PREDICTING INDUSTRIAL GROWTH

WITHIN THE METROPOLITAN REGION

by

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A.B., Harvard College

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Submitted in Partial Fulfillment

of the Requirements for the degree of

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Submitted to the Department of City & Regional Planning
on January 14, 1963 in partial fulfillment of the requirements
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ABSTRACT

A number of methods for forecasting the intra-metropolitan distribution of a specified future regional total of industrial employment based upon published studies such as The Chicago Area Transportation Study, The Baltimore-Washington Interregional Study, and the New York Metropolitan Region Study were applied to five major parts of the Boston Area for the period 1950-1960. The employments assigned under the methods were then compared with the actual recorded employments in 1960.

No method made less than a 10% "average" error in over- or under-estimating the five 1960 zonal employments in manufacturing. Differences in the predictive power of the methods were observed, but their statistical significance was unclear.

Based upon this performance, the methods sampled were judged unsatisfactory. The belief was expressed that significant improvement would require deepening of our knowledge of industrial location process.

Thesis Supervisor: John T. Howard

Title: Professor of City Planning

Letter of Transmittal

Professor John T. Howard, Head
Department of City & Regional Planning
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Professor Howard:

I am pleased to submit herewith my thesis entitled, "Predicting Industrial Growth Within the Metropolitan Region", in partial fulfillment of the requirements for the degree of Master in City Planning.

Sincerely yours,

William R. Pokross

Cambridge, Massachusetts

January 14, 1963

ACKNOWLEDGMENTS

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I. INTRODUCTION

The present study seeks to contribute to the under-
standing of the forces underlying the changing distribution of
industry among the parts of metropolitan regions. The ability
to predict, and ultimately, to influence this growth and move-
ment of industry is an issue in its own right, but our interest
in prediction methods centers on the exposure of crucial rela-
tionships or validation of theories concerning the distribution
of industrial growth.

> Part of the payoff of a good prediction are
> the cues it provides to mechanism and rela-
> tion. (12, p. 4)

Of course, when we test theory by adducing verifiable predic-
tions from it, we must be sure the variables chosen and actually
manipulated faithfully reflect the concepts they represent. For
example, the concept of "accessibility" stands at one level,
travel time between areas at another, and a matrix of numbers
purporting to constitute these travel times at still another.
Bearing this qualification in mind, we can frame the thesis prob-
lem as the comparative evaluation of alternative procedures for
forecasting the internal distribution of manufacturing activity
within a metropolitan area based upon actual performance in at
least one situation - i.e., based upon an exercise in "retro-
spective prediction".

The procedures selected, with one exception, constitute
the simplest and at the same time systematic class of forecasting

methods for industrial employment available. They represent at
least the type of method which is enjoying great popularity in
current practice - it being understood that most of the work in
this area at present occurs in connection with regional transpor-
tation planning studies. By systematic methods, we refer to a
minimum of subjective judgment, a maximum of inter-personal agree-
ment. For example, "holding capacity" or the "ultimate" amount
of population or land in industrial use an area is going to at-
tain fails this criterion. (unless a series of assumptions con-
cerning policy, technology, etc. are agreed upon), while the cur-
rent amount of undeveloped land in an area does not. Again, er-
rors of measurement may arise (as in determining travel times).

Most of these methods are deterministic in character,
making no allowance for policy alternatives. They give no insight
into process - i.e., into the complex interchange among vari-
ables - but only describe a pattern at a high level of abstrac-
tion.

> These models have nothing to say about the
> processes of change or about the causes of
> change.... In addition, these models say
> nothing about the possibilities for willful
> redesign of land use patterns; it is assumed
> that land use patterns are positively deter-
> mined by forces lying outside human control.
> (32, p. 375)

Accordingly, these procedures must stand or fall on performance -
as with any empirical rule. Based upon verifiable results, we
can ask whether more is required - for these methods do offer
the virtue of simplicity and economy - whether or not they can

meet a tolerable limit of error, as tested by retrospective application. And if the period for which the predictions are made is relatively short, this at least sets a lower limit on the error that can be expected for long-range forecasts. (12, p. 11)

Ironically, the day for prediction in planning - prediction, that is, of the kind we consider here - may be drawing to a close. Prediction and planning are no longer viewed as antagonistic - which they remain so long as prediction provides no foothold for the influence of alternative policy or changes in living and working patterns. The questions asked are no longer what is going to happen, but rather what will be the response if a set of public policies are carried out and certain economic conditions prevail. Here, a good prediction method must expose the crucial channels for planned change as well as the properties of the system under study which must be respected.[1] Under this new framework, where normative planning and research into urban processes meet, optimization techniques, which probe the most efficient or goal-maximizing alternatives rather than those "likeliest" to develop spontaneously, become feasible. The Penn-Jersey study expresses this spirit. (27) The past is used as a laboratory to establish relationships among variables, not as a basis for determining the particular values they are going to assume in the future. In contrast to the work of the

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[1] This "new framework for planning" is discussed in references (21) and (32) as well as in Lowdon Wingo, Jr., Transportation and Urban Land, Washington, Resources for the Future, 1961, at pp. 5-9.

C.A.T.S., where the model yields results which policy must face, the P-J study seeks to develop a "Regional Growth Model" under which policy helps to formulate the projection. (10) Nevertheless, with the inevitable lag in practice, testing the kind of methods under examination in this study is not without value. Such follow-up, or, in this case, validation in the planning field of prognoses as to what is going to happen or how best to meet it is not to be found in abundance. Yet only through such exercise can the adequacy of current knowledge and technique be documented, and the directions for refinement be lined out.

It may well be that the present study, necessarily carried out under limitations of resources and knowledge, furnishes no truly definitive tests of recognizable prediction methods - where these methods were freely "operationalized", where the data employed bear certain inadequacies and uncertainties, and where, after all, methods have been exposed to the conditions prevailing in one place at one time. No matter; a research method has been used which could be applied to additional data under conditions of greater control and uniformity.

Where essential data had in some cases to be estimated, and where published statistics and statistical compilations precluded rigorous comparability in the problem set for each method, we were constrained to take the position that if methods yielded future employment assignments at considerable variance with those actually realized, we would possess the grounds for rejecting their reliability, but that as the gap narrowed, possible errors

in the data would rule out a positive finding.[2] In the terms of
statistics, we have reduced our type I error (of falsely rejecting
a reliable method) at the expense of our type II error (of accept-
ing an unreliable method, or at least failing to reject it). In
some instances, on the other hand, we fed "perfect" information
regarding the future into a method, so that if it produced accu-
rate assignments, the outcome would be indeterminate, while pre-
dictive failure would support a strong conviction of "real" in-
adequacy. Thus, viewed as an experiment, only certain outcomes
of our work would yield conclusive evidence of "functional fail-
ure".

The "laboratory" we have chosen is the Boston area
during the decade, 1950-1960. This case poses a great challenge
to prediction methods, because great changes in the composition
and spatial distribution of industrial employment took place while
the total of industrial employment changed very little. Some
areas experienced sharp declines in employment while others re-
ceived large gains. The most dramatic growth occurred along
certain portions of Route 128, a circumferential expressway whose
central link was completed in 1951, passing through a band of
towns situated just beyond the area of dense urban and suburban
development with an abundance of buildable, undeveloped land.
Bone and Wohl have shown that some 77% of the employment involved
(as of 1957) represented relocations, either of companies or

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[2] In the end, the errors of estimate were of sufficient magni-
tude to permit at least certain statements to be made re-
garding the power of the various methods explored.

branch plants - with the majority formerly located in Cambridge or Boston. (7) The increase in manufacturing employment in the band of towns adjacent to the highway during the decade was several-fold the employment created in new plants fronting upon Route 128. Clearly, the impact of the highway must be measured in terms of its influence upon the surrounding area as well as its influence upon the "system" of the metropolitan region.

