Land Use Projections For Predicting Future Traffic

JOHN R. HAMBURG, Chicago Area Transportation Study,
Chicago, Illinois

● FORECAST is a fearsome word. Some soften it by referring to the process as estimation; others provide a wide range of conditions and then refrain from choosing a "best" or "most probable" condition. The very brave simply decide on the future and require no graphs or charts to bolster their choice.

Regardless of the name or process, anticipation of future events, and planning for them, is necessarily and regularly practiced by people and organizations.

There is no shortage of brave men in the field of transportation planning, but courage alone will not provide adequate forecasts of future traffic against which proposed facilities can be tested. Ideally, one should know all of the factors which are related to traffic, understand how these factors have been changing through time, and anticipate technological changes which will be significant.

The outlook for achieving the ideal is not too bright; one may never expect to know the future so precisely and must concentrate on approaches and techniques which temper boldness with caution and attempt to scale problems, set limits, and avoid gross errors that result from the extrapolation of imperfectly understood relationships.

Although knowledge of traffic is far from ideal, a strong case has been made for examining traffic in terms of land use. The order of presentation is as