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16. Abstract

The Highway Performance Monitoring System (HPMS) was developed by the Federal Highway Administration to collect sample data on the public highway system in the United States and to provide information to the U.S. Congress and others on the current status of the highway system and future needs. This report covers a detailed examination of the HPMS sample data for possible use in estimating Texas' needs.

The report presents the results of a simulation model used to estimate the accuracy of various sample sizes and stratification strategies. They are compared to the assumed accuracy, to make recommendations on the sample size required to make needs estimates at the district level in Texas.

The report also gives some comparisons of the HPMS construction costs with estimates of Texas construction costs.

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RESULTS OF THE EVALUATION OF

THE HIGHWAY PERFORMANCE MONITORING SYSTEM

FOR USE IN TEXAS

by

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Assistant Research Economist

Research Report 480-2F
Research Study Number 2-10-85-480
Evaluation of Highway Performance Monitoring
System for Use in Texas

Sponsored by

Texas State Department of
Highways and Public Transportation

in cooperation with

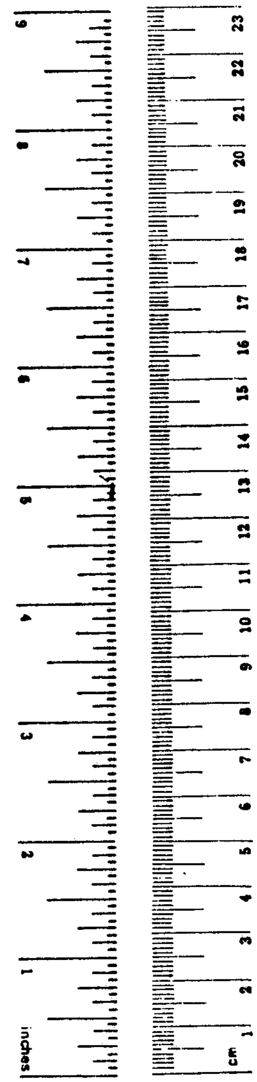
U. S. Department of Transportation
Federal Highway Administration

June 1988

METRIC CONVERSION FACTORS

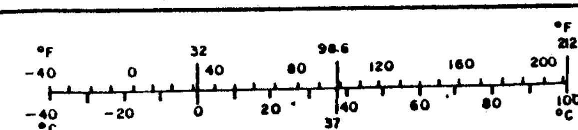
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

The author wishes to thank Tom Griebel, Bernard F. Barton, Bryan E. Stampley, Robert R. Guinn, Robert L. Mikulin, and Ted Miller for their helpful comments and suggestions in the direction of the current research and avenues of future research. Appreciation is also due Dr. William F. McFarland, Margaret K. Chui, and Thomas Scullion for their assistance, efforts, and suggestions during the course of the research.

The contents of this report reflect the views of the author and do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas State Department of Highways and Public Transportation. This report does not constitute a standard, a specification, or a regulation.

SUMMARY

This report covers a detailed examination of the adequacy of the Highway Performance Monitoring System (HPMS) sample for making needs estimates at the district level in Texas and recommends increases in the current sample based upon the results of the examination.

In order to test the accuracy of sample sizes, a simulation model was developed to calculate the errors of a given sample size. Since the FHWA procedure uses average annual daily traffic (AADT) to calculate the required sample size, the simulation model was used to compare the accuracy of needs estimates with the assumed accuracy using AADT. It was found that in general, the errors were larger than the assumed error range at the functional class level, but the errors decreased substantially as functional classes were aggregated.

The simulation model was also used to test the usefulness of stratifying the functional classes by volume group. It was found that in most cases stratifying did improve the accuracy of the sample estimates. Further, it was found that in most cases calculating the sample at the functional class level and distributing the sample to volume groups proportionately by mileage performed better than calculating the sample at the volume group level.

Some comparisons of HPMS construction costs and Texas construction costs are also presented. In most cases the costs are roughly similar, with the biggest difference in urban reconstruction to freeway, where the Texas costs are substantially higher.

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INTRODUCTION

The Highway Performance Monitoring System (HPMS) (1) was developed by the Federal Highway Administration (FHWA) to collect data on a large sample of highway sections throughout the United States and to make estimates on the current condition of the highway system and future needs, including effects of different funding levels. For that purpose each state was required to select a random sample of highway sections and collect several items of information on each section. They are further required to maintain and update that information with annual submittals to FHWA.

FHWA also developed a package of computer programs to summarize and analyze the data submitted by the states. The programs provide an analysis of the current or existing condition of the highway system, and a number of options, to look at future needs as well as impacts of different funding limitations. The basic procedure the analysis package uses is first to estimate the current condition of the sample highway sections. Those conditions are then compared to minimum tolerable conditions. For those sections which have values falling below those minimum values, an improvement is simulated. Both the type of improvement needed and the construction cost are estimated internally within the program. If a funding limitation is imposed, then the program selects the highest ranked needed improvements until the next funding period.

FHWA also provided to the states a version of the analysis package for use at the state level. Since the states must collect the HPMS information anyway, it would be advantageous to make use of that data if it can successfully be adapted to the needs within Texas. That is the purpose of this study, to examine the sample and analysis package for possible adaptation and use in Texas.

One potential use of the HPMS data and analysis package for Texas is to provide information on the current condition of the highway system in Texas and estimates of future needs, similar to what is done at the federal level. Currently the Texas Department of Highways and Public Transportation (SDHPT) compiles a document called the Strategic Mobility Plan (SMP) (2). This gives estimates of twenty year needs of the department and is updated every two years. The estimates are a combination of the projects submitted by the districts which cover the anticipated needs over the next twenty years; and a computer program, which estimates aggregate rehabilitation and maintenance needs over the same twenty year period.

HPMS has the potential to be used in combination with or as a substitute for the current procedure. Use of HPMS sample data would eliminate the need for submitting individual projects for estimating needs and estimating several categories of needs together in one analysis eliminates the double counting in the current system. For example, the same highway section could have an added-capacity project submitted by the district and a pavement rehabilitation estimated with the computer program. HPMS would eliminate that type of double counting if the improvements are needed in the same time frame, usually five years (which can be varied).

A disadvantage of the HPMS system is that it does not cover all construction areas SDHPT is interested in. These include new location projects, bridges, interchanges, and routine maintenance. These would have to be handled outside the HPMS framework.

Overall, however, HPMS does seem to have a potential for providing consistent needs estimates over time. Another significant advantage is the ability to quickly and easily make estimates of the effects of changes in funding levels, something which cannot be done with the present system. This could be very beneficial at the policy level and when working with the legislature in determining the required funding for SDHPT.

This report documents some of the work that has been done in examining the HPMS sample and analysis package for use in Texas. Extensive work has been done in examining the adequacy of the sample size and making recommendations for increasing the sample to make needs estimates at the district level.

ADEQUACY OF THE HPMS SAMPLE

Current Sampling Procedure

FHWA has recommended to the states the procedures that should be followed in calculating the size of the sample needed for each state, the selection of the samples, and criteria for selecting additional samples as needed over time. The highway system is first stratified into rural, small urban, and urbanized categories. The urbanized areas can either be handled collectively or as individual areas. Currently, there are thirty designated urbanized areas in Texas that are sampled separately. Each area is broken down by functional class and further stratified by volume group (up to 13) within each functional class using average annual daily traffic (AADT).

FHWA provides a formula for calculating the required sample size for the highway sections in each volume group. The formula is given below and is from Appendix G of the HPMS Field Manual (3). The minimum sample size is three unless there are three or fewer sections in the volume group, in such case all sections are sampled.

$$n = F/[1+1/N(F-1)] \text{ with } n \geq 3 \tag{1}$$

where

- n = required sample size
- F = $[(Z_\alpha)(c)/d]$
- Z_α = value of the standard normal statistic for α confidence level (two-sided)
- c = AADT coefficient of variation
- d = desired precision rate
- N = universe or population stratum size

FHWA has recommended values of both Z_α and d, based upon functional class, with generally higher precision and confidence levels for higher functional classes. TTI Research Report 480-1 (4) shows that the current procedure can cause a problem in calculating the required sample size in some circumstances. The problem results from using AADT as both the variable for stratifying the highway sections and in calculating the required sample size within each of those stratified volume groups.

An example from a TRB paper on the same subject should illustrate the class from the Houston urbanized area. In volume group 1, from 0 to 2,499 AADT, there are 40 sections. Using Formula (1), n = 11.34. However, in volume group 5, from 15,000 to 19,999, with 154 sections, Formula (1) gives n = 0.29, which would use the minimum of 3. The paper describes the reasons that this can happen and recommends a procedure for eliminating the problem by calculating the required sample size at the functional class level using Formula (1) and then distributing the sample to the volume groups.

It should be noted that the problem with the FHWA procedure described above does not seem to be serious in most cases since there are not usually a large number of sections in higher volume groups where the problem is most significant. In addition, as shown in the simulation results, aggregating tends to reduce the error introduced in under sampling some volume groups. It should not affect estimates at the national level but it could have some effect at the state level and sub-state level. For that reason, the sampling simulation in the next section uses the changes in the recommended procedure for testing and determining the required sample size for district level HPMS estimates.

HPMS Sample Simulation

The objective and goal of taking a sample is that if chosen properly it can be used to represent the population being sampled subject to a known margin of error. In the case of HPMS, the sample is being used to represent the entire highway network. One of the main concerns is how well the sample represents the overall network in terms of the estimated needs over time. However, those needs are not known before the sample is selected and data collected and analyzed.

As described previously, the size of HPMS sample is calculated using AADT, a commonly available data item on most highway sections. Since the sample size calculations and the margin of error is based on AADT, the accuracy of estimating needs is not known. In a sense, AADT is being used as a proxy for sampling purposes for other unknown items such as needs. While AADT may be a good proxy for some needs, it clearly does not cover all possibilities over time. For example, AADT and 20 year needs tend to be correlated but that correlation varies considerably, with higher correlations in rural areas than in urban areas. Therefore, it became necessary as part of this study to devise a method to determine the accuracy of various sampling rates for estimating needs.

A simulation model was developed to test several sampling rates and methods using the Texas HPMS sample data as the base of comparison. Only those samples on the state maintained highway system were used because estimates of needs are required by SDHPT for those highways. The sample was treated as the universe, like a district, and samples taken from that universe. The sample sizes were calculated for this universe using the formula and procedure described in the previous section and samples were selected randomly. The accuracy of the sample was calculated by comparing the needs estimate of the sample with the needs estimate of the universe. This was repeated several times to generate an error distribution curve. This gave the probability of any margin of error occurring, which could then be compared to the assumed accuracy, based upon AADT, used to calculate the sample size. This was done for both 5 and 20 year HPMS needs estimates.

Three different groups of precision rates were tested in the simulation model. The precision rates recommended by FHWA for statewide sampling and for individual urbanized areas were used along with a lower precision rate developed by the author for testing. The three groups of precision rates are shown in Table 1. The precision rates specify the probability that the sample mean will fall within a specified range. For example, if a 90-5 precision is specified, it means that the sample mean AADT will be within ±5 percent of the universe mean AADT 90 percent of the time. If a sample were drawn 100 times from the universe, the sample mean AADT would be expected to be within 5 percent of the universe mean 90 times.

A sample size was calculated for each precision rate on all the functional classes. Formula (1) was used to calculate the required sample size. These numbers, along with the associated needs estimates, are shown in Table 2. The estimated needs for all the HPMS sections, shown in columns 4 and 5, were used as the basis of comparison in calculating the sample errors. For example, in rural class 1, there are a total of 176 HPMS sections. For the statewide precision rate, 142 of those sections need to be sampled. Sections were randomly selected, without replacement, until 142 out of the 176 total had been selected. Selection without replacement was used so that the same section could not be in the sample more than once.

After the samples were selected, the 5 year and 20 year costs were summed and then expanded to represent all the sections using the ratio of the universe

Table 1. Precision Rates Used in Sample Simulation

Functional Class	FHWA Statewide Precision Rates[1]	FHWA Individual Urbanized Area Rates[1]	Lower Precision Rates
Rural			
1 - Interstate	90 - 5	80 - 10	70 - 10
2 - Principal Arterial	90 - 5	80 - 10	70 - 10
3 - Minor Arterial	90 - 10	80 - 15[2]	70 - 15
4 - Major Collector	80 - 10	70 - 15	60 - 15
5 - Minor Collector	80 - 10	70 - 15	60 - 15
Small Urban and Urbanized			
1 - Interstate	90 - 5	80 - 10	70 - 10
2 - Other Freeway	90 - 5	80 - 10	70 - 10
3 - Principal Arterial	90 - 5	80 - 10	70 - 10
4 - Minor Arterial	90 - 10	80 - 15[2]	70 - 15
5 - Collector	80 - 10	70 - 15	60 - 15

[1] FHWA rates taken from Appendix F, HPMS Field Manual (3).

[2] Precision rates changed from those recommended in HPMS Manual to make them consistent with statewide rates. The recommended precision rate is 70 - 15.

mileage to sample mileage as the expansion factor. That is the same process used in the HPMS analytical package. It should be noted that the samples were not stratified by volume group during this part of the simulation, stratification is tested in the next section. The error then can easily be calculated by taking the difference between the expanded sample cost and the universe cost and dividing by the universe cost. This was repeated 350 times to give a distribution of the errors. The number of replications, 350, was chosen because the distribution seemed to stabilize at about that point in initial testing of the simulation model and the distribution changed very little with higher replications.

Figures 1 through 6 give some examples of the simulation results in graphical form. The complete set of graphs is contained in Appendices A and B.

Each of the figures depict the accuracy range along the horizontal axis which is based on the calculated percent sample error described above. The vertical axis gives the percent of the 350 samples which fall within that range of accuracy. For example, in Figure 1, rural function class 1, the top line represents the error distribution using the statewide precision rates. About 82 percent of the samples were within 5 percent of the actual 20 year needs estimate and about 98 percent were within 10 percent of the actual amount. None of the samples were more than 15 percent off.

The assumed precision rates are also shown on each figure when applicable. The cross with a circle around it at 90-5 in Figure 1 is the statewide precision rate used to calculate the sample size. The actual simulated error is somewhat below the assumed precision rate but not by much. The other precision rates miss by more. For example, the lower precision rate assumes 70 percent of the samples will be within 10 percent of the actual amount but only 54 percent are in that range in the simulation. It does go over 70 percent at the 20 percent range but doesn't reach 100 percent of the distribution until about a 50 percent range of accuracy.

Figure 2, rural functional class 4, gives much better results in terms of the accuracy of the simulation versus the assumed precision. In each case the actual simulated accuracy is much higher than the assumed precision. For example, the assumed statewide precision is 80-10, whereas the simulated results give about 98 percent of the distribution within 10 percent of the actual value.

Table 2. Summary of Sample Sizes and Costs Used in HPMS Simulation
(Uses 1985 HPMS On-System Data, with 100% Willacy County; and HPMS Analysis Package, Version 2.0)

(1)	(2)	(3)			(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Total #	Sample Size			5-Yr	20-Yr	% Total	Adj 5-Yr			
Funct Class	HPMS Sections	State Precsn	I URB Precsn	Lower Precsn	Cost ($1000)	Cost ($1000)	State Mil In Sample	Cost ($1000)	% of Total	Cost ($1000)	% of TOTAL
Rural											
1	176	142	69	52	411570	1293938	49.5	831455	2.4	2614016	3.4
2	437	355	174	132	889316	2127291	34.0	2615635	7.5	6256738	8.2
3	165	112	60	45	180392	352498	16.6	1086699	3.1	2123241	2.8
4	173	139	94	76	103940	345366	2.4	4330833	12.4	14390250	18.9
5	162	111	63	48	40932	188023	4.7	870894	2.5	4000489	5.3
ALL	1113	859	460	353	1626150	4307076		9735516	27.9	29384734	38.6
Small Urban											
1	42	38	27	23	373770	890438	64.9	575917	1.6	1372015	1.8
2	25	23	18	16	163741	303394	64.6	253469	0.7	469650	0.6
3	264	184	69	49	354956	885528	32.1	1105782	3.2	2758654	3.6
4	57	49	36	30	38456	93247	6.0	640933	1.8	1554117	2.0
5	8	7	6	6	4871	11048	19.0	25637	0.1	58147	0.1
ALL	396	301	156	124	935794	21833655		2601738	7.5	6212584	8.2
Urbanized											
1	148	112	48	35	8888941	14215762	69.0	12882523	36.9	06025544	27.1
2	167	137	69	52	3586856	6477532	54.4	6593485	18.9	11907728	15.7
3	442	291	100	71	1104106	2553045	44.2	2497977	7.2	5776120	7.6
4	147	97	51	37	127189	478094	22.8	557846	1.6	2096904	2.8
5	15	13	11	10	12924	19086	31.4	41159	0.1	60783	0.1
ALL	919	650	279	205	13720016	23743517		22572990	64.7	40443590	53.2
State	2428	1810	895	682	16281960	30234248		34910244	100.0	76040908	100.0

Table 2. (continued)

Notes on columns:

(1) Functional class designation used in HPMS, also shows totals by area and statewide total.

(2) Total number of HPMS sample sections on state system in Texas, currently 2428.

(3) Sample size refers to the sample taken from the HPMS sections (1), for each precision level.

(4) The 5-year cost is the sum of the estimated needs for the HPMS sections (1) for the next 5 years.

(5) The 20-year cost is the sum of the estimated needs for the HPMS sections (1) for the next 20 years.

(6) This is the percent of total statewide on-system mileage the HPMS sample represents, used to adjust costs to statewide totals.

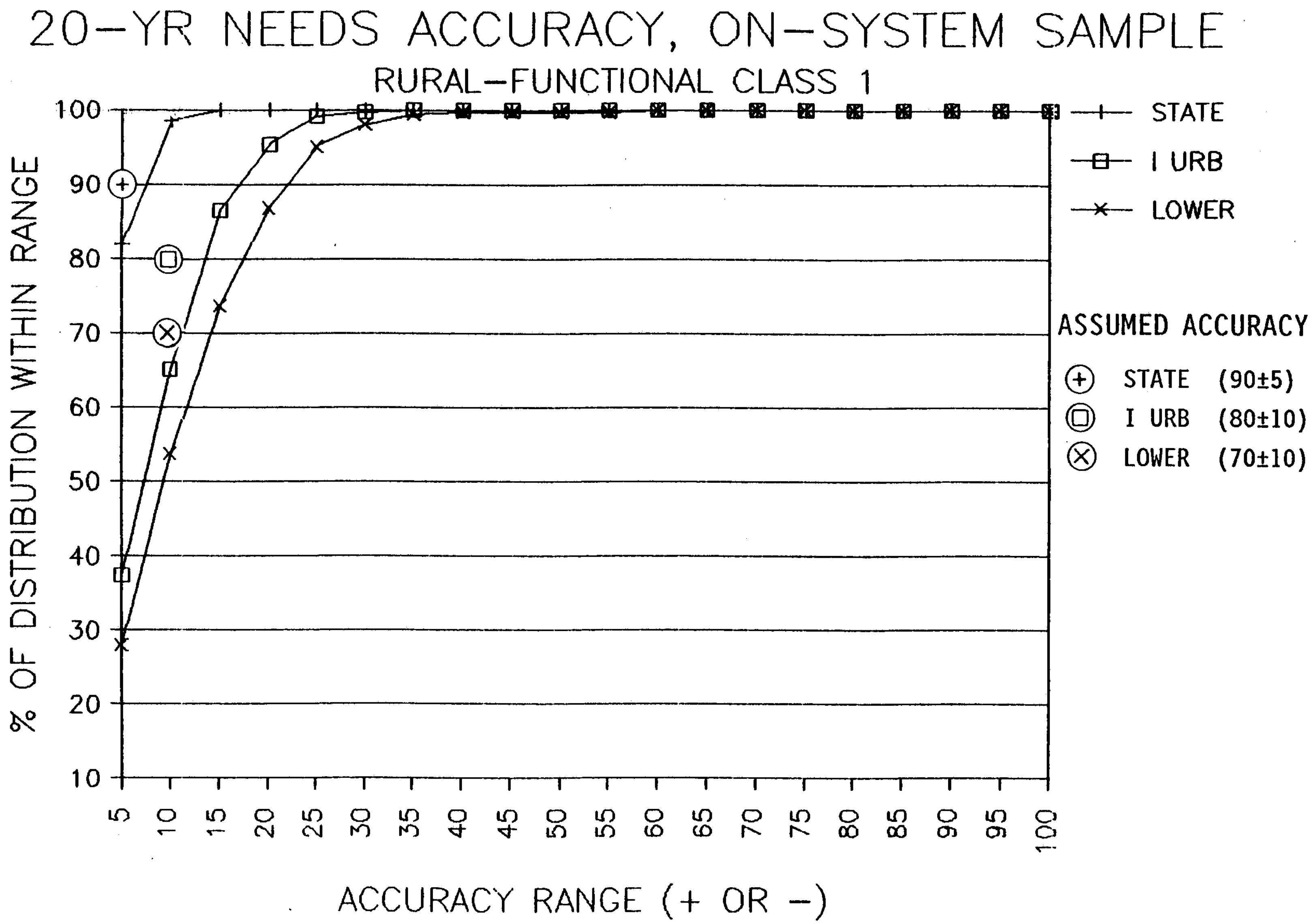
(7) This is the total 5-year estimated statewide on-system needs, which is the 5-year needs (4), adjusted for the percent statewide mileage (6).

(8) This is the percent of the total statewide on-system 5-year estimated needs.

(9) This is the total 20-year estimated statewide on-system needs, which is the 20-year needs (5), adjusted for the percent statewide mileage (6).

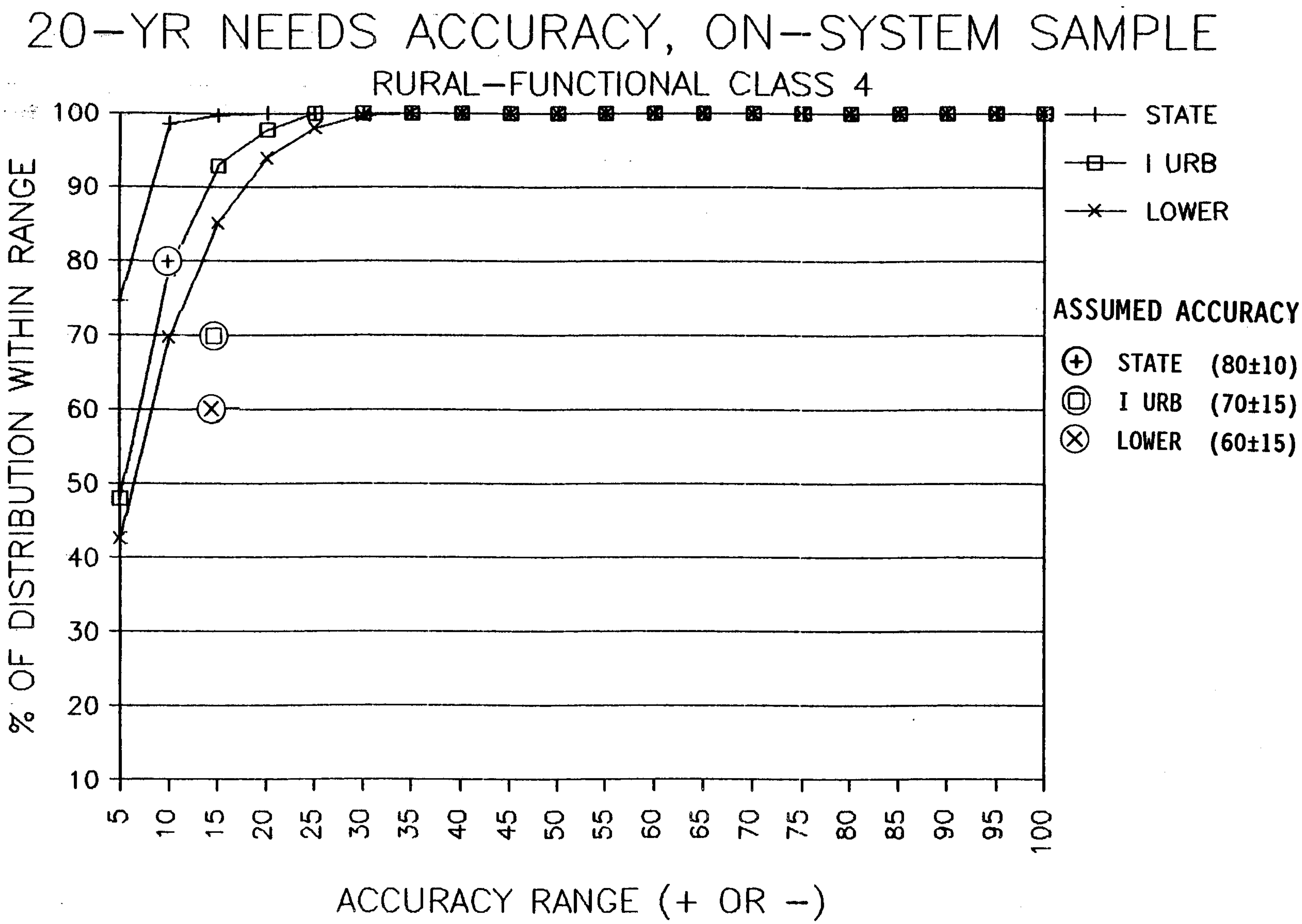
(10) This is the percent of the total statewide on-system 20-year estimated needs.