In terms of underlying theories or postulated relationships, we are, in the process of testing prediction methods, exploring relationships between growth of industrial employment and: composition or mix of industries represented, pattern of past industrial growth, concurrent growth of population, growth potential as a joint product of the availability of land for industry and relative accessibility. The results are at least provocative.

II. STUDIES AND FORMULATION OF METHODS

A. General Comments

The phenomenon we wish to explore is the growth - i.e.,
the changing distribution - of industrial activity among the parts
of a metropolitan area. For some purposes, it is the use or re-
use of land by industry which is of interest. For others, it is
the numbers of persons employed, rather than the land area in-
volved, that is required, as for estimating traffic generation.
Changes in the total number employed in an area, however, may
mask increases in some types of industry "netted out" by decreases
in others. Industry group statistics, in turn, offset the influx,
formation, growth and expansion of individual firms located in an
area with the exodus, decline, and dissolution of others. The
problem arises because a record of changes in the amount of land
used for industrial purposes (or indeed any land use information)
is sometimes not available. Then the translation from employment
to land must be made via the application of estimated worker den-
sities - which are notoriously variable.[3] Unfortunately, only
records over time of total employment by employment groups are
kept for the Boston area. It is this variable that is to be pre-
dicted as the measure of industrial activity. *

The regional boundaries followed those of the "full"
region of 153 cities and towns as defined by the Greater Boston

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[3] Regrettably, there is so far nothing to compare in the indus-
trial field with records kept of newly constructed dwelling
units in the housing field.

* Note follows.

* "The chief reason for the lack of analytical studies

of industrial movement is to be found in the deficiency of

relevant pertinent data. Those studies which have been under-

taken were generally limited to the comparison of statistics

provided by the periodic U.S. Census of Manufactures or the

local state offices of the department of labor. These sources

alone, useful as they are for some other purposes, are not

sufficient to measure either the magnitude or the direction

of individual movements. Comparing the number of manufacturing

establishments for two separate time periods, two Census years

for example, will yield the aggregate net results of all changes

which transpired during the intervening period. However, this

will disclose nothing about the nature or the size of the multiple

movements and counter movements which preceded the cumulative net

totals shown for the terminal year."

> "Industrial Movements and Expansion, 1947-1957 –
> City of Chicago and Chicago Metropolitan Area",
> Economic Base Study Series: Study No. 3, Chicago,
> Department of City Planning, 1961.

Economic Study Committee, upon whose land use inventory and com-
pilation of employment statistics so much reliance was placed.
(15) However, this same reliance required some variation in
the total area and in the definition of sub-areas (zones) - and
even in the years used - to comply with those employed in the va-
rious compilations. The final predictions were expressed as as-
signed employments for a division of the region into five zones -
defined as uniformly as possible among the several methods, as
illustrated in the maps, infra. They represent combinations and
adaptations of a system of zones developed by the G.B.E.S.C. for
its economic and demographic studies, consisting of the Core and
an inner and outer band of suburbs and urban sub-centers with
the bands divided into eight radial sectors. (The concentric
areas are represented in Map 2.) Some of the choices of zones
can be justified on the basis of a common and distinguishable
growth pattern during the period under investigation; others
were based upon convenience. Together, however, these five zones
abstract a coherent picture of industrial redistribution within
the region: in the Core, sharp decline shading into stagnation
and modest growth on the fringes; generally strong growth in
the Inner Ring (the Route 128 zone plus Weymouth, Hingham, and
Hull); decline in the Lynn-Salem, Brockton, and Lawrence-Lowell
areas representing old urban centers; and, finally, generally
modest increase in the remaining Outer Ring. The test of any
prediction method must be its ability faithfully to reflect
these five basic patterns of change. To isolate this allocation

problem, the correct regional totals of future industrial employ-

ment was taken as the starting point.

> The forecasting of future land use is treated
> as a distributional problem in which aggregate
> population and worker forecasts are distributed
> spatially to small areas.[4]

The prediction period taken cuts across a reclassifi-

cation of employment among Standard Industrial Classification

(SIC) categories undertaken for Massachusetts by the Division

of Employment Security (DES) in its counts beginning in January,

1958. A number of 3- and 4-digit categories were attached to

different 2-digit categories. The net effect at the time upon

manufacturing employment, SIC categories 19-39, was an increase

for "Metropolitan Boston" (DES definition roughly comparable to

the U.S. Census Boston S.M.S.A.) by a factor of 1.018 and an in-

crease for the state as a whole by a factor of 1.014 (indicating

a factor of 1.012 for "non-Boston"). Our knowledge does not ex-

tend to finer areas. However, the factor of change for nearly

all the 2-digit manufacturing categories falls within 10%, and

the exceptions make up a small proportion of total manufacturing

employment while we are dealing with "real" changes of several

times that factor, so that we can have some confidence about the

effect of varying mix at the 2-digit level among our five zones.

It is possible, but doubtful for such large zones, that the

[4.] Voorhees and Morris, "Estimating and Forecasting Travel for
Baltimore by Use of a Mathematical Model", Highway Research
Board Bulletin #224, 1959.

composition of 2-digit categories differs sufficiently between
the zones to bias the total manufacturing figures. All reclassi-
fications <u>within</u> the group of manufacturing categories do not con-
cern us when we deal with total manufacturing employment. Where
relevant, 1950 employments were adjusted to reflect the mean ex-
pansion in employment counts over the region suggested by the
figures above. Such an "average" adjustment reduces the <u>net</u>
growth for the region by about one-half, depending upon the parti-
cular boundaries taken.

B. Expected Growth

Following the point of view of the New York Metropoli-
tan Region Study, future zonal employment (for any industrial
category or combination of categories) can be analyzed into the
tautology:

> future zonal employment = (future regional
> employment) x (present zonal share) x (zonal
> change-in-share) = ("expected growth") x
> (zonal change-in-share)

As a first step in prediction, therefore, "expected
growth" can be calculated, being the projection of present zonal
employment shares onto the new total of regional employment.
(29, p. 215) The projection of present shares into the future
can also serve as a standard of comparison with more refined
methods. The "method of constant shares" refers to "expected
growth" determined on the basis of shares of total manufacturing
employment and we have calculated it five times to serve as a

baseline for all the prediction methods. Since the zonal change-
in-share factor for manufacturing employment is appreciable in
our problem, the method proved not very successful.

We then formed the employment by 2-digit categories
into three categories, "high loss", "high gain", and "balance"
on the basis of regional growth. This process has been called
"adjusting for mix". It can as well be applied to the employment
growth of the region vis a vis the nation. (25) Other things
being equal, zones that are rich in high-growth lines of indus-
try should grow more rapidly and increase their share of total
manufacturing employment. Unfortunately, the zonal change-in-
share factor, which is ignored under "expected growth", may be-
come quite significant. Indeed, the theoretical contribution of
"expected growth" methods is to expose the significance of changes-
in-share by allowing for the effects of zonal mix of industries
with differential regional growth rates, after which the residual
errors of estimate are referable to share redistribution. Bone
and Wohl noted that plants which had moved to Route 128 generally
expanded their employment over previous levels. (7) And one of
the fundamental findings of the NYMRS was that the Core experi-
enced a decline in share of all industries with growing regional
employment - referable to the "search for space" - except for the
special industries where a central or present location was an
overriding consideration. (24, pp. 29-30) Here, change-in-
share for the Core would nullify the effect of a greater number
of jobs to be allocated, and to consider only the forces fostering

growth could lead to an inflated estimate worse than the hypothesis of a constant share of total industrial employment for the Core. Such appears to have been the case. For an "open" area, on the other hand, such as the Route 128 zone, growth resulting from migration bore no necessary resemblance to the mix of industries located there in 1950. The one had little to do with the other.

