Comparison of Urban Transportation Modes in a Developing Country Context

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A COMPARISON OF URBAN TRANSPORTATION MODES FOR USE IN DEVELOPING COUNTRIES

I. Introduction

The original proposal for this project stated that the prime concern would be the analysis of urban transportation in developing countries. Attention has been given to Latin America as an example of developing countries. The goal was producing an understanding of the dissimilarities in the transport needs and systems between the cities of the U.S. and L.A.

In the past year, this goal has not been completely reached. However, strides along the path have been accomplished.

Three sections follow this brief Introduction. The first section covers the general description of the L.A. city and compares them to the cities of the U.S. The use of U.S. developed land-use models in undeveloped countries is attacked. Also, the undeveloped countries tend to use aid and loans in a disadvantageous manner. Secondly, three transport supply and cost models with fixed demand and two supply models with varied demand are presented. The group of three models were developed with the use of L.A. data whenever possible. The other two models are quite general and are used for comparisons and in order to introduce other transport characteristics. The final section concludes this project. The nature of the problems of this project are discussed and possible directions of future development in this topic are suggested.

II. General Description + Comparison of L.A. Urban Areas with U.S. Cities

Most of the more populous cities in Latin America are situated on or near the coast. Mexico City and Bogota are well-known exceptions. The coast location reflects a harbor-oriented economy going back to the colonial period. This has been experienced during colonial periods of many nations, most notably the United States. But the similiarity ends here. Due to the temperate climate, the United States relatively quickly expanded westward, building cities throughout the country.

The basic assumption of much of the land use theory developed for the United States is the "featureless plains". This assumption produces great limitations if used in respect to Latin America. The reason is that all the major cities are constrained by the structures of nature. Cities were built in mountain valleys (Caracas), on plateaus (Bogota), along the coast where growth was usually contained by topographic features (Buenos Aires) or in the mountains (Mexico City). All sites do have one common trait, that being that all the cities have a year round mild climate, since no major city has been built in the low elevations of the tropical zones. The topographic conditions of Latin America limit the locations of cities and their growth.

The form of urban areas in developing nations is generally unlike the cities of the United States. First, the cities in Latin America have grown in patches, instead of the outward growth in the U.S. The slums of the U.S. are in the central city while they tend to be peripheral in developing countries. Thirdly, middle and upperclass suburbanization is occurring in both cities. And lastly, that slums of Latin American cities are composed of groups, a rural village migrating to the urban area

and living together.[1]

William Alonso in his paper "The Form of Cities in Developing Countries" put forth the premise that the conditions that exist in developing countries are not the same as those which exist in the United States. He does not attempt to develop a model of city form for developing countries. Instead he examines the characteristics of the cities which would eventually be used in the formulation of a model.

During his examination, six major conditions were described:

1. Urban population growth is taking place at a much faster rate than in the developed countries. The increase is coming from rural villages, other cities, and from other countries. This produces great differences in values, attitudes, and income.
2. Developing countries are adapting to the automobile. Meanwhile, a great variety of transport modes exist side-by-side, including animals + humans as carriers of goods.
3. A rise in personal income exists, but is distributed in a very skewed manner (small middle class).
4. Social and political power plays a significant part in land controls; free market forces are minimal.
5. Developing countries are usually in the warmer climates. Thus many cities have developed along the coast or in the valleys where breezes or other amenities of the site can be taken advantage of.
6. The decision-making unit for residential or industrial purposes is the group.

[1]William Alonso, "The Form of Cities in Developing Countries", Papers of the Regional Science Association.

[2]Ibid.

These six characteristics can be found throughout Latin America.

Meanwhile suburbanization of the middle and upper classes exist for the same reasons that it occurred in the United States. First, there is the improvement in transportation that allows for longer trips, especially those for work. Second, the change in taste and culture produce a preference for more living space. And lastly, the rise in family income which allows for the purchase of land.

All of the movements and shifts that are occurring have placed large demands upon the transportation systems of the city. Economic growth development of the cities will be stifled if improvements in transport do not continue. In the past, countries have depicted piecemeal plans for developing their cities' systems. Furthermore, their analysis has been limited to the short run. This situation resulted from the requirements of foreign aid and loan programs. The foreign organizations required short term results to support their actions. Therefore, projects have not been judged as long term development plans; rather the merits of projects have been determined as degree of success within the individual work. It has been possible that a project is rated a success but in fact is a failure in the context of a total development plan for the city.

The deficiencies of transportation planning and analysis can be summed by the following three principles.[3] First, total system effects are ignored in the evaluations of the project. Second, transportation projects have not been related to overall development plans especially economic plans of the city. And lastly, different effects of alternative

3 Brian V. Martin and Charles B. Warden, "Transportation Planning in Developing Countries", Traffic Quarterly, Vol. 29, Jan. 1965.

pricing policies are not considered in conjunction with investment decisions.

A general conclusion is that cities of developing countries cannot be considered in the same framework as the U.S. city. Topographic conditions destroy the use of the "featureless plain" concept in land use planning. Population is more varied than in the U.S. and income standards are greatly below the U.S. The political powers due to unstable consitutions feel that they must dictate market controls. Even social decisions are made by groups rather than by individual families.

The governments are so eager for foreign investments that they tend to ignore long run planning. Advice to the developing countries and the aid and loan agencies through the world should be to change their attitudes. Investments for long range development can be very rewarding. Also, although the United States may be their ideal as development, it is not necessary nor proper that they attempt to develop their situation in an analogous manner. For too many of the characteristics of the developing countries differ from the United States. Grwoth of cities does not necessarily imply improvement unless programs are completed in an orderly and disciplined way toward common objectives.

III. Supply + Cost Models

Introduction

In this section, supply and cost models, two bus models, one por puesto (jitney) model and two shared taxi (or Dial-A-Ride) will be presented. For the first bus and shared taxi models and for the por puesto model three cases will be examined. These cases use known information from the existing transportation system behavior from the cities of Caracas, Venezuela, Bogota, Columbia and general Latin American cities. These cases were produced from data extracted from a minimal number of sources. Wherever required, assumptions were initiated to fit into the model so that reasonable output could still be expected. The two alternative models presented, developed by Warren Yamamoto in his Masters thesis "A Comparative Analysis of Transit Alternatives for Non-Work Trips" will be adapted to the South American criterion.

A) Bus

Basic Network and Model Assumptions

The basic assumption for the bus model is that the route network is a 5 mile by 5 mile (25 square mile) square grid. The population density is considered to be uniform throughout the "city". This results in routes which are a length of five miles, or two-way ten miles, straight and non-overlapping. A Venezuelan Ministry of Transport study reports that the citizens of Caracas will walk on the average only 2.7 blocks. For trips of longer lengths, they will utilize a motor vehicle. To satisfy the needs of this current report, 2.7 blocks, approximately equal to 1/8 mile, will be taken equal to the average walk distance to

a bus stop. Since twice this distance, 1/4 mile, is the maximum walk, routes are spaced at 2 x 1/4 mile = 1/2 mile. Therefore there are ten East-West routes and ten North-South routes within the grid. This basic network form is used for both the Caracas and the Bogota situations.

In the analysis, demand for travel was held constant. It was determined from papers written on the Caracas transportation system and travel behaviors that on the average each day every person makes 1.6 trips. In Bogota this figure was estimated to be .75 trips/person each day. The bus is assumed to be the only mode of travel for these trips.

Population densities were varied from 1,000 persons/sq. mile to 10,000 persons/sq. mile at increments of 1,000.* The purpose was to discover where economies of scale, if any occurred. In fact, this is a major concern of this work. It helps to determine the optimal or best mixture of input variables where it would be most profitable for operation of a bus system.

Due to local customs and traditions workers of many South American cities travel home for lunch. Bogota and Caracas are prime examples. The effects of this tradition are that the "peak period" can be found to last from 7 AM to 7 PM. For the purposes of this work a total of 8 peak hours was chosen since they all carry greater than 6% of the daily traffic for a combined total of 60%. The 10 non-peak hours carry most of the remaining 40% with the hours of 12AM to 6 AM being ignored as negligible (approximately 2%).

Cost Model

In its simplest form a cost model is no more than the sum of all

*It is noted that Caracas has an average pop. dens. of 38,000 people/sq. mile.

cost components equated to a common time span (day, month, year) which can be divided by a measure of productivity (trips, seats-miles, passengers etc.) yielding unit costs. The cost equation is the functional relationship which relates total cost to the quantity of the purchased factors of production.

In developing the cost model (see table , pages), single uniform bus route was assumed. During the peak hours 14 buses operated with a round trip time of 1 hour over the ten mile 2-way route. For the off peak hours only 12 buses with a total trip time of 3/4 hour were assumed required. The purpose of building this simple route model was to construct a base unit in which representative costs for each component could be related. Once these costs were calculated to an acceptable degree, they were translated into a generalized form similiar to the method used by Meyer, Kain and Wohl in their The Urban Transportation Problem. The generalized costs were in terms of cost per bus per year and mileage costs per year.* Finally the mileage costs per year were multiplied by a factor representing the mileage per bus per year so that all costs would be related to the number of buses. This final step was broken down into peak and off peak periods so that two cost relationships resulted. The concluding cost allocations assigned 60% of vehicle costs to peak and 40% to the off peak, and then a summation resulted in the completed peak and off peak cost equations.

The differences in the results of the model between the cities of Caracas and Bogota can be contributed to the inherent contrast in the characteristics of the two cities. Only the major dissimilarities are required here. These are: 1) per capita income is greater in Caracas

*Slight modifications occurred in this step.

Table Ia - Caracas

Bus Cost Model

Assumptions	Peak	Off Peak
# bus	14	12
Round trip time	1 hr.	3/4 hr.
2-way length of route	10 mi.	10 mi.

Category	$ Cost/Yr.
Stops, storage and main yeard, office space	$ 20,000
Vehicles - $35,000 @ 8% - 10 yrs. $5250/veh/yr	73,000
Administrative (labor, supplies, utilities, etc.)	30,000
Driver's Wages + Benefits (1.50 $/hr)((14 bus)(8 hr/pk) + (12 bus)(10 hr/off))300 day/yr.	105,000
Fuel (oil included) $\frac{(25¢/gal)(270\ RT/day)(10\ mi./RT)(300\ day/yr)}{10\ mpg}$	20,000
#bus RT/day = (14 bus/pk)(8 hr/day)(1 RT/hr) + (12 bus/off) (10 hr/day)(1 1/3 RT/hr)	
Parts, tires, paint, materials for upkeep for vehicles + structures	40,000
Taxes, insurance, license, fees etc.	40,000
Misc. labor + charges	80,000
	$408,000

Table IIa

Generalized Cost Model

Bp = # peak hr. bus

Bo = # off peak bus

M = miles

Category	Cost/Yr.
Storage and main yeards etc.	$1200 Bp
Vehicles (35,000 @ 8% for 10 years)	5250 Bp
Driver Costs (8 hour shifts)	3500 (1 Bp + 5/4 Bo)
Fuel and Oil	.025M
Insurance, safety, taxes, etc.	.030M
Administration	.050M
Maintenance + garage (inc. parts)	.070M
Transport charges	.030M
Misc.	.070M
	.275M

pk hrs miles/yr = Mp = (Bp)(hr/day)(day/yr)(miles/bus RT)(RT hr)
= Bp(8)(300)(10)(1) = 24000 Bp

off peak = Mo = Bo(10)(300)(10)(4/3) = 40,000 Bo

Cost Allocation

Peak	Off Peak
.275(24000) Bp	.275 (40000) Bo
(1200) Bp	---
.6 (5250) Bp	.4 (5250) Bp
(3500) Bp	5/4 (3500) Bo
14,500 Bp	15,300 Bo + 2100 Bp

Table IIa - Bogota

Bus Cost Model

Assumptions	Peak	Off Peak
# bus	14	12
Round trip time	1 hr.	3/4 hr.
2-way length of route	10 mi.	10 mi.