FIGURE 1



20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
RURAL-FUNCTIONAL CLASS 1
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±5)
I URB (80±10)
LOWER (70±10)

FIGURE 2



20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
RURAL-FUNCTIONAL CLASS 4
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (80±10)
I URB (70±15)
LOWER (60±15)

FIGURE 3

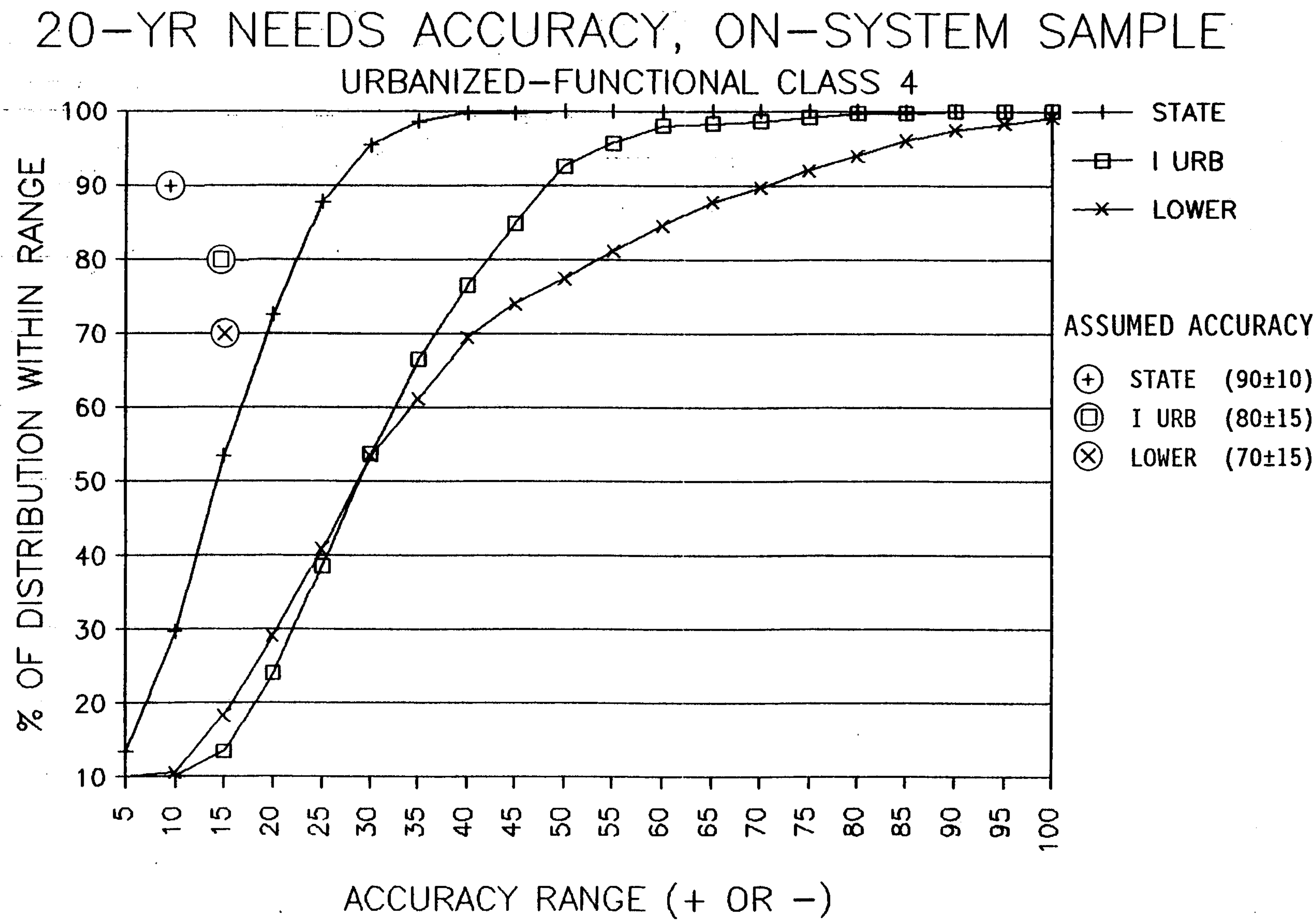
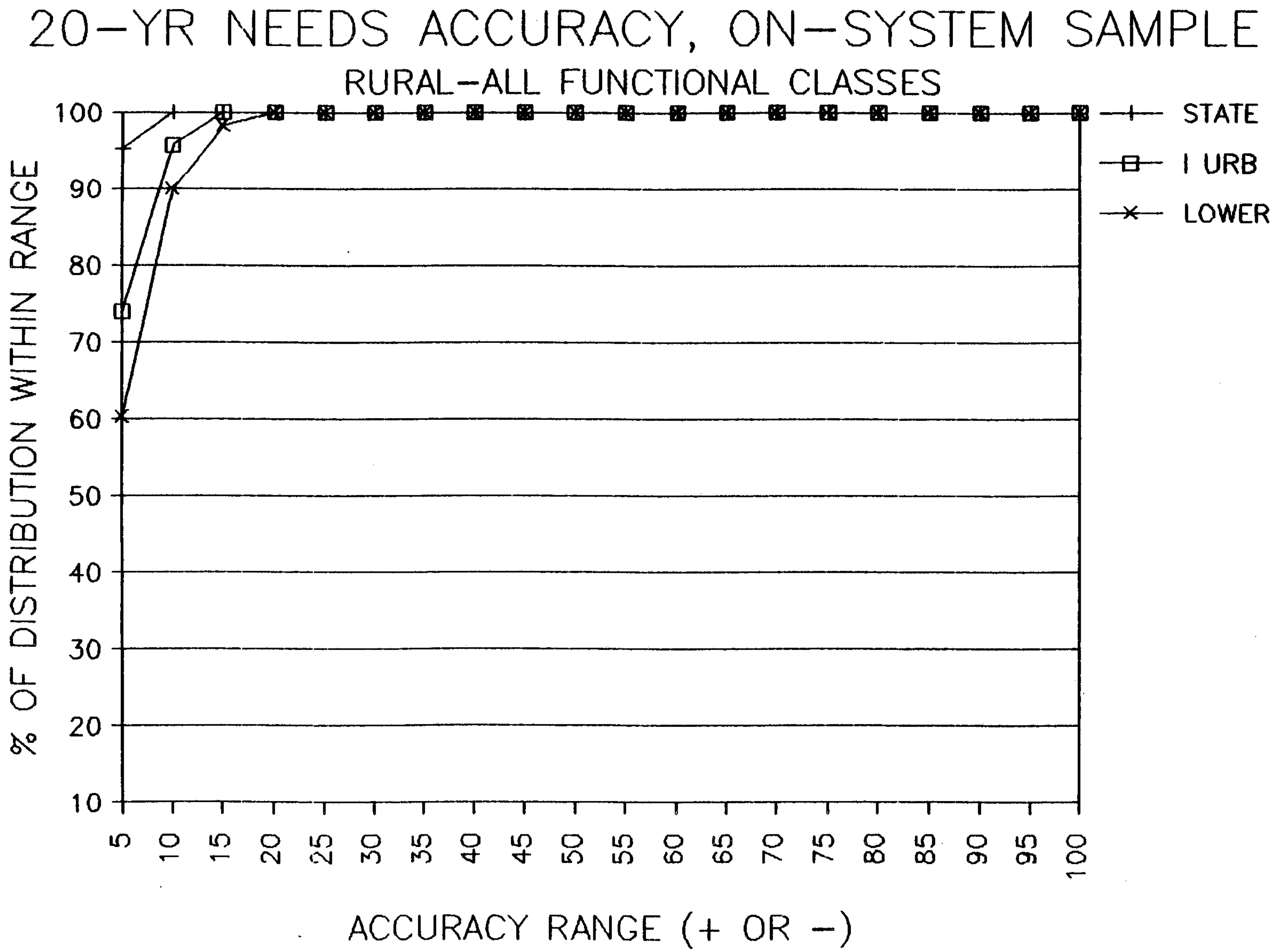

20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
URBANIZED-FUNCTIONAL CLASS 4
% OF DISTRIBUTION WITHIN RANGE
10
20
30
40
50
60
70
80
90
100
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
ACCURACY RANGE (+ OR −)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±10)
I URB (80±15)
LOWER (70±15)

FIGURE 4


20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
RURAL-ALL FUNCTIONAL CLASSES
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
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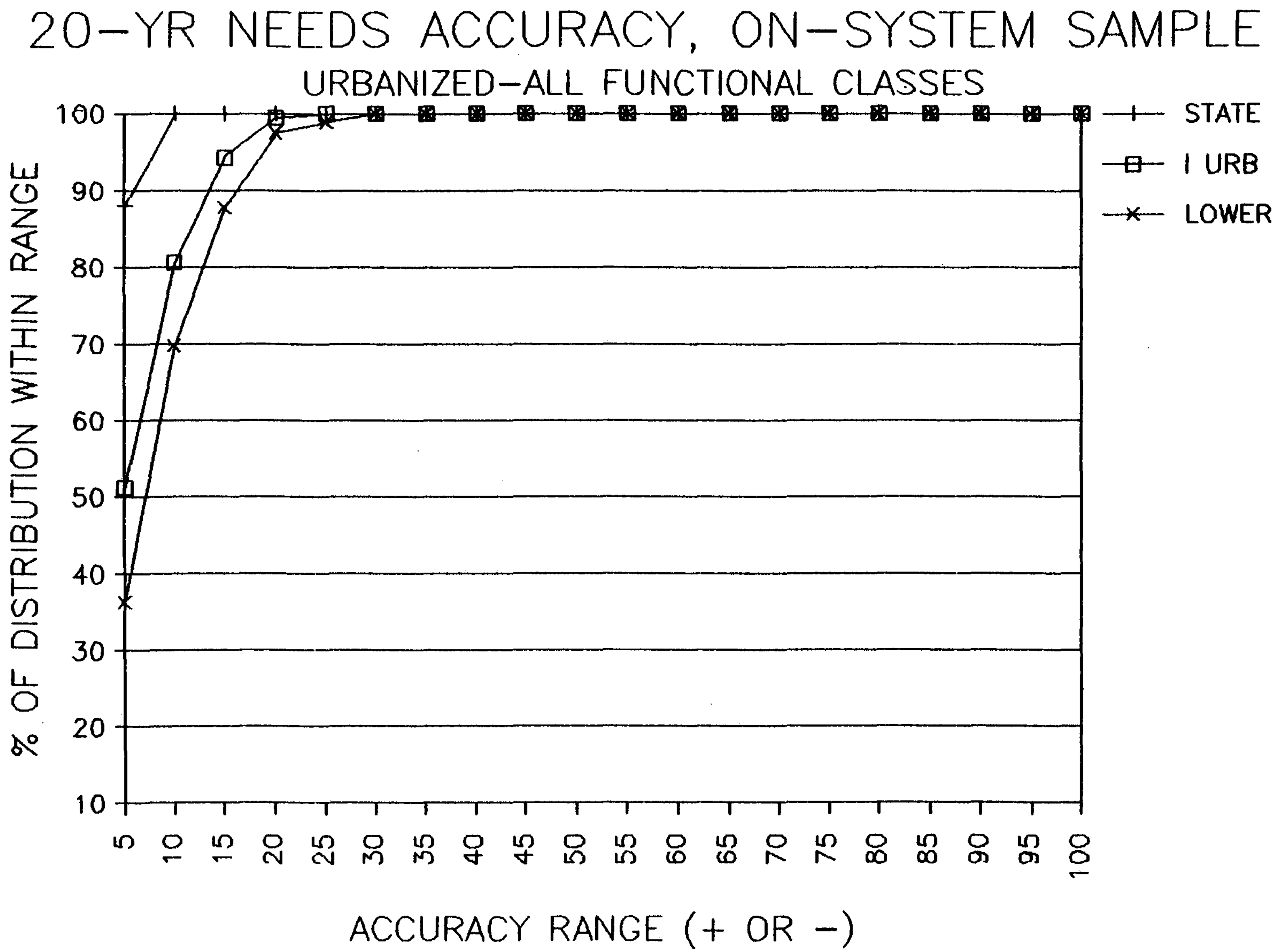
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER

FIGURE 5


20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
URBANIZED-ALL FUNCTIONAL CLASSES
% OF DISTRIBUTION WITHIN RANGE
100
90
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15
20
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35
40
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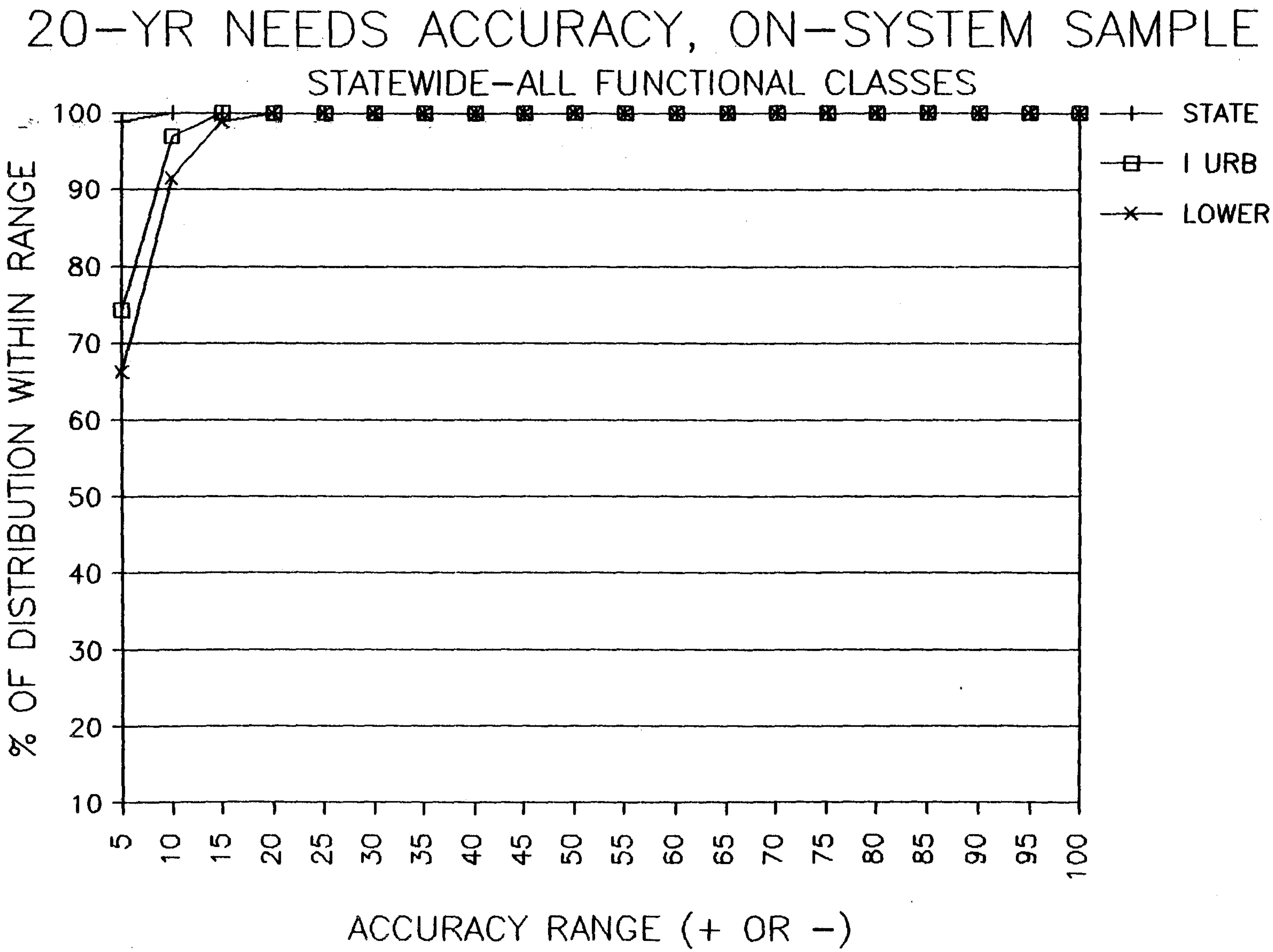
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER

FIGURE 6


20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
STATEWIDE-ALL FUNCTIONAL CLASSES
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
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60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER

At the other extreme, Figure 3 gives the results of urbanized, functional class 4. Here the errors are much larger than was assumed in calculations of the sample sizes. For example, the statewide precision rate assumes 90 percent of the distribution will be within 10 percent of the actual amount but only about 30 percent of the distribution is within that range. At the lowest precision rate there are some samples that have an error greater than 100 percent.

Fortunately, aggregating substantially reduces the errors for individual functional classes. Figure 4 depicts the combined functional classes in the rural area. The assumed precision rates are not shown because they vary by functional class. The statewide precision rate gives about 96 percent of the samples within 5 percent and 100 percent within 10 percent. Even the lower precision rate has 90 percent of the samples within 10 percent and 100 percent within 20 percent.

As would be expected, the combined urbanized area, shown in Figure 5, is not as high as the combined rural area but the improvements are substantial. The statewide precision rate gives about 88 percent of the samples within 10 percent and 100 percent within 10 percent. The lower precision rate gives about 88 percent within 15 percent and 100 percent within 30 percent.

Figure 6 shows the combined statewide distributions. The statewide precision rate is very high with 100 percent of the distribution within 10 percent. The other two are somewhat lower, but still very high, with both above 90 percent at the 10 percent accuracy level.

There appears to be considerable increases in the accuracy levels when functional classes are combined, even if the accuracy of individual functional classes are not very high.

Stratification by Volume Group

One common way to improve the accuracy of the sample is to stratify it into more homogenous groups. The HPMS sampling procedure attempts to do this by stratifying functional classes by volume group. The objective is to reduce the required number of samples for a given precision rate. One reason for that was to reduce the data collection burdens on the states when the HPMS sample data was originally collected. It should be noted that stratification does not necessarily improve the accuracy of the sample and it can actually make it worse, though it generally helps.

In an effort to determine the usefulness of stratifying the HPMS sample by group using AADT, the simulation model was used to test two stratification strategies. The first is the current technique recommended by FHWA. The HPMS sections are stratified by AADT volume group and then the required sample size for each volume group is calculated using Formula (1). The second method uses the same AADT volume group stratification but distributes the sample proportionately by mileage to the volume groups.

Tables 3 through 5 give the sample sizes by volume group used in the simulation. The volume group sample number refers to the sample sizes by volume group using the current procedures with the stratified precision rates of Table 1. The next column, the proportional sample number, gives the same total samples for each functional class but distributes them proportionately by mileage into the volume groups. The functional class sample number is not stratified at all and is used as the basis of comparison. The functional class level of sampling was also used in the sampling simulation presented in the previous section so they can also be compared with the previous graphs.

It is interesting to note that for these HPMS sections, the sample size calculated at the volume group level using the statewide precision rate gives roughly the same sample size as using the individual urbanized precision rate at the functional class level. For example, the rural individual urbanized sample is 460 in Table 2 compared to 456 in Table 3. Of course, the sample sizes for some functional classes vary considerably, influencing the accuracy of individual functional classes.

Figures 7 through 11 present some examples of the simulation results of stratification. In Figure 7, rural functional class 1 is presented. All three lines are below the assumed precision of 90-5, with the proportional distribution performing the best. Surprisingly, the unstratified functional class distribution is higher than the volume group calculated distribution. In this case, the calculation of sample size by volume group actually was worse than if no stratification at all had been done.

Figure 8 presents a somewhat different result for rural, functional class 3. Here the highest is the volume group calculation with the stratified proportional distribution higher at most levels of accuracy than the unstratified distribution.

Table 3. Comparison of Volume Group Stratification Accuracy Rural Sample Size

Functional Class	Volume Group	Total HPMS #	Vol. Group Sample #	Proportional Sample	Functional Class Sample #
1	1	78	48	42	
	2	54	22	27	
	3	27	10	10	
	4	6	4	3	
	5	6	3	3	
	6	2	2	2	
	7	2	2	2	
	8	1	1	1	
	All	176	92	92	92
2	1	261	118	113	
	2	111	27	37	
	3	35	10	9	
	4	13	4	3	
	5	10	6	3	
	6	4	3	3	
	7	1	1	1	
	8	1	1	1	
	13	1	1	1	
	All	437	171	171	171
3	1	95	34	34	
	2	43	9	11	
	3	18	4	4	
	4	8	5	3	
	6	1	1	1	
	All	165	53	53	53
4	1	129	58	58	
	2	16	6	5	
	3	16	3	4	
	4	8	3	3	
	5	2	2	2	
	6	1	1	1	
	7	1	1	1	
	All	173	74	74	74
5	1	136	54	56	
	2	13	5	3	
	3	6	3	3	
	4	6	3	3	
	5	1	1	1	
	All	162	66	66	66
Total		1113	456	456	456

Table 4. Comparison of Volume Group Stratification Accuracy
Small Urban Sample Size

Functional Class	Volume Group	Total HPMS #	Vol. Group Sample #	Proportional Sample #	Functional Class Sample #
1	1	7	6	5	
	2	12	9	8	
	3	11	6	8	
	4	5	3	3	
	5	3	3	3	
	6	1	1	1	
	7	1	1	1	
	8	2	2	2	
	All	42	31	31	31
2	1	5	4	5	
	2	7	6	5	
	3	7	5	5	
	4	4	3	3	
	5	1	1	1	
	6	1	1	1	
	All	25	20	20	20
3	1	94	41	29	
	2	88	31	35	
	3	40	11	14	
	4	24	7	9	
	5	13	4	7	
	6	4	3	3	
	11	1	1	1	
	All	264	98	98	98
4	1	24	15	17	
	2	13	7	5	
	3	9	5	4	
	4	4	3	3	
	5	4	3	4	
	6	1	1	1	
	7	1	1	1	
	8	1	1	1	
	All	57	36	36	36
5	1	3	3	3	
	3	1	1	1	
	4	2	2	2	
	5	2	2	2	
	All	8	8	8	8
Total		396	193	193	193

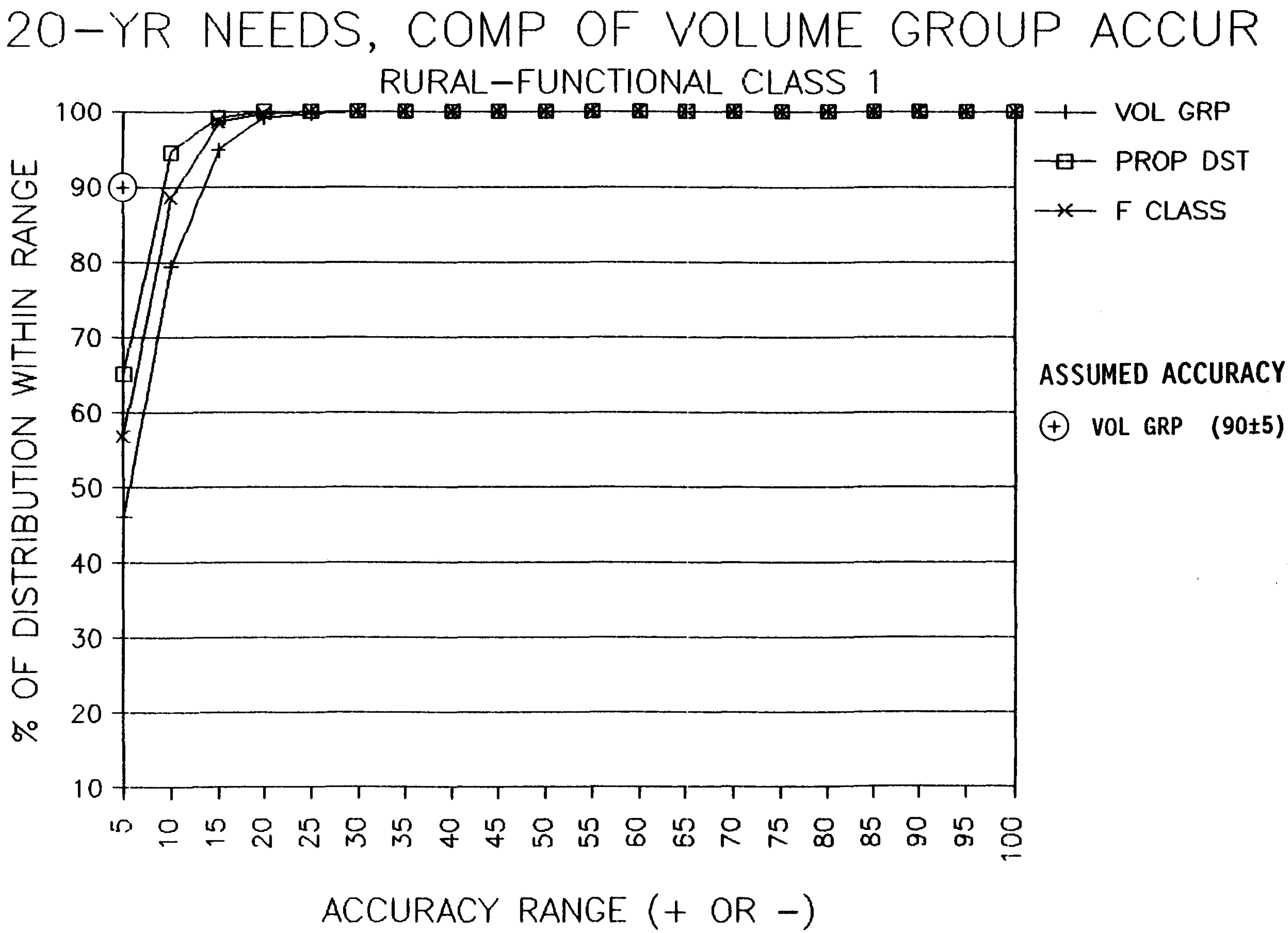
Table 5. Comparison of Volume Group Stratification Accuracy
Urbanized Sample Size

Functional Class	Volume Group	Total HPMS #	Vol. Group Sample #	Proportional Sample #	Functional Class Sample #
1	1	22	15	8	
	2	35	17	16	
	3	21	8	10	
	4	20	5	9	
	5	14	3	4	
	6	14	3	3	
	7	10	3	4	
	8	8	3	3	
	9	4	3	3	
	All	148	60	60	60
2	1	62	44	36	
	2	52	21	27	
	3	22	9	10	
	4	7	3	3	
	5	14	3	4	
	6	7	3	3	
	7	2	2	2	
	8	1	1	1	
	All	167	86	86	86
3	1	4	3	3	
	2	38	21	8	
	3	88	28	17	
	4	104	11	21	
	5	68	6	14	
	6	55	3	9	
	7	57	9	11	
	8	13	5	3	
	9	6	3	3	
	10	4	3	3	
	11	2	2	2	
	13	3	3	3	
	All	442	97	97	97
4	1	27	17	8	
	2	30	7	9	
	3	43	10	14	
	4	20	3	5	
	5	15	3	4	
	6	5	3	3	
	7	5	3	3	
	10	2	2	2	
	All	147	48	48	48

Table 5. Comparison of Volume Group Stratification Accuracy
Urbanized Sample Size (Continued)

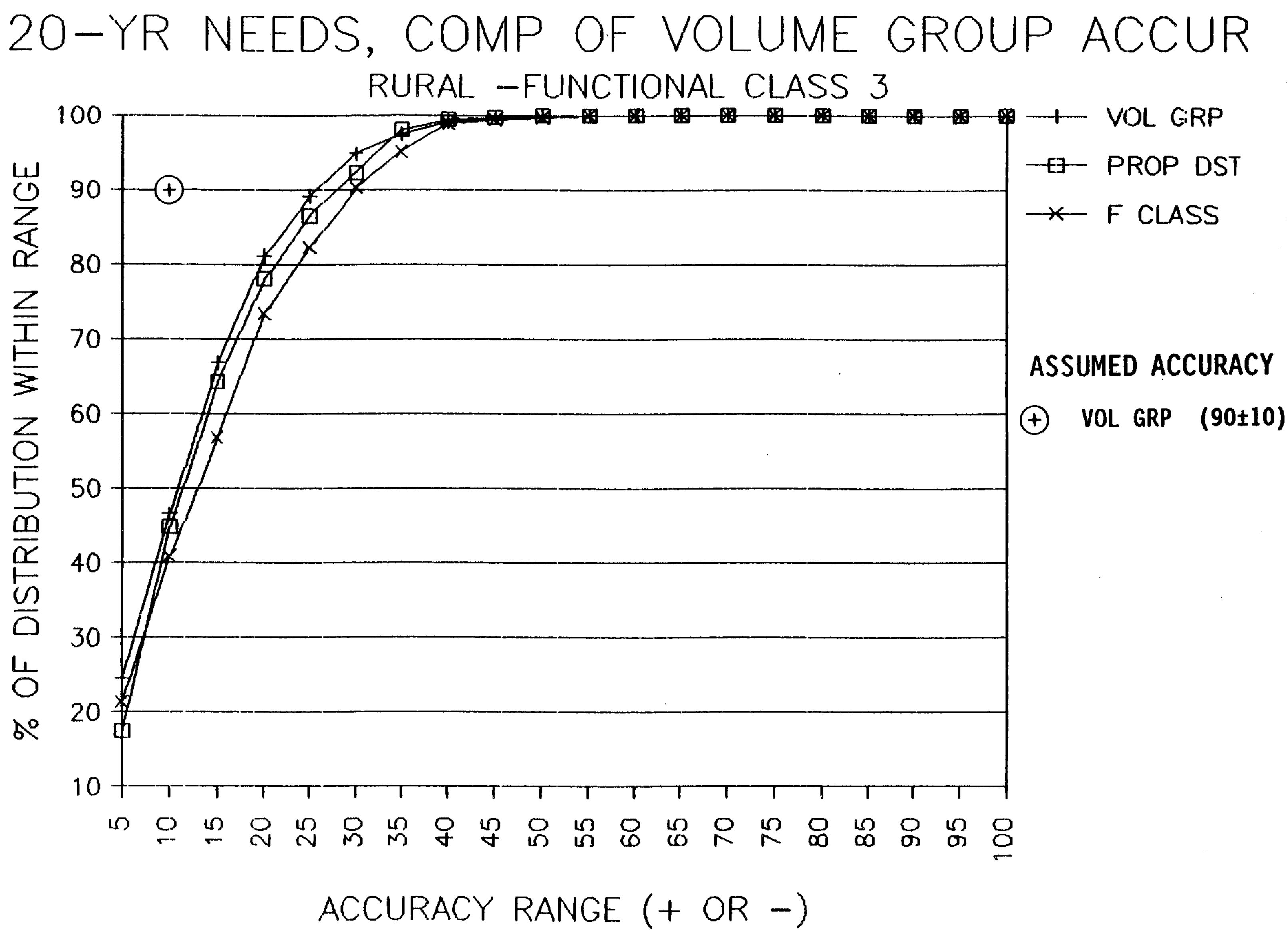
Functional Class	Volume Group	Total HPMS #	Vol. Group Sample #	Proportional Sample #	Functional Class Sample #
5	1	3	3	3	
	2	2	2	2	
	3	4	3	3	
	4	2	2	2	
	5	3	3	3	
	6	1	1	1	
	All	15	14	14	14
Total		919	305	305	305

Figure 7



20-YR NEEDS, COMP OF VOLUME GROUP ACCUR
RURAL-FUNCTIONAL CLASS 1
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
VOL GRP
PROP DST
F CLASS
ASSUMED ACCURACY
VOL GRP (90±5)

Figure 8



20-YR NEEDS, COMP OF VOLUME GROUP ACCUR
RURAL -FUNCTIONAL CLASS 3
% OF DISTRIBUTION WITHIN RANGE
ACCURACY RANGE (+ OR -)
VOL GRP
PROP DST
F CLASS
ASSUMED ACCURACY
VOL GRP (90±10)