Employment was then analyzed at the 2-digit level into four worker-density categories, following closely groupings used in reference (14) at pp. 80ff (based upon a study of conditions in the Philadelphia region). 1950 shares of the new totals for each class were assigned to zones as before. The main object was to establish a comparison with the classification based upon regional growth.[5]

For these "expected growth" assignments, zonal employment at the 2-digit level was needed, so the predictions had to be made for 1959. The zones are shown on Map 1.

C. Share-Trending

Extrapolation of a curve (i.e., of the "trend" of past growth) is perhaps the most wide-spread technique of forecasting

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[5] 75% of regional employment in the high-growth class, as measured in 1959, falls in the two highest density classes. Of the 75%, 80% - representing SIC 36 falls in the highest density class. All employment in the high-loss class falls in the next (i.e., lower) density class. The fourth or lowest density class, consisting entirely of SIC 32, is of negligible size.

MAP 1 ZONES FOR "EXPECTED GROWTH" METHODS
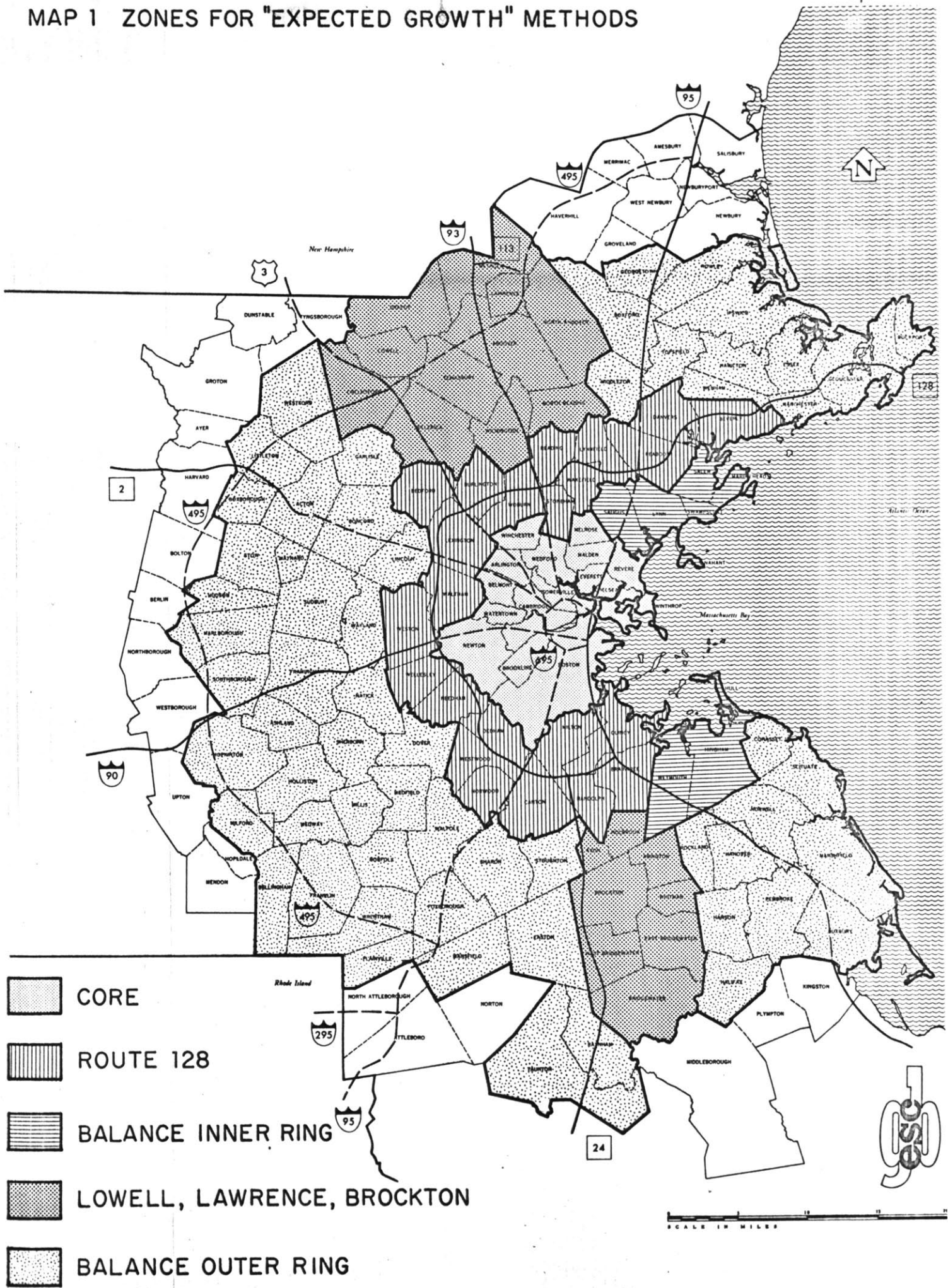
CORE

ROUTE 128

BALANCE INNER RING

LOWELL, LAWRENCE, BROCKTON

BALANCE OUTER RING

√ population or employment growth. Mixed with judgments about exceptions or expected discontinuities, a recent study of industrial land needs in the Boston area (14) relied upon this method, and it figured into such a refined study as the NYMRS. When the future total of employment is open-ended, there is considerable freedom in the selection of an extrapolation equation. However, when a series of employments moving over time are to be individually extrapolated under the constraint that together, they must meet a fixed total at time t, much of this freedom is lost - and we enter a struggle between elaborating complex, discontinuous, and seemingly arbitrary rules which can guarantee that we meet our constraints, or sacrificing the assurance of meeting a specified total and avoiding an assignment of negative employment in the interest of a simple rule that tests a meaningful proposition. In the end, we arrived at a simple series of rules of ascending complexity that hypothesize certain mathematical relationships between growth of zonal employment during the prediction period and change in the past, where the immediately preceding period, 1947-1950, is used to represent the past:

If $s(t)$ = a zonal share of employment at time t

Then we can hypothesize:
$$s'(t) = o \qquad \text{or } s(t) = k$$
$$s'(t) = k \qquad \text{or } s(t) = at + b$$
$$s'(t) = k \cdot s(t) \qquad \text{or } s(t) = ae^{kt}$$

