = 37%
Zone 17
ADT = 3120
Des.Cap.= 6381
% Cap. = 49%
Zone 18
ADT = 3360
Des.Cap.= 8164
% Cap. = 41%
KOUNTZE
POP 1,768
SILSBEE
POP 6277
REEVES
HARDIN
NECHES RIVER
COUNTY
JACKSON-DOTY OIL FIELD
VICKERS OIL FIELD
HAMPTON SOUTH OIL FIELD
NONA MILLS OIL FIELD
KIM-ADA OIL FIELD
FORTENBERRY OIL FIELD
SILSBEE OIL FIELD
Smart School Fire Tower
Kountze Fire Tower
KOUNTZE MUNICIPAL AIRFIELD
Young-Douglas Chapel
AT & SF RY
SOUTHERN PACIFIC
Village Creek
Hardin Creek
Pinock
Fresenius
To Kirby
Twin Lakes



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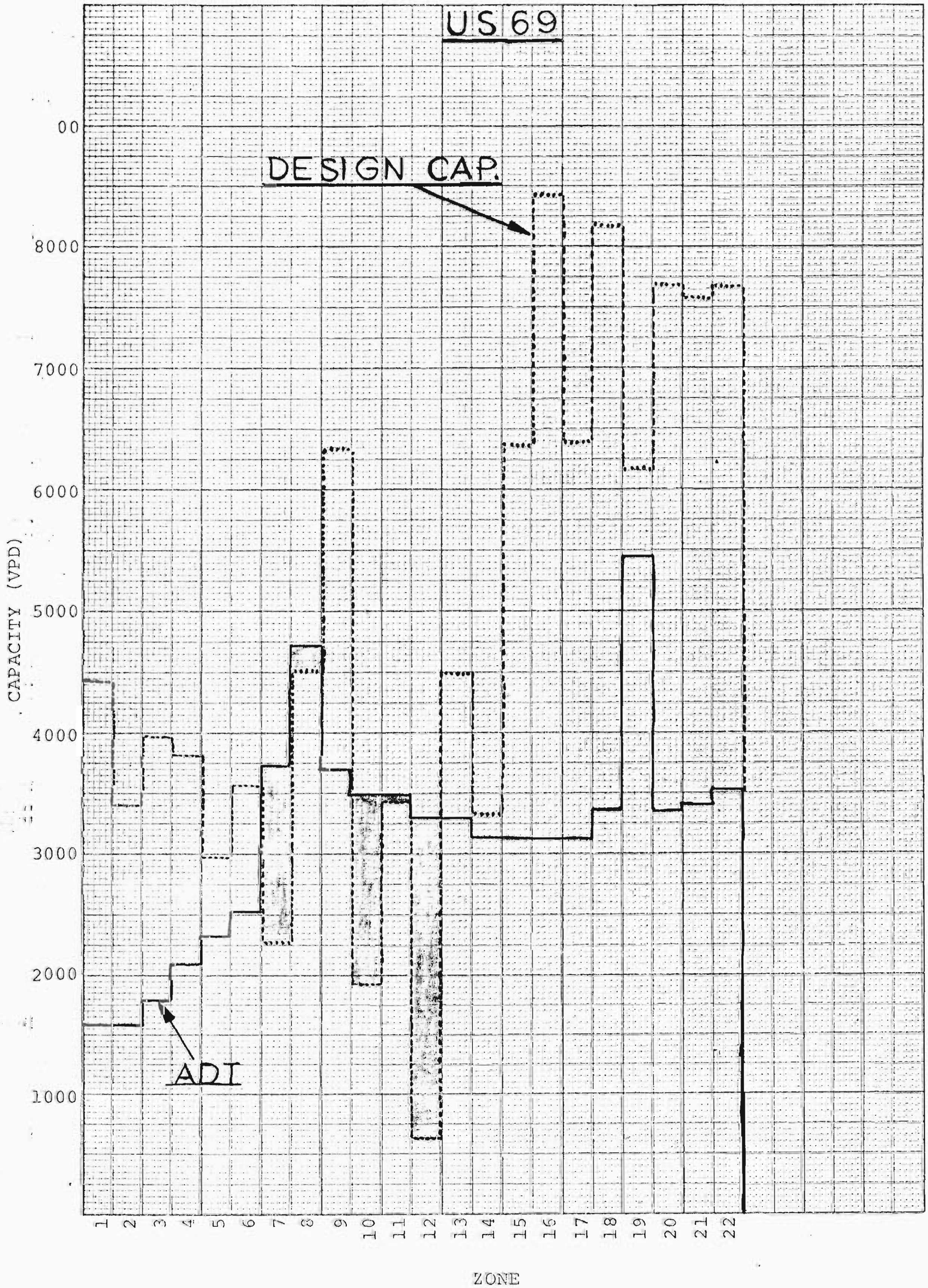

[illegible] [illegible] ~~11~~ ~~12~~ ~~13~~ ~~14~~ ~~15~~ ~~16~~ ~~17~~ ~~18~~ ~~19~~ ~~20~~ 21

DEFINITIONS AND SAMPLE PROBLEM

A. DHV Factor. This factor (30th Highest Hour) can be furnished by D-10 for each traffic count location on the traffic map. This is given as a percentage of ADT. For example, this factor may be 12.7%.

B. ADT. This is the Average Daily Traffic and may be obtained from the latest Traffic Maps. For purpose of typical problem, assume 3000 vpd.

CAPACITY REDUCTION FACTORS:

1. Estimated Percent of Trucks: This information may be obtained from D-10. Type of terrain should be from field observations. T_C (Truck Reduction Factor) may be obtained from Table 2. For instance, 10% trucks, rolling terrain, Level of Service C gives a reduction factor $T_C = 0.71$.

2. Lane width and lateral clearance and other roadway restrictions may be obtained from field measurements or from Highway Logs. W_C (Adjustment Factor for these Restrictions) may be obtained from Table 1. For instance, 2 foot clearance from narrow bridge obstruction with 10 foot lanes, Level of Service "C" (Interpolated) gives a reduction factor of $W_C = 0.72$.

3. Service Volume/Capacity Ratio (v/c) may be obtained from Table 3. Working with factors relating to Level of Service "C", with, for instance, 50% passing sight distance and average highway speeds of 48 miles per hour by interpolation, v/c = 0.41.

C. Level of Service "C" Volume = 2000 v/c T_C W_C

Substituting the above reduction factors into this equation:

$$2000\ (0.41)(0.71)(0.72) = 419 \text{ vph}$$

D. Existing Design Capacity $= \dfrac{\text{Factor C}}{\text{Factor A}} = \dfrac{419 \text{ vph}}{12.7\%} = 3300$ vpd

Therefore, if this highway has 3000 vpd (Factor B) from Traffic Map then it is operating at $\dfrac{3000}{3300} = 91\%$ of Level of Service "C" Capacity.