Figure 9

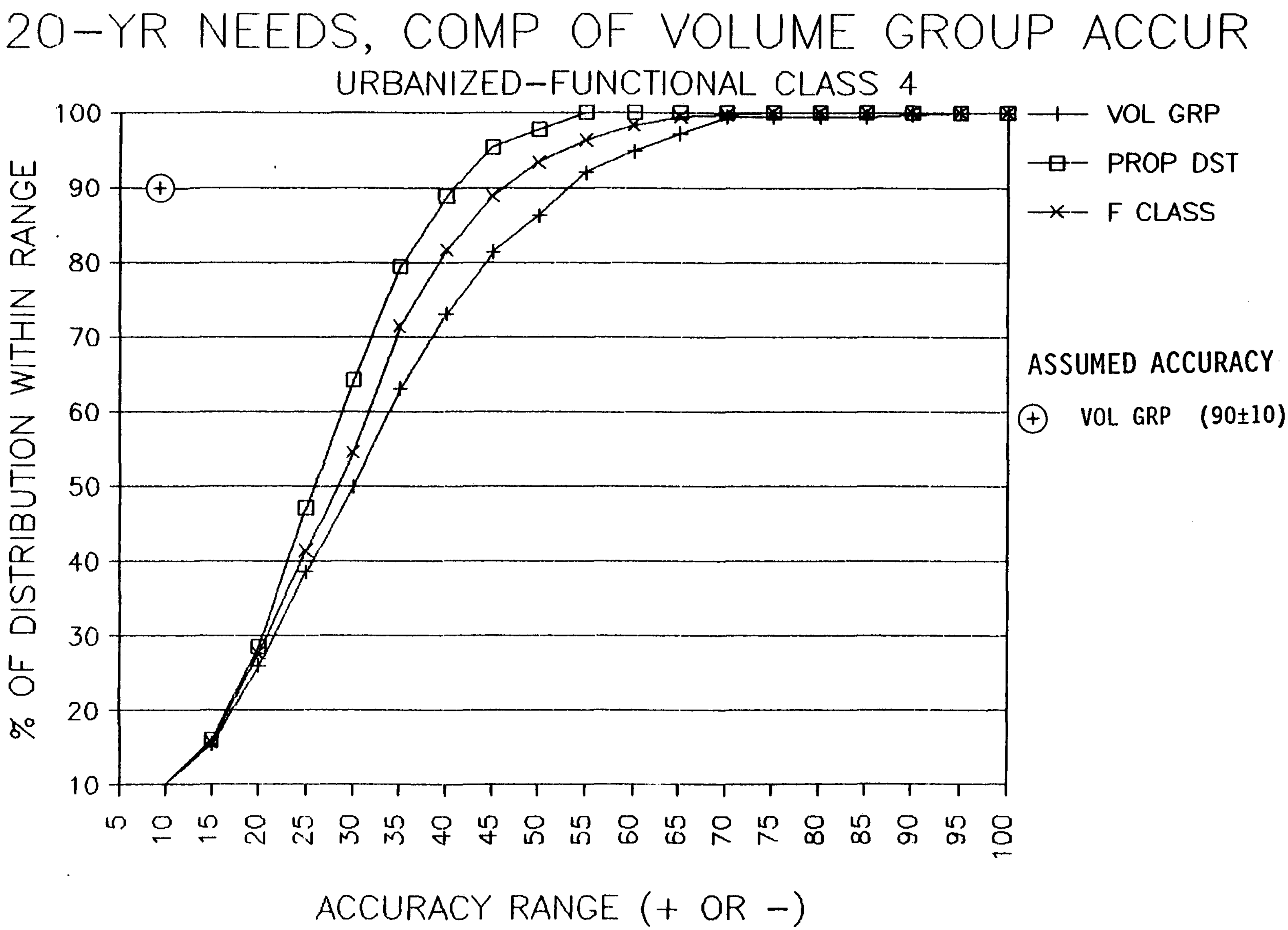

20-YR NEEDS, COMP OF VOLUME GROUP ACCUR
URBANIZED-FUNCTIONAL CLASS 4
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR −)
VOL GRP
PROP DST
F CLASS
ASSUMED ACCURACY
VOL GRP (90±10)

Figure 10

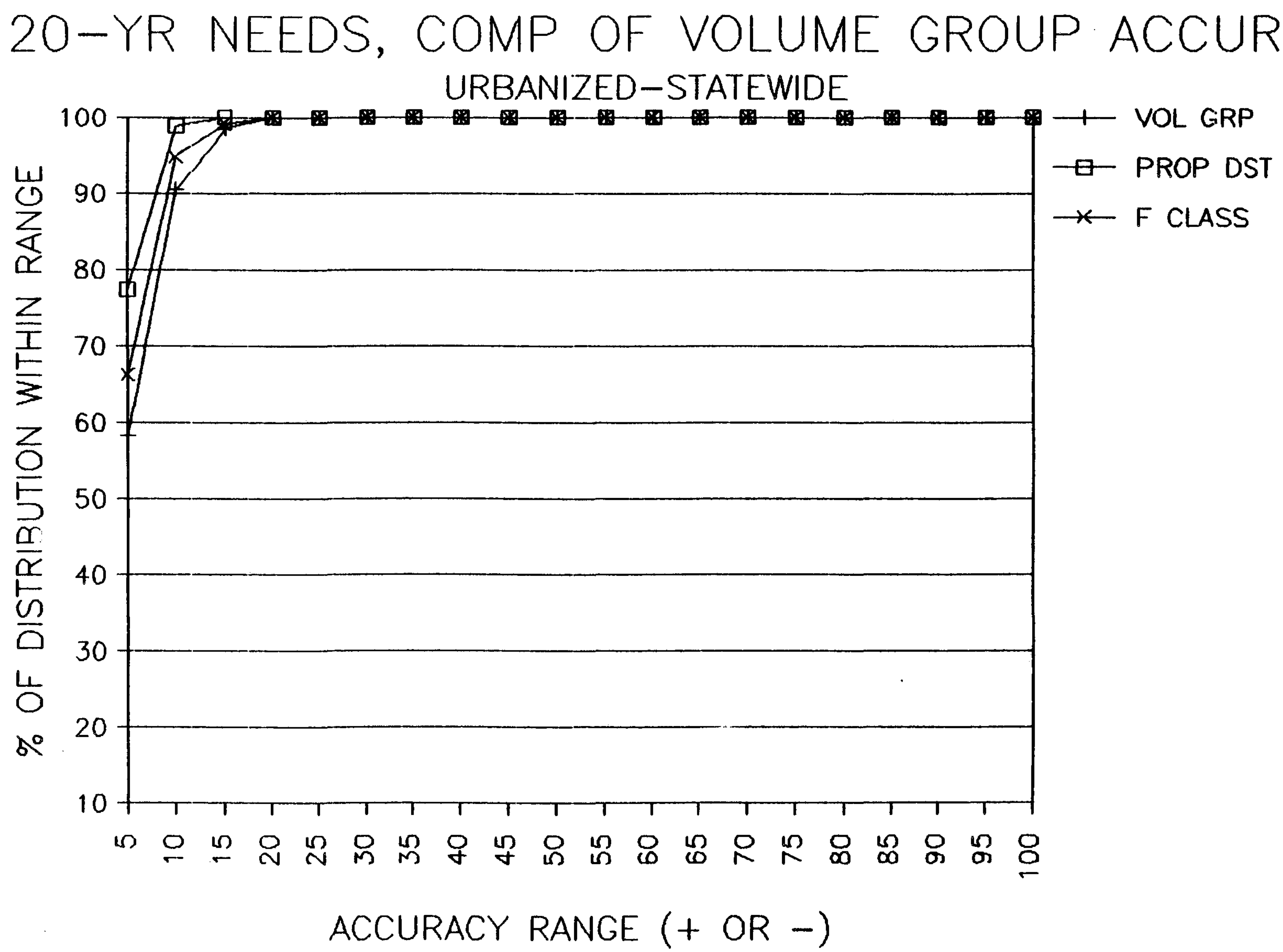
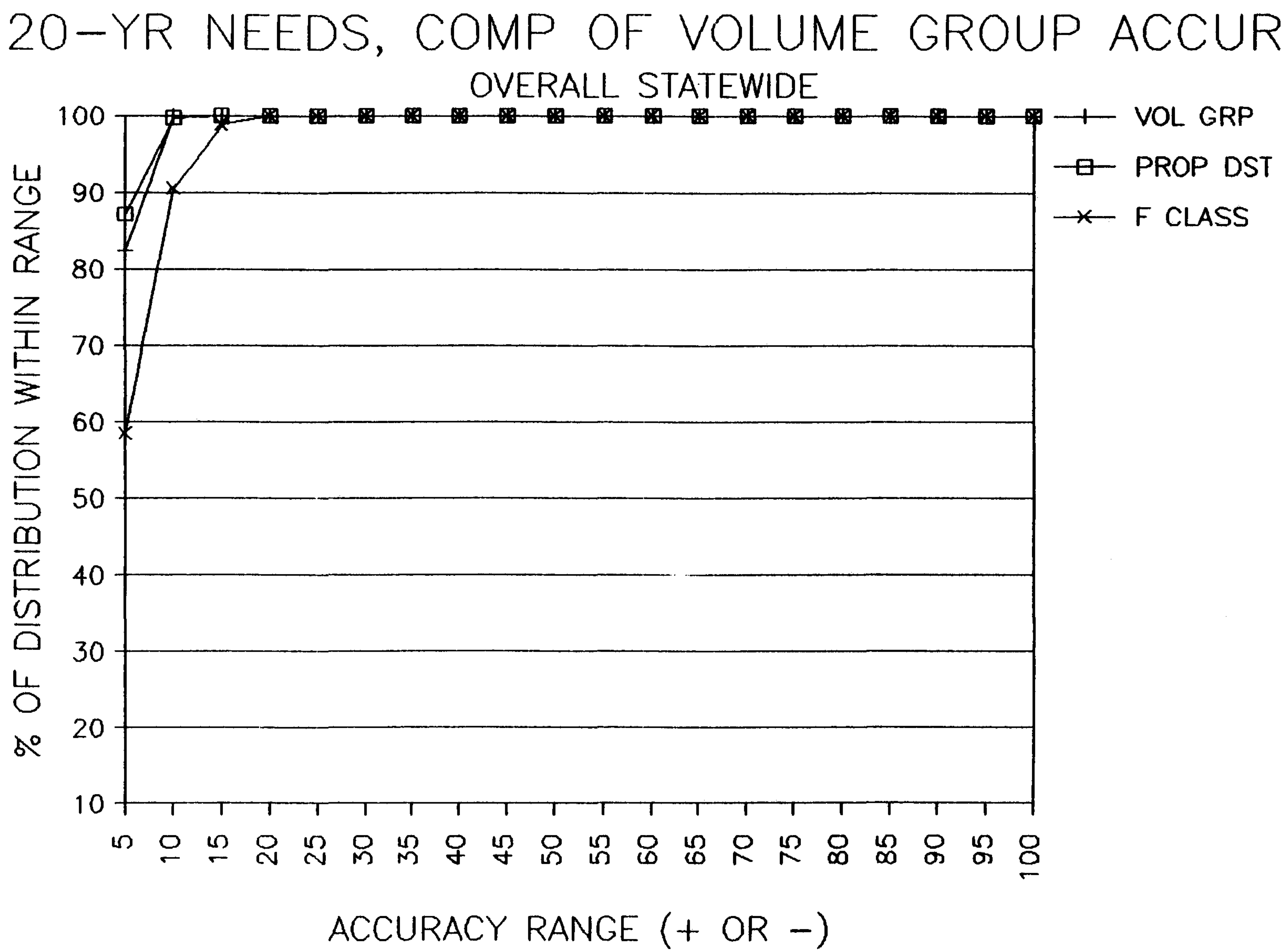

20-YR NEEDS, COMP OF VOLUME GROUP ACCUR
URBANIZED-STATEWIDE
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
VOL GRP
PROP DST
F CLASS

Figure 11



20-YR NEEDS, COMP OF VOLUME GROUP ACCUR
OVERALL STATEWIDE
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR −)
VOL GRP
PROP DST
F CLASS

As was the case with the simulation results of the previous section, the errors tend to be much larger in the urban areas, Figure 9, but decline substantially as functional classes are combined, Figures 10 and 11.

In general, stratification improved the overall accuracy of a given sample. This can be seen clearly in the combined statewide distributions in Figure 11. Both stratification strategies give a substantial improvement at the 5 percent level and a lesser improvement at the 10 percent level. In most cases, the proportional stratification improved the sample accuracy as compared to the volume group calculated accuracy, though that isn't always the case, and many times the difference is very small. The difference tended to be larger in urban areas.

HPMS Sample Size Recommendation for Texas

As a result of the simulation results, and taking into account the requirement to estimate needs at the district level, the SDHPT advisory committee for this project selected the recommended HPMS sample size presented in Table 6. The recommended sample represents about a 133 percent increase in the on-system HPMS sample in Texas.

The recommended samples size was calculated at the functional class level by district, with proportional distribution of samples within volume groups. The individual urbanized precision rates were used for the urban area and the lower precision rates, presented in Table 1, were used for the rural and small urban areas.

The lower precision rates were used for the rural area because the simulation results indicated satisfactory accuracy levels with that precision rate. The small urban areas constitute a very small proportion of the estimated statewide needs, see Table 2, so the lower precision rates were also used for that category. There was also a concern to keep the increase in samples as low as possible since it would entail a significant data collection burden for the districts.

The procedure to maintain the required sample size for HPMS district-level sampling is described in Appendix C.

Table 6. Recommended Sample Size for HPMS Use In On-System Highways at District Level In Texas

District	Rural			Small Urban			Urbanized			All Areas		
	Total Section	Current Sample	Recom. Sample	Total Section	Current Sample	Recom. Sample	Total Section	Current Sample	Recom. Sample	Total Section	Current Sample	Recom. Sample
1	869	30	109	174	20	52	80	31	40	1,123	81	201
2	738	49	244	161	24	64	250	52	93	1,149	125	401
3	651	47	121	95	23	41	73	34	56	819	104	218
4	693	44	144	105	10	31	52	19	38	850	73	213
5	978	41	166	182	15	41	104	25	64	1,264	81	271
6	432	37	141	71	14	34	92	33	44	595	84	219
7	599	50	146	13	3	11	49	24	34	661	77	191
8	648	42	118	75	12	34	73	30	60	796	84	212
9	794	46	127	71	3	43	219	85	108	1,084	134	278
10	1,038	45	102	155	18	54	103	46	52	1,296	109	208
11	925	42	100	150	31	61				1,075	73	161
12	494	33	108	106	23	45	520	127	173	1,120	183	326
13	879	53	114	123	21	38	37	8	23	1,039	82	175
14	701	64	196	122	28	59	103	45	68	926	137	323
15	969	65	167	180	28	59	224	61	110	1,373	154	336
16	605	32	125	130	10	31	81	32	51	816	74	207
17	675	39	86	94	14	41	65	25	40	834	78	167
18	965	51	147	182	30	65	378	56	179	1,525	137	391
19	820	38	79	128	11	44	61	19	38	1,009	68	161
20	526	35	79	122	16	57	130	52	70	778	103	206
21	590	87	126	73	16	26	225	79	95	888	182	247
23	533	46	150	91	23	38				624	69	188
24	245	53	124	11	0	8	103	36	67	359	89	199
25	539	44	150	17	3	14				556	47	164
All	16,906	1,113	3,169	2,631	396	992	3,022	919	1,503	22,559	2,428	5,664

ASSUMPTIONS IN ANALYTICAL PACKAGE

Construction Costs

As stated in the Introduction, the HPMS analytical package estimates costs of improvements when improvements are simulated in the needs analysis portion of the package. There are default costs built into the program that can be adjusted by the user.

As part of this study, an attempt was made to compare the default construction costs in HPMS with the cost of construction projects in Texas. For that purpose SDHPT's Project Development Plan (PDP) was used to make estimates of Texas construction costs. The PDP represents the construction projects SDHPT is planning to undertake during the next ten years.

There are several problems in trying to compare construction costs in the PDP with HPMS construction costs. One problem is the different categories each system uses. HPMS construction categories are by type of improvement and functional class in rural areas, or type of highway in urban areas. Texas uses funding categories to distinguish projects, which may include a wide variety of improvement types. Another problem is the project itself. Many times projects include a variety of activities which are difficult to classify in the HPMS system of improvement types. In addition, some categories of improvements in the PDP had very few projects that could be identified for comparison purposes. Therefore taking an average to represent statewide costs is suspect.

Given the problems described above, a limited comparison was made of HPMS and Texas construction costs for three categories of improvements, reconstruct to freeway, reconstruct with more lanes, and major widening (add lanes). The cost comparisons are presented in Tables 7 through 10.

In general the costs are roughly the same, with Texas costs tending to be somewhat higher in most cases. The biggest difference is in the reconstruct to freeway category in urban areas. The Texas costs are substantially higher than the HPMS numbers.

The HPMS figures are from the latest HPMS technical manual (1) which are given in 1984 values. The Texas PDP represents projects submitted in 1986, so the costs are probably in 1985 or 1986 values. But since costs did not increase much between 1984 and 1986, that should not be a major factor in the difference between the two sets of figures.

A more detailed look should be made in determining the average construction costs for HPMS use in Texas. Since HPMS needs estimates are going

Table 7. Comparison of Rural Construction Costs from HPMS with Texas Estimates (in Thousands of Dollars per Lane-Mile)

Category	HPMS Flat	HPMS Rolling	Texas Estimates Cost	Texas Estimates No. of Projects
Reconstruct to Freeway				
Interstate	433	451	527	9
Other Prin. Art.	457	457	918	9
Minor Art.	0	0	1012	13
Reconst. with More Lanes				
Other Prin. Art.	434	452	112	6
Minor Art.	342	361	356	58
Major Coll.	307	320	373	29
Minor Coll.	216	225	367	35
Major Widen (Add Lanes)				
Interstate	184	228	490	20
Other Prin. Art.	220	259	293	12
Minor Art.	262	326	427	256
Major Coll.	205	235	397	105
Minor Coll.	241	300	465	259

NOTE: Total cost of improvement is calculated by multiplying costs per lane-after the improvement.

Table 8. Comparison of Rural Right-of-Way Costs from HPMS Texas Estimates (In thousands of Dollars per Lane Mile)

Category	HPMS		Texas Estimate	
	Flat	Rolling	Cost	No. of Projects
Reconstruct to Freeway				
Interstate	39	41	8	9
Oth. Prin. Art.	43	43	0[a]	9
Minor Art.	0	0	152	13
Reconst. with More Lanes				
Oth. Prin. Art.	40	53	2	6
Minor Art.	42	48	32	58
Major Coll.	29	46	26	29
Minor Coll.	23	38	19	35
Major Widen (Add Lanes)				
Interstate	28	33	15	20
Oth. Prin. Art.	37	42	76	12
Minor Art.	38	43	28	256
Major Coll.	33	38	23	105
Minor Coll.	38	43	14	259

NOTE: Total cost of improvement is calculated by multiplying costs per lane-mile by total number of lanes after the improvement.

[a] The right-of-way costs of these projects are zero because all projects consist of adding main lanes, with existing frontage roads already open.

Table 9. Comparison of Urban Construction Costs from HPMS with Texas Estimates (In Thousands of Dollars per Lane-Mile)

Category	HPMS		Texas Estimate	
	Built-Up	Outlying	Cost	No. of Projects
Reconstruct to Freeway				
Frwys and Expressways	0	0	0	0
Other Divided	959	612	1938	106
Undivided	1227	752	2086	22
Reconstruct with More Lanes				
Frwys and Expressways	1307	1506	1854	22
Other Divided	788	728	321	7
Undivided	506	437	354	65
Major Widening (Add Lanes)				
Frwys and Expressways	2476	1571	3248	186
Other Divided	937	799	1454	63
Undivided	1200	727	968	260

NOTE: Total cost of improvement, for reconstruct to freeway and reconstruct with more lanes, is calculated by multiplying costs per lane-mile by total number of lanes after the improvement. Total cost of improvement for major widening (add lanes) is calculated by multiplying costs per lane-mile by number of added lanes.

Table 10. Comparison of Urban Right-of Way Costs from Texas HPMS with Texas Estimates (In Thousands of Dollars per Lane-Mile)

Category	HPMS Built-Up	HPMS Outlying	Texas Estimates Cost	Texas Estimates No. of Projects
Reconstruct to Freeway				
Frwys and Expressways	0	0	0	0
Other Divided	86	85	213	106
Undivided	365	337	581	22
Reconst. with More Lanes				
Frwys and Expressways	553	557	86	22
Other Divided	236	237	2	7
Undivided	132	126	37	65
Major Widening (Add Lanes)				
Frwys and Expressways	550	410	337	186
Other Divided	341	256	175	63
Undivided	250	187	104	260

NOTE: Total cost of improvement, for reconstruct to freeway and reconstruct with more lanes, is calculated by multiplying costs per lane-mile by total number of lanes after the improvement. Total cost of improvement for major widening (add lanes) is calculated by multiplying costs per lane-mile by number of added lanes.

to be made at the district level, it may be appropriate to estimate the construction costs at the district level also. It would also be advantageous to include in the construction project accounting system a code for the category of improvement the project principally fits, so historical data can be collected over time for updating purposes.

Other Assumptions

The two principal sets of assumptions which should be examined and modified for Texas use of HPMS are the design standards and minimum tolerable conditions. Both of these can have a significant impact on the estimated needs over time.

When the HPMS analytical package examines sample sections for deficiencies, the minimum tolerable conditions are used to determine whether any deficiencies are present, and the type of deficiency, as well as the combination of deficiencies, determines what improvement is simulated to correct those deficiencies. Once an improvement is simulated, the design standards are used to determine the status of the section after the improvement.

It is important that those assumptions cause improvements to be simulated that match what is actually done as closely as possible. However, some of the same types of problems encountered in the construction cost comparison have occurred here. Texas does not have a set of explicit criteria for determining when an improvement should by made and what type of improvement should be undertaken to correct the problem. It is a more subjective process that includes a screening process by various levels of knowledgeable individuals both inside and outside SDHPT. For that reason, no changes in these default HPMS assumptions are recommended at this time.

Further work in a followup study, 1115, will attempt to define those assumptions indirectly using the output results and comparing them to planned work by the district for those same sections. The HPMS output for those counties will be compared to the district plans. Adjustments will be made to the assumptions and compared again in an iterative process. When the process is complete, reasonable assumptions for HPMS use in Texas should be the result. That way the HPMS assumptions do not have to be modified directly, but the results will be similar.

CONCLUSION AND RECOMMENDATIONS

The HPMS sample data and analytical package offer an opportunity for Texas to make estimates of future needs in a consistent and comprehensive fashion which is not available at the present time. In addition it provides a tool for estimating the effects of different funding levels on the condition of the highway system and the motorists using the highways. This should be very valuable in the future.

One of the biggest areas of concern using HPMS is the sample. Anytime a sample is used to represent a larger population, in this case the highway network, there is a legitimate concern that the sample may not accurately represent the population for estimating those unknown things from the population. In the case of HPMS, the sample is based upon AADT, a commonly used and widely available data item for highways. However, one of the principal items of interest is not the input AADT, by itself, but how it affects, along with the other data items, the estimated needs in the output. For that reason a simulation model was developed to determine how good a sample, based on AADT accuracy, is in estimating needs.

The results of the simulation showed that in general the needs accuracy is not as high as assumed when calculating the sample size for individual functional classes. But when aggregating over functional classes the accuracy significantly improves. That would suggest that for highly aggregated needs estimates the sample is probably not introducing much error; in other words, the sample is accurately representing the overall highway network. However, more caution should be exercised when making estimates at lower levels of aggregation.

The recommended increases in the HPMS sample for use in Texas represent the results from the simulation model, as well as the need to stratify the sample to the district level. The increased sample will provide adequate coverage for district level needs estimates, and since it is far above the minimum required sample from FHWA, should pose no problems for reporting purposes to FHWA.

More work needs to be done on the assumptions within the analytical package and determining the appropriate values to use in Texas. As the package is used and the output becomes familiar to SDHPT personnel, the value of HPMS will become apparent. That should also create some incentives to examine some of the assumptions more closely, since those assumptions will have to be defended when presenting the output results.

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3. "Highway Performance Monitoring System Field Manual," Office of Highway Planning, Federal Highway Administration, January 1984.

4. Memmott, J.L. "Sample Size and Accuracy of Highway Performance Monitoring System," Research Report 480-1, Texas Transportation Institute, the Texas A&M University System, College Station, Texas, May 1986.

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APPENDIX A

FIGURE A1

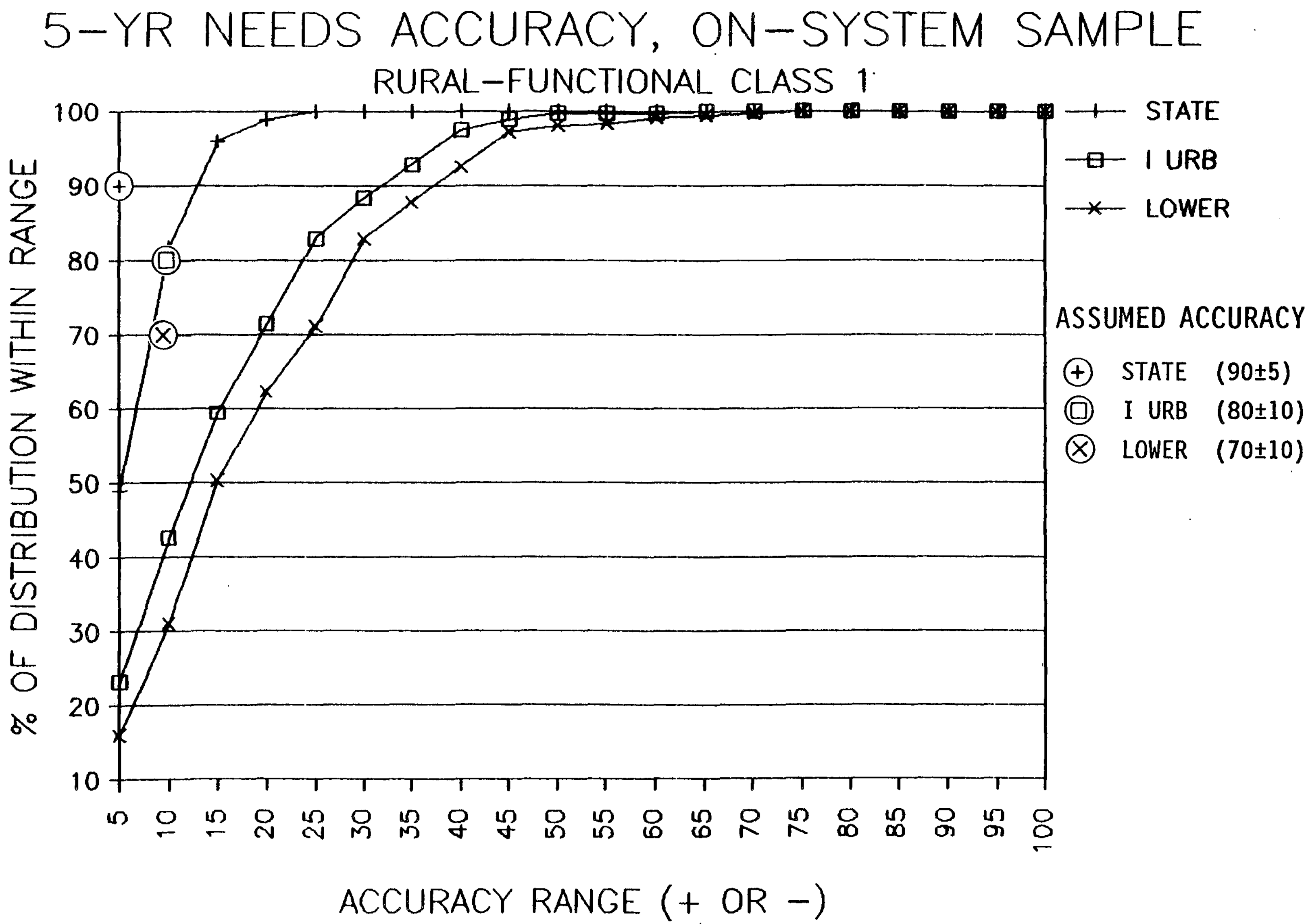

5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
RURAL-FUNCTIONAL CLASS 1
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR −)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±5)
I URB (80±10)
LOWER (70±10)