These lead to the rules,
$$s(1959) = s(1950)$$
(method of constant shares)
$$s(1959) = s(1950) + 3[s(1950) - s(1947)]$$
(linear trend method)
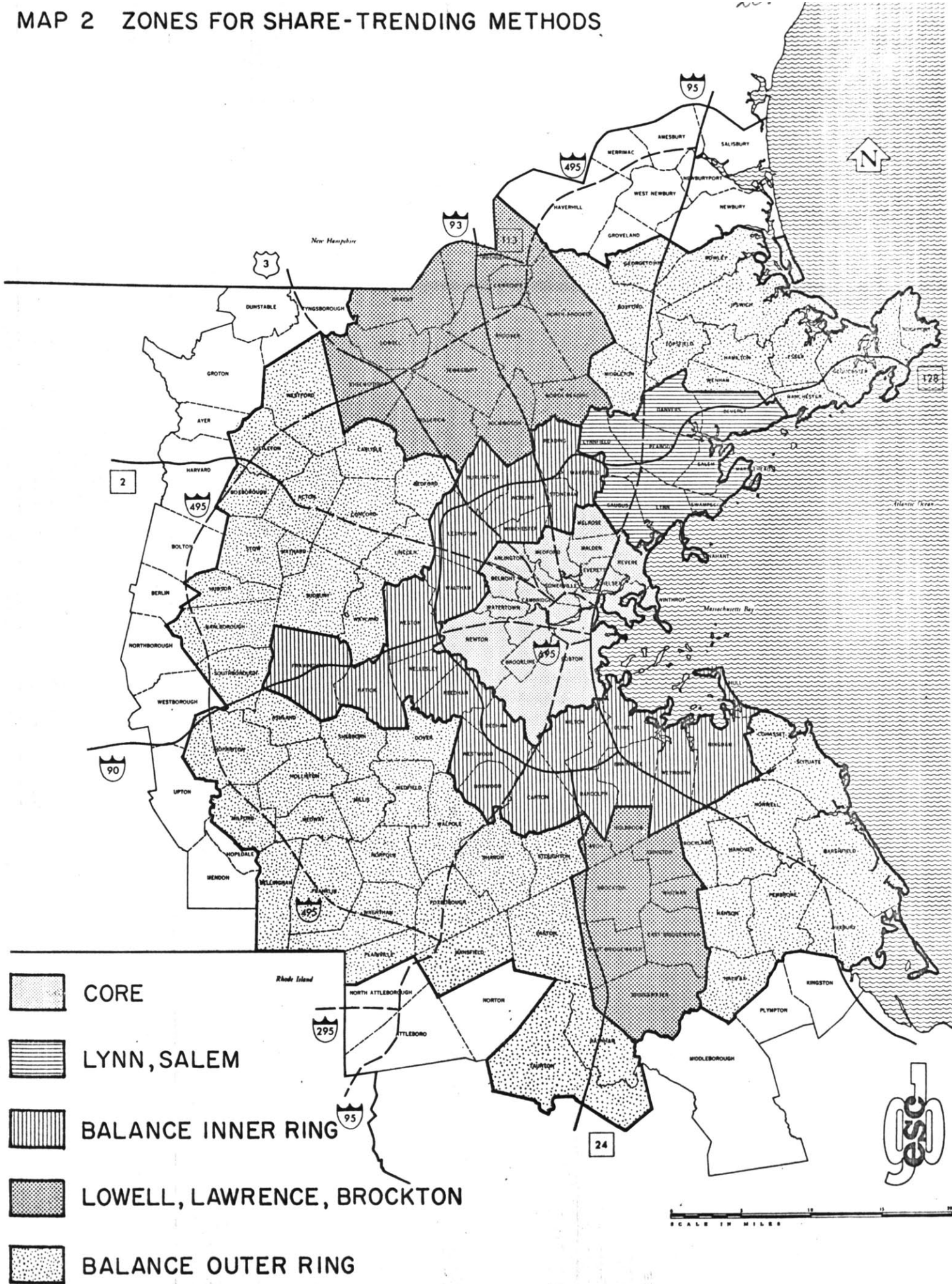$$s(1959) = \frac{[s(1950)]^3}{[s(1947)]} \times s(1950)$$
("compound interest" method)

Constant shares have been described as "expected growth".
"Linear trend" posits for each zone a constant yearly incremental
change in employment. "Compound interest" posits for each zone
a constant yearly _factor_ of change.

These methods were applied only to shares of total man-
ufacturing employment for the set of zones given in Map 2. They
give no insight into process. But they do offer an economy that
more complex methods must offset in sufficiently greater accuracy
or stability.

The search for "reasonable" extrapolation rules led to a
graphical study of actual growth in industrial employment in the
seventeen G.B.E.S.C. employment analysis zones (mentioned earlier)
through the period, 1947-1959. This study disclosed a pattern
of increasing growth for zones as their radial distance from the
center of the Core increased, up to a peak in the Inner Ring,
falling off as radial distance increased further, but with losses
in the older, more urbanized zones irrespective of radial distance.
We hypothesized that a combination of the two factors, distance
to CBD, and some measure of density, age, or urbanization could
account for the variation among zonal growth rates. Various "ur-
banization" factors were tried: workers per industrial acre, per
cent undeveloped land, gross residential density, population per
acre total land, per cent of gross residential land in multi-
family use. The results were highly unsatisfactory, indicating
either a failure to operationalize the concepts or that factors
other than radial distance to the CBD and "maturity" - for

MAP 2 ZONES FOR SHARE-TRENDING METHODS

Legend:

- CORE
- LYNN, SALEM
- BALANCE INNER RING
- LOWELL, LAWRENCE, BROCKTON
- BALANCE OUTER RING

example, local policy - play an important part, or that an ex-
planation of the changes must consider the composition of total
employment.

D. NYMRS Study

The New York Metropolitan Region Study developed a
typology of manufacturing industries according to intra-regional
locational requirements. For each of eight groups of industry,
the set of outstanding forces and concerns were developed and be-
came the basis for determining changes in the shares of employ-
ment in the various groups for each part of the region - i.e.,
the rates of migration outward of employment in the eight groups.

Changes for the same groups of industries were deter-
mined for the City of Boston and the full G.B.E.S.C. region be-
tween 1947 and 1957. Part of the results are illustrated in
Table 1. The study showed that the "communication-oriented" and
the "local market-consumer" groups of industries both figured
significantly more prominently in the industrial composition of
the City of Boston than in the rest of the region, while the
"national market" groups were significantly under-represented.
Boston's employment in the "special manufacturing" industries
(the first three given in Table 1) remained nearly stationary,
while there were heavy losses in the remaining groups. Boston's
loss of regional share in the "national market-large plant" group
was significantly greater than in the "small plant" group. Cor-
respondingly, the "large plant" group expanded its regional

TABLE 1

CITY OF BOSTON - SHARE OF REGIONAL EMPLOYMENT IN

SELECTED N.Y.M.R.S. CATEGORIES, 1947 AND 1957

	Category	1947 Share	1957 Share
	All Manufacturing	.254	.208
"special"	Communication-Oriented	.494	.427
mfg.	Nuisance and W.T.	.207	.219
industries	Raw Mat. Oriented	.027	.034
	Local Mkt.-Consumer	.498	.401
	Local Mkt.-Intermediate	.238	.157
	Nat'l Mkt.-Large Plant	.204	.107
	Nat'l Mkt.-Small Plant	.191	.176

TABLE 1A -- EMPLOYMENT IN N.Y.M.R.S. CATEGORIES OF MANUFACTURING ACTIVITY
CITY OF BOSTON VS. BALANCE OF REGION -- 1947-1957

Manufacturing Category	Share of Local Activity 1957 Boston	Bal. Region	Boston Change in Share of Region Factor	Regional Growth Factor	Boston Growth Factor **
Communication-Oriented	27.4 %	9.7 %	0.864	1.137	0.982
Nuisance & Water-Transport	7.3	6.8	1.058	0.998	1.058
Raw Material Oriented	0.05	0.4	1.259	1.238	1.567
Local Market - Consumer	12.9	5.1	0.805	0.944	0.760
Local Market - Intermediate	4.6	6.4	0.659	0.888	0.586
National Market - Large Plant	13.3	29.2	0.525	1.550	0.813
National Market - Small Plant	34.4	42.4	0.921	0.810	0.747
ALL MANUFACTURING	99.95	100.0	0.819	1.001	0.819

** Boston Growth Factor = Boston 1957 employment / Boston 1947 employment =

[Change-in-share Factor
X Regional Growth   =   [Boston 1957 share of region x Regional 1957 employment]
       Factor]   ――
                            [Boston 1947 share of region x Regional 1947 employment]

- 22A -

employment by nearly 55%, while the small plant group fell in regional employment by 19%. It was assumed that the allocation of industries at the 3- and 4-digit levels in our region to the eight NYMRS groups would follow the New York pattern. Only an exhaustive and detailed examination into the make-up and conditions of manufacturing firms in the Boston area could confirm the general validity of this assumption - and, doubtless, exceptions would be found. Further, once the composition of the groups were correctly determined, the behavior of the groups could not be assumed to be the same in Boston as in New York. Nevertheless, the striking similarities we find on the broad level confirm the soundness of the NYMRS analysis and recommend its approach - something it is well to remember should the more mechanical but less laborious techniques turn out to be inadequate.