Stops, storage/main, yard, office space	20,000
Vehicles $7000 @ 8% for 10 yrs $1050/veh/yr	15,000
Administrative	15,000
Driver's Wages + Behefits ($.40/hr)	30,000
Fuel (oil included) (15¢/gal) @ 7 mpg	20,000
Parts, tires, paint, materials for upkeep for vehicles + structures	20,000
Taxes, etc.	20,000
Misc. labor + charges	80,000
	180,000

Table IIb

Generalized Bus Cost Model

Category	Cost/Yr.
Storage and main yards etc.	1200 Bp
Vehicles	1050 Bp
Driver Costs	1000 (Bp + 5/4 Bo)
Fuel and Oil	.025M
Insurance, safety, taxes, etc.	.015M
Administration	.025M
Maintenance + garage (inc. parts)	.035M
Transport charges	.015M
Misc.	.035M
	.150M

Cost Allocation

Peak	Off Peak
.15(24000) Bp	.15(40000) Bo
1200 Bp	
.6 (1050) Bp	.4 (1050) Bp
1000 Bp	5/4(1000) Bo
6430 Bp	7250 Bo + 420 Bp

thus the value of time is also greater and 2) buses in Bogota are constructed with truck chasses, drive shafts and engines, which are combined with poor construction habits;a less costly bus is created.

Supply Model

The supply model describes the possible behavior of goods or services. The value of the supply model is used to determine the lowest unit price at which industry is willing to supply a given output or conversely, the maximum quantity which then will supply at a given price. The purpose of this model is to establish the number of vehicles needed to serve an estimated ridership while minimizing unit cost. The number of vehicles is a function of a measure of their capacity or some desired productivity. In addition the headway between buses affects the number of buses and subsequently the length of the passenger's waiting time. Headway along with productivity are two of the more important characteristics of a bus service.

Computer runs for three different sets of criteria were processed. Table III , below lists the criteria for each run.

Table III

	General	Caracas	Bogota**
Round trip time*	1 hr/3/4 hr	1.4 hr/1 hr	1.2 hr/.8 hr
Cost equation	14,500 Bp/15,300 Bo + 2100 Bp		6430 Bp/7250 Bo+420 B
Ave pass trip length	2 miles	3 miles	4 miles
Value of time	60¢/hr	60¢/hr	45¢/hr
Trips/person	2	1.6	0.75
Time/pass. boarding, alighting, paying fare		1 minute	

*Time needed to complete round trip if no stops for passengers are made.

**Determined from discussions with Gustavo Jaramillo

Table

Bus and Jitney Models Variable Dictionary

1	PD	Population density
2	TY	Trips/year
3	--(I)	Represents incremental use of population density
4	T-	Round trip time (hours)(no stops)
5	P-	Productivity →Pass/round trip
6.	TY-	Trips/year
7.	TD-	Trips/day
8.	TH-	Trips/hour
9.	TIME-	Total round trip time (including stops)
10.	-B	Number of vehicles
11.	-HD	Headway
12.	-C	Total cost
13.	-CP	Cost/pass (breakeven fare)
14.	TVLC-	Travel cost for passengers
		(A "P" found in the bland spaces in 4-14 represents
		"peak hour", an "O", "off peak hour")
15.	--(K)	Represents incremental changes in productivity measure
16	ZZ	Cost/peak hr. vehicle
17	XX	Cost/off peak vehicle
18.	YY	Cost/peak hr. vehicle (allocated to off peak hours)

Since the 25 square mile area is uniform in respect to population density the computer runs calculate results for one route.

A description of the model using the general situations should suffice. The information from the preceding table easily converts to thos specific cities.

For each population density, total trips per year is calculated, which is then allocated 60% to peak hours and 40% to off peak hours. Daily and hourly trips are also computed. A productivity measure of passengers per round trip is incorporated into the model. The initial values are 15 pass/RT for peak hours and 10 pass/RT for off peak hours, and the increments, it so happens, are identical. The remainder of the discussion will focus on the peak hours, with the off peak hours analogous.

A revised round trip time is calculated taking into consideration the time the passengers require for boarding, alighting and paying the fare. The number of buses needed to serve a given productivity is a function of the hourly trips demanded, round trip time and the productivi

$$\text{Timep}(k) = TP = BFA * PP \qquad \#1$$

$$PB = \frac{THP * \text{Timep}(k)}{PP} \qquad \#2$$

[Timep(k) measured in hours]

The headway is the spacing between buses and is assumed uniform. It is found by dividing the time by the number of buses operating.

$$PHD(k) = \frac{\text{Timep}(k) * 60 \text{ minutes/hour}}{PB} \qquad \#3$$

The cost of the system can now be determined

$$PC = ZZ * PB \qquad \#4a$$

$$OC = XX * OB + YY * PB \qquad \#4b$$

The unit costs are found by dividing the yearly passengers into the total cost.

$$PCP(k) = PC/TYP \qquad \#5$$

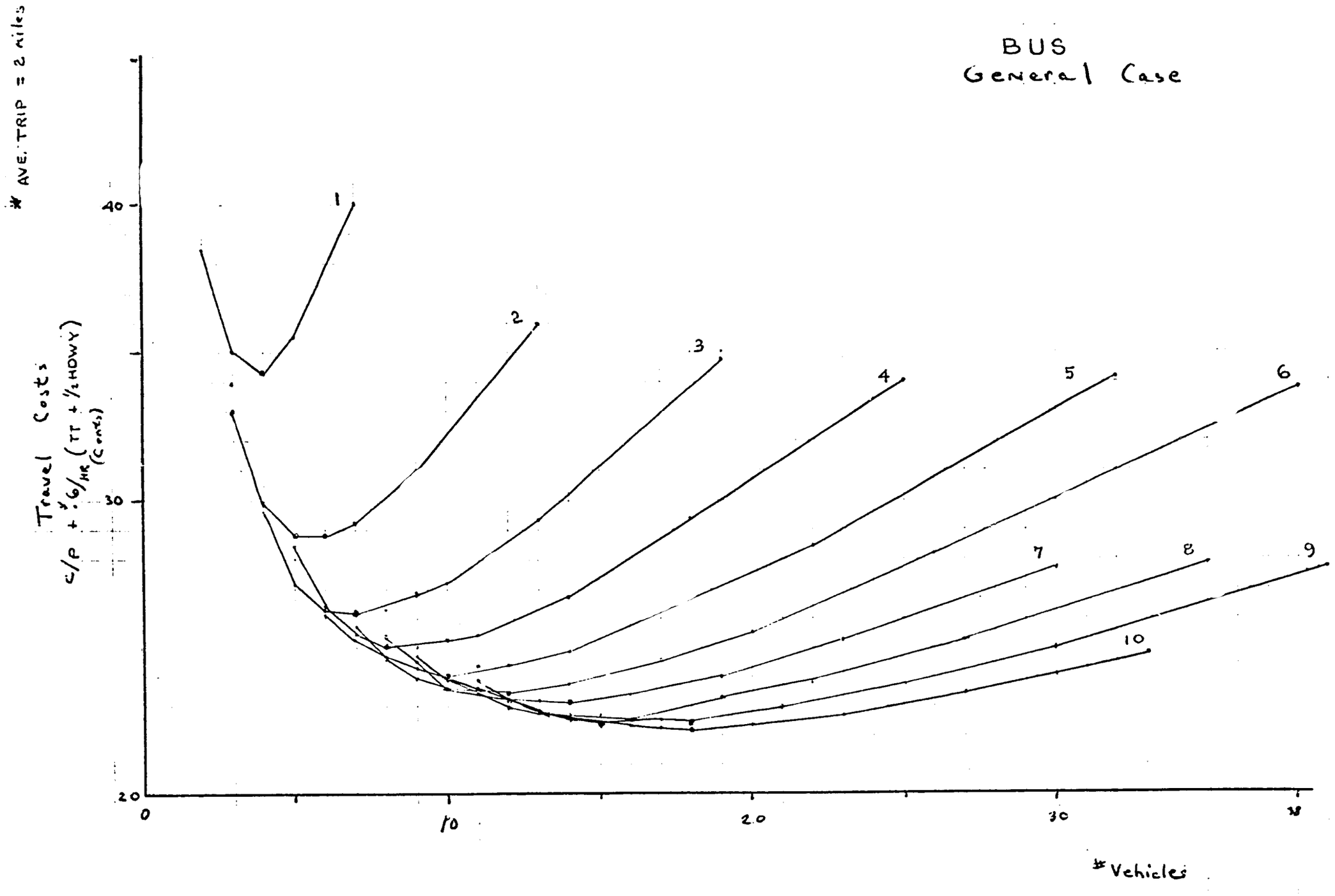
This figure is analogous to a breakeven fare. One other useful variable can now be calculated, travel costs for the riders.

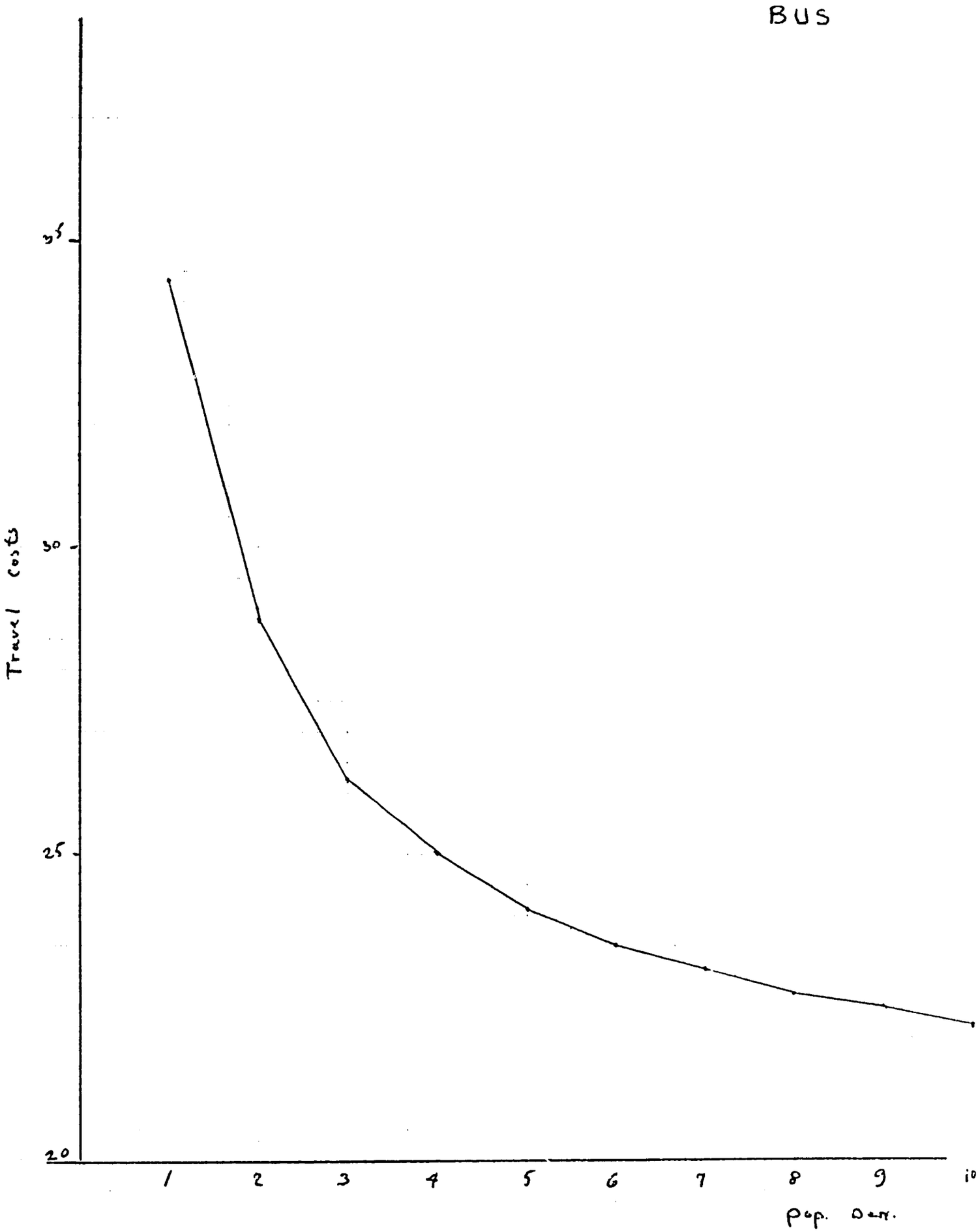
$$TVLCP = PCP(k) + \left(\frac{PHD(k)}{2} + TL * Timep(k)\right) * \text{Value } M \qquad \#6$$