FIGURE A2

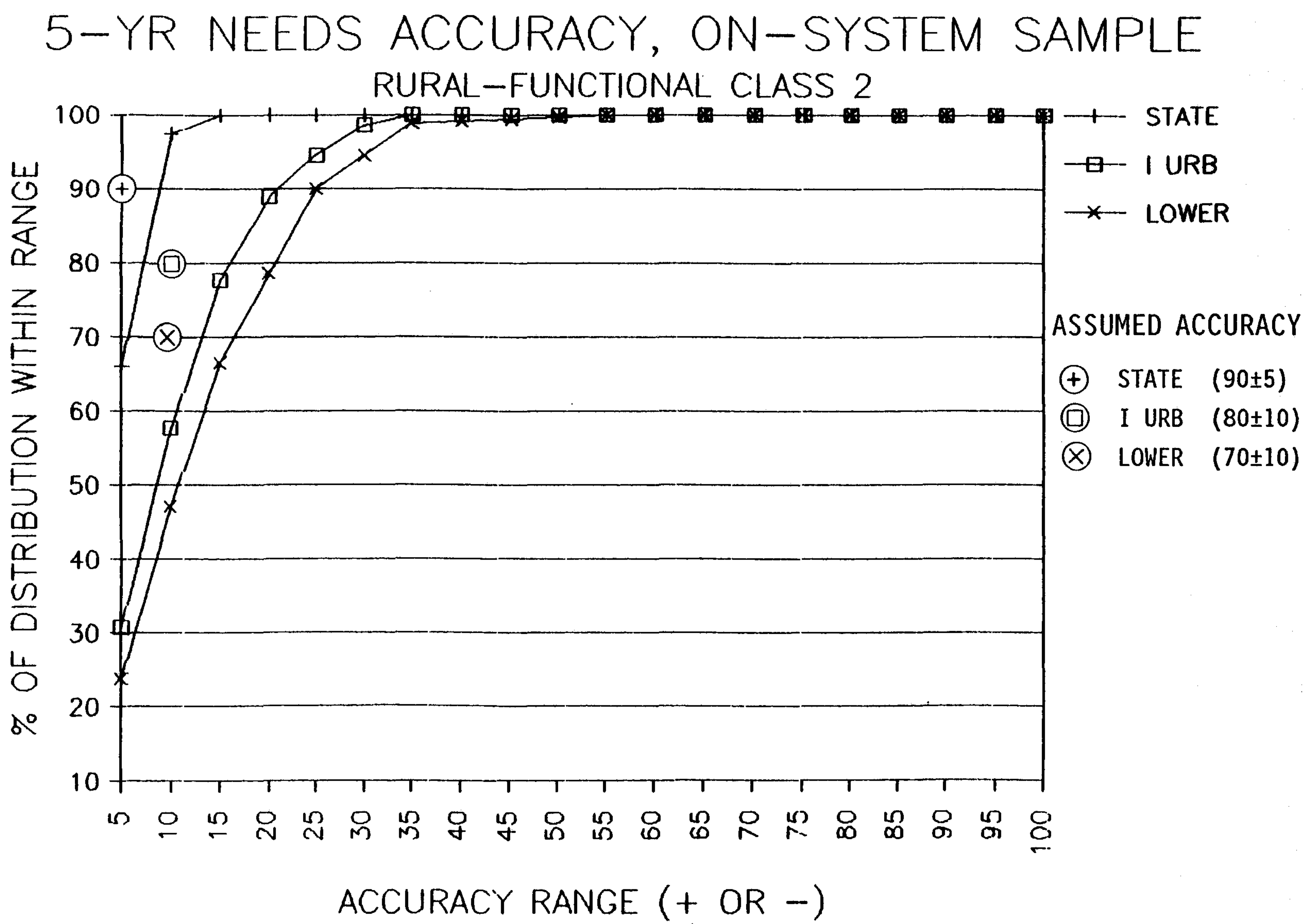
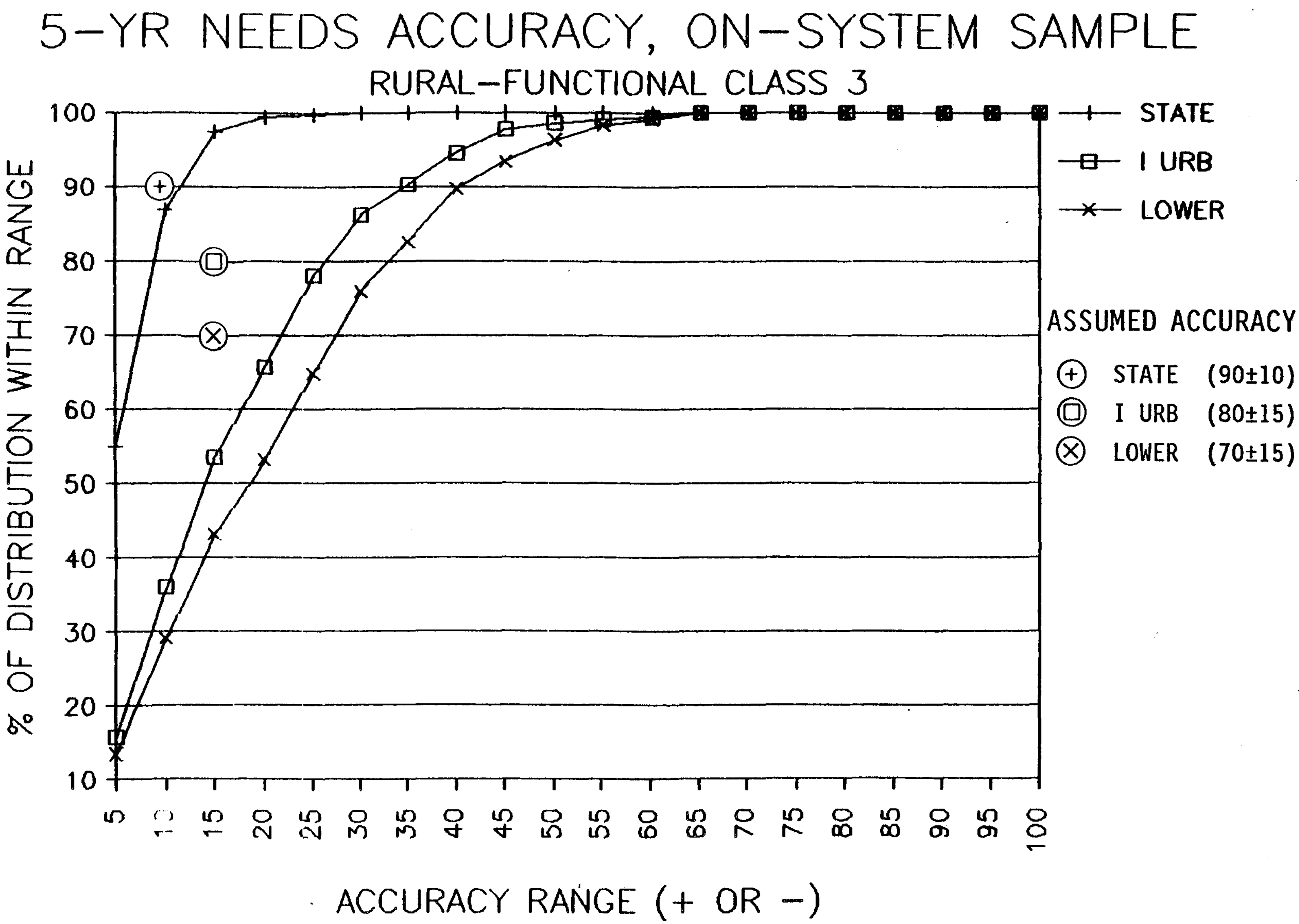

5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
RURAL-FUNCTIONAL CLASS 2
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±5)
I URB (80±10)
LOWER (70±10)

FIGURE A3



5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
RURAL-FUNCTIONAL CLASS 3
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR −)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±10)
I URB (80±15)
LOWER (70±15)

FIGURE A4

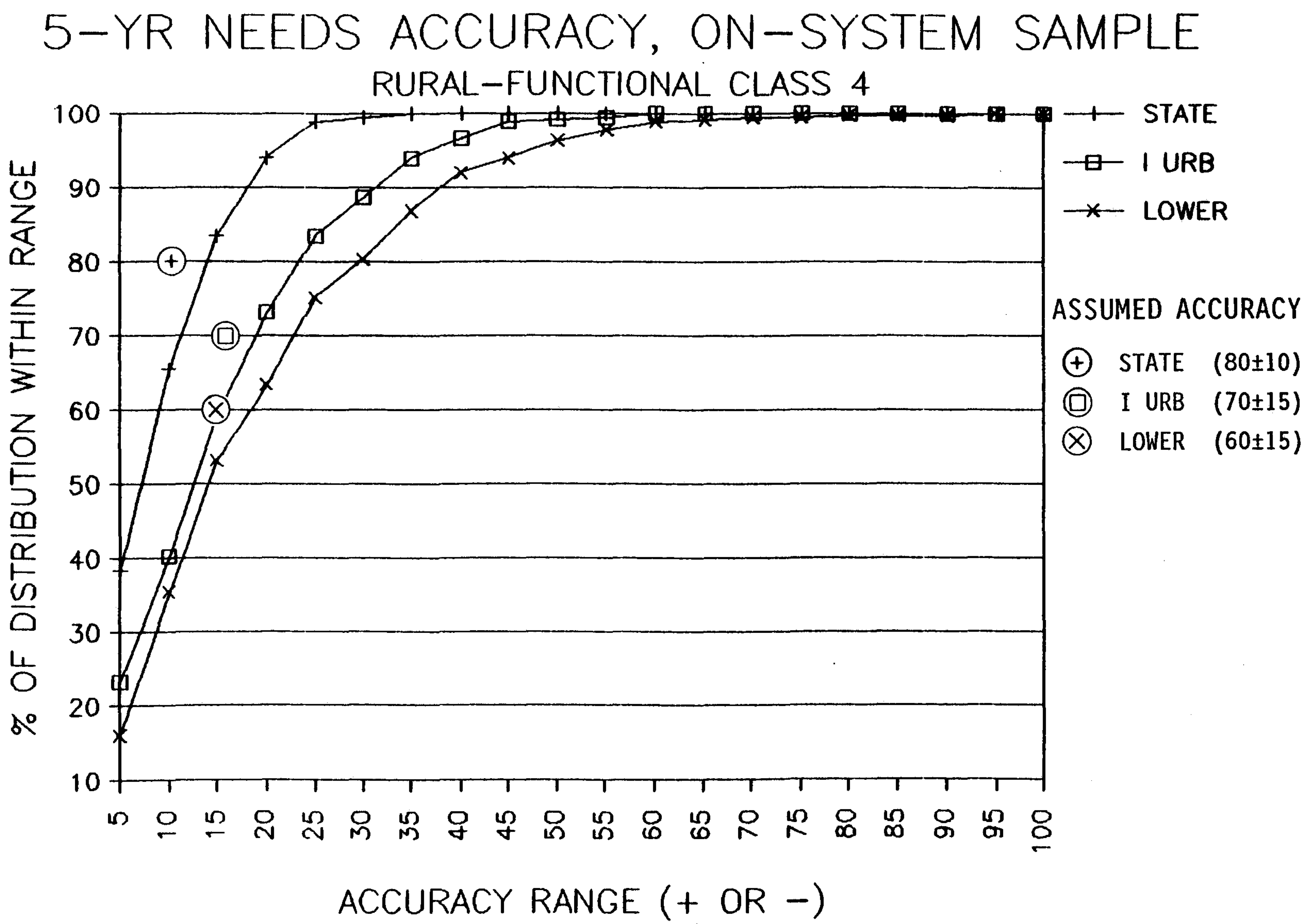
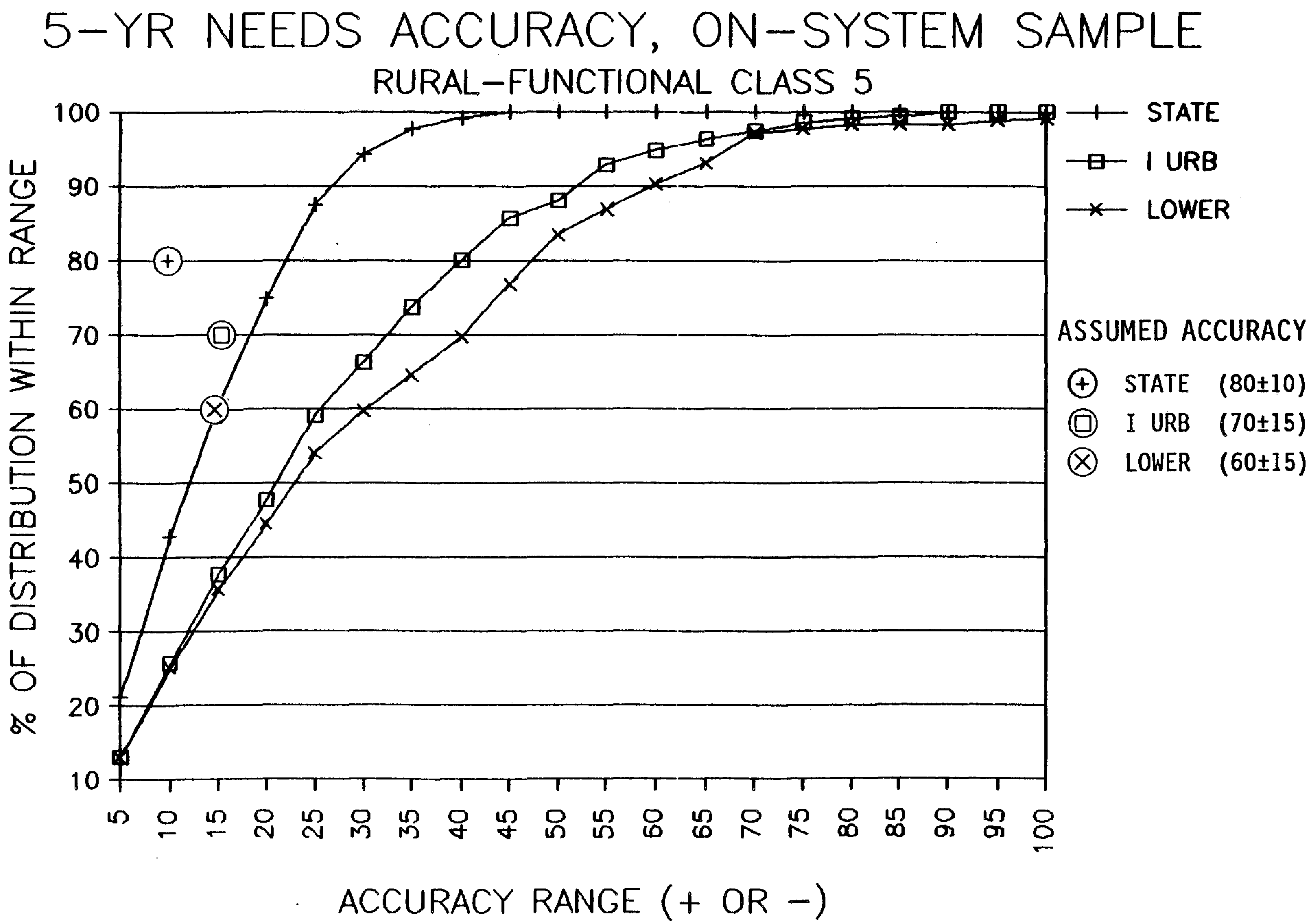
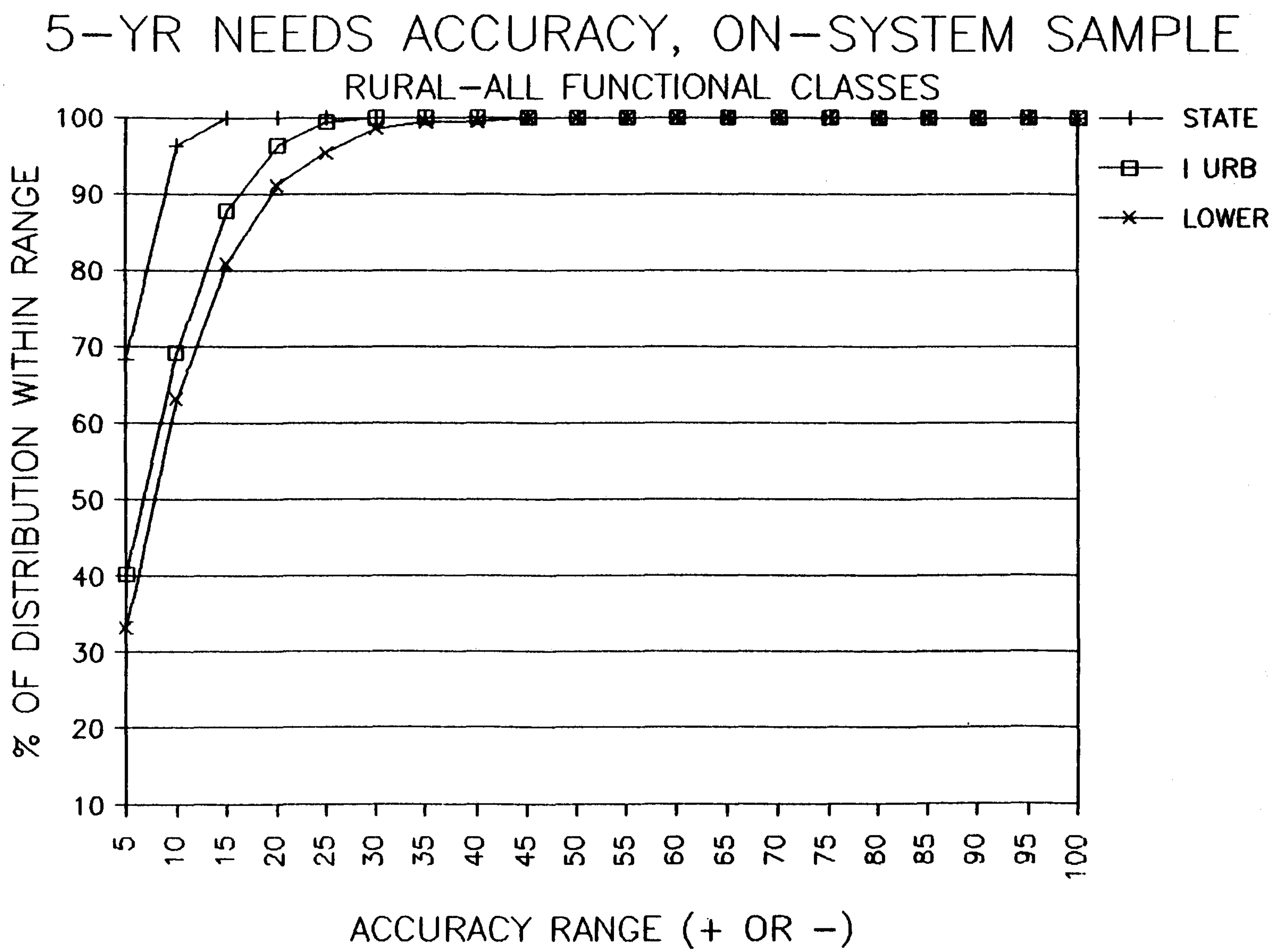

5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
RURAL-FUNCTIONAL CLASS 4
% OF DISTRIBUTION WITHIN RANGE
10
20
30
40
50
60
70
80
90
100
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR −)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (80±10)
I URB (70±15)
LOWER (60±15)

FIGURE A5



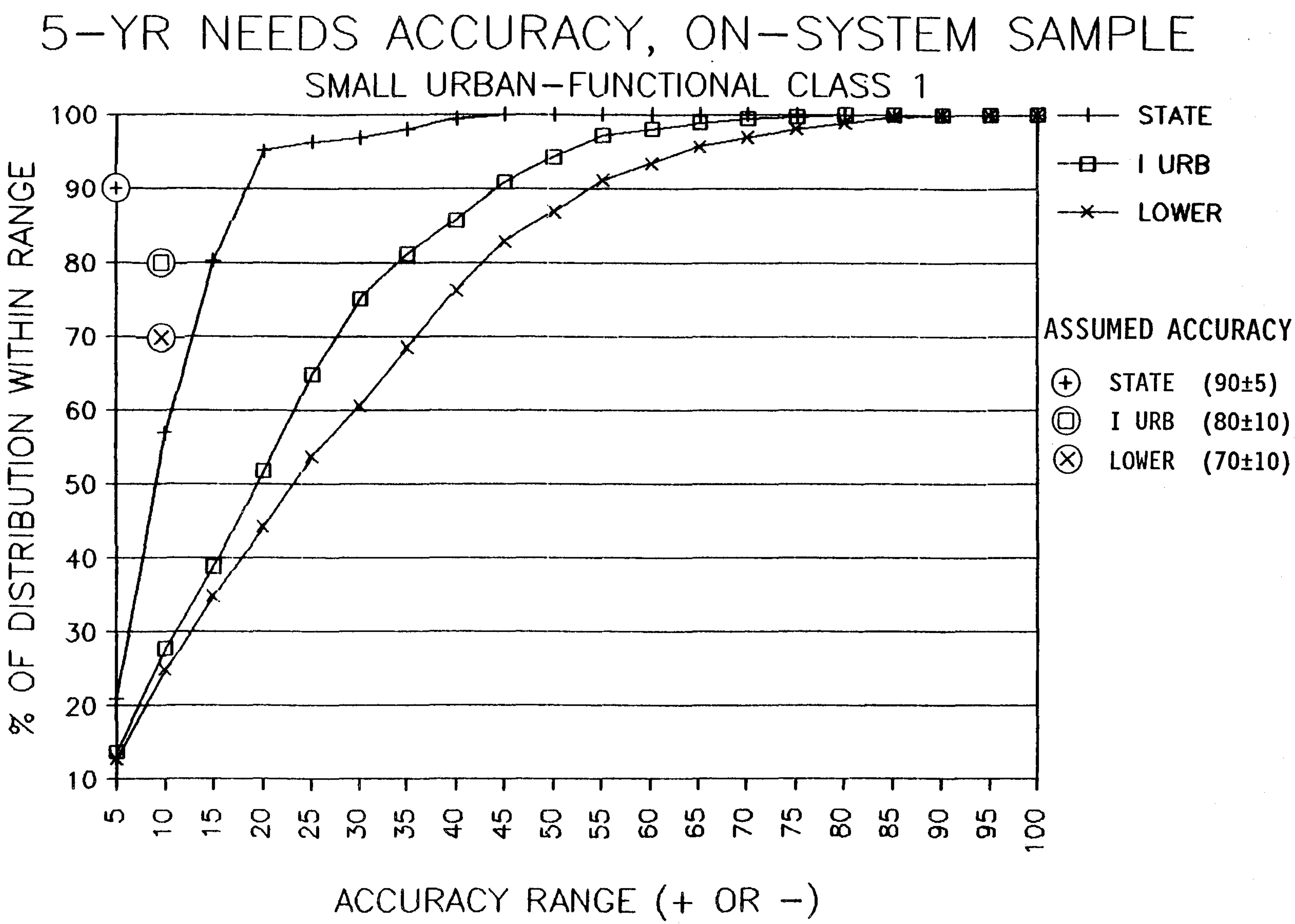
5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
RURAL-FUNCTIONAL CLASS 5
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR −)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (80±10)
I URB (70±15)
LOWER (60±15)

FIGURE A6



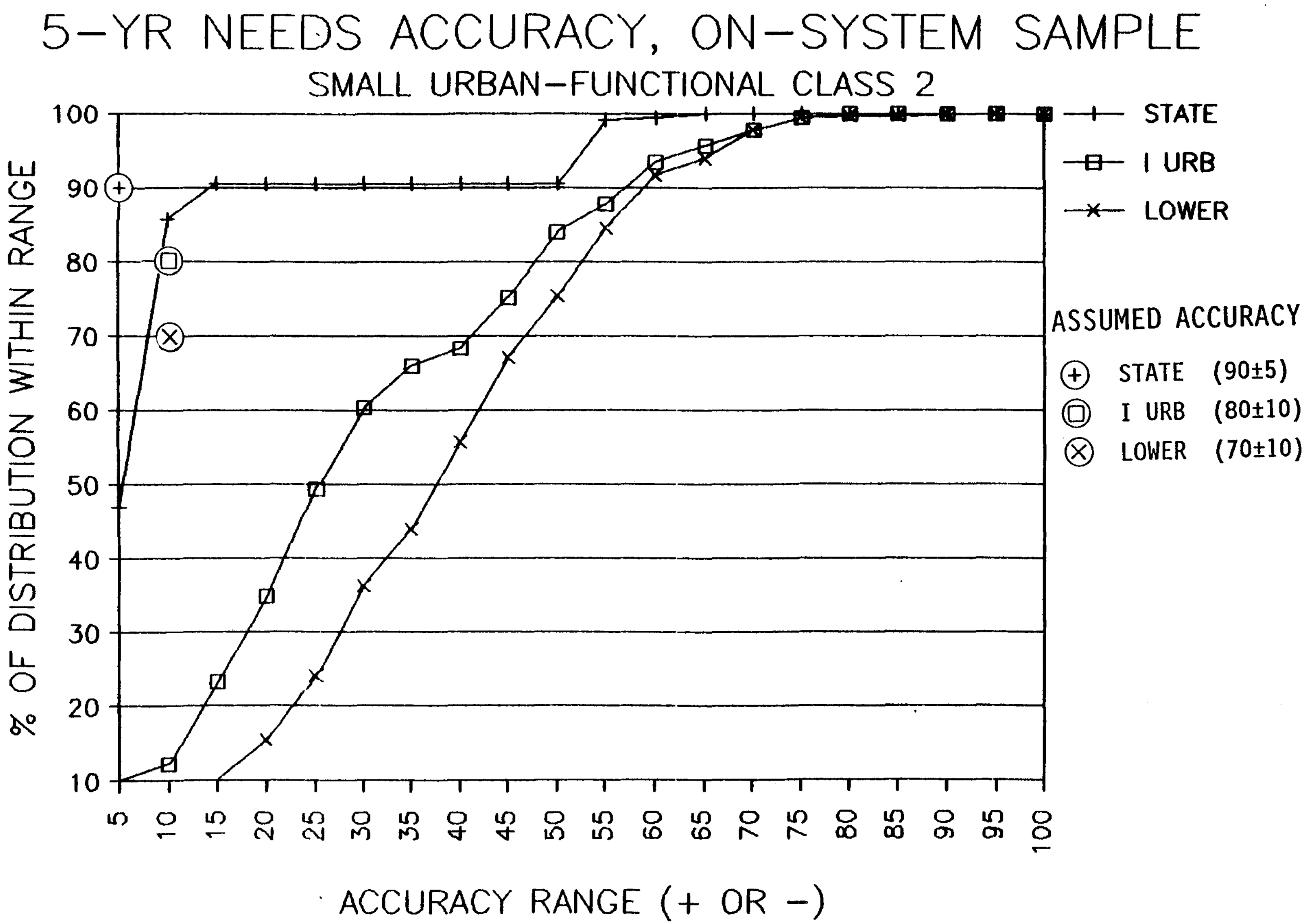
5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
RURAL-ALL FUNCTIONAL CLASSES
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER

FIGURE A7



5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
SMALL URBAN-FUNCTIONAL CLASS 1
% OF DISTRIBUTION WITHIN RANGE
10
20
30
40
50
60
70
80
90
100
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±5)
I URB (80±10)
LOWER (70±10)

FIGURE A8


5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
SMALL URBAN-FUNCTIONAL CLASS 2
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
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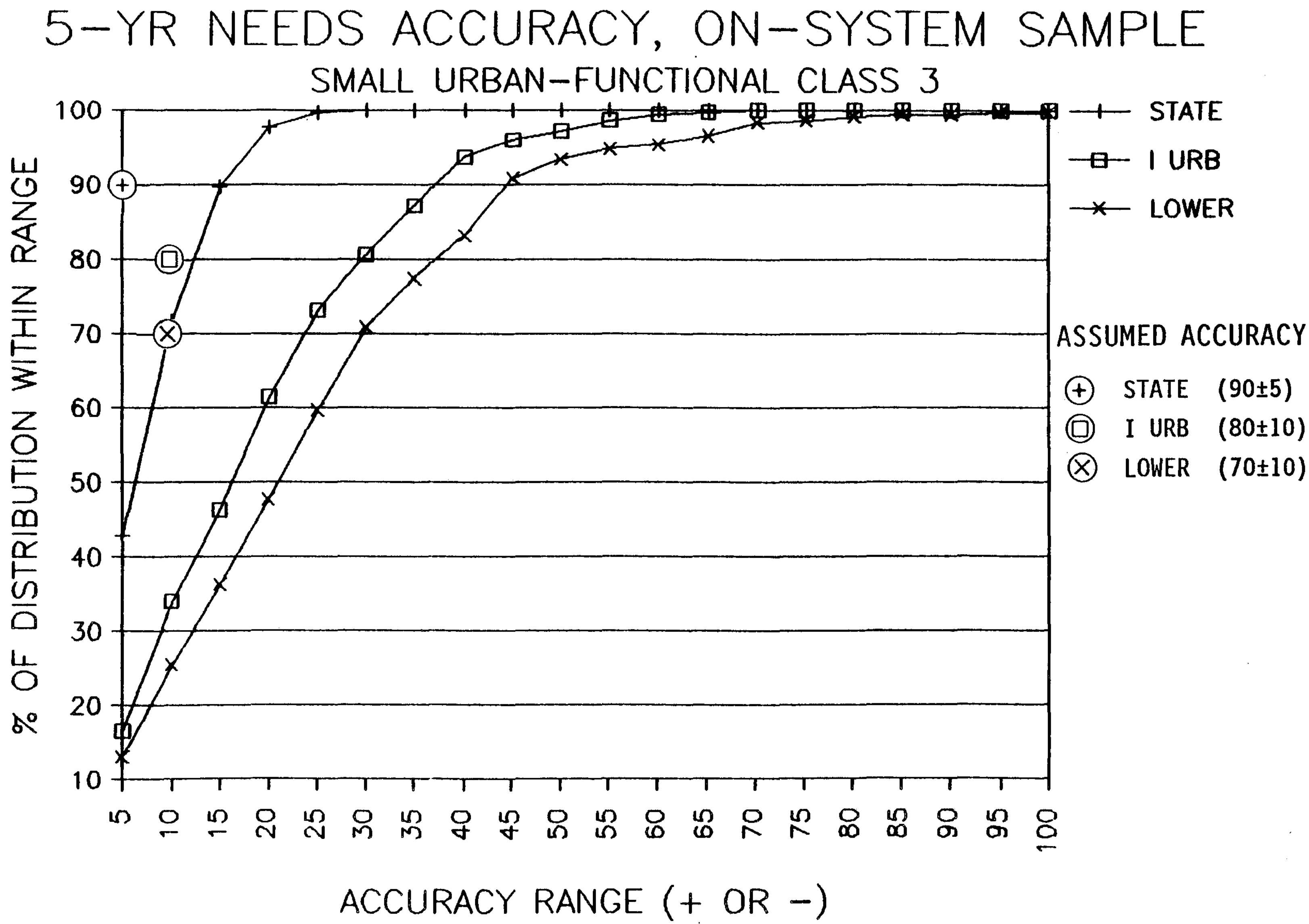
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±5)
I URB (80±10)
LOWER (70±10)