We continued the exploration of the NYMRS groups, within the limitations of the data, by identifying those 2-digit industries all or nearly all of whose employment is classified in a single NYMRS group (or in two related groups). Table 2 illustrates the results. The Route 128 zone shows gains in share for all the industries sampled, but the highest gain occurred in SIC 36, falling in the national market - large plant group. (The zones are shown in Map 1.) The Core zone share of all the industries declined, but again most heavily in the industry belonging to the "national market - large plant" group.

TABLE 2

COMPARISON OF EMPLOYMENT GROWTH UNDER
VARIOUS N.Y.M.R.S. CATEGORIES

Category	Core		Route 128		Downtown Boston	
	1950 Share	1959 Share	1950 Share	1959 Share	1947 Share	1957 Share
27 (Communication- Oriented)	.752	.688	.100	.145	.372	.290
24 (Local Market)	.457	.317	.074	.110	.021	.027
25,31 (Nat'l Mkt. - Small Plant)	.302	.258	.157	.183	.044	.026
36 (Nat'l Mkt. - Large Plant)	.437	.261	.197	.404	.042	.019
21,35,38 (Nat'l Mkt. - Mixed)	.489	.392	.222	.284	.029	.011
All Manufacturing	.473	.406	.128	.214	.083	.062

E. Population

In order to discover whether there was any simple re-
lationship between the distribution of population growth and
changes in industrial employment, and to test the strength of
such a relationship as a predictor, we hypothesized several
forms it might take:

> If $h(t)$ is a zonal household population at time t;
> $H(t)$ is household population for the region at time t;
> $e(t)$ is a zonal employment at time t; and if
> $E(t)$ is industrial employment for the region at time
> t, then we can assign future zonal employments
> in at least three ways:

(1) $e(1960) - e(1950) = K[h(1960)-h(1950)]$
     (simple increment relation)

(2) $\dfrac{e(1960)}{e(1950)} = K \dfrac{h(1960)}{h(1950)}$
     (ratio growth relation)

(3) $\dfrac{e(1960)}{E(1960} - \dfrac{e(1950)}{E(1950} = K \dfrac{[h(1960)}{H(1960)} - \dfrac{h(1950)]}{H(1950)]}$
     (share increment relation)

The constants are to be uniform among zones. By the
requirement that the zonal employments assigned for 1960 must sum
to the given regional total for 1960, the constants under the
first two rules are specified. The constant under the third rule
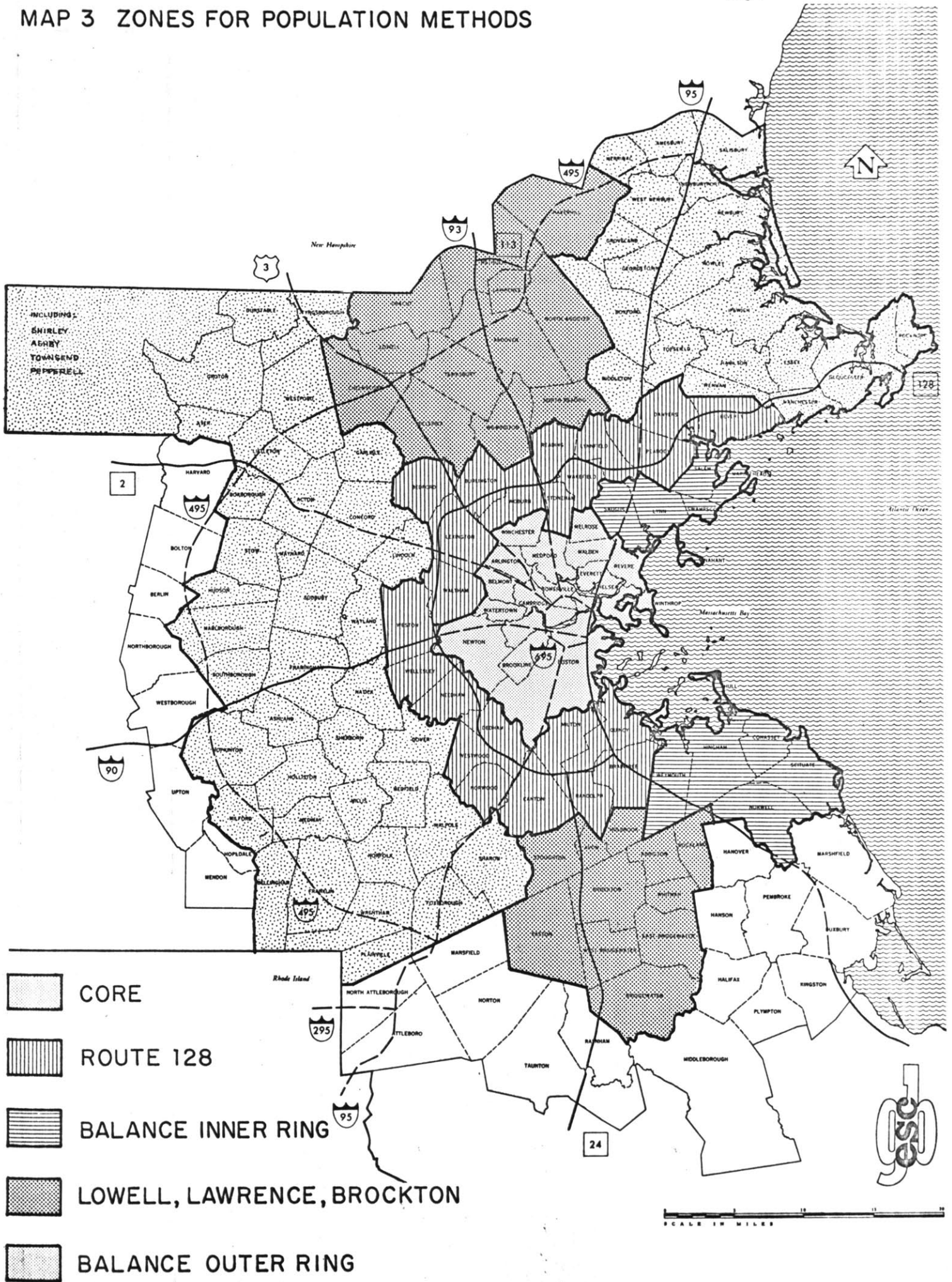is free to vary, but here we took $K = 1$.*

The difficulty with these methods (applied to the zones
shown on Map 3) is that they require a knowledge of the popula-
tion movements concurrent with the employment changes - which com-
pounds the uncertainties and really serves to shift the predic-
tion problem. This is an advantage if population prediction
methods are felt to be more reliable and do not require a knowledge
of changes in manufacturing employment. Such was the case under

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*However, whatever positive value is chosen, this rule could, in
some cases, assign a negative future share of employment to a
zone.

MAP 3 ZONES FOR POPULATION METHODS

26.

New Hampshire

INCLUDING:
SHIRLEY
ASHBY
TOWNSEND
PEPPERELL

Rhode Island

Atlantic Ocean

Massachusetts Bay

CORE

ROUTE 128

BALANCE INNER RING

LOWELL, LAWRENCE, BROCKTON

BALANCE OUTER RING

SCALE IN MILES

the Chicago Area Transportation Study.