where TL = ave trip length as a % of the 2-way distance

Value M = value of time per minute

Analysis of the results found that a plot of travel cost vs. # vehicles is "U" shaped, and for greater population densities the curves move lower and to the right (more vehicles in operation at lower costs to the users). The point at the bottom of the "U" is the optimal operating position from the view of the user. Bus fares can be decreased further if less vehicles were used by this maneuver increases trip travel times.


BUS
General Case
* AVE. TRIP = 2 miles
Travel Costs
c/p + .6/HR (TT + 1/2 HDWY)
(Cents)
40
30
20
0
10
20
30
1
2
3
4
5
6
7
8
9
10
* Vehicles


BUS
Travel costs
35
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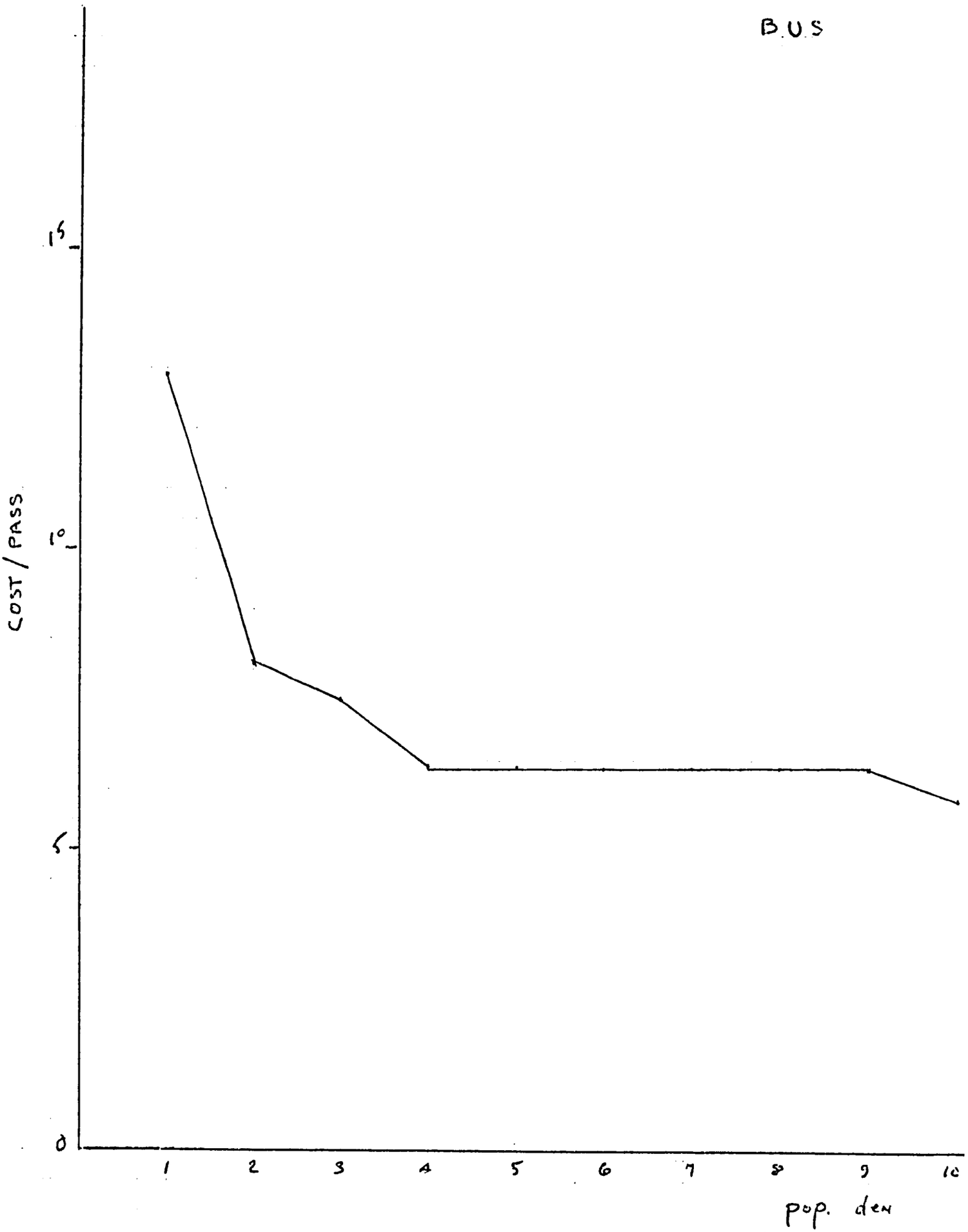
10
Pop. Den.


B.U.S
COST / PASS
15
10
5
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3
4
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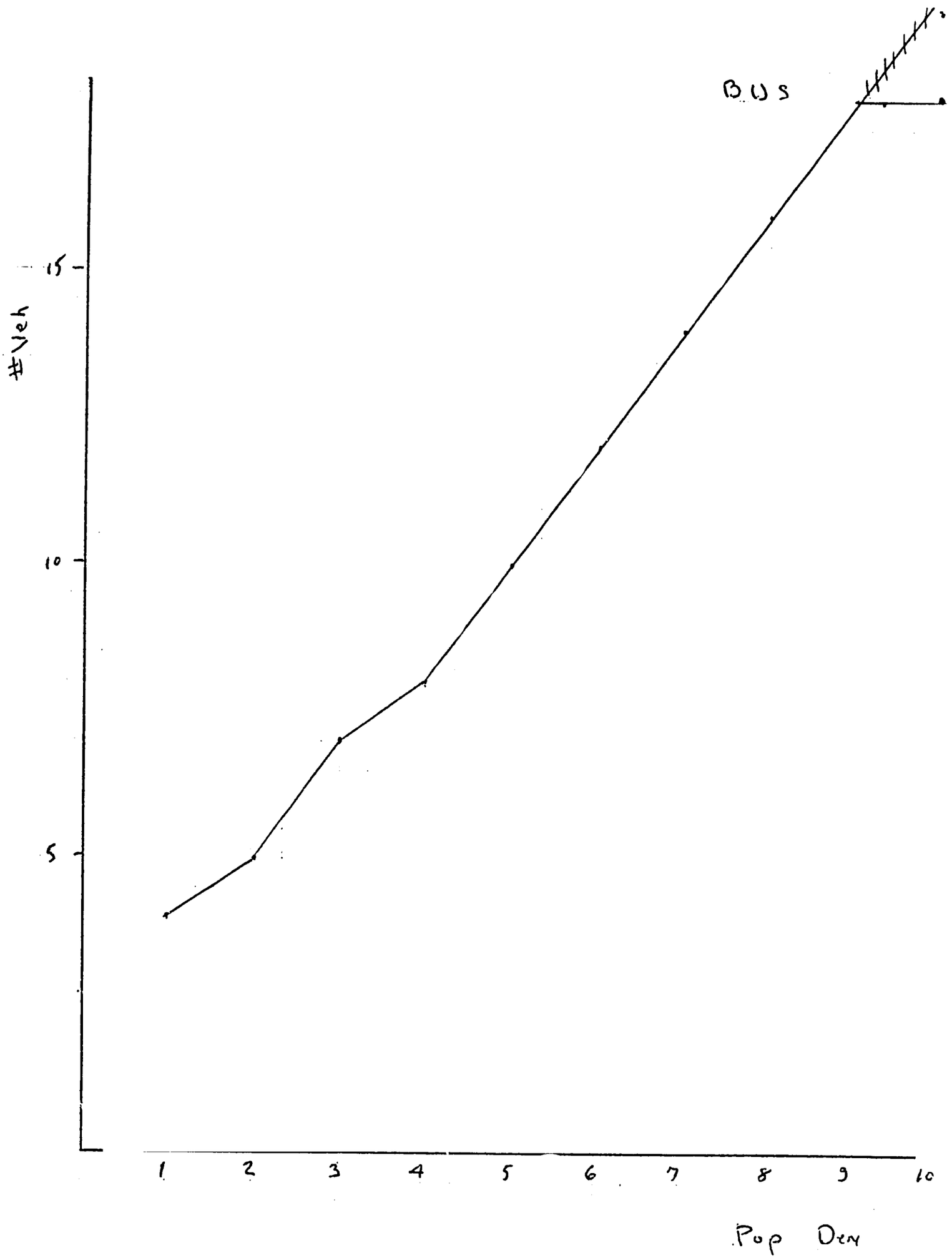
pop. den