FIGURE A9



5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
SMALL URBAN-FUNCTIONAL CLASS 3
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
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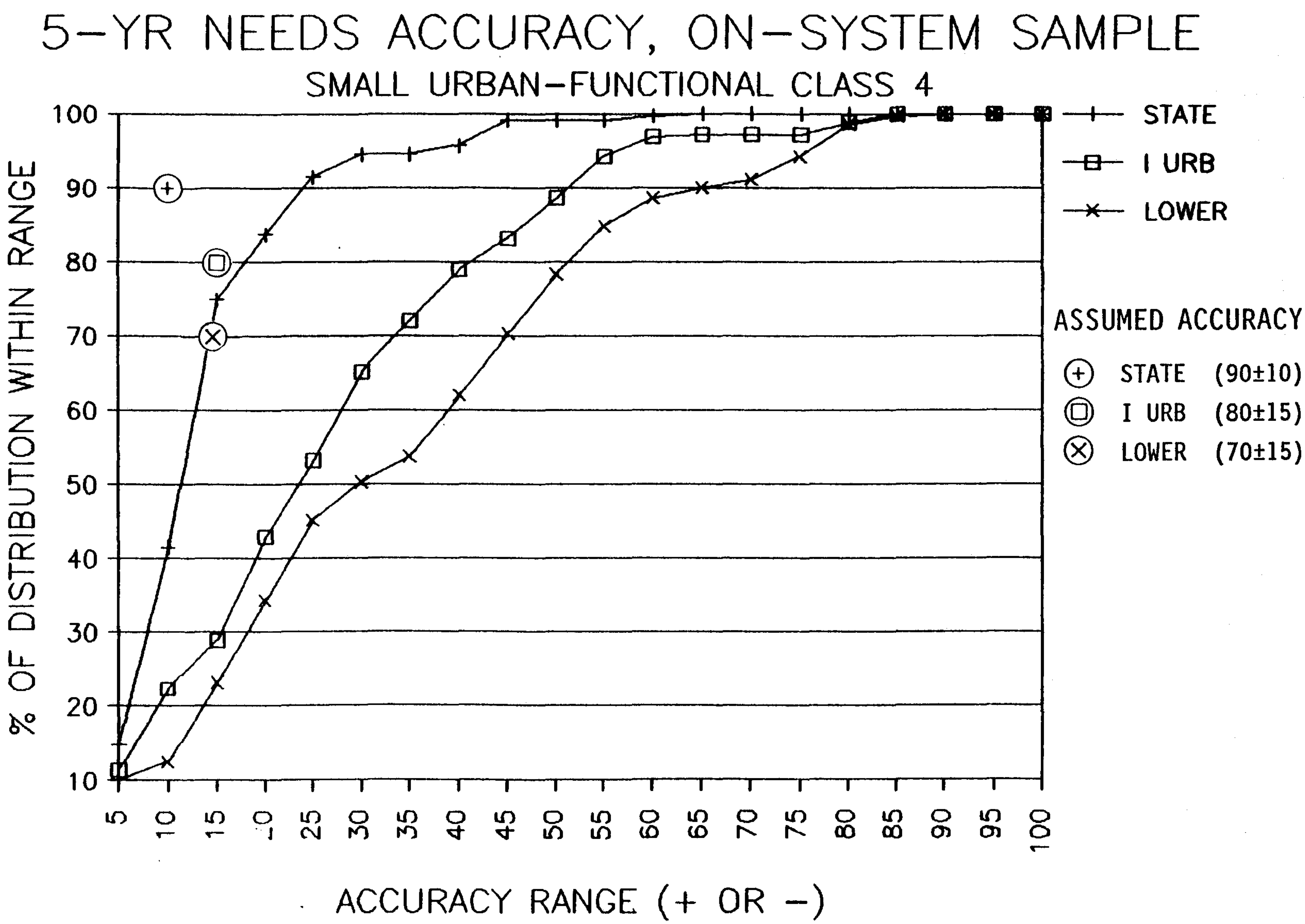
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±5)
I URB (80±10)
LOWER (70±10)

FIGURE A10



5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
SMALL URBAN-FUNCTIONAL CLASS 4
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
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20
10
5
10
15
20
25
30
35
40
45
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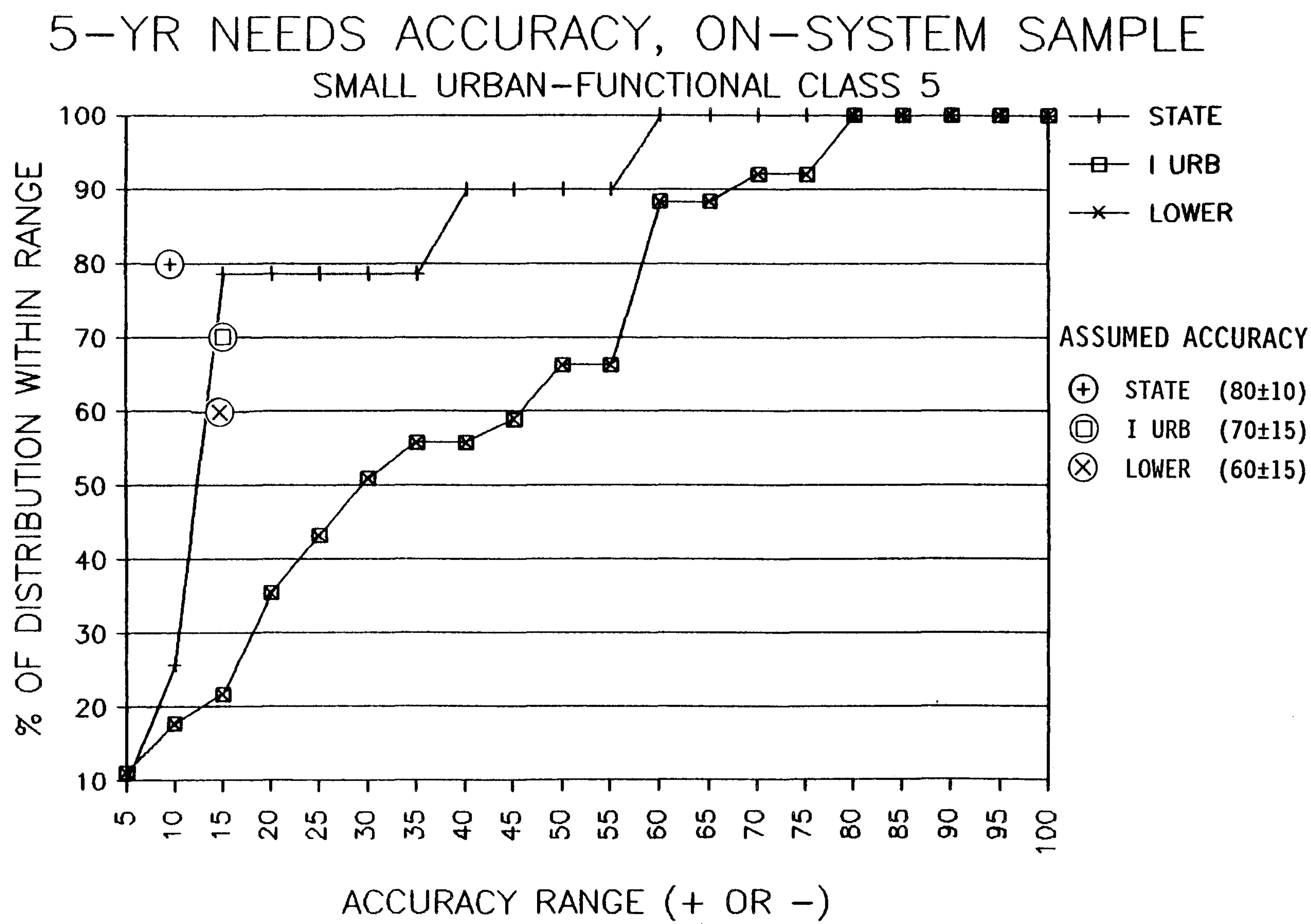
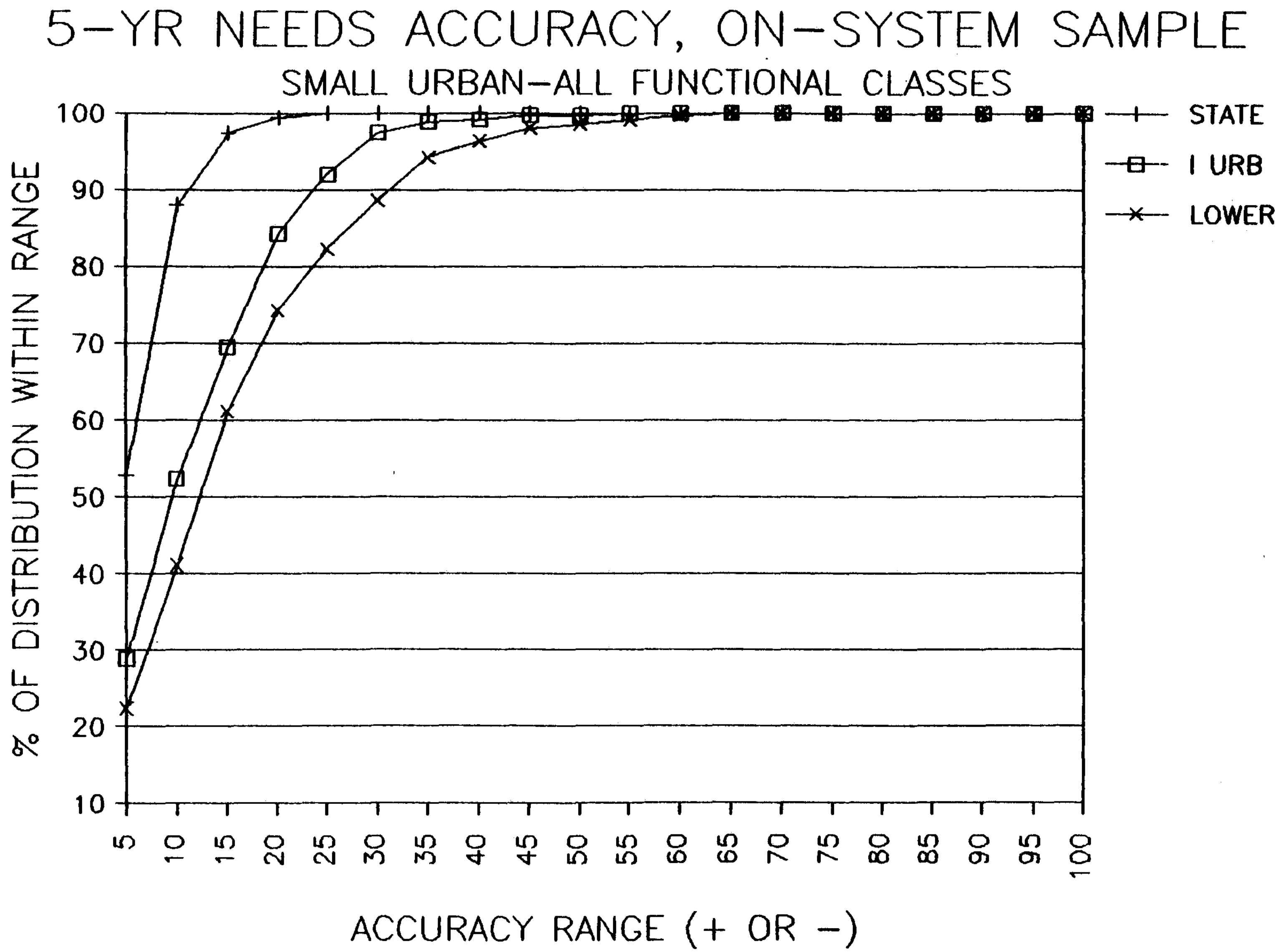
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±10)
I URB (80±15)
LOWER (70±15)

FIGURE A11



5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
SMALL URBAN-FUNCTIONAL CLASS 5
% OF DISTRIBUTION WITHIN RANGE
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (80±10)
I URB (70±15)
LOWER (60±15)

FIGURE A12



5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
SMALL URBAN-ALL FUNCTIONAL CLASSES
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
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40
30
20
10
5
10
15
20
25
30
35
40
45
50
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60
65
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75
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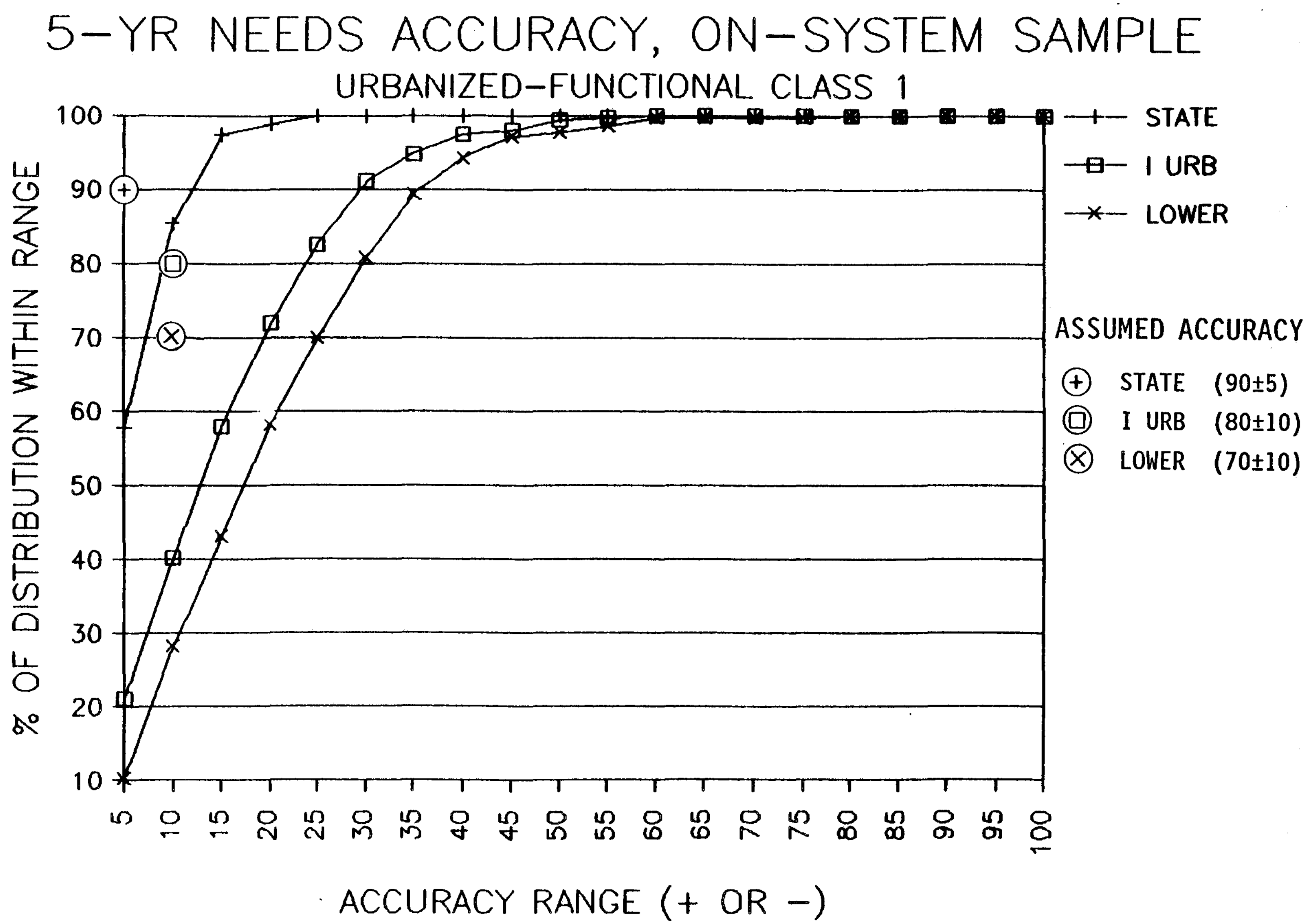
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER

FIGURE A13


5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
URBANIZED-FUNCTIONAL CLASS 1
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
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20
10
5
10
15
20
25
30
35
40
45
50
55
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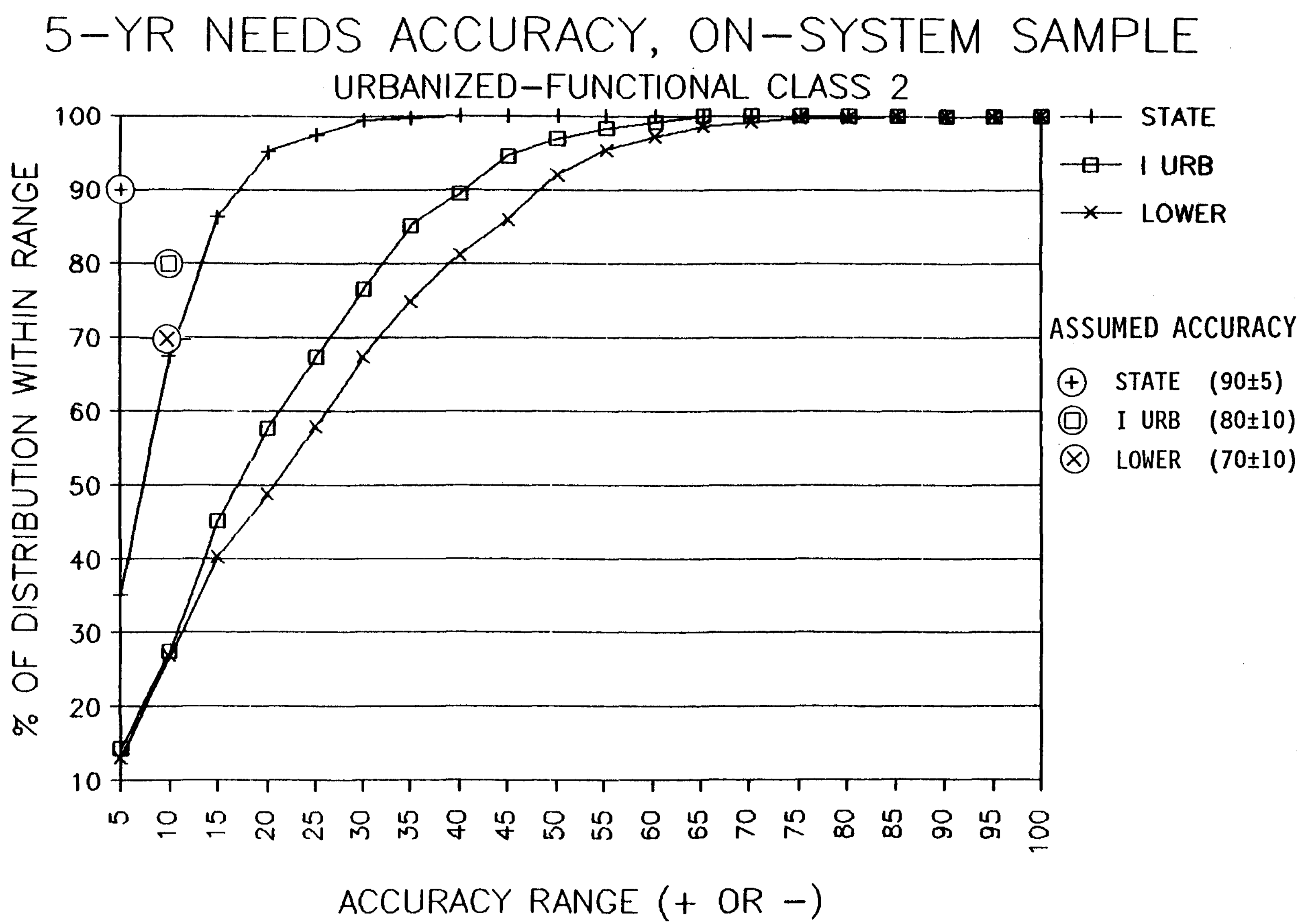
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±5)
I URB (80±10)
LOWER (70±10)

FIGURE A14


5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
URBANIZED-FUNCTIONAL CLASS 2
% OF DISTRIBUTION WITHIN RANGE
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90
80
70
60
50
40
30
20
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5
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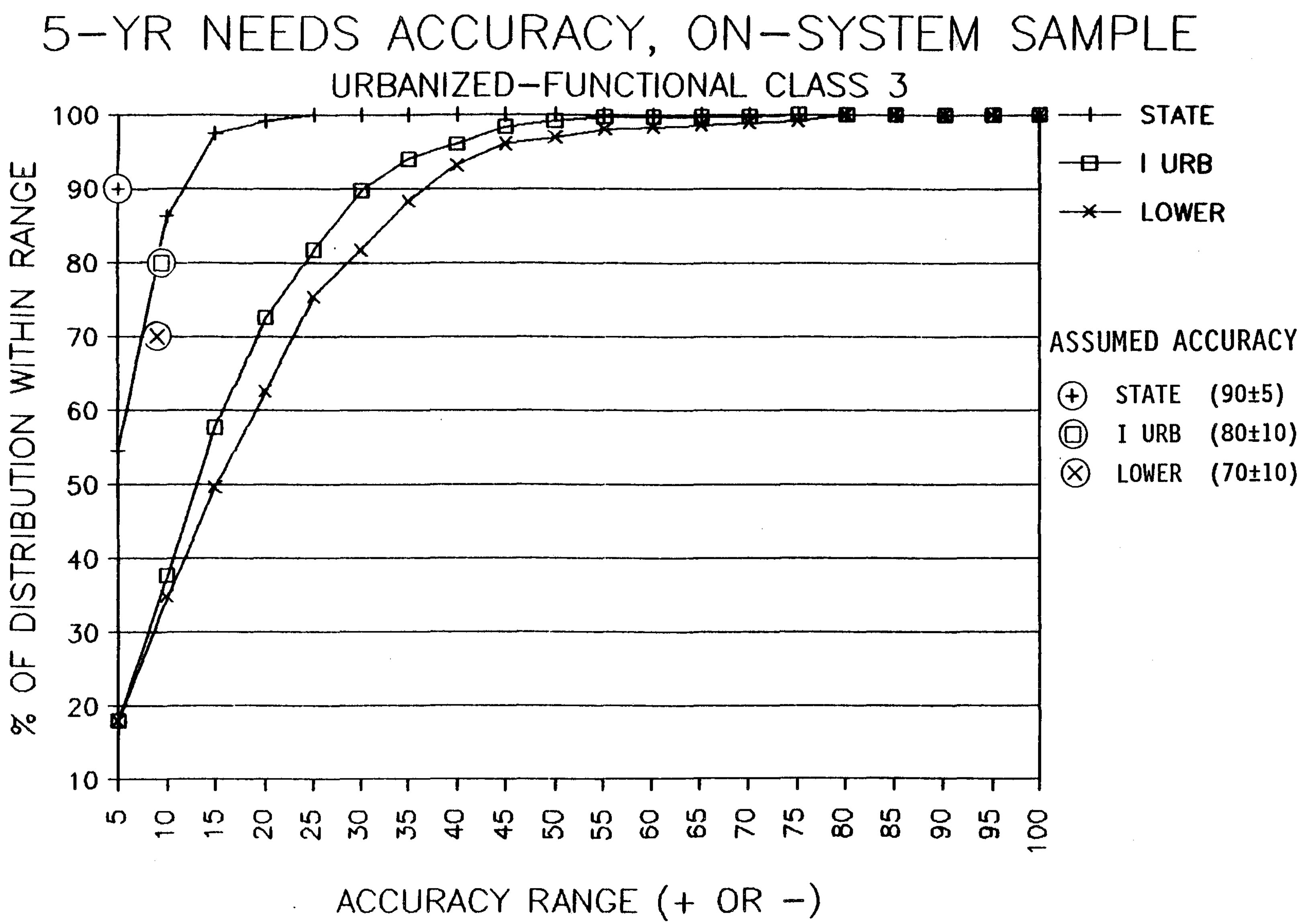
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±5)
I URB (80±10)
LOWER (70±10)

FIGURE A15


5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
URBANIZED-FUNCTIONAL CLASS 3
% OF DISTRIBUTION WITHIN RANGE
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90
80
70
60
50
40
30
20
10
5
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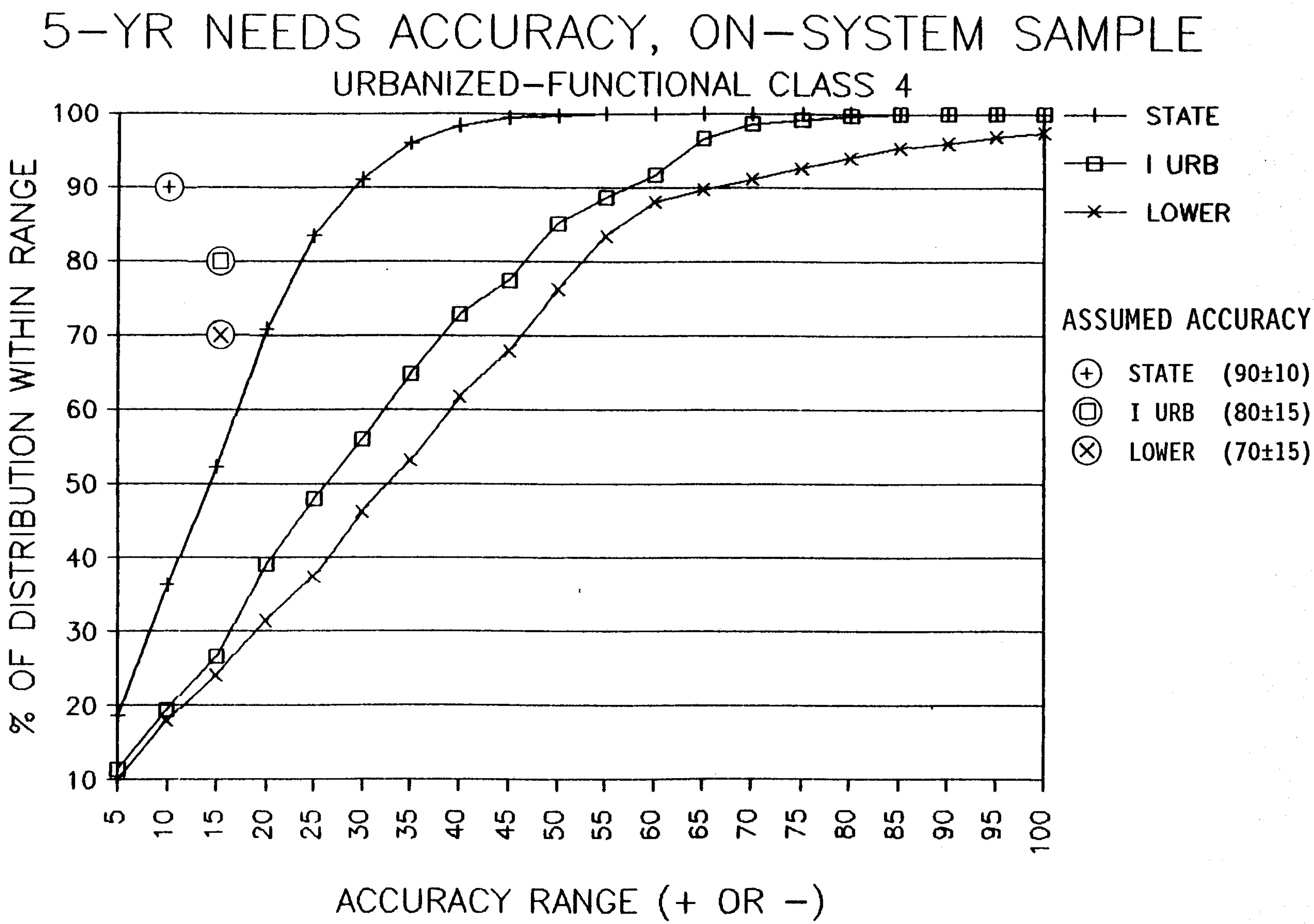
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR −)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±5)
I URB (80±10)
LOWER (70±10)