F. Cumulative Distribution

The method finally arrived upon to forecast the dis-
tribution of manufacturing employment in the Chicago study was
the assumption of a simple relationship linking it to the popula-
tion distribution. Radial distance to the regional CBD was the
organizing concept. The present relationship between the cumula-
tive distribution of population and the cumulative distribution
of manufacturing employment at varying radial distances from the
Loop was assumed to remain constant in the future (apart from
some minor smoothing of irregularities which cannot be incorpor-
ated into a 10-year prediction). (11, p. 124)

In adapting the method, we employed a travel time scale
rather than straight-line distance in delineating successive zones
about the center - in the belief that travel time gives a more
sensitive reading of central influence. These time-distance zones
are shown in Map 4. They are based upon the values determined
by the Boston College study (8) to represent average off-peak
driving times from towns or small groups of towns to downtown
Boston. The City of Boston takes in a considerable range of driving
times, but our data required cities and towns to be assigned as
integral units. Figure 1 shows the relationship between cumulative
household population and cumulative manufacturing employment. The
45-degree line represents the curve of a hypothetical situation in
which both quantities are identically concentrated about the center.

MAP 4   ZONES FOR CUMULATIVE DISTRIBUTION METHOD

Legend:
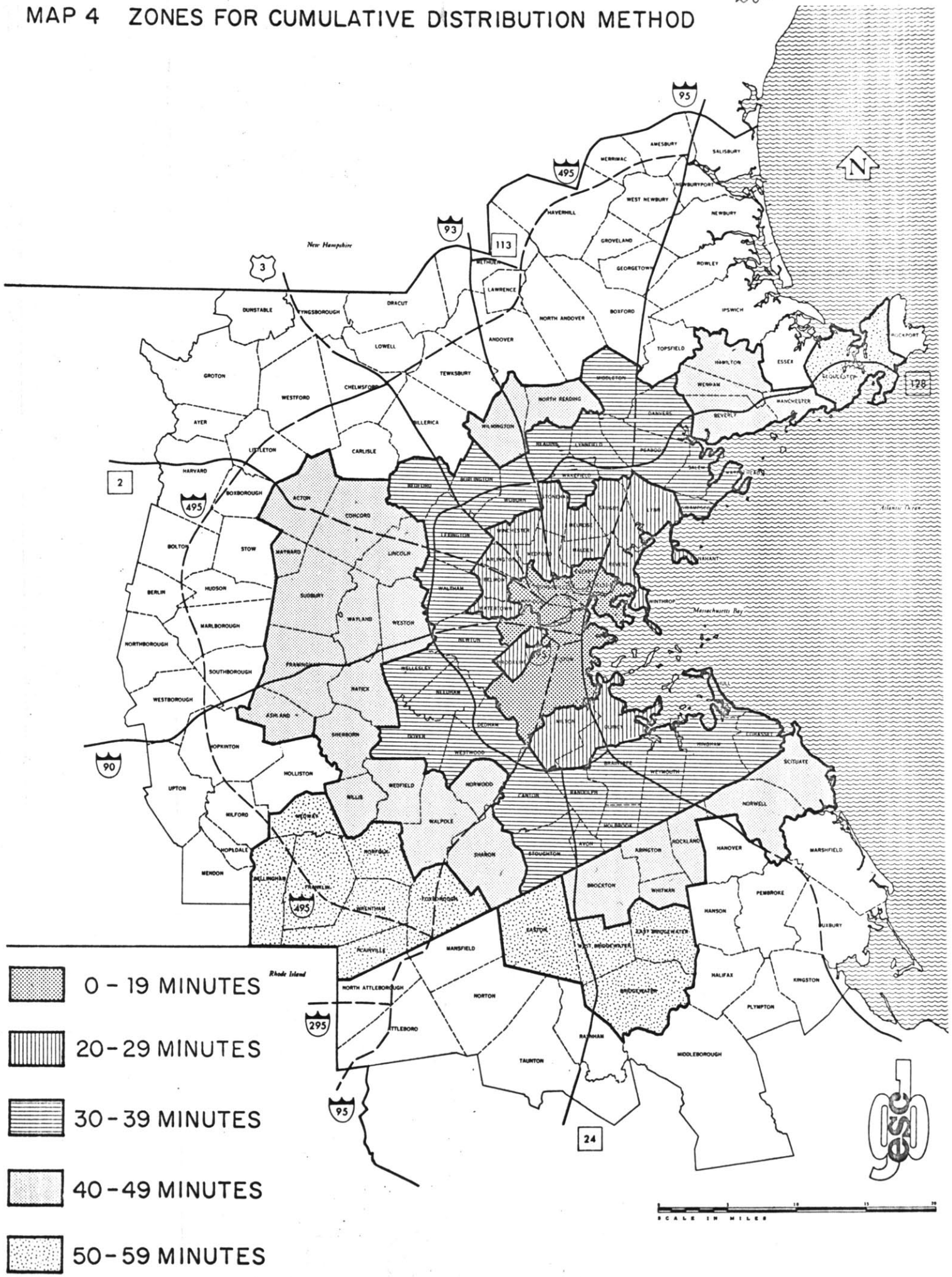
- 0 – 19 MINUTES
- 20 – 29 MINUTES
- 30 – 39 MINUTES
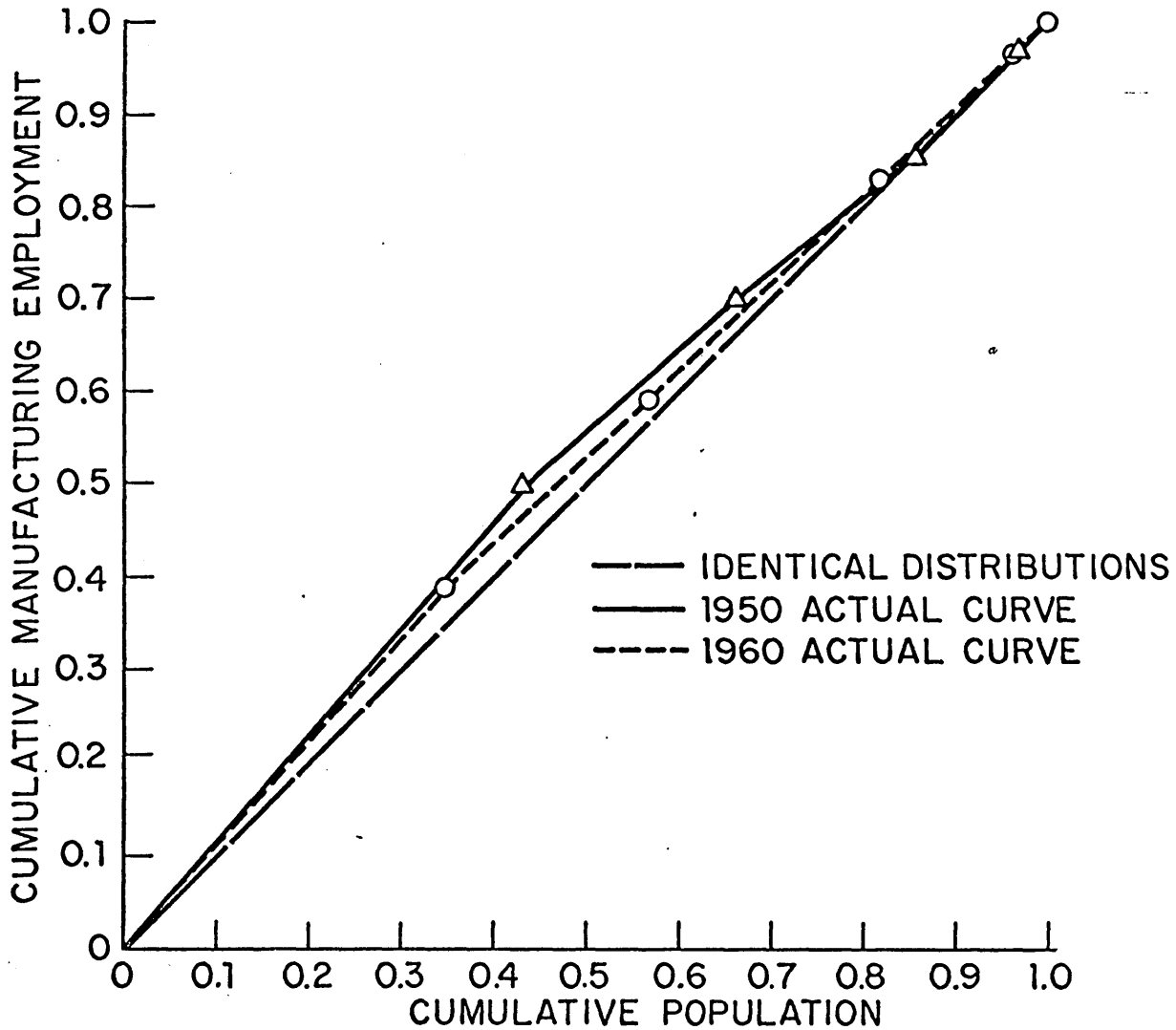- 40 – 49 MINUTES
- 50 – 59 MINUTES