BUS
15
10
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#Veh
1
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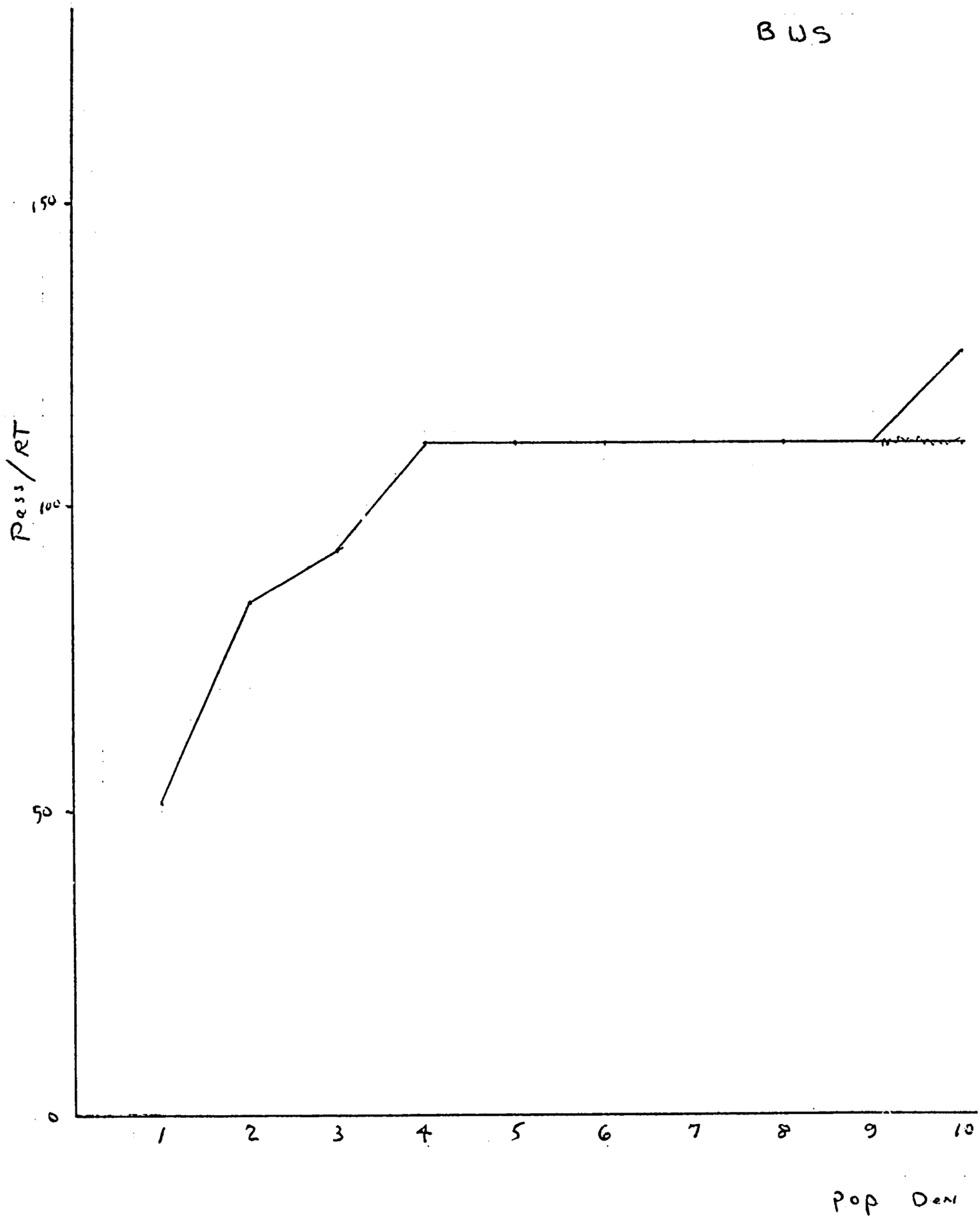
Pop Den


BUS
150
100
50
0
Pass/RT
1
2
3
4
5
6
7
8
9
10
Pop Den

B. Jitney

The jitney mode as a public transport service had considerable usage in the U.S. prior to 1920. Transit operations felt that the jitney created an undue competition and sought for legislation prohibiting its operation. The jitney has been virtually dormant since.

The jitney is a five, eight or twelve passenger vehicle (private car, station wagon, van respectively), operated along fixed or semi-fixed routes analogous to a bus. It serves as a cross between individual service taxi operations and scheduled passenger bus operation. The jitney (also por puesto, colective, jeepney, peresa, piratcha, pak-pai etc.) developed in many developing countries as a substitute for bus and tram operations.

The jitney is a demand-activated mass transportation system. Most cases find that the vehicles are individually owned and operated joined together in independent operators' associations, commonly found in the taxi industry. These associations allow their members to receive the same savings for fuel, parts, insurance, etc. as fleet operations. More people are carried per vehicle than a taxi but less than a bus, but the results are a flexibility in routing and scheduling without sacrificing all the efficiencies of large-scale operations.

The model developed within for the jitney, known as a "por puesto" in Caracas, adheres to the same basic network and model assumptions. In addition, a further characteristic of the por puesto, upon request the drivers will depart from the route to discharge passengers for an extra fee, is limited to 1/4 mile so that total deviation will be no greater than 1/2 mile. This does not affect the spacing of routes.

Cost Model

The cost model for the jitney mode is analogous to bus cost model. The fact that most jitneys are owner-operated, and that they maintain and repair their own vehicles resulted in a simpler model. Storage yards and office space are not required. In Caracas all por puestos must belong to an association in which dues are collected.

Table IV lists the cost model in the same form designed for the bus. Jitneys' speeds are assumed equal to 12.5 miles per hour during the peak periods and 16.7 miles per hour during the off peak. These speeds include deviations from the main route but exclude stops for passengers.

The only significant difference between Caracas and Bogota is the expected wages of the driver.

Table IV

Caracas [---] Bracket Values for Bogota

Jitney Cost Model

Category	Cost/Yr.	
Vehicle $3200 4 year @ 8% (50,000 miles/yr)	$ 960	
Driver Costs	4000	[2000]
Fuel + Oil	1200	
Tires, Parts	200	
Maintenance	900	
Insurance + Taxes	800	
General (Dues, fees, etc.)	500	
	$6560	

Generalized Cost Model

Vehicle	960 Jp	
Drivers	4000 (Jp + Jo)	[2000(Jp + Jo]
Repairs, maint. and tires	.020(M)	
Fuel + Oil	.025(M)	
Insurance + Taxes	.015(M)	
Misc.	.025(M)	
	.085(M)	

Mp = (12.5 mph) (8 hr) Jp = 100 Jp
Mo - (16.7 mph)(10 hr) Jo - 167 Jo

Table IV (CON'T)

Cost Allocation

Peak	Off Peak
.085(300)(100) Jp	.085 (300)(167) Jo
400 Jp [2000]	4000 Jo [2000]
.6 (960) Jp	.4 (960) Jp
7030 [5030] Jp	8250 [6250] Jo + 380 Jp

Supply Model

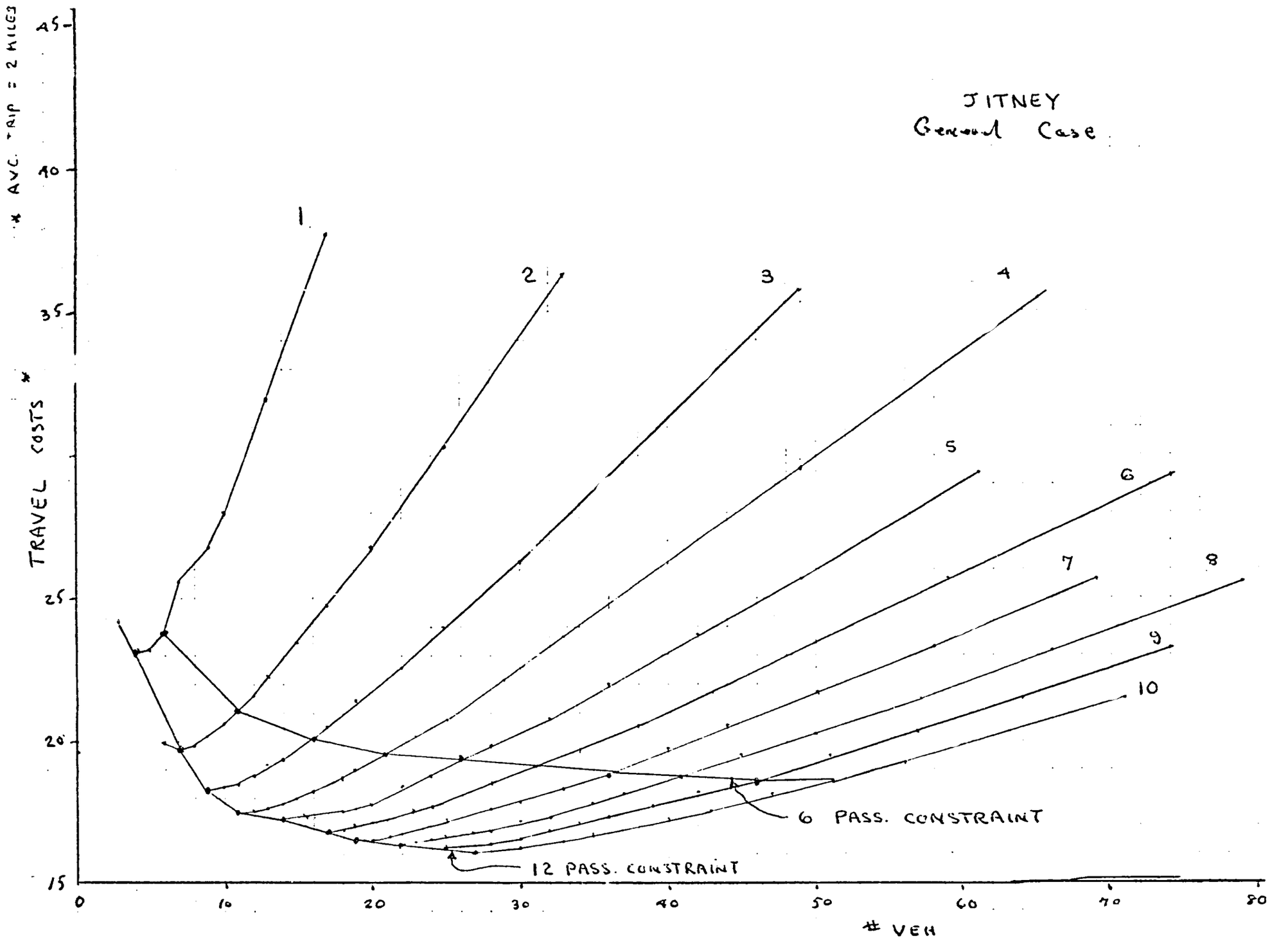
As in the case for the cost model, the supply model for the jitney is analogous to the bus. The reason is that the model treats the jitney as a small bus. Since jitneys are usually individually owned, government controls are required. The results of this model could be used as a means of assigning vehicles to the route and places limitations upon their numbers.

Again three separate Computer Runs with different sets of criteria were processed. Table V lists the information relevant to each.

Table V

	General	Caracas	Bogota
Round trip Fare	.8 hr/.6 hr	1.1 hr/.9 hr.	.9 hr/ .75 hr.
Cost Equation	7030 Jp/8250 Jo + 380 Jp		5030 Jp/6250Jo+38(
Ave. pass trip length	2 miles	3.4 miles	4 miles
Value of time	60¢/hour	60¢/hour	45¢/hour
Trips/person	2	1.6	.75
Mex pass/Rt			
6 pass. vehicle	30	18	15
12 pass. vehicle	60	36	30

During analysis of the results, one discovers that the "U" shaped curve of the travel cost vs. # vehicle plot is cut prior to reaching its lowest point. This is due to the constraints caused by small vehicles. The best operating point of the jitney system is not optimal in regard to the bus system optimality. Jitneys cannot discover all the efficiencies of a large scale operation.