FIGURE A16



5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
URBANIZED-FUNCTIONAL CLASS 4
% OF DISTRIBUTION WITHIN RANGE
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90
80
70
60
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30
20
10
5
10
15
20
25
30
35
40
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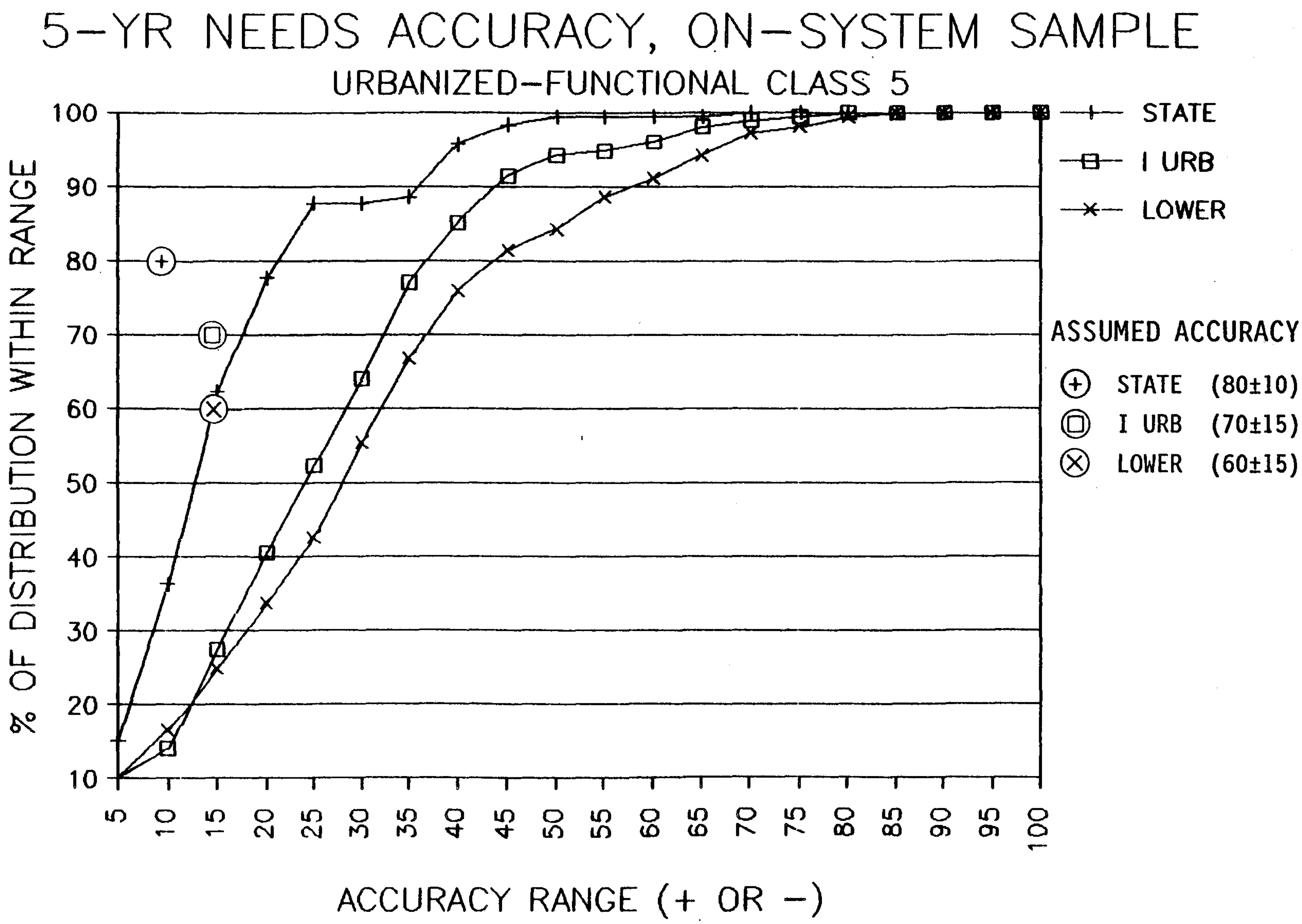
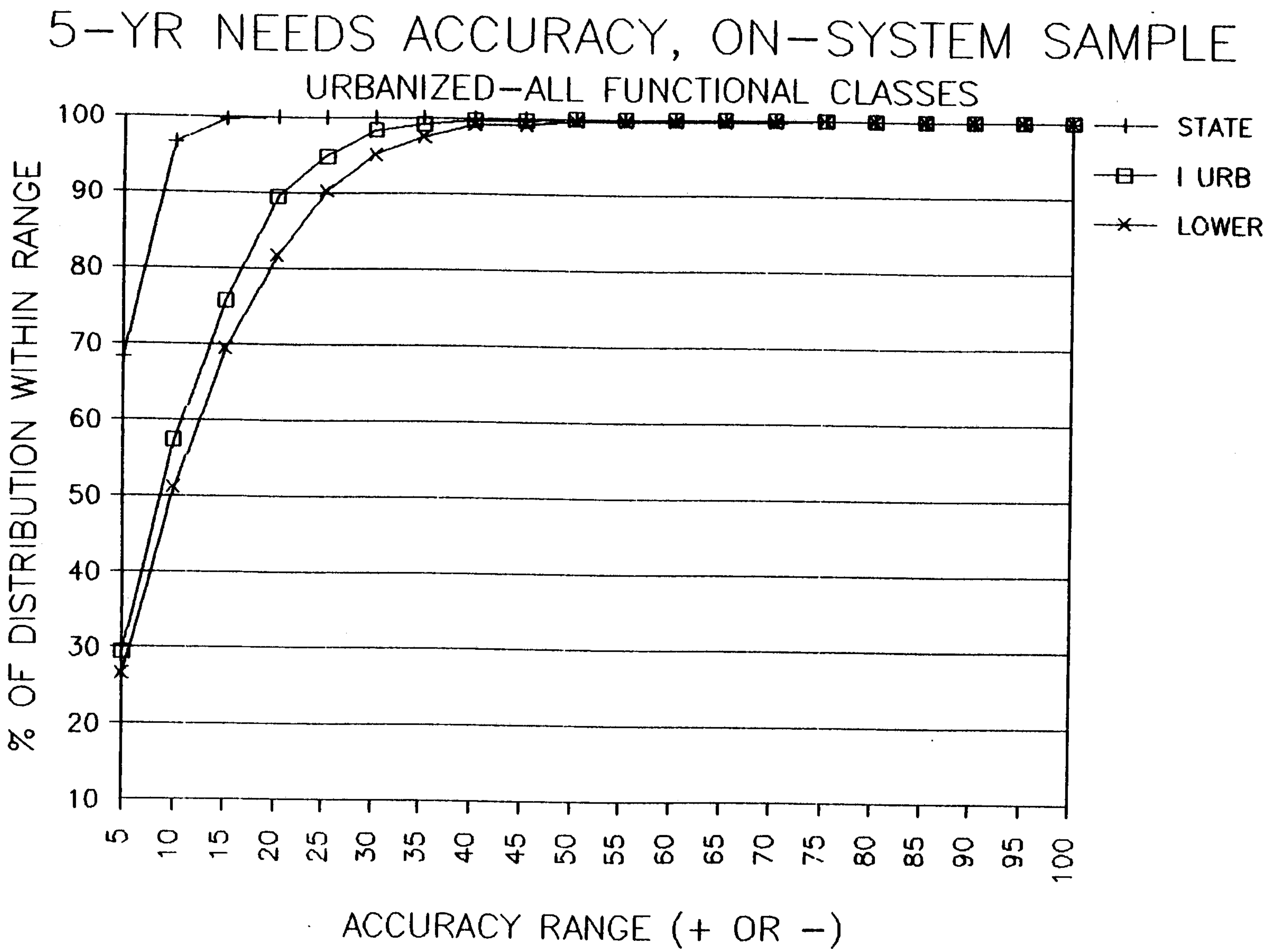
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR −)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±10)
I URB (80±15)
LOWER (70±15)

FIGURE A17



5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
URBANIZED-FUNCTIONAL CLASS 5
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (80±10)
I URB (70±15)
LOWER (60±15)

FIGURE A18


5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
URBANIZED-ALL FUNCTIONAL CLASSES
% OF DISTRIBUTION WITHIN RANGE
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80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
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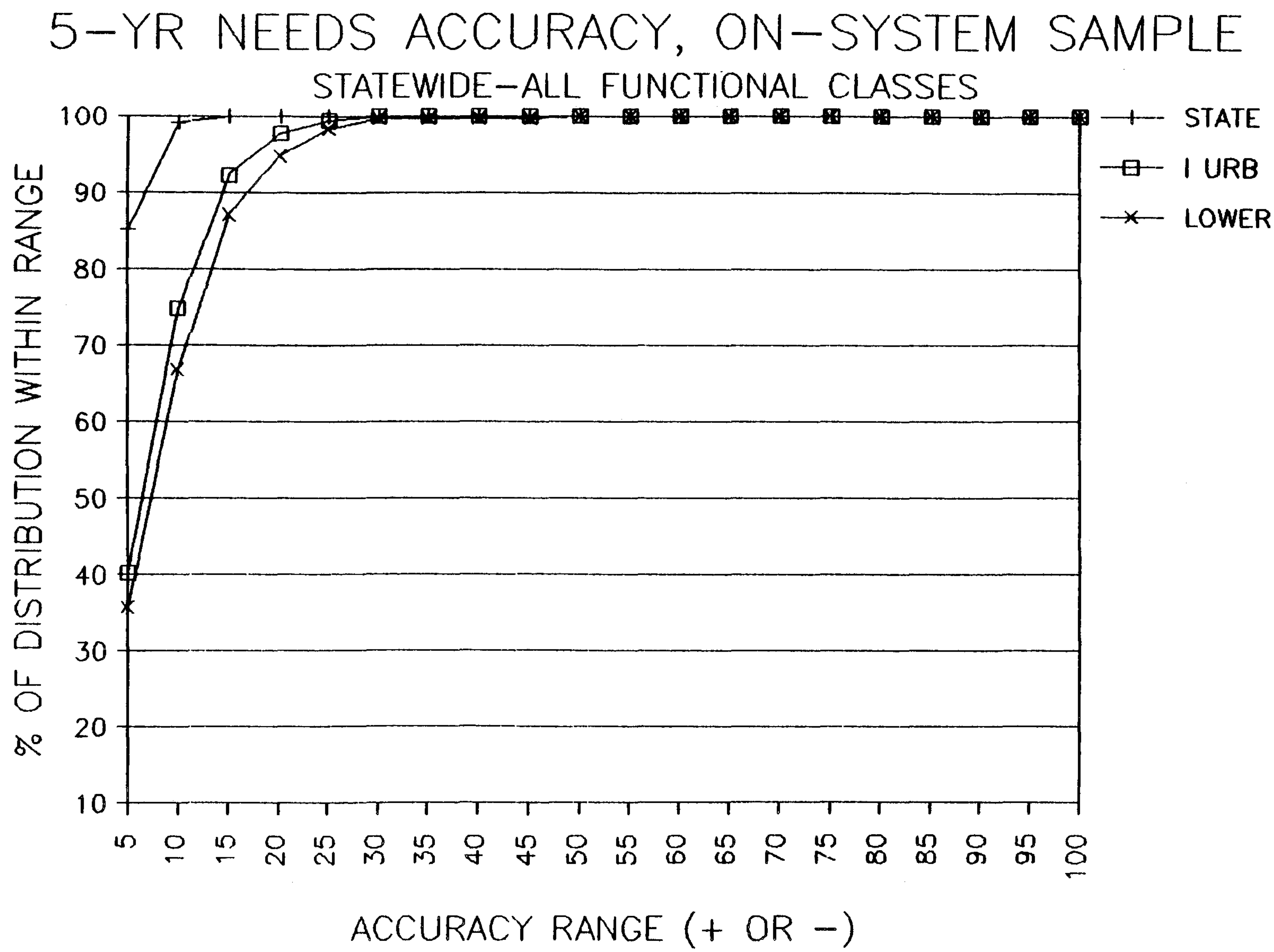
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER

FIGURE A19



5-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
STATEWIDE-ALL FUNCTIONAL CLASSES
% OF DISTRIBUTION WITHIN RANGE
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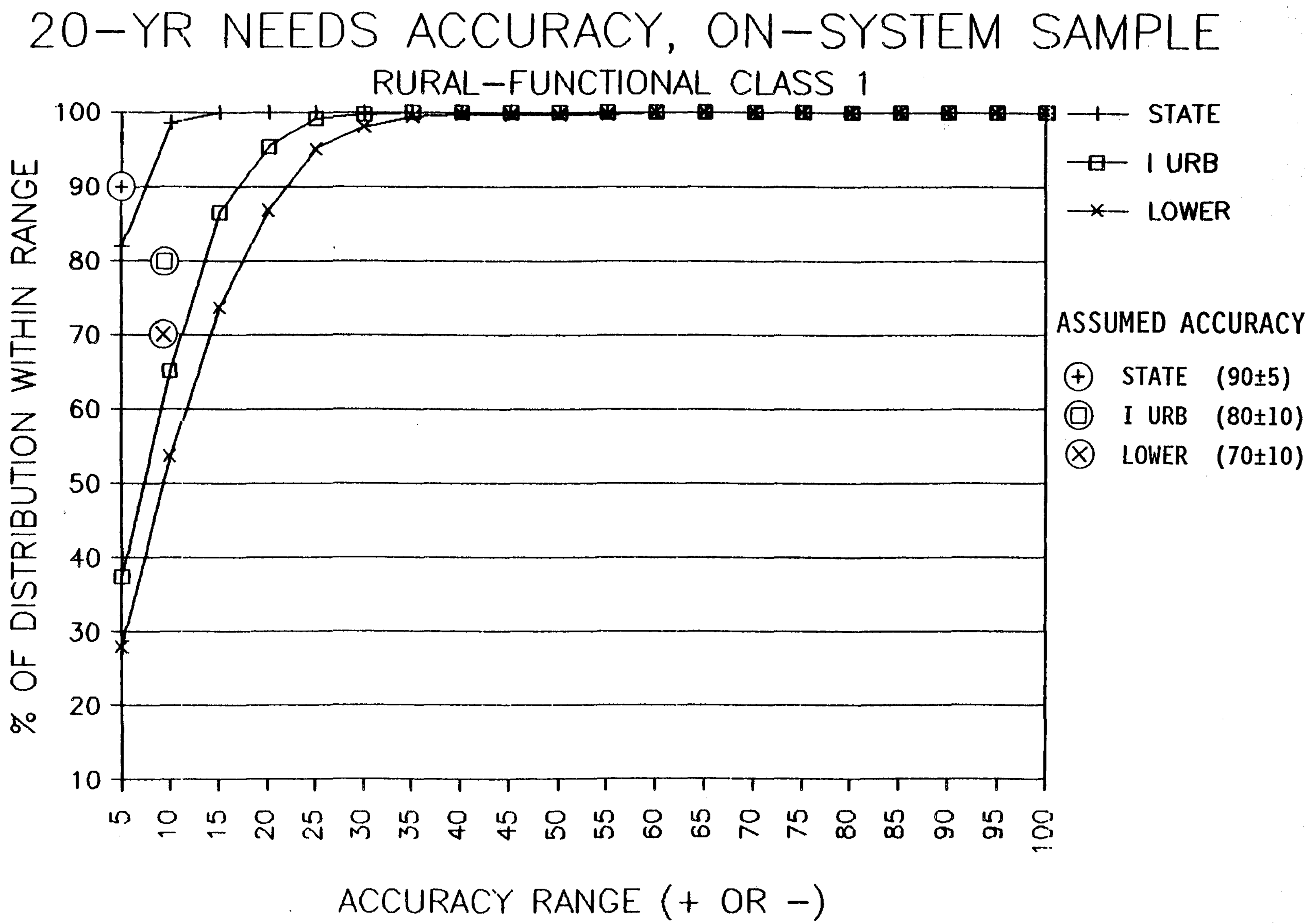
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER

APPENDIX B

FIGURE B1


20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
RURAL-FUNCTIONAL CLASS 1
% OF DISTRIBUTION WITHIN RANGE
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70
60
50
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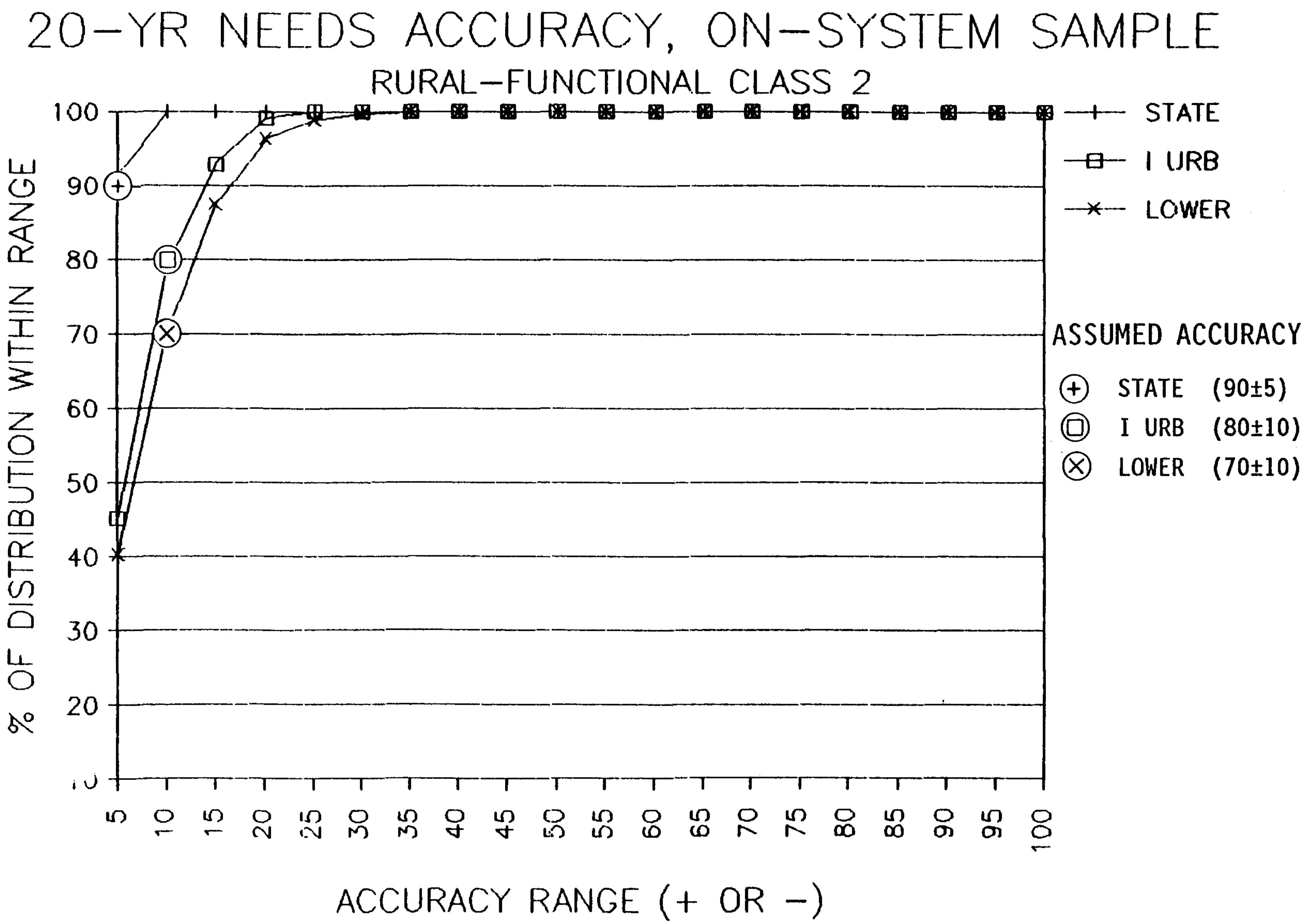
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR −)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±5)
I URB (80±10)
LOWER (70±10)

FIGURE B2


20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
RURAL-FUNCTIONAL CLASS 2
% OF DISTRIBUTION WITHIN RANGE
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5
10
15
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25
30
35
40
45
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55
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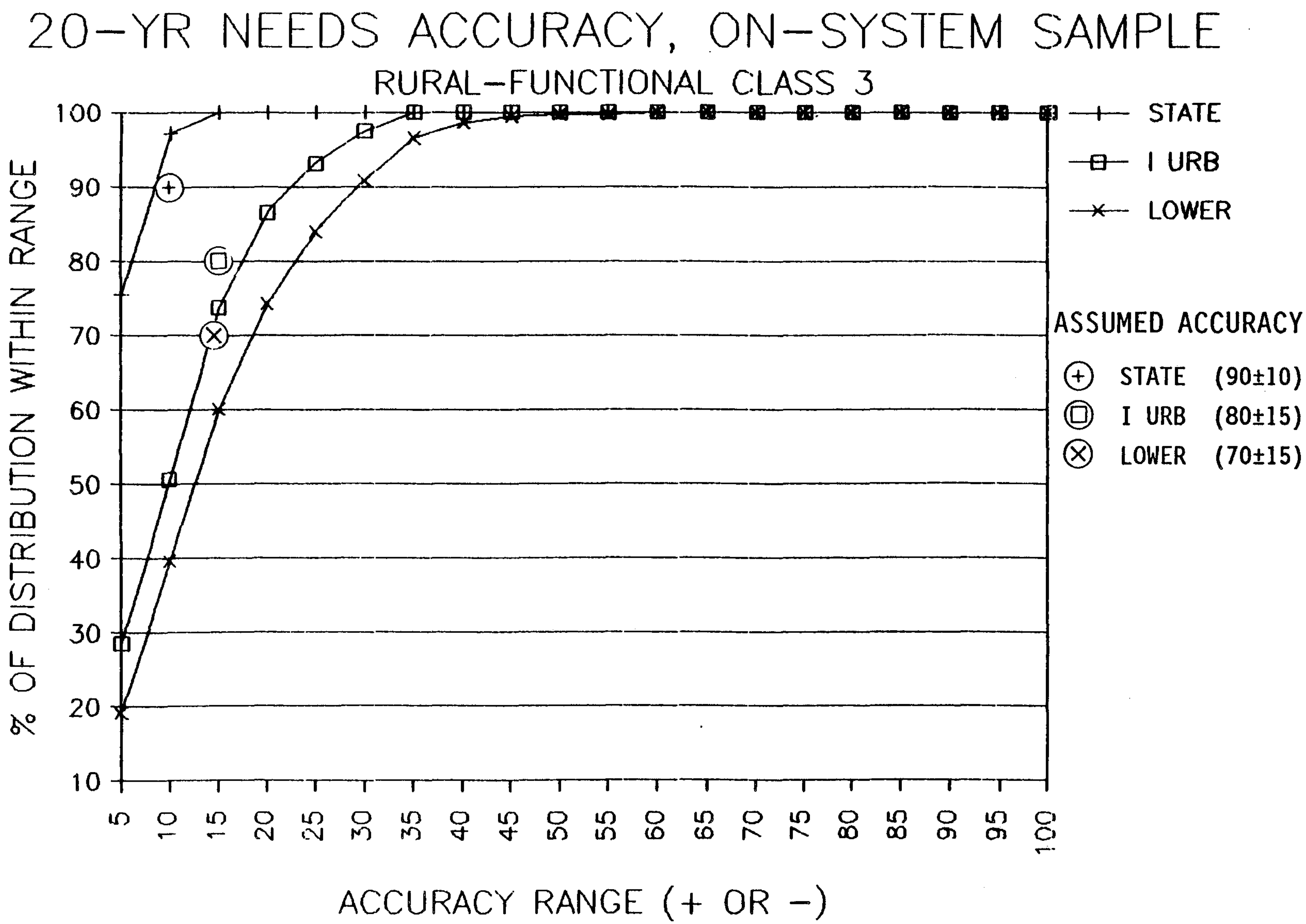
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR −)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±5)
I URB (80±10)
LOWER (70±10)

FIGURE B3


20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
RURAL-FUNCTIONAL CLASS 3
% OF DISTRIBUTION WITHIN RANGE
100
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80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±10)
I URB (80±15)
LOWER (70±15)

FIGURE B4

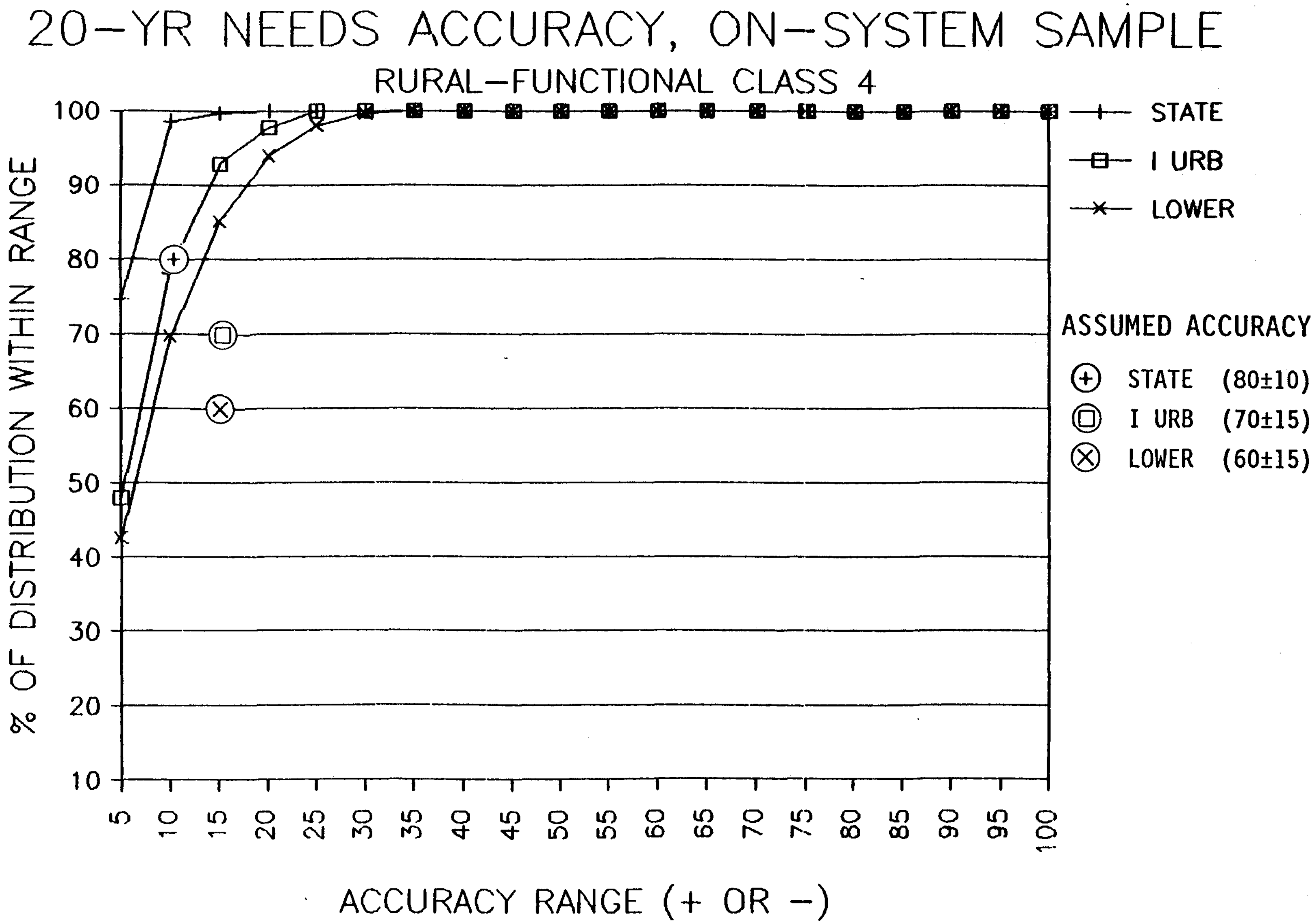
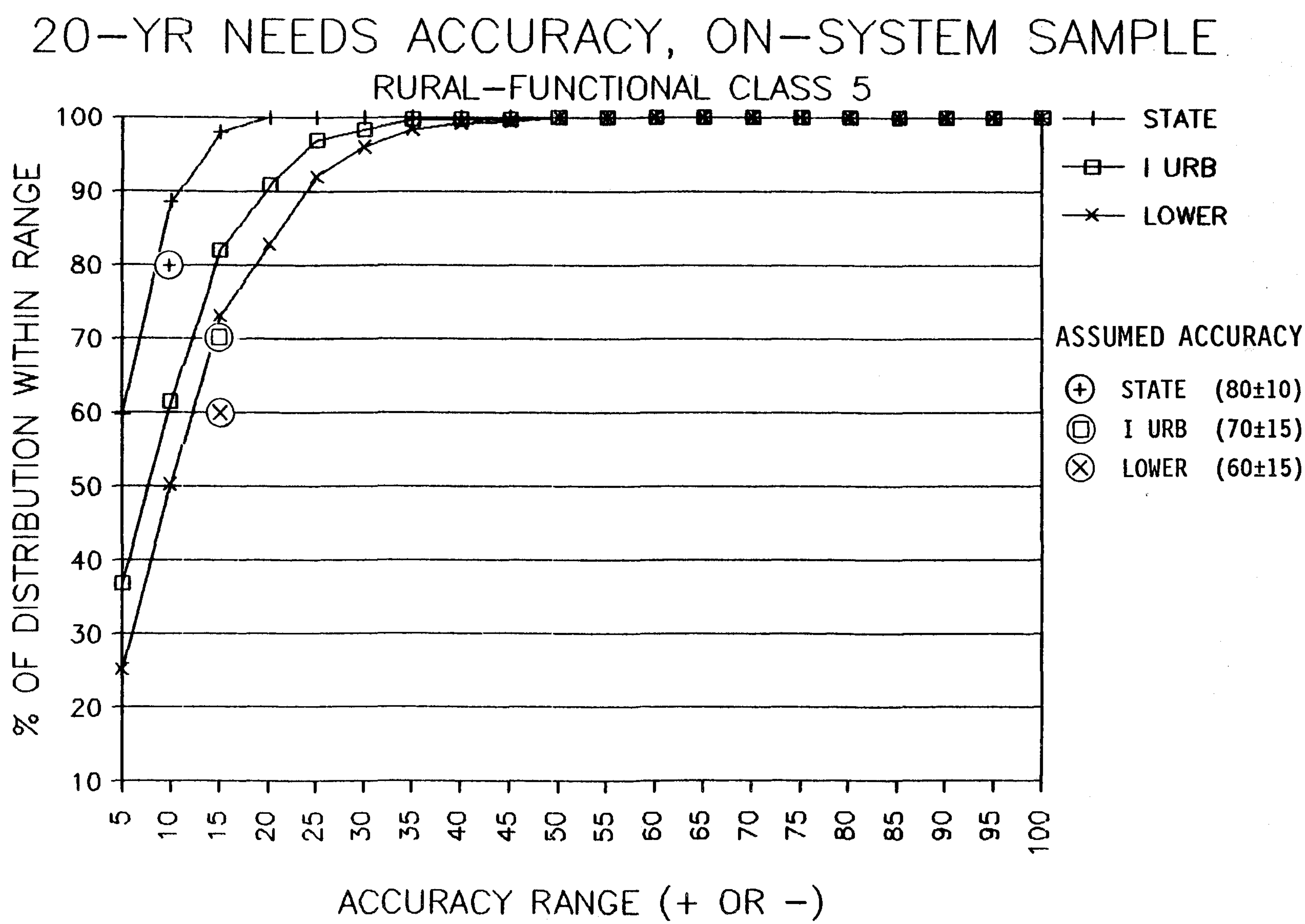
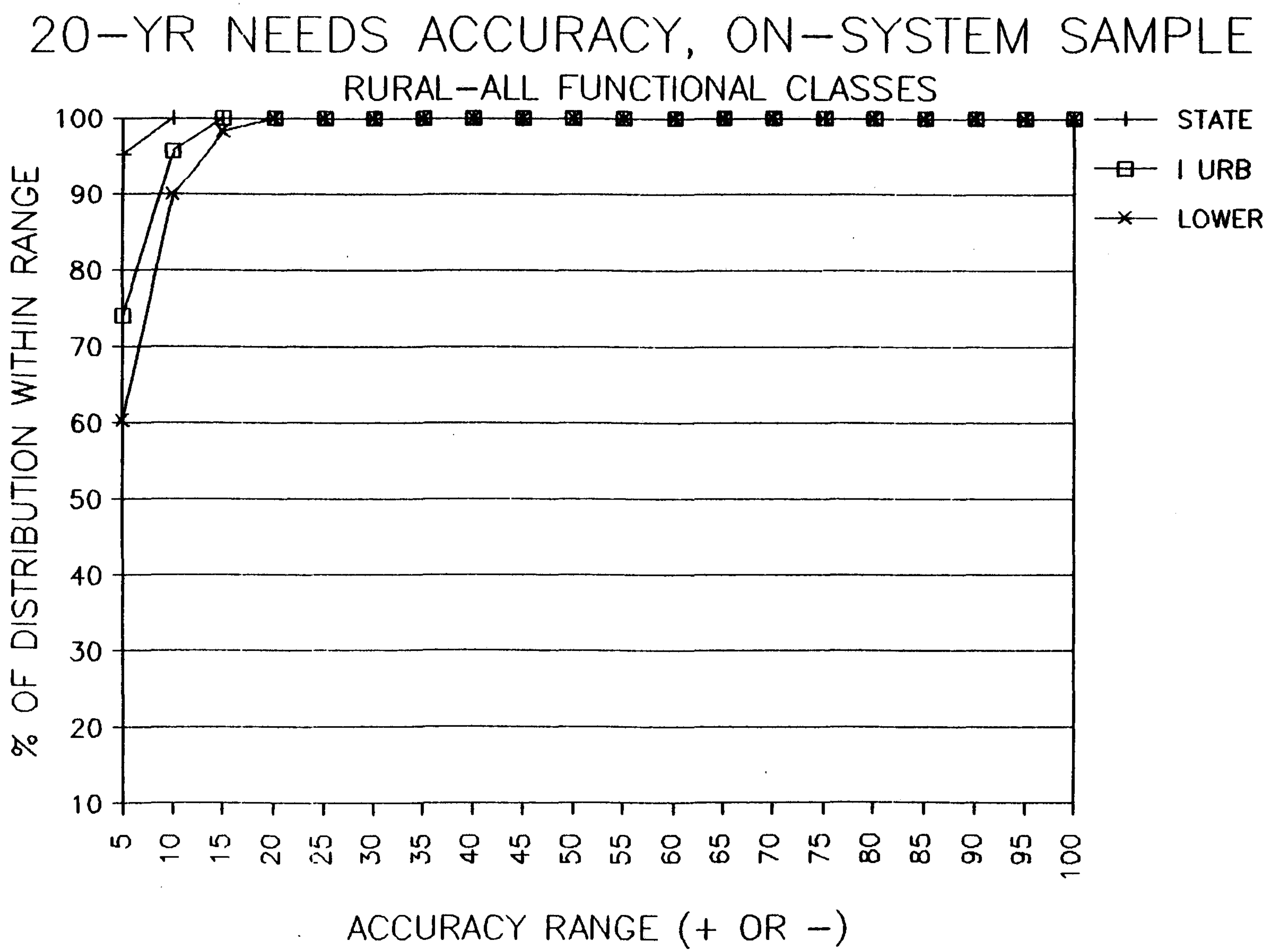