SCALE IN MILES

FIGURE 1   CUMULATIVE MANUFACTURING EMPLOYMENT VS. CUMULATIVE
POPULATION - 1950 & 1960 FOR MAP 4 BOSTON REGION

The points along the curves showing the actual relationship in
1950 and again in 1960 correspond to the values found at the boun-
daries of the five time-distance zones - theoretically, to 19, 29,
39, 49, and 59 minutes. The vertical distance between the points
on the 1960 curve and the 1950 curve shows exactly the difference
between the actual cumulative employment at that point and the
cumulative employment assigned by reference to the 1950 relation-
ship. Over the decade, the region analyzed moved toward a more
identical distribution.

G - Growth Potential

In the Baltimore-Washington study, Voorhees and his as-
sociates used the following equation to allocate a predicted re-
gional total of growth in manufacturing employment (1, pp. 32ff):

$$G = K (C \times A)$$

where G is the zonal share of the forecast regional increase in
manufacturing employment; C is "available manufacturing employment
capacity" in the zone, or the product of the amount of land des-
tined to enter industrial use ultimately and the assumed future
worker density for the zone; A is the zone's accessibility poten-
tial to population in the region; and K is a variable assigned
to each zone to represent "'other' growth factors", where

$$A_i = \sum_j \frac{P_j}{d_{ij}{}^n}$$

That is, the accessibility potential to population for zone i is

defined as the sum of the populations in all zones in the region

weighted respectively by their travel time to zone i raised to

some (possibly variable) exponent, n, conveniently defined if one

has a companion transportation study on hand (involving the fitting

of a gravity model to work-trip data for the same region). The

variable K-factor, as it stands, represents the failure of the

defined parameters to arrive at correct predictions. Yet the

possibility of zero and negative values of the K-factor is required

to obtain even tolerable fit.

We "operationalized" the model by eliminating any vari-

able K-factor or reference to "ultimate" land use. We used all

vacant, buildable land (as defined by the G.B.E.S.C., based on

slope and drainage) and, as an alternative, all vacant, buildable

land zoned for industry (irrespective of restrictions) to measure

C, zonal available capacity. It turned out to be impossible to

reconstruct the pattern of zoning in 1950 for the Boston area,

and, in the end, 1960 zoning had to serve in its stead. In search-

ing for densities at which to assign new industrial development

taking place between 1950 and 1960, the conviction grew that there

was no systematic relationship between the location of new indus-

trial development and its worker density. Differences are the

result of type of operation. However, the mix of industrial growth

has no place in the model. Household population and residents

employed in manufacturing industries were alternatively applied

in determining zonal accessibilities, while the travel times we

employed were those of the Boston College study.[6]

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[6] See (8), Vol. II, pp. 41-45 for an account of how these times
were determined.

These travel times refer to the end of the prediction period, which the Baltimore-Washington study specifies. Exponents on travel time of 0.5, 1.0, 2.0, 2.5, and 3.5 were tried. Vacant, buildable land in 1950 had to be estimated from the known amount in 1960. The method used was to apply to the intervening population growth a density equivalent to 1960 developed land per unit 1960 household population. Finally, the problem as just described was run on a computer for the fifteen zones shown on Map 5, yielding twenty sets of predictions.

III. Results

For each of the twenty sets of growth predictions for fifteen zones that were generated by the growth potential method, using all possible combinations of parameters, the coefficient of linear correlation with the set of actual zonal employment growths was determined (Table 3). All versions of the method involving vacant land zoned for industry in 1960 yielded small, negative correlations. In every case, higher values of the travel time exponent yielded improved correlations - throughout the range of values sampled. 3.5 was found to be the best-fit exponent for distributing work trips in the Boston College study. The study included allowance for terminal time, while we used raw travel times. 3.5 stands out as a higher value than is usually found to be the "best-fit" for data applying to the present. The correlations indicated that no important difference in accuracy of