JITNEY
General Case
TRAVEL COSTS *
* AVG. TRIP = 2 MILES
# VEH
1
2
3
4
5
6
7
8
9
10
6 PASS. CONSTRAINT
12 PASS. CONSTRAINT
45
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35
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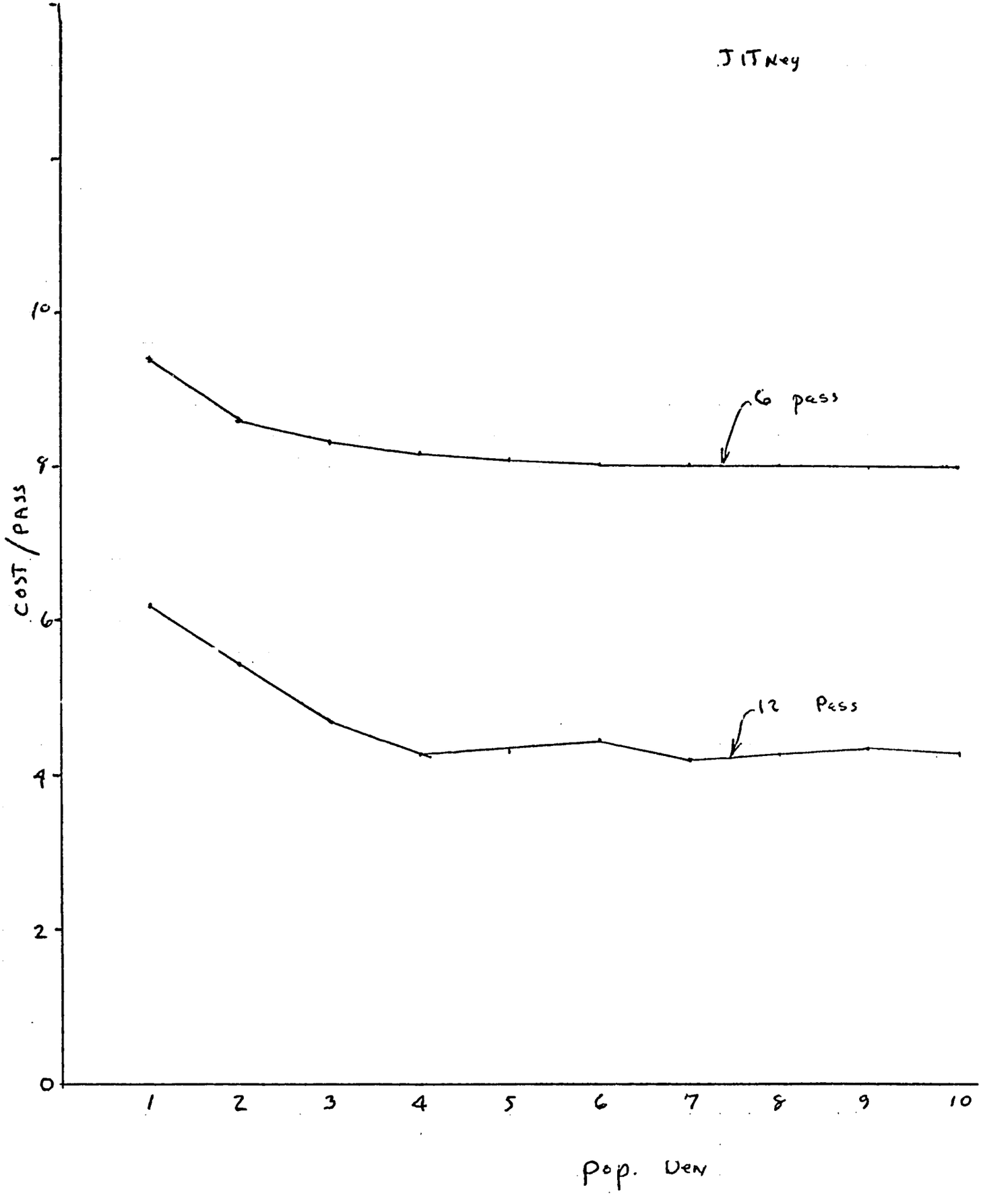
80


J IT Ney
6 pass
12 Pass
COST / PASS
0
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4
6
8
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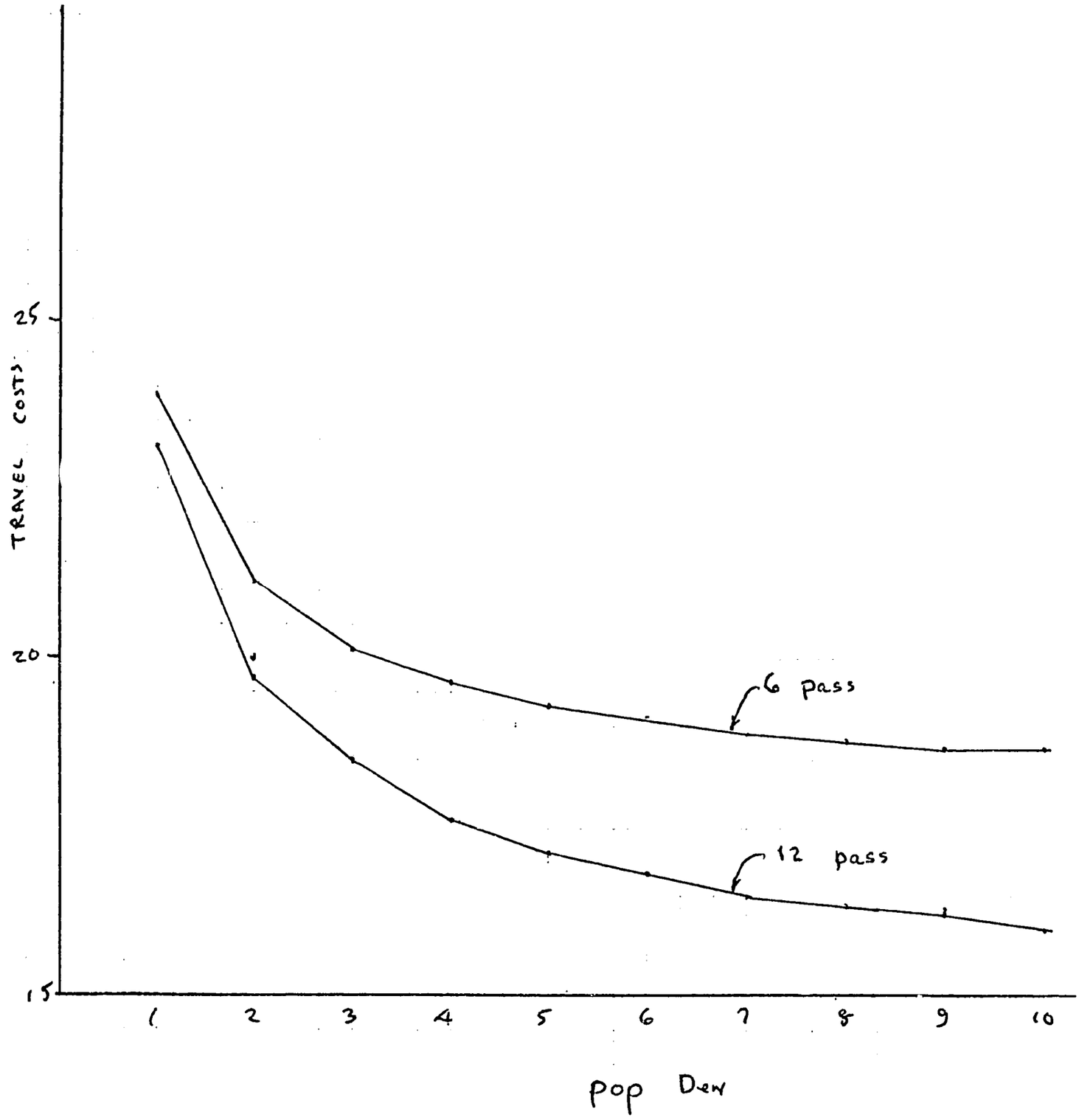
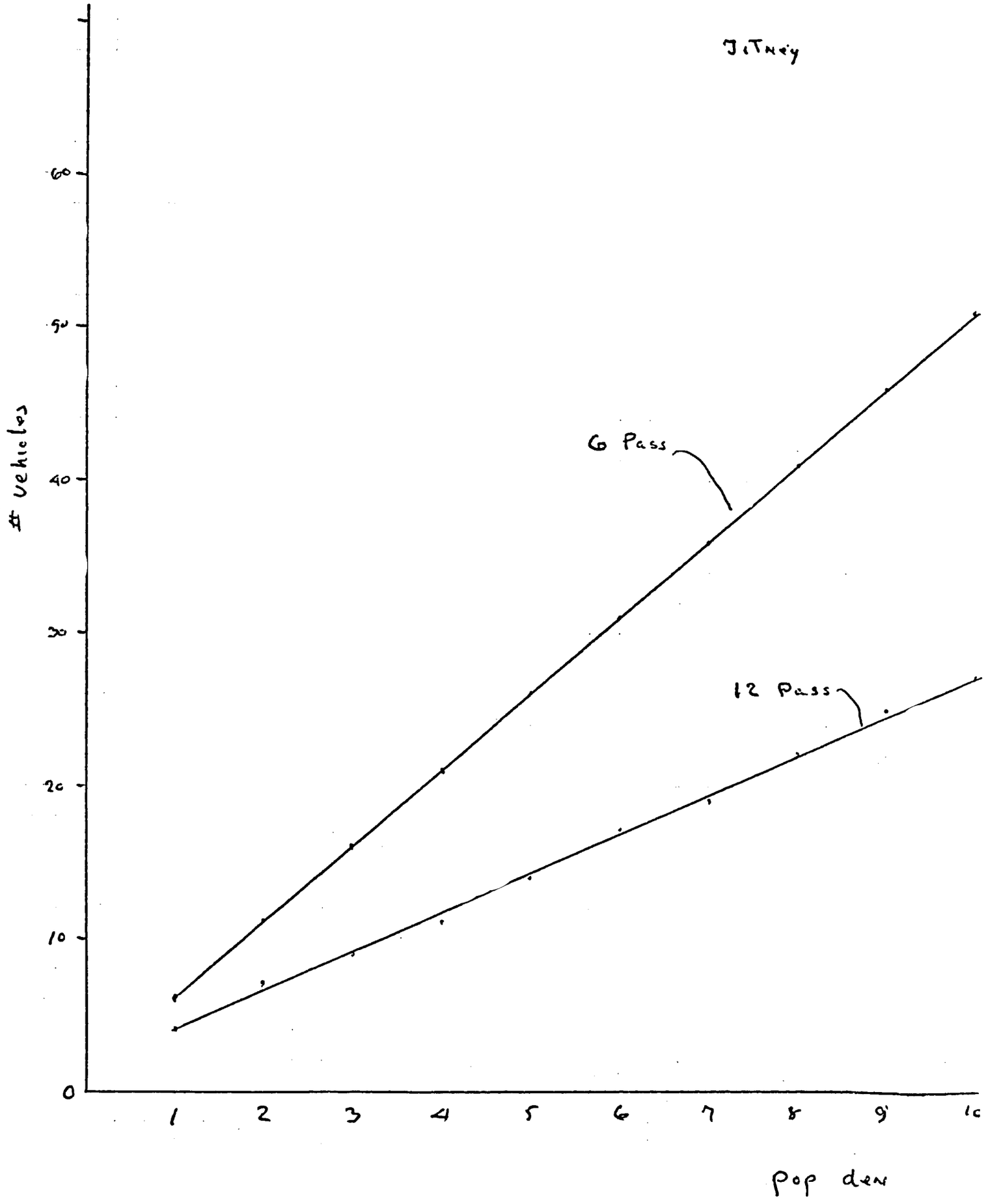
JITNEY




Jitney
vehicles
60
50
40
30
20
10
0
6 Pass
12 Pass
1
2
3
4
5
6
7
8
9
10
pop den

Dial-A-Ride (Shared Taxi)

Shared taxi or Dial-A-Ride as it is more commonly known, is a demand responsive transportation system. A door-to-door service neither requiring fixed routes or fixed schedules is offerred by a combination of taxi and fixed bus operation characteristics.