20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
RURAL-FUNCTIONAL CLASS 4
% OF DISTRIBUTION WITHIN RANGE
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (80±10)
I URB (70±15)
LOWER (60±15)

FIGURE B5



20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
RURAL-FUNCTIONAL CLASS 5
% OF DISTRIBUTION WITHIN RANGE
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (80±10)
I URB (70±15)
LOWER (60±15)

FIGURE B6


20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
RURAL-ALL FUNCTIONAL CLASSES
% OF DISTRIBUTION WITHIN RANGE
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90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
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75
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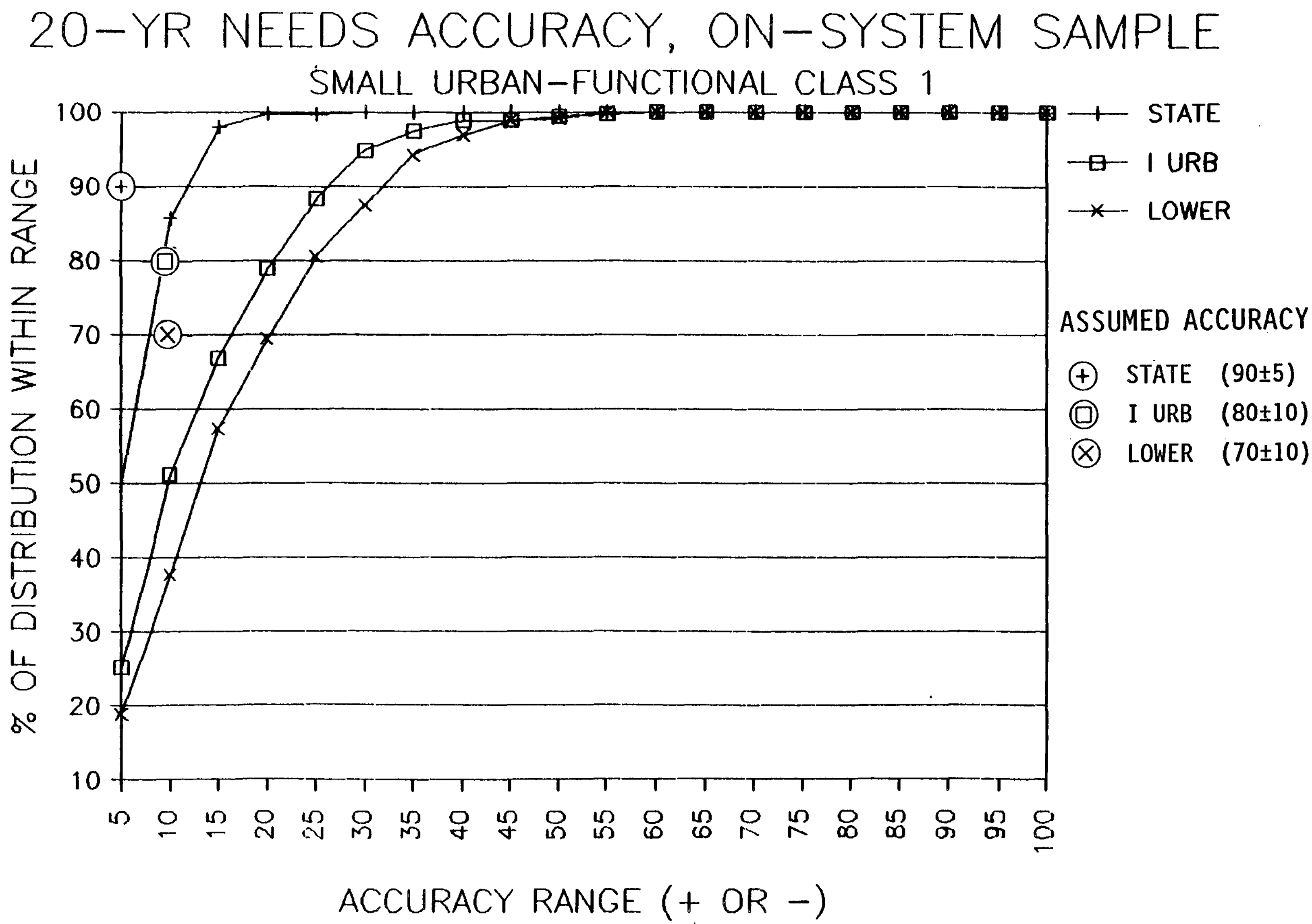
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER

FIGURE B7


20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
SMALL URBAN-FUNCTIONAL CLASS 1
% OF DISTRIBUTION WITHIN RANGE
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40
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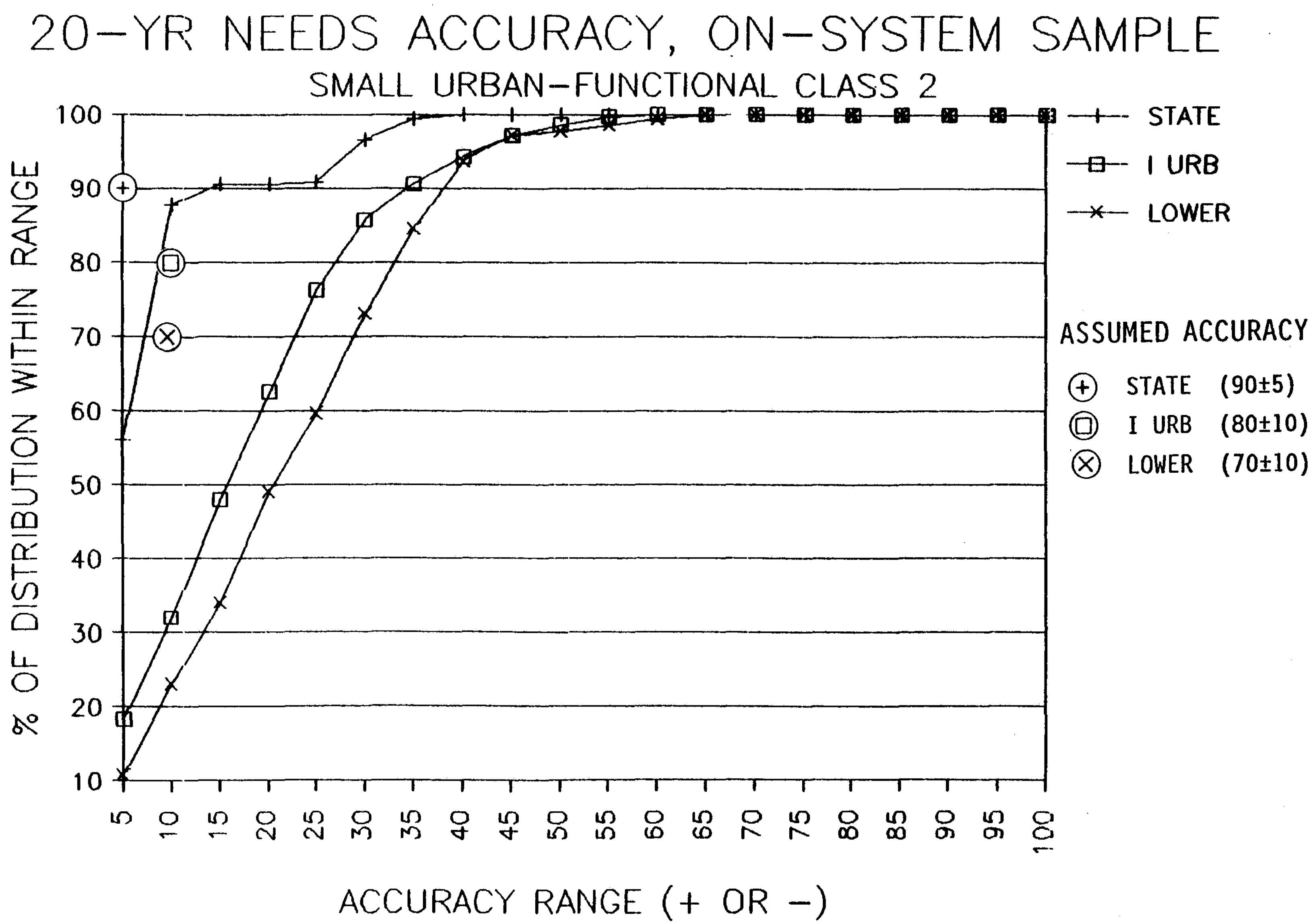
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±5)
I URB (80±10)
LOWER (70±10)

FIGURE B8



20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
SMALL URBAN-FUNCTIONAL CLASS 2
% OF DISTRIBUTION WITHIN RANGE
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50
40
30
20
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5
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15
20
25
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35
40
45
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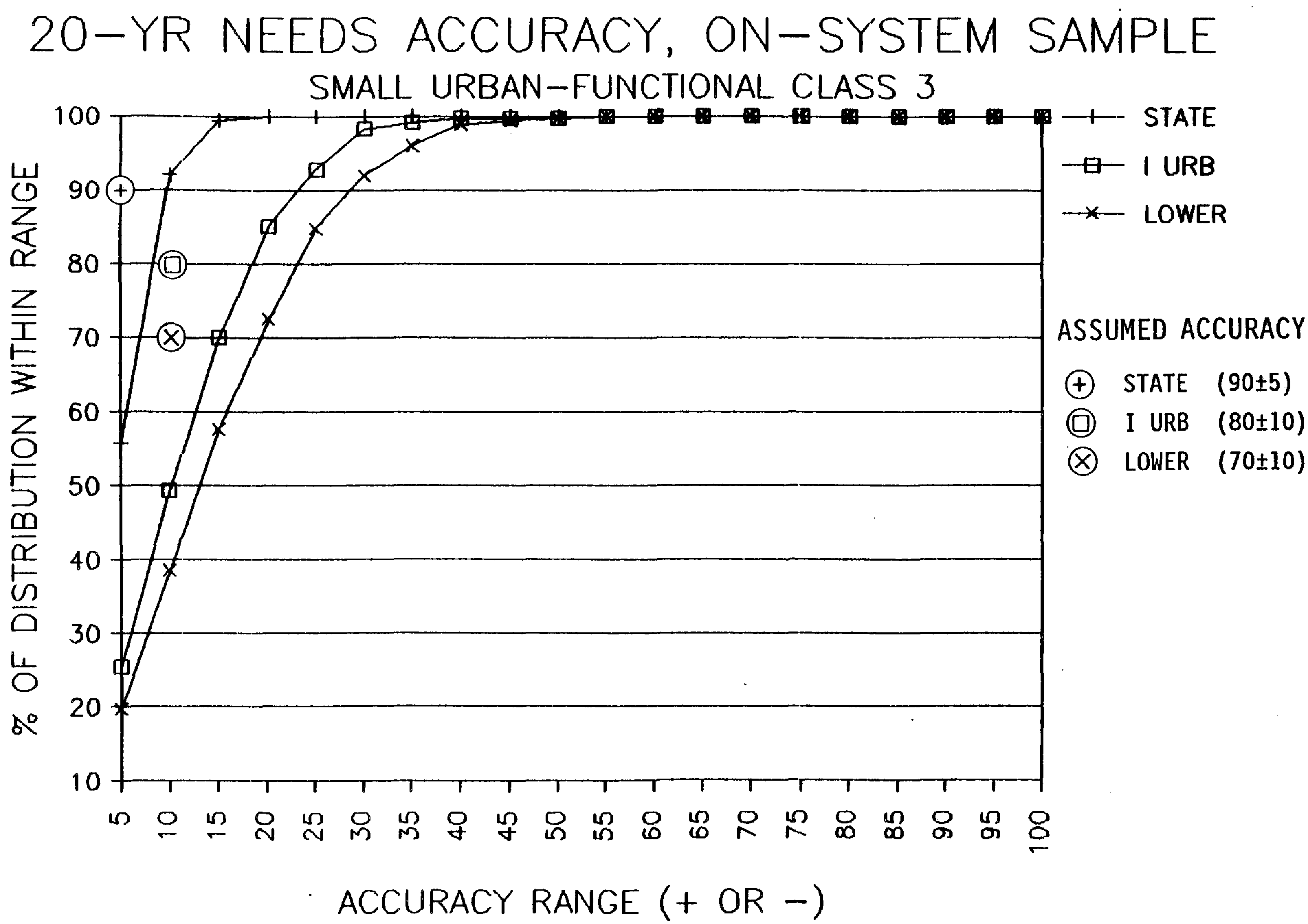
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR −)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±5)
I URB (80±10)
LOWER (70±10)

FIGURE B9



20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
SMALL URBAN-FUNCTIONAL CLASS 3
% OF DISTRIBUTION WITHIN RANGE
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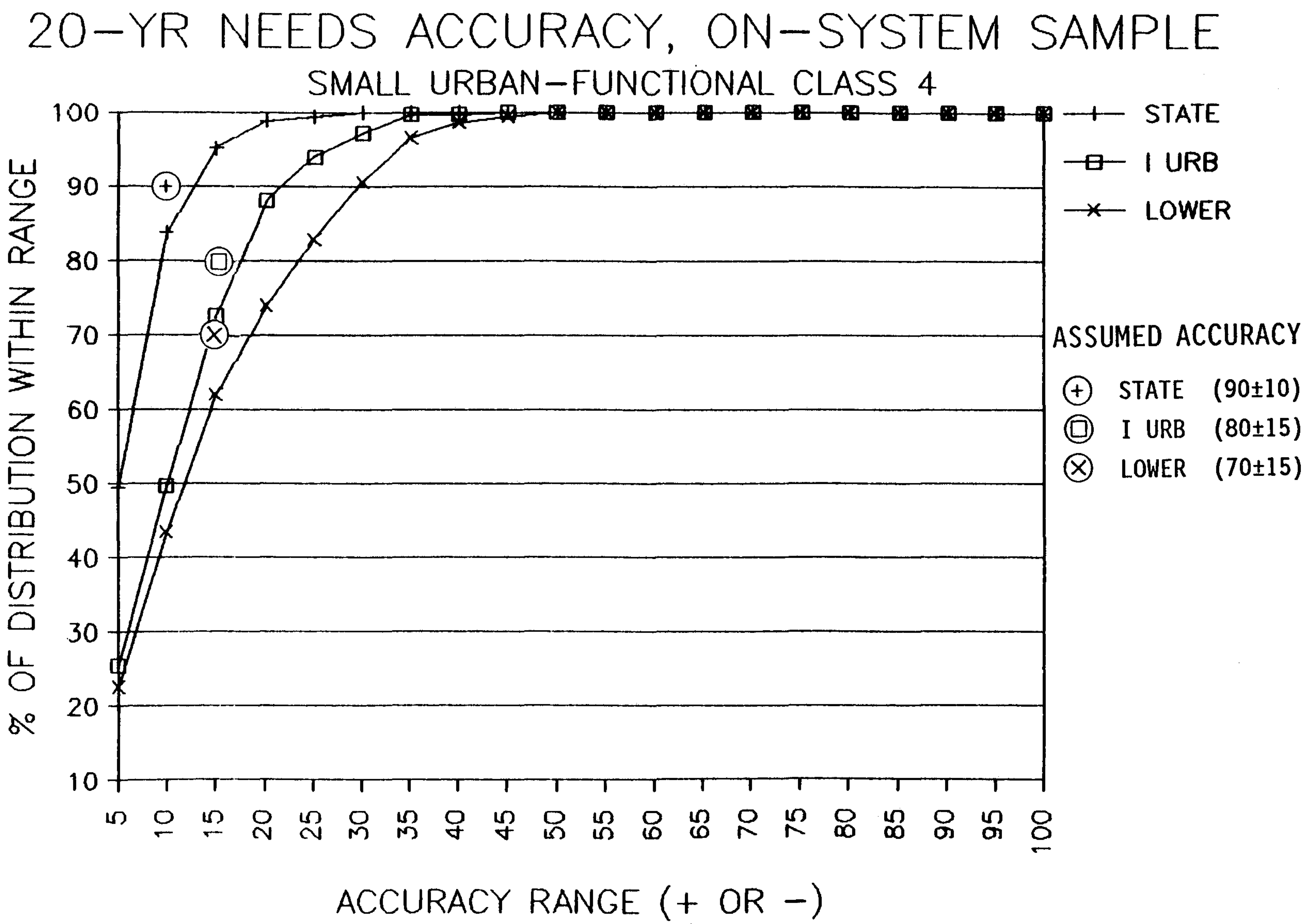
60
50
40
30
20
10
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±5)
I URB (80±10)
LOWER (70±10)

FIGURE B10


20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
SMALL URBAN-FUNCTIONAL CLASS 4
% OF DISTRIBUTION WITHIN RANGE
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5
10
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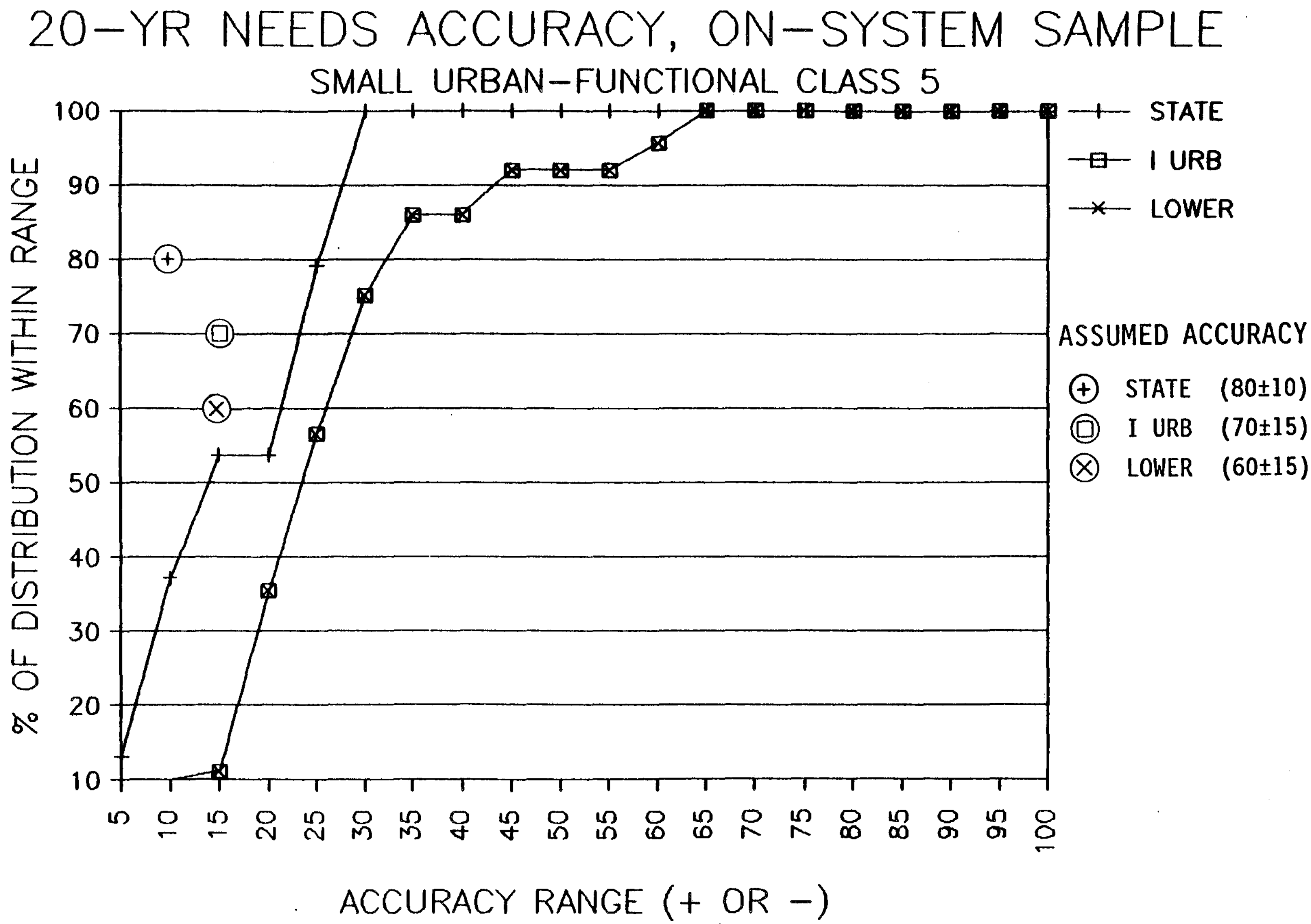
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±10)
I URB (80±15)
LOWER (70±15)

FIGURE B11



20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
SMALL URBAN-FUNCTIONAL CLASS 5
% OF DISTRIBUTION WITHIN RANGE
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40
45
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55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (80±10)
I URB (70±15)
LOWER (60±15)

FIGURE B12

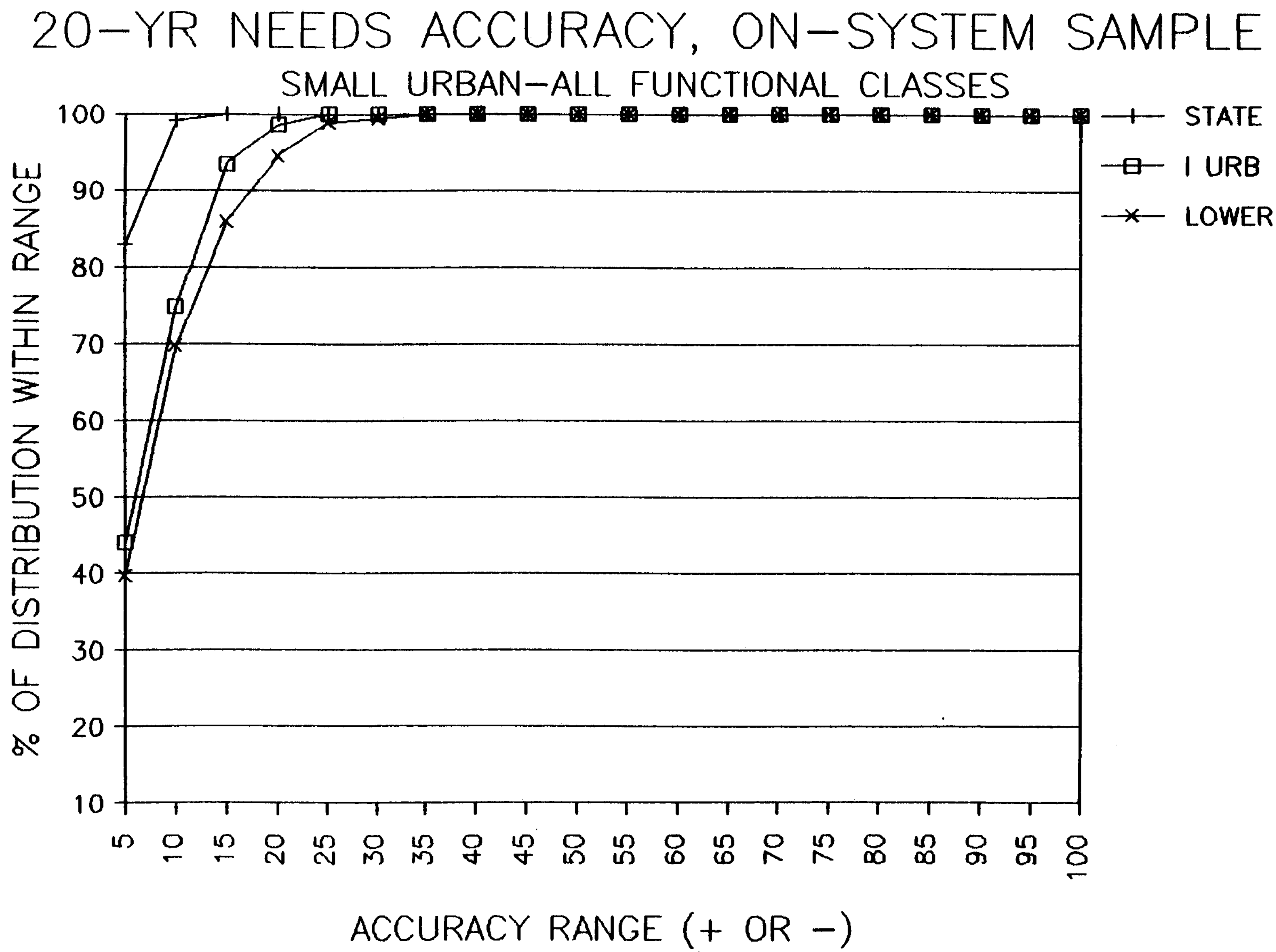

20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
SMALL URBAN-ALL FUNCTIONAL CLASSES
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER

FIGURE B13

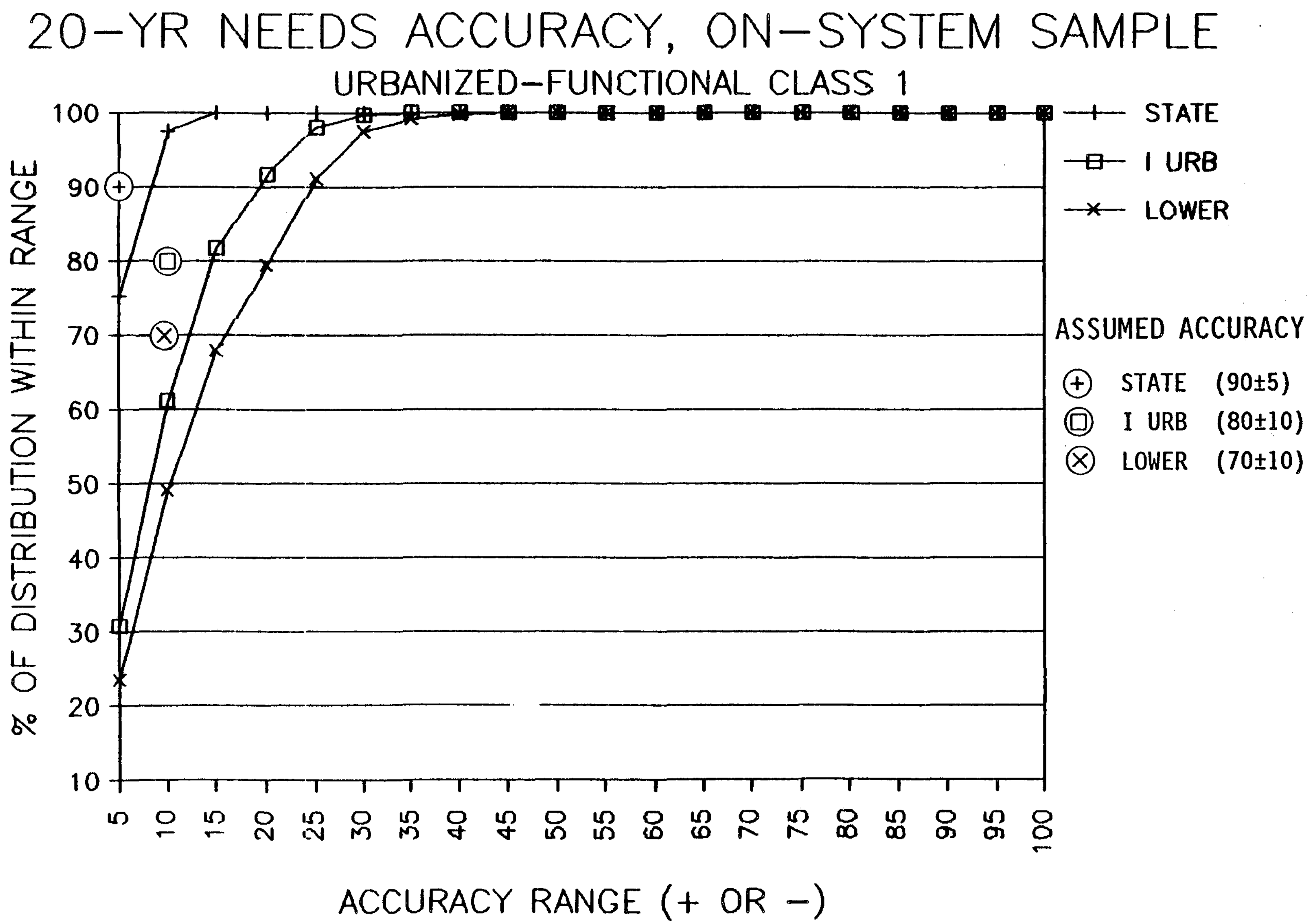
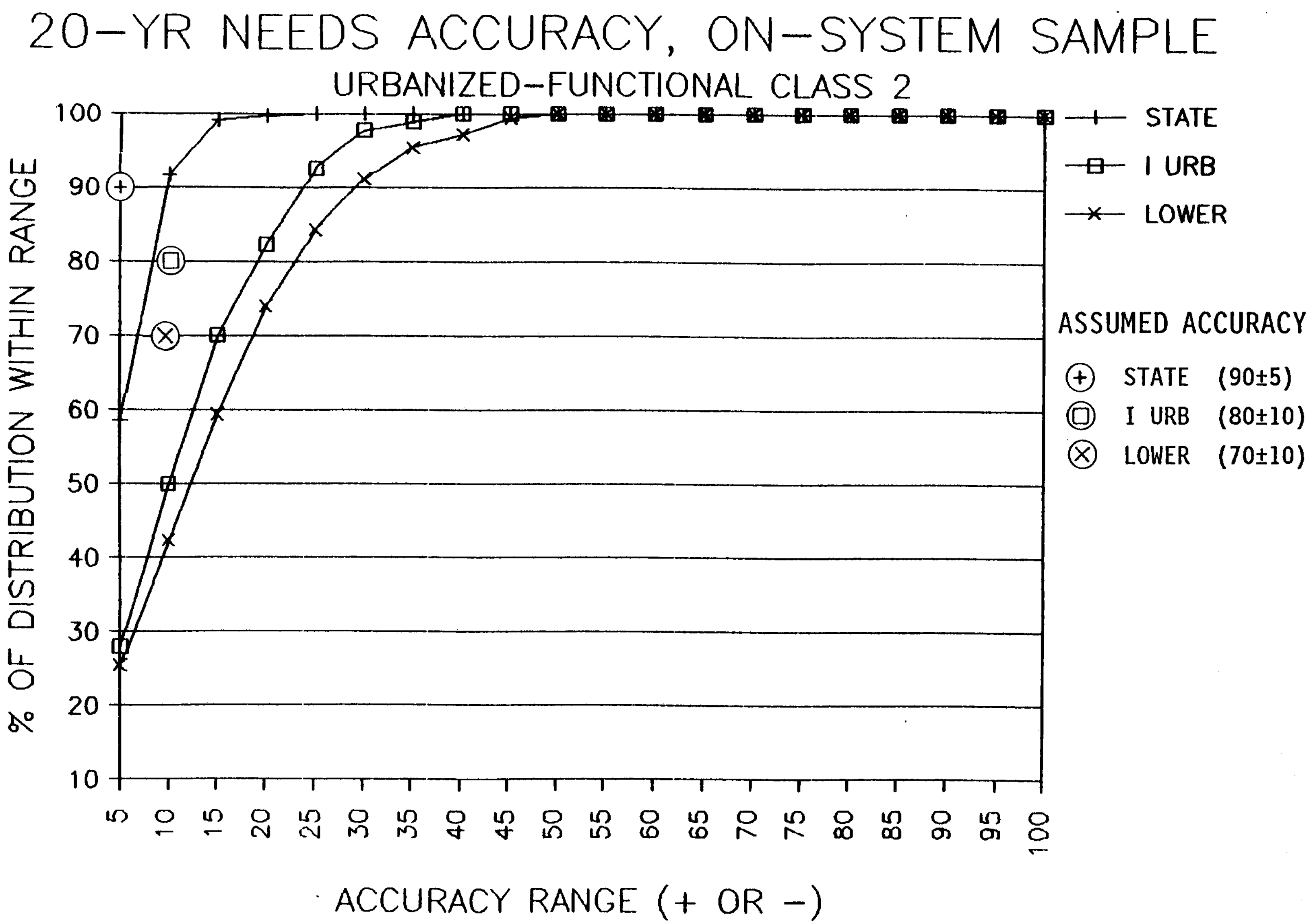
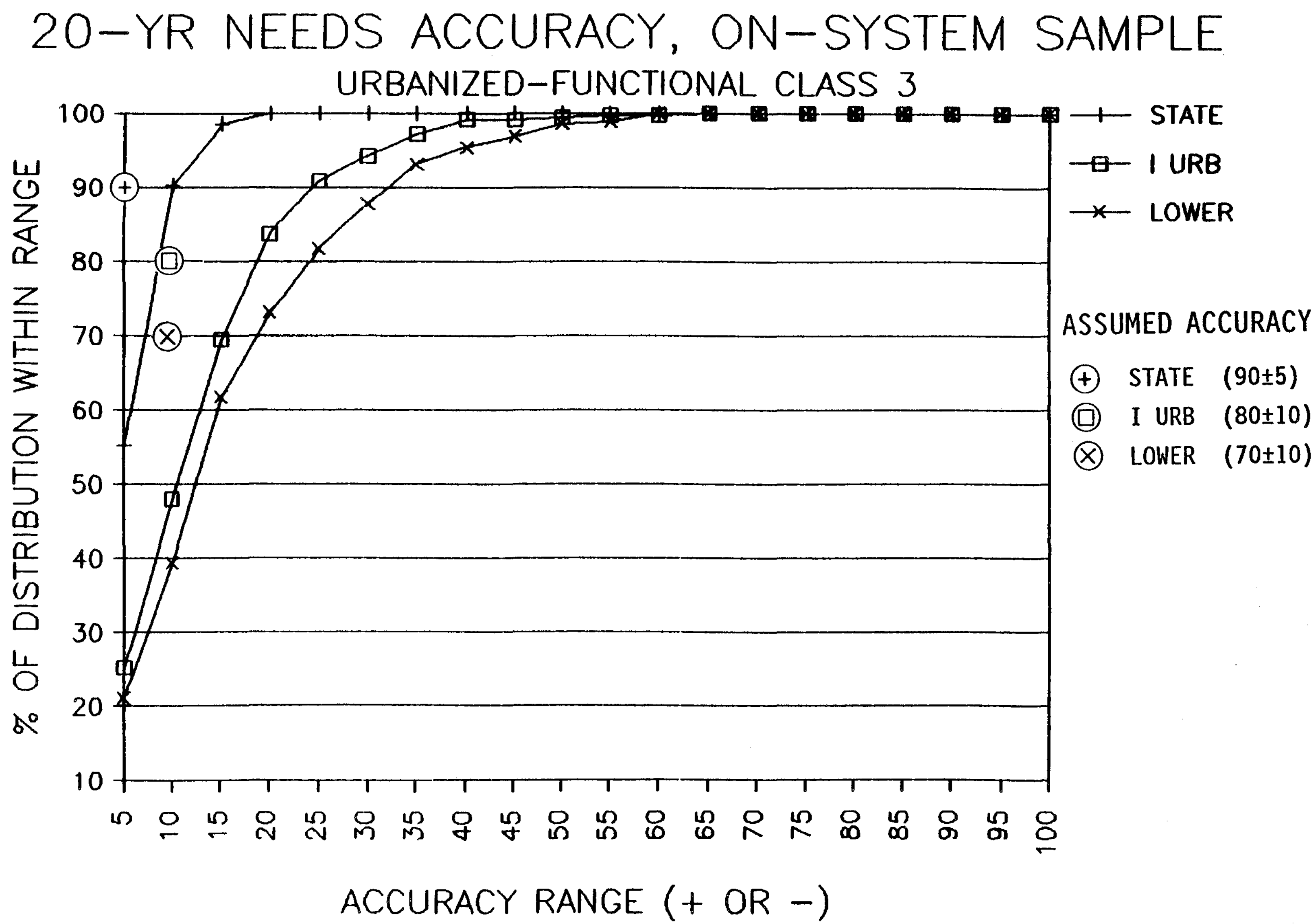

20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
URBANIZED-FUNCTIONAL CLASS 1
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR −)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±5)
I URB (80±10)
LOWER (70±10)

FIGURE B14



20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
URBANIZED-FUNCTIONAL CLASS 2
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±5)
I URB (80±10)
LOWER (70±10)

FIGURE B15



20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
URBANIZED-FUNCTIONAL CLASS 3
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±5)
I URB (80±10)
LOWER (70±10)

FIGURE B16

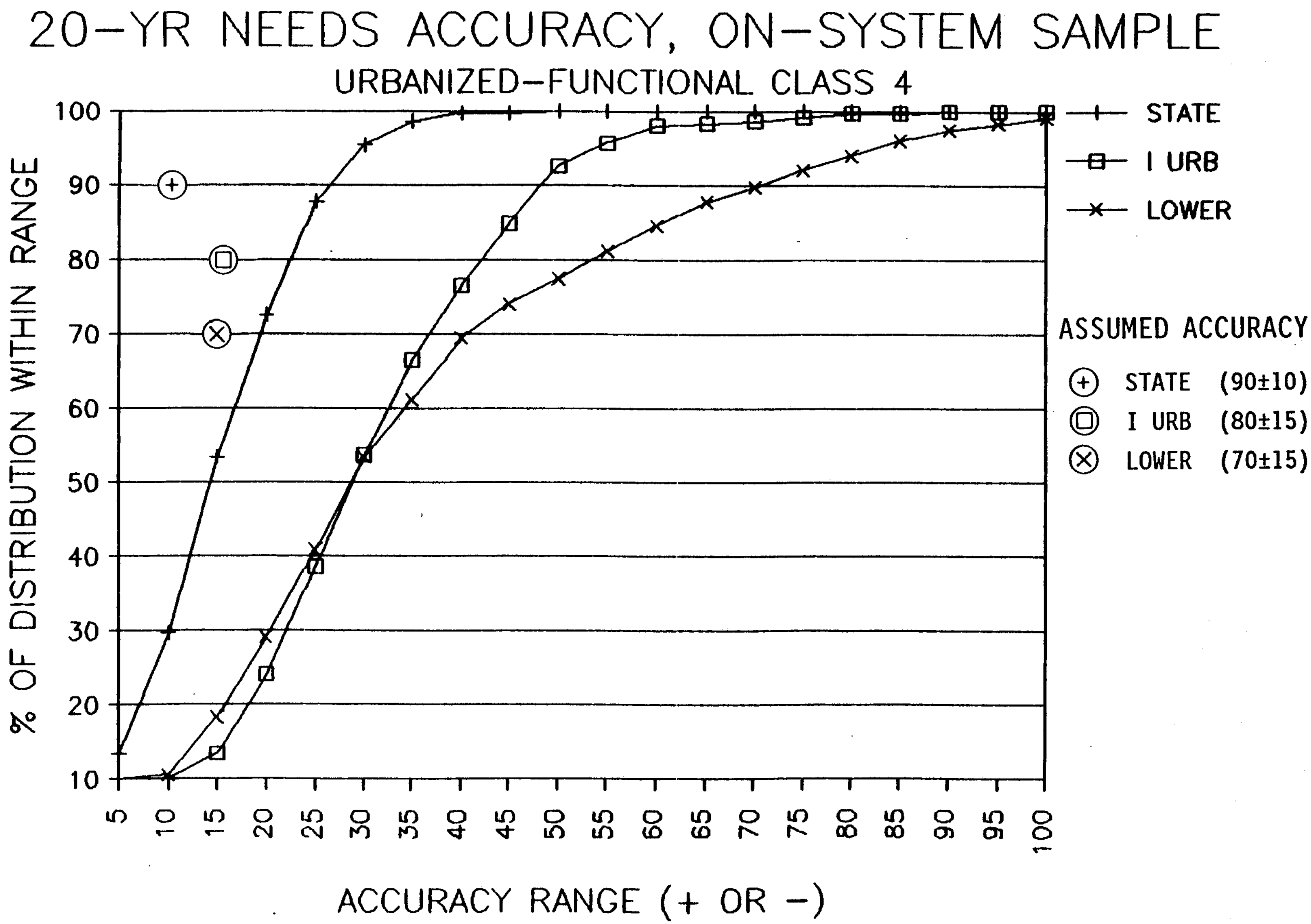
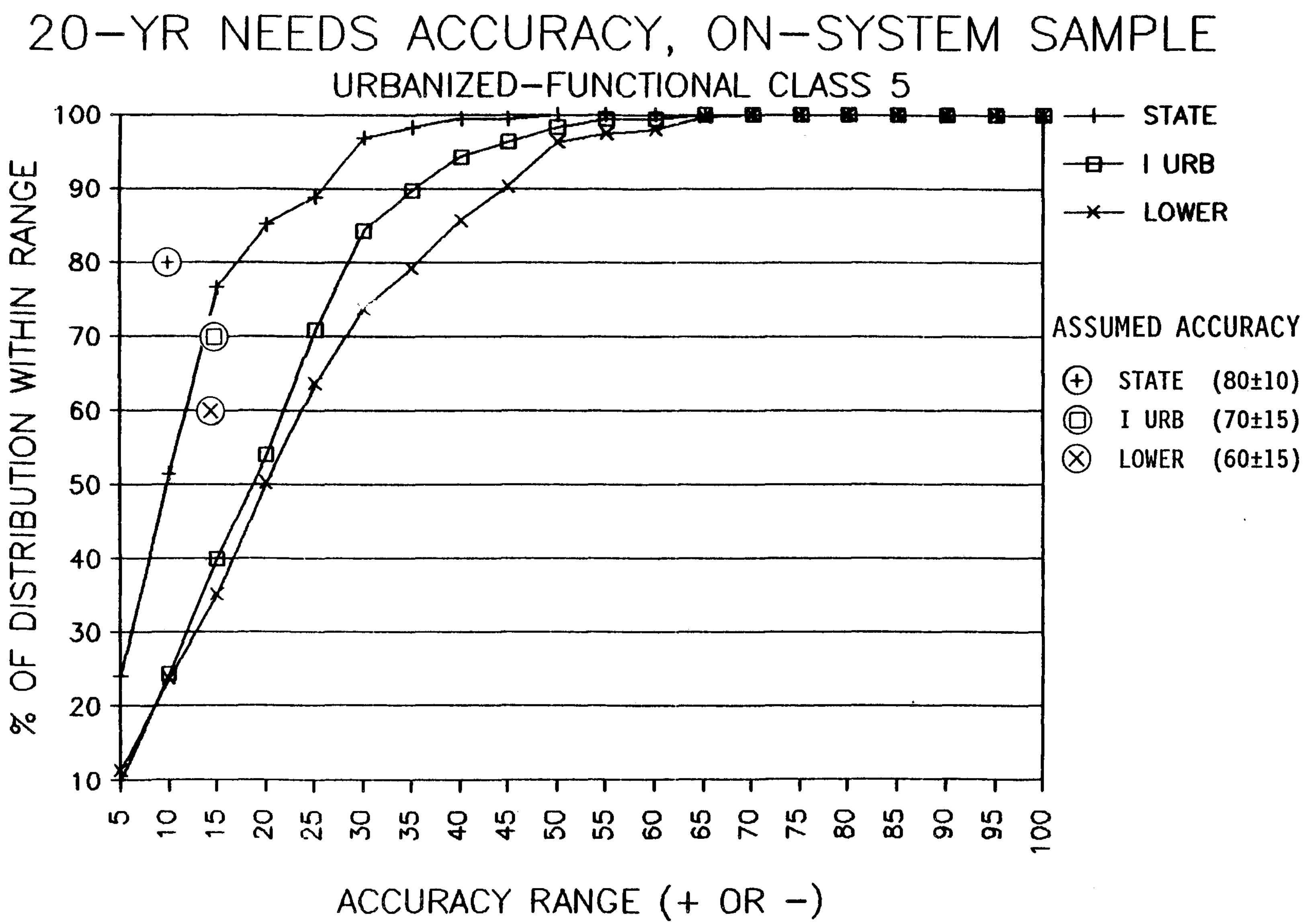
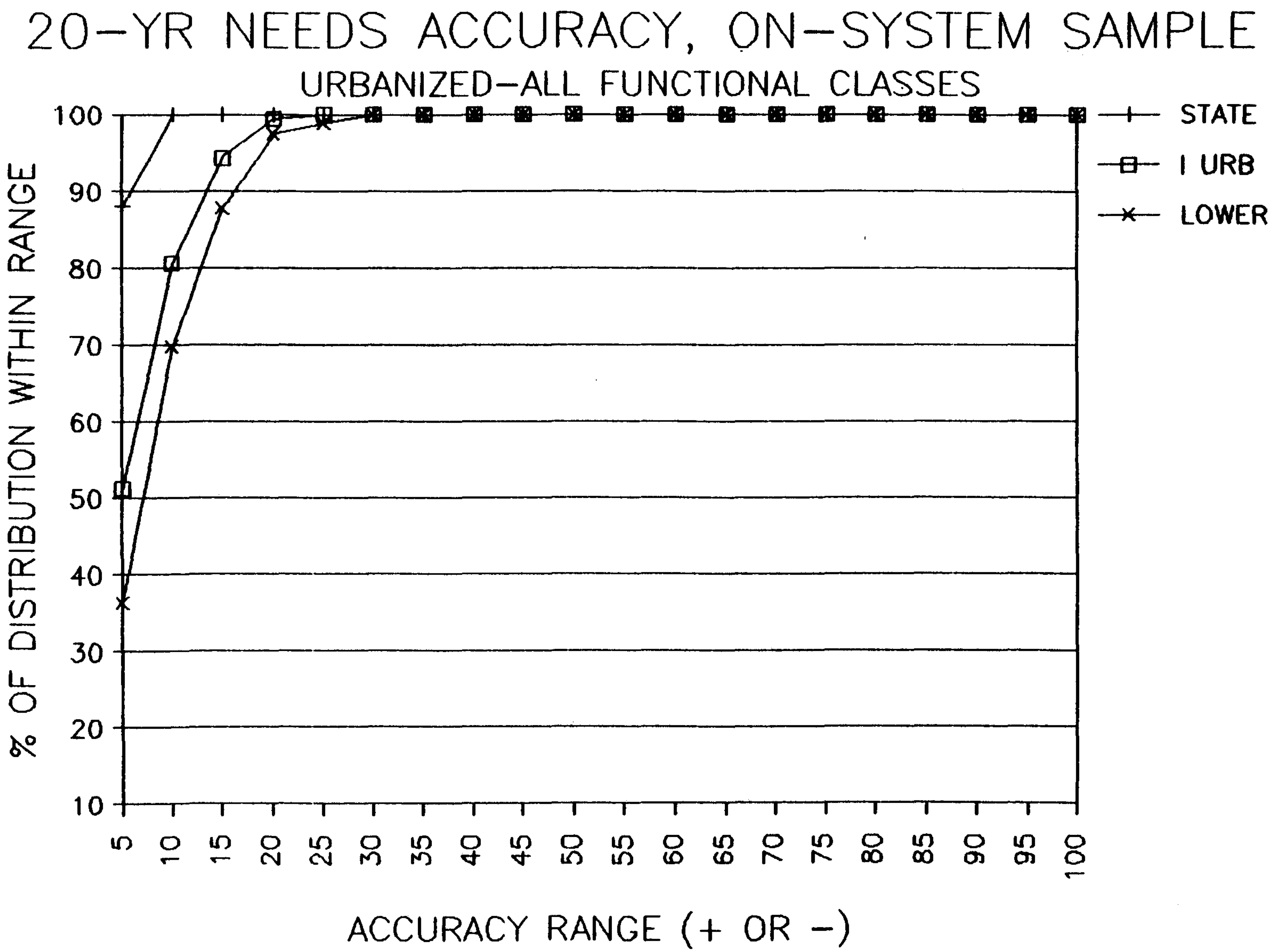

20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
URBANIZED-FUNCTIONAL CLASS 4
% OF DISTRIBUTION WITHIN RANGE
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (90±10)
I URB (80±15)
LOWER (70±15)

FIGURE B17



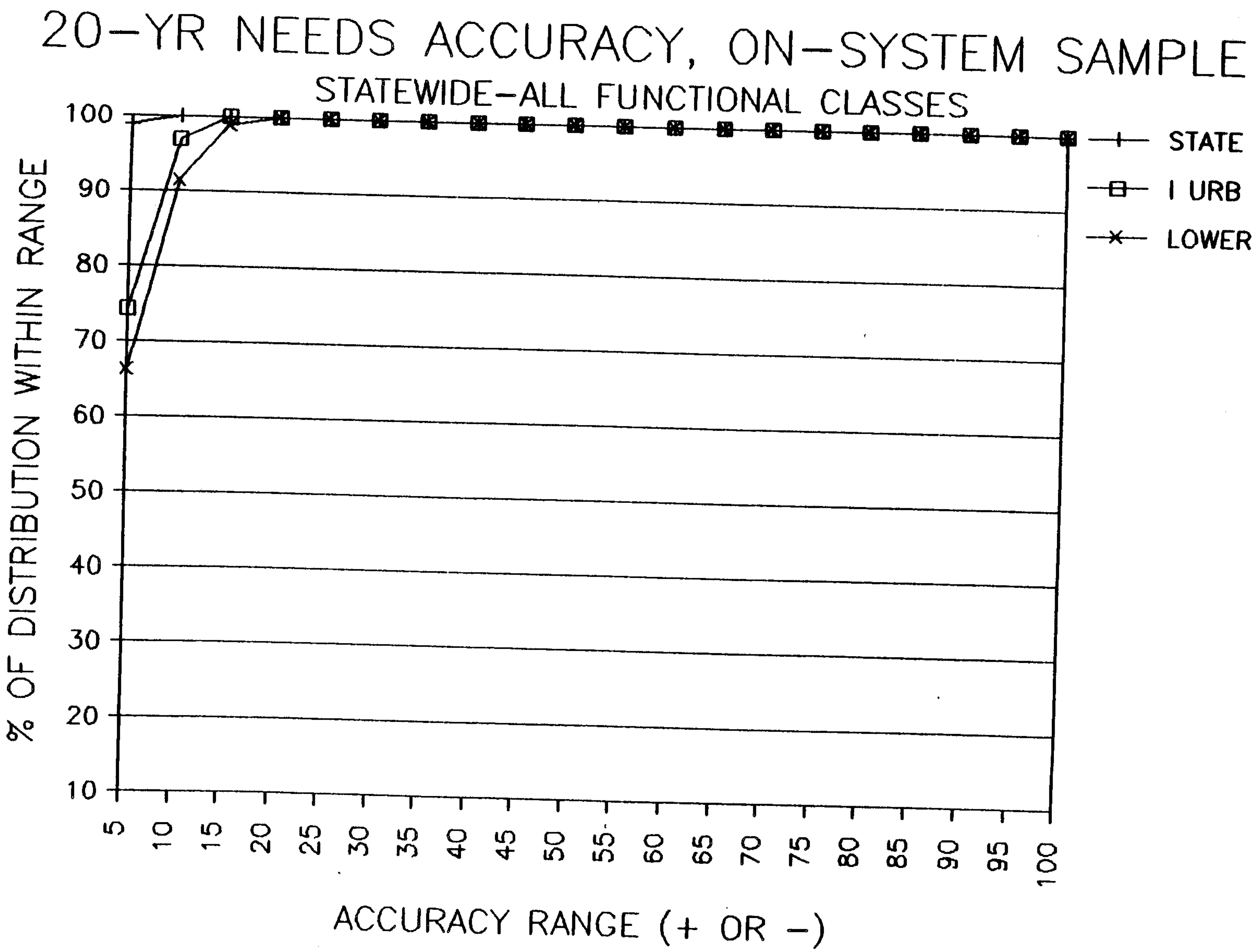
20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
URBANIZED-FUNCTIONAL CLASS 5
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER
ASSUMED ACCURACY
STATE (80±10)
I URB (70±15)
LOWER (60±15)

FIGURE B18



20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
URBANIZED-ALL FUNCTIONAL CLASSES
STATE
I URB
LOWER
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)

FIGURE B19



20-YR NEEDS ACCURACY, ON-SYSTEM SAMPLE
STATEWIDE-ALL FUNCTIONAL CLASSES
% OF DISTRIBUTION WITHIN RANGE
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
ACCURACY RANGE (+ OR -)
STATE
I URB
LOWER

APPENDIX C

Procedure to Update Required Sample Size for Use at District Level in Texas

The sampling procedure described here is similar to the FHWA recommended procedure, with the major difference being that the sample size is calculated at the functional class level rather than at the volume group level.

The recommended procedure is:

1. Stratify the HPMS universe, on-system, data set by district, area (rural, small urban, and urbanized), functional class, and volume group, in that order. The universe data set includes both the sampled and unsampled HPMS sections. It is not necessary to stratify by individual urbanized area because most districts have at most one urbanized area, and some individual urbanized areas cover more than one district. This should not affect the adequacy of the sample for those individual urbanized areas for FHWA reporting purposes. The sample being used in each area is much larger than the minimum required by FHWA.
2. All volume groups should have a minimum of three samples. Add samples to volume group cells that have a sample size less than three, unless the total number of sections in the cell is three or less, in which case all sections in the cell should be in the sample.
3. Sum the current samples and the additional samples in Step 2 together for a total by volume group. Then sum volume groups together for totals by functional class for each district.
4. Calculate the AADT coefficient of variation for each functional class, not volume group, in each district. The coefficient of variation is the standard deviation divided by the mean. Use the AADT for the universe sections in each functional class to calculate the coefficients of variation.
5. Use Formula (1), repeated below, to calculate the required sample size for each functional class, within each district.

$$n = F/[1+1/N(F-1)] \text{ with } n \geq 3 \qquad (1)$$

where

n = required sample size

F = $[(Z_\alpha)(c)/d]$

Z_α = value of the standard normal statistic for α confidence level (two-sided)

c = AADT coefficient of variation

d = desired precision rate

N = universe or population stratum size

The values to use for Z_α and d are given in Table C1.

6. Compare the required samples in Step 5 with the sample sums for functional classes in Step 3. Identify any functional classes that are deficient and the number of additional samples required for each functional class within each district (the required sample minus the sample sum).

If any deficiencies are identified in Step 6, then the additional required samples should be distributed proportionately to the volume groups within the functional class, using Steps 7 through 11.

7. Eliminate any volume groups that have 100 percent sample in Step 3.
8. Adjust the required sample size from Step 5 for those volume groups that have been eliminated. Simply subtract the number of samples in those eliminated volume groups from the required sample to give an adjusted required sample size.
9. Sum up the universe mileage for all volume groups that have not been eliminated in the functional class. Calculate the proportion of universe mileage that each volume group represents of the total. The proportions should sum to one.
10. Multiply the proportions for each volume group from Step 9 by the total adjusted required sample size for that functional class from Step 8. Round to nearest whole number.
11. Compare the sample size sums by volume group from Step 3 to the adjusted required sample size by volume group in Step 10. If the required sample sizes are greater or equal to than the sample size sums for each volume group and if none of the required sums are greater than the total universe sections in the volume group, then the sample distribution to the volume groups is complete. If not, eliminate those volume groups that do not meet the above requirements by setting the sample for those groups to the sample size sum or total universe size, as appropriate, then go back to Step 8.

Table C1. Recommended Values for Calculating Sample Size

Functional Class	α	$Z\alpha$	d
Rural			
1	70	1.036	.10
2	70	1.036	.10
3	70	1.036	.15
4	60	0.842	.15
5	60	0.842	.15
Small Urban			
1	70	1.036	.10
2	70	1.036	.10
3	70	1.036	.10
4	70	1.036	.15
5	60	0.842	.15
Urbanized			
1	80	1.282	.10
2	80	1.282	.10
3	80	1.282	.10
4	80	1.282	.15
5	70	1.036	.15