MAP 5   ZONES FOR GROWTH POTENTIAL METHOD
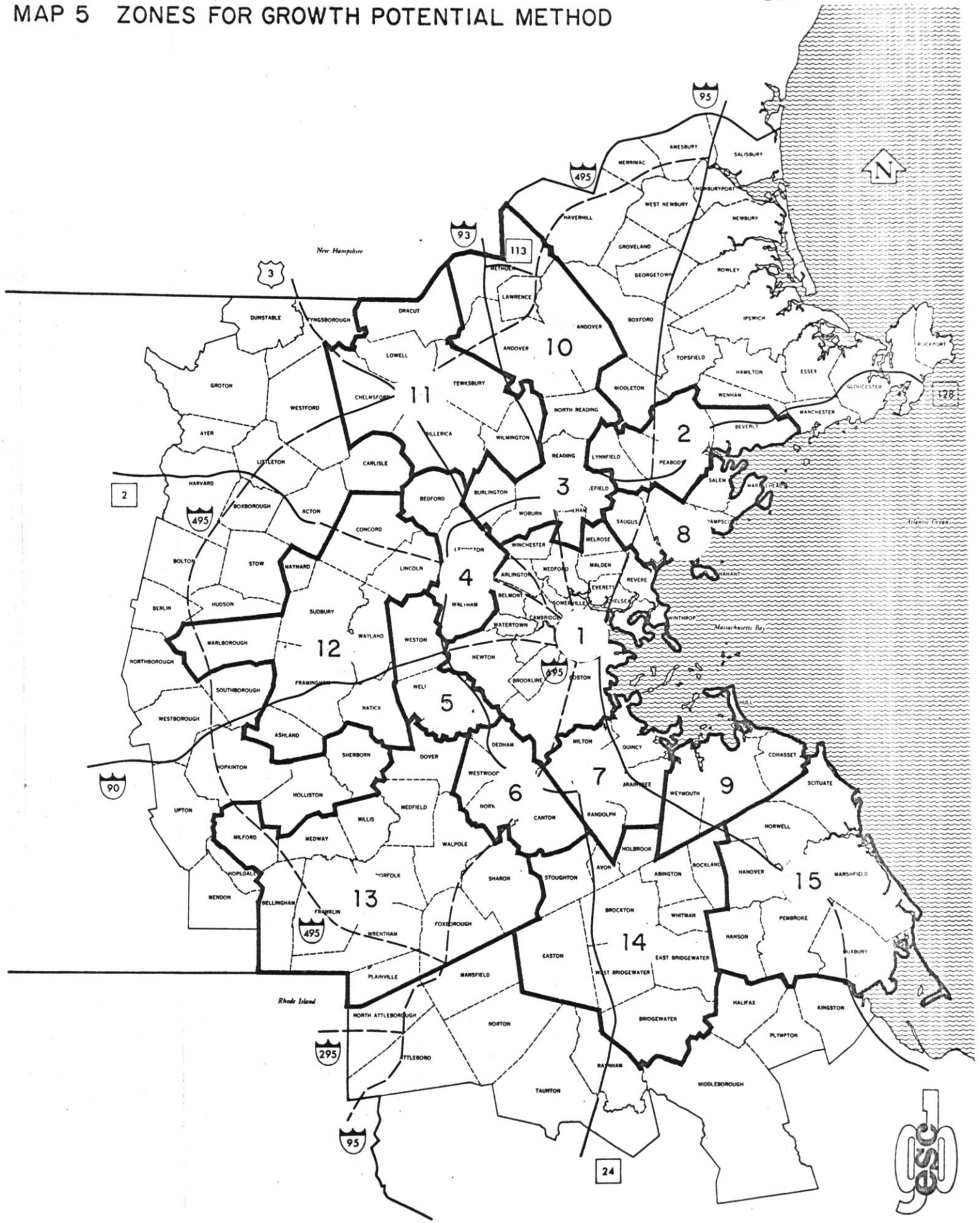
TABLE 3

LINEAR CORRELATION BETWEEN ACTUAL ZONAL GROWTH
AND ZONAL GROWTH ASSIGNED UNDER
GROWTH POTENTIAL METHODS
(15 ZONES)

P	C	n	r
H	Vacant	0.5	.12
"	"	1.0	.15
"	"	2.0	.22
"	"	2.5	.27
"	"	3.5	.39
RMW	Vacant	0.5	.12
"	"	1.0	.15
"	"	2.0	.21
"	"	2.5	.26
"	"	3.5	.35
H	Zoned	0.5	-.14
"	"	1.0	-.14
"	"	2.0	-.13
"	"	2.5	-.12
"	"	3.5	-.06
RMW	Zoned	0.5	-.14
"	"	1.0	-.14
"	"	2.0	-.14
"	"	2.5	-.13
"	"	3.5	-.08
Constant	Shares		-.87

(See Note on Following Page)

Note for Table 3

The series of zonal growths under the constant share method were presented for contrast. The high negative correlation observed arises from consideration that, under constant shares, zonal growth is proportional to zonal employment in 1950, while, for the set of fifteen zones we defined (Map 5), more or less the inverse happened to apply. The Core is the largest zone, while the Route 128 area was finely divided.

prediction resulted from using resident manufacturing workers
in place of household population. Viewed as a sampling from a
population of actual growths in industrial employment and the cor-
responding populations of assignments under the twenty related
methods, the results in no case justified rejection of the hy-
pothesis that the "true" correlation between the population of
actual growths and any of the assignment populations here sampled
is zero. Further, the difference between the two most extreme
values among the methods does not warrant rejection of the hy-
pothesis that their "true" correlations with actual zonal growth
are the same. However, the sample size (fifteen zones) has much
to do with these results.

The highest correlation attained was +.39, using zonal
vacant, buildable land, accessibility to household population, and
a travel-time exponent of 3.5. The 1960 zonal employments corres-
ponding to this choice of variables, summed into five zones: Core
(zone 1), Route 128 (zones 2 through 7), Balance Inner Ring (zones
8 and 9), Lawrence-Lowell-Brockton (zones 10, 11, and 14), and
Balance Outer Ring (zones 12, 13, and 15), were taken as the final
prediction under the growth potential model. What stands out is
the "functional failure" of the method, because it is unable to
predict a decline in zonal employment without resorting to non-
systematic adjustment for "other growth factors."[7] It would appear

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[7] In an effort to overcome this problem, predicted growth under
the best version of the growth potential methods was "adjusted"
to the corresponding values of the linear regression line be-
tween these predicted and the actual growths for the five sum-
mary zones. The results of this "adjustment" can only be ex-
amined for the remaining discrepancies with the actual 1960
zonal employments.

to be a better predictor of "new physical growth" - of new employ-
ment resulting from construction of industrial plant on vacant
land.

The chi-square statistic was determined for the assign-
ments made under all the methods considered (Table 4). The assigned
distributions of 1960 zonal employments were compared with the ac-
tual distribution among the zones in the same year.[8]

The average error of estimate, derived for each assigned
distribution from its chi-square value and the total employment
distributed, represents a percentage discrepancy expressed in ab-
solute terms between assigned and actual zonal employment which,
if it had characterized the estimate of employment for every zone,
would have produced the same value of chi-square as was observed.
The percentage errors of estimate actually observed in the Core
and Route 128 (or comparable) zones were also determined.

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[8] The year was 1959 for "expected growth" and share-trending
methods.

TABLE 4

EVALUATION OF ASSIGNMENTS OF FUTURE

MANUFACTURING EMPLOYMENT TO FIVE

SUB-AREAS OF THE BOSTON REGION

Method	Chi-Square (4 df)	Average Error of Estimate	Route 128 Error of Estimate	Core Error of Estimate
"EXPECTED GROWTH"				
Constant Shares	23,661	24%	-40%	17%
Density Classes	27,955	26%	-41%	21%
Regional Growth Classes	27,896	26%	-35%	24%
SHARE-TRENDING				
Constant Shares	20,680	22%	-38%	16%
Linear Trend	10,491	16%	-10%	13%
"Compound Interest"	8,434	14%	-0.9%	10%
POPULATION METHODS				
Constant Shares	22,379	23%	-42%	17%
Simple Increment	20,978	23%	-41%	16%
Ratio Growth	12,250	17%	-29%	-0.2%
Share Increment	10,527	16%	-26%	-1.45%
CUMULATIVE DISTRIBUTION				
Constant Shares	20,810	25%	-34%	28%
Cumulative Distribution	3,389	10%	-17%	3%
GROWTH POTENTIAL				
Constant Shares	24,138	25%	-41%	18%
"Best of 20"	20,679	23%	-39%	16%
Adjusted "Best of 20"	5,326	12%	- 9%	0.4%

Note for Table 4

The errors of estimate given in the table for each method under Route 128 and Core refer to the error made in the zones most nearly equivalent to the Route 128 and Core zones as delimited under the "expected growth" and population methods (which are identical in this respect). In particular, Balance Inner Ring represents the Route 128 zone under the share-trending methods while, under the cumulative distribution method, the 30-39 minute zone represents Route 128 and 0-19 minutes represents the Core.

IV. CONCLUSION

A number of approaches to forecasting the intra-metropol-
itan distribution of industrial employment have been examined
through application to recent changes in the Boston area.

None of the assignment methods as formulated and applied
to the present data and to estimates made from it could cope with
the actual movements in the setting studied within acceptable tol-
erances of error.

The assignment methods considered: present zonal shares
of employment, simple trends of zonal employment over time, re-
lationships between zonal employment and zonal population growth,
changes in the cumulative distribution of population about the
regional CBD, and zonal potential for industrial growth in terms
of available land and population or labor-force accessibility
potential. The fit of these hypothesized relationships to reality,
therefore, was found to be insufficient.

The development of improved techniques for forecasting
industrial growth among the parts of metropolitan regions can
proceed in the direction of further elaborating a fixed set of
hypotheses. We believe, however, that it can be more effectively
advanced through a deeper understanding of the processes underlying
industrial location within the metropolitan structure and the
translation of that knowledge into prediction methods.

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