Similar to the taxi, riders phone their request for service to the dispatching office. The dispatcher assigns the vehicles so that maximum usage is obtained, and so that the customer is picked up and delivered within a reasonable length of time.

Although the vehicles are on the order of 12 to 20 passenger mini-buses or vans, bus-like behavior does exist. As a function of ride requests, the dispatcher determined a route for the vehicles. This route (routes are unique i.e. the same route is rarely if ever travelled over again) is constructed connecting the origin and destination points of the customers. Similar to the bus and dissimilar to the taxi, some passengers must remain on the vehicle while others are picked up and delivered.

Cost Model

The cost model for this Dial-A-Ride system is quite simplistic. Costs are allocated into three categories.

1) CD (cost/day) - overhead, including dispatching, communications administration, taxes, rent, depreciation, etc.

Vehicles $4000 @ 8% - 4 yrs.	1200
Garage, Storage	900
Taxes, fees, etc.	2000
Administration, disp ± communication	5000
	$9000/300 = $30/day

2) CH- (costs/vehicle hour) - primarily wages and benefits to driver
$2/hour

3) CM - (costs/vehicle mile) - fuel, oil, tires, maintenance etc.

$.10/mile

These above costs were used in the general and Caracas cases. The corresponding figures for Bogota are cost/day: $15; cost/hour: $.90/hour; cost/mile; $.06 mile.

The cost equation is:

$$TC = ZN(I) * CD + ZN(I) * CH + ZN(I) * V1 * T * \frac{1 - (G*A)}{ZN(I)} * (TE+TP) * CM\ (xy)$$

(See Dial-A-Ride Variable Dictionary for description)

This cost model was created to satisfy the Dial-A-Ride supply model which is presented in the next section. It is felt that the cost values that were finally selected are slightly high. But under no circumstances does this (approximately 10%) inaccuracy disrupt the purposes of analysis.

Supply Model

The model which was chosen for this project was developed by Steven Lerman in his paper "A Supply Model for Dial-A-Ride Operation". Dial-A-Ride level of service is composed of a number of time components. The model must specify everyone since each component does influence the service demand. For this model a fixed demand as used for the bus and jitney models, once again is utilized. But once a demand model was calibrated to correspond with this supply model, it could easily be substituted for the fixed demand.

The model is sensitive to design criteria especially the number of vehicles and the area served. A greater number of vehicles assuming constant demand will lower the passenger's waiting time and will allow

for more direct, less time-consuming trips. But a greater number of vehicles for constant demand will increase the cost of the service for each passenger. An important tradeoff exists between total trip time and costs.

If the service area increases with no increase in vehicle availability, trip times will increase correspondingly. A final tradeoff must be analyzed prior to operation. A dispatching policy which sets a maximum service time (total trip time, request to delivery) must be determined. Once set within a given service area the number of vehicles required for the chosen criteria can be calculated.

As seen previously, the trip behavior characteristics of Bogota, Caracas and general South America are used for calibration purposes.

Table VI

	General	Caracas	Bogota
Ave Pass. Trip Length	333	333	333
Value of Time	60¢	60¢	454
Trips/person	2	1.6	.75
Costs			
Daily	30	30	15
Hourly	2.0	2. 0	.9
Mileage	.10	.10	.06

General Input Data

Area = 25 sq. miles

Speed = 15 mph or 1/4 MPM

Pass. Pick-up time = 1/3 minute

Pass. dropoff time = 1/3 minute

hours of service = 18 hours/day

Line Haul time = ave trip length/speed = $\frac{3\ 1/3}{1/4}$ = 13.3 minutes

Dial-A-Ride Model

Variable Dictionary

DE	Ave trips/person/day
A	Area of service zone
V	Speed (miles/min)(not including stops)
V1	Speed (miles/hour)(not including stops)
TP	Time to pick up passenger (min)
TE	Time to drop off passenger (min)
ZL	Ave trip length (miles)
CD	Cost/day
CH	Cost/hour
CM	Cost/mile
T	Number of service hours/day
PD	Population density
Z	1/1000*(PD)
D	Ave detour length per call serviced
ZLW	Direct distance between vehicle ana rider at time of request
TLH	Line haul time (min)
ZN	# vehicles
G	Demands/sq. mi./min.
TD	The difference between the time a passenger spends on a vehicle and the value of TLH
TW	The time from when a passenger calls for service until he is picked up
TC	Total cost
TT	Total time
CP	Cost/pass.

The model's LOS is composed of five time conponents, three, TP, TLH, TE are exogenous time variables while the remaing two, TD and TW, are computed within the model.

$$TD = \frac{\frac{G * A}{2N} * TLH * \left[\frac{D}{V} + TP + TE\right]}{1 - \frac{G * A}{2N}\left[\frac{D}{V} + TP + TE\right]} \qquad (\# 2)$$

$$TW = \frac{\frac{2LW}{V}}{1 - \frac{G * A}{2N}\left[\frac{D}{V} + TP + TE\right]} \qquad (\# 3)$$

where

$$G = \frac{DE * PD}{60 * T} \qquad (\# 4)$$

& therefore Total Time is:

$$TT = TLH + TP + TE + TD + TW. \qquad (\# 5)$$

Two modifications to Lerman's work were required in order to use it within the criteria of varying the population density and the large area. Lerman calibrated a sample problem using data from the Batavia, New York Dial-A-Ride system. His area was only 3 square miles*, the average detour length, D, equalled 3/10 mile and the average distance between vehicle and customer at the time of the request was 1.1 miles. These

*A total of 8 vehicles served the area.

values produced poor results when used in the South American model.

The changes were concerned with the variables D and ZLW. As the magnitude of demand increases (function of population density (PD)), routing of the vehicles can be accomplished more effectively, thus decreasing the Detour Distance (D). Continuing from the same line of reasoning, more vehicles will be required to serve the area, thus the average distance between a vehicle and the caller (ZLW) will decrease. As D and ZLW decrease, the detour and waiting times will also diminish. Therefore, it is reasonable to expect that D and ZLW would vary inversely as the demands/sq. mile/minute (G) increase. In fact this is proven by the results of the model.

Demand is a function of the population density. As they increase the density of the vehicles must also increase but not necessarily at the same rate. Economies of scale are expected at greater population densities. Likewise, as vehicle density increases, the distance between a vehicle and a caller decreases. A least squares regression was completed on data which was determined by varying the vehicle density as population density vehicle. The final equation calculates the distance ZLW as a function of population density.

$$ZLW = .2 - .014 * Z \qquad \#6$$

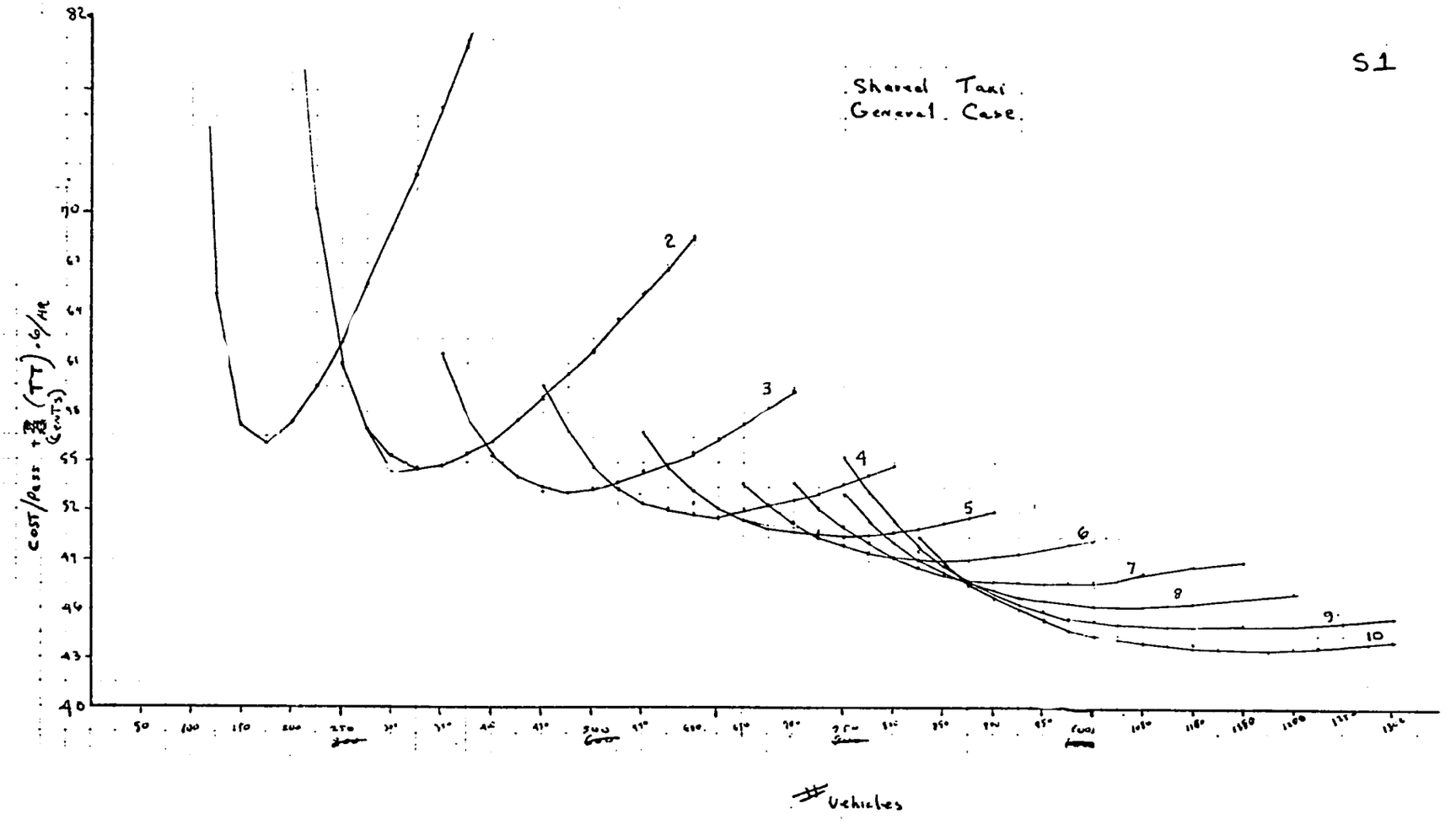
A regression equation was also computed for the detour distance in a similar fashion.

$$D = .32 - .02 * Z \qquad \#7$$

Results and Conclusions

From the results of the general case (Caracas' results differences are minimal) it can be seen that economies of scale do exist. The optimal

points from the travel cost vs. # vehicles curve decreases with population density increases. A plot of # vehicles vs. population density exhibits diminishing marginal returns. Travel time, time costs, and the breakeven costs per passenger all decrease as population density increases. The conclusions one must receive from these results is that more efficient and effective operations can be developed as a function of population density (remembering that demand is a function of population density).


S1
Shared Taxi
General Case
Cost/Pass + (TT) · 6/HR
(Cents)
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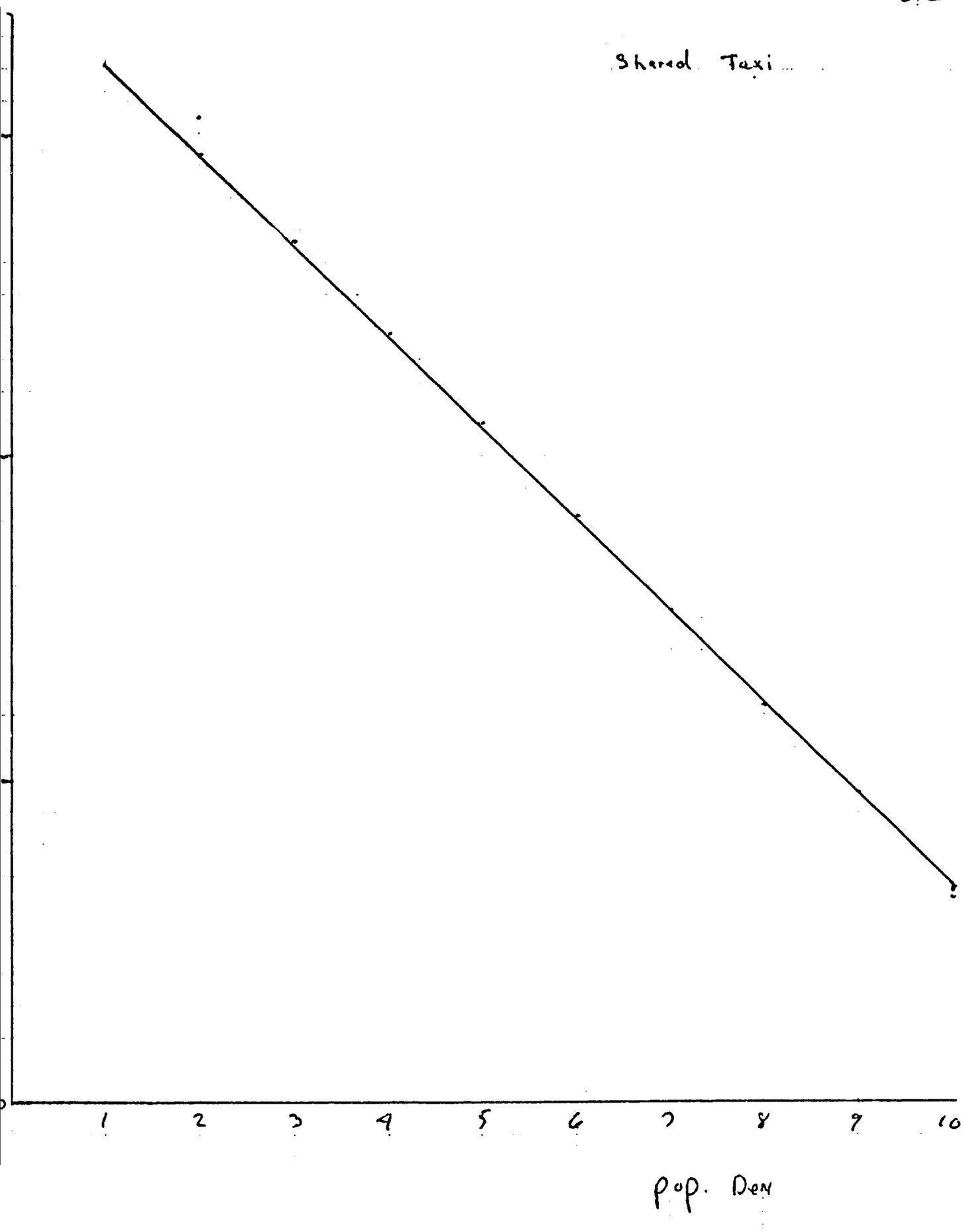
Shared Taxi
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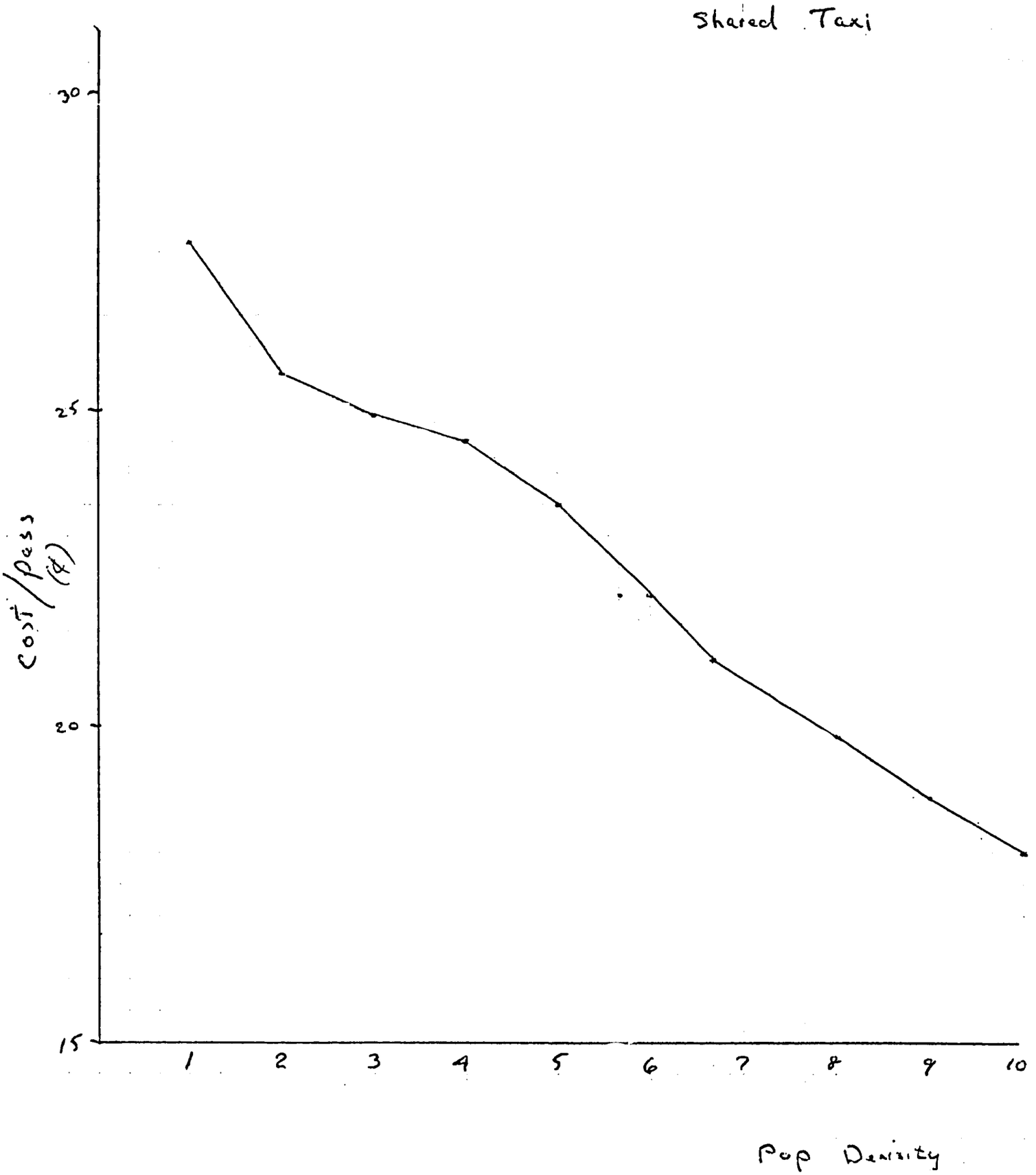
Shared Taxi
30
25
20
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Cost/pass (¢)
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6
7
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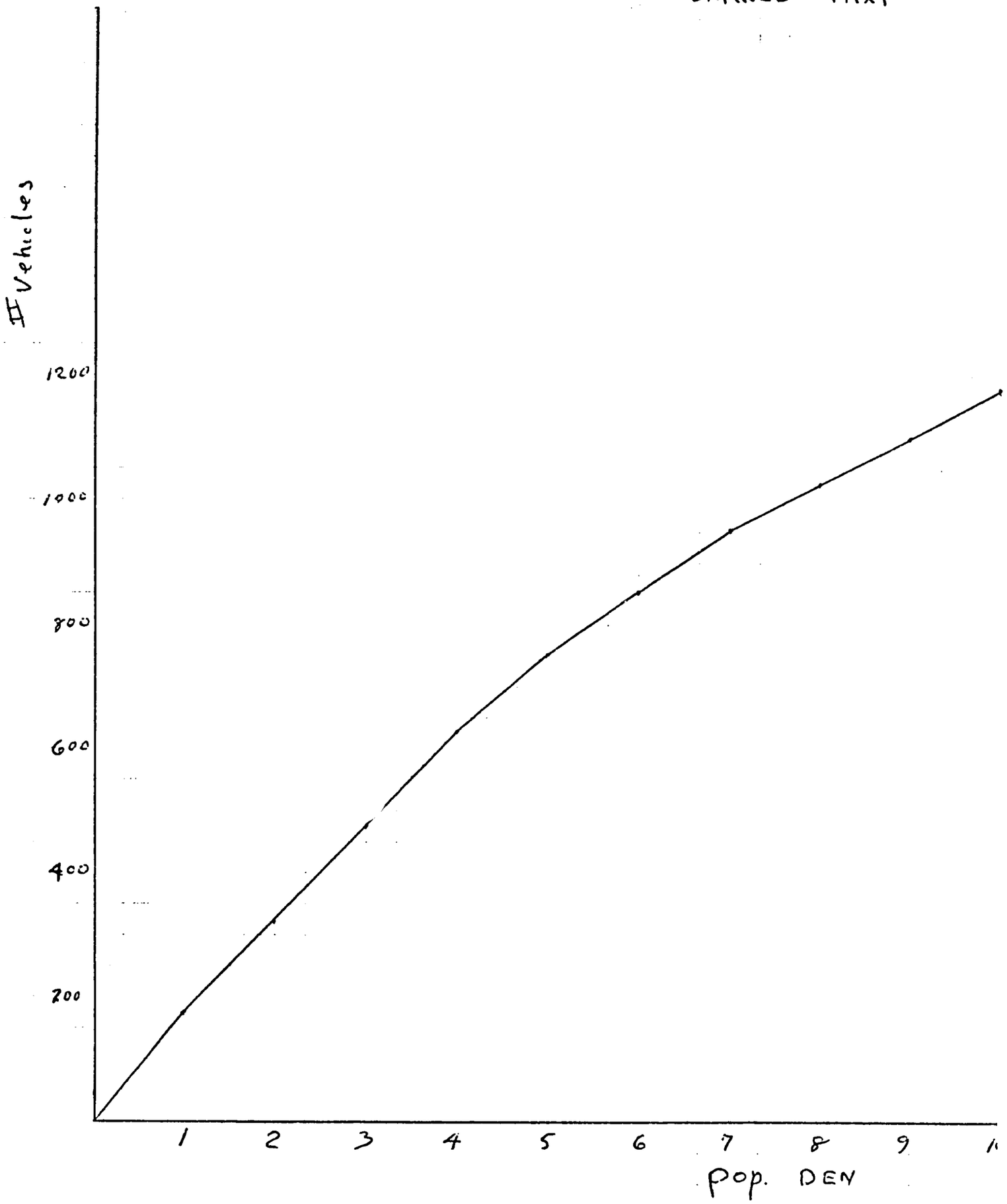
Pop Density

SHARED TAXI



B. Bus Alternative Model

An alternative bus model is presented for two reasons. First, for comparison purposes and secondly as a method to introduce other bus systems characteristics that were not mentioned previously. The major difference in this model, developed by Warren Yamamoto, is that demand can be varied. In the previous supply and cost model, demand was assumed fixed. Yamamoto created a supply model and demand model.

The bus supply model is rather simple. The model is based on a one square mile grid with routes spaced at "Y" miles. Vehicle headways are assumed equal on all routes. TAU, the mean wait time, is taken to be equal to one half the vehicle headway for this adaptation. This is referred to as the deterministic headway; headway factor is equal to two. If this factor was equal to one, an exponential headway distance would be the case.[1]

From the basic assumption, it is logical to assume that there are 2/Y miles of route per square mile and twice this figure for two way route mileage. The number of veh. trips/sq. mile/hour (CAP) is equal to:

$$CAP = 4/Y \times 1/VHDWY \qquad \#1$$

and

$$VEHHR = 4/Y \times 1/CHDWY \times 1/VY = CAP/VY \qquad \#2$$

The final selection of the supply model computes the foad factor.

$$LF = \frac{PAX}{CAP} \times \frac{SUM}{LOAD} \qquad \#3$$

This variable, treated superficially in section "A", relates the actual passengers at any time with the number of seats. Equation #3 quickly

[1]See Kulash for further description.

exhibits feasible combinations of VHDWY, CAP, PAX, SUM, and LOAD. In this manner possible systems can be grouped as either under or over utilized.

The model in section "A" handles load factor differently. Possible passenger productivities are matched with the number of required vehicles for that productivity. Therefore, all load factors are in the vicinity of one. The only constraint is the capability of a single vehicle to handle the wanted productivity.

The major shortcoming is its insufficient declining with time variables. It is concerned with headways but it substitutes speed for travel time. This is a crude approximation since it is unclear if the speed includes stop time.

Bus Alternative Model - Variable Dictionary

Y	distance in miles between routes
HDWY	headway factor 1 = for exp. dist. 2 = for deterministic dist.
TAU	mean wait time
VHDWY*	actual headway between buses
CAP	vehicle trips/sq. mile/hour
VEHHR	vehicles/hour
VY	ave vehicle speed
PAX	pass/hr/sq. mile
SUM	ave trip length
LOAD	vehicle capacity
LF	load factor pass/bus seat
Z	cost of a trip (travel cost)
Fare	fare
Value	Value of time
ET	Excess time
RT	Riding time
TAMAX	Max. allowable excess time
VMEX	Max. Z
A	Mode split
AMEX	Mode split when Z = 0
ABWALK*	Max. walk dist. to transit stop
VX	Walking speed about 3 mph
TMS*	Total mode split
VOL	Representation for # transit users in a section
PD*	Population density

Variable Dictionary (Con't)

F	Daily trips factor
HF	Hourly factor
S	Station spacing

*These symbols not consistent with Yamamoto's original symbols changed for ease in programming.

The demand model needs inputs of fare, value of time, waiting time and ride time, where the waiting time is one half the headway for this case. The values used for these variables were the optimal values from the model in section "A". Excess time (ET) is a function of wait time, adhere

$$ET = \text{wait time} + 2/3 \text{ wait time} \qquad \#4$$

The reasoning is that approximately 67% of all transit trips have required transfers therefore additional out-of-vehicle time. The cost of the trip to the passenger,

$$Z = \text{fore} + \text{value } (ET + 1/2\ RT) \qquad \#5$$

uses the notion that in-vehicle time is perceived differently from waiting time. This idea was ignored in the previous model due to the low value of time expressed for the Latin American market.

The maximum walking distance is taken at 1/4 mile with an average speed at 3 mph. Value of time is taken from the Latin American criteria as 60¢/hour. From the relationship

$$ABWALK = 1/2(UMAX - Z)\ \frac{VX}{VALUE} \qquad \#6$$

VMAX can be calculated

$$VMAX = .10 + Z \qquad \#6a$$

But for the purposes of this report

$$VMAX = .10 + Z + TJ * .10 \qquad \#6b$$

when TT varies from 1 - 5.

In order to calculate the mode split a 1/2 mi. x 1/2 mi. area is established. This is determined by the spacing of routes which is 1/2 mile. The spacing of the stops is set at 1/4 mile. The procedure is to sum the

mode splits over each infintesmal point which covers the area. The following equations

$$A = AMAX(1 - \frac{Z}{UMAX}) \qquad \#7$$

is used to find the magnitude of the greatest mode split which coincides with the stop. The mode split decreases as a function of the maximum walk distance. The slope of mode splits

$$B = A/ABWALK \qquad \#8$$

assumes that a zero mode plit is found wherever a point is equal to or greater than the maximum walking distance.

$$DM = 2\frac{Y}{S} - 1 \qquad \#9$$

is a finction of route and stop spacing.

The variable from equations 7 - 9 are now utilized to find the volume of the mode splits over the area. In the case where

$$S/2 \leq AB \leq S \qquad (\#10)$$

$$VoL = -\tfrac{2}{3} A \times ABwalk^2 + (DM+1) A \times S \times (ABwalk - S/2) + \tfrac{1}{6} B \times S^2 \times Y \qquad (\#11)$$

$$\cancel{+ \tfrac{1}{6} B \times S^2 \times Y}$$

$$\left[\begin{array}{ll} VoL = \tfrac{2}{3} \times DM \times A \times ABwalk^2 & \text{if } ABwalk \leq S/2 \\ VoL = \tfrac{8}{3} \times A \times ABwalk\,(\tfrac{Y}{2} - \tfrac{1}{3} ABwalk) & \text{if } S < ABwalk < Y/2 \\ VoL = A \times Y^2 \times (1 - Y/2/ABwalk) & \text{if } ABwalk > \tfrac{Y}{2},\ S = Y \\ VoL = \tfrac{2}{3} Y^2 \times (A - \tfrac{1}{3} \times B \times Y/2) & \text{if } ABwalk > Y/2,\ S < Y \end{array}\right]$$

Therefore the final mode split of the 1/4 sq. mile area is

$$TMS = VOL/Y^2 \qquad \#12$$

Travel characteristics relating daily and hourly factors are then used to find passenger demands

$$PAX = PD * F * HF * TMS \qquad \#13$$

These passenger demands are for one quarter of a square mile and should

converted to a single square mile.

The major complaint of the bus model must be its lack of determining actual travel times. Instead time must be read into the demand model.

This model needs further work in order that it be fully adapted to South American situations. At the present time, it is geared to U.S. standards upon which it was developed.

E. Dial-A-Bus Alternative Model

Yamamoto's Dial-A-Bus model is based upon a one square mile area similar to his bus model. The basic control variable is RO, taken from standard queue theory. Varying RO in its normal range of .1 to .8 results in travel time ratios.

$$TTR = 1 + .4\left(\frac{RO}{1-RO}\right)^{.57} \qquad \#1$$

where RO varies from .1→.8

Table

TTR	vs	RO
1.114		.1
1.182		.2
1.247		.3
1.317		.4
1.400		.5
1.504		.6
1.648		.7
1.882		.8

As expected RO increases (functions of delay time) travel time for Dial-A-Bus increases.

TAU, the waiting time, is a function of # vehicles and RO.

$$TAU = \frac{4.64}{VEH} + 4.59\left(\frac{RO}{1-RO}\right) \qquad \#2$$

Waiting time decreases as the number of vehicles in service is increased. But as RO, thus TTR increases, waiting time is lengthened.

Dial-A-Bus

Variable Dictionary

TAU	wait time
TTR	travel time ratio $\frac{\text{D-A-B}}{\text{auto}}$
PAX	passengers/mile^2
Veh	# veh./mile^2
RO	variable based upon standard queue theory related to LOS
PDENS	population density
F	daily trip factor
HF	hourly trip factor
A	mode split
RT	ride time auto travel time

The number of passengers which can be handled, sensibly increases with vehicles. But passengers also increase with greater values of RO.

PAX = RO x VEH x 8 #3

where 8 is max vehicle productivity for a 25 sq. mile area, would be larger for a smaller area.

The demand model is shorter and simpler than the supply model. The first equation determining the ride time from the supply model.

RT = TTR x ATL #4

The second equation relates trip making characteristics and population density to determine an actual ridership demand.

PAX = PDENS x F x HF x A #5

Lerman's supply model is considerably more extensive. Components of time are explicitly determined and can be used to structure a dispatching policy. Yamamoto's model relies on finding auto times before total travel time can be found. Also as in his bus model he ignores the time necessary for the passenger to enter, pay the fare, and then exit the vehicle. This tends to be a significant portion of the travel time for the passengers. This can be experienced by the bus model of section "A".

IV. Summary and Conclusions

The work for this project as outlined in the original proposal is incomplete. The goal of understanding urban transport systems in L.A. and their differences with U.S. systems so that policies regarding developing countries' urban transport system was intended to be completed in a number of steps. It can be seen now that not one of these steps were completely satisfied.

Data was most difficult to collect. For any transport system study it is mandatory that a thorough knowledge of existing conditions be obtained. Numerous articles describing problems and criteria of systems throughout the world were gathered. This produced only a superficial background of a general urban transport system in a developing country. Sufficient information on any single city was not available. For this project to continue the holes in the data should be filled.

The models developed from the data that existed appear reasonable in the framework constructed. The grid pattern eliminates route overlapping, major terminal centers for multiple routes and produces a uniform structure. These situations do not exist over large scale city wide networks. Lack of information had limited the continuation of the model so that they could be applied to a typical network.

Alsono's paper "The Form of Cities in Developing Countries" goes a long way toward explaining the differences between U.S. and developing countries. The major variables in developing models (especially land-use models) must be built upon the conditions it is to be used. U.S. models cannot explain L.A. situations.

While U.S. models have been applied incorrectly to studies in

urban areas of developing nations, governmental powers have accepted foreign aid as loans whenever offered. Conditions of these offers is that the project which is being funded must produce immediate positive results. To guarantee the funding agency of acceptable results, plans are geared to the short run, while possible long run disastrous effects are ignored. The unstable political processes causes this dreadful error in development. Current political powers require support from the people, and have determined that the quickest means is to borrow money for large urban projects. In this way people sense a note of progress in their regime. Therefore, the responsibility for long run development plans lies within the power of foreign aid and loan agencies. They should not require immediate results which neglect the long run.

Future research requires additional data. This data should come directly from existing operations. Mexico City has recently completed a rapid transit facility. Transit systems appear feasible for some cities of L.A. due to large population densities. Original plans and operational data from Mexico City would be invaluable. This information plus the knowledge from social, political and economic conditions of individual cities can be placed into Alonso's framework. From the framework models which will explain L.A., rather than U.S. occurrences will result. But the key is the accumulation of data, a combination of written documents and first hand experiences would be preferable. Without information the original goals of the project cannot realistically be completed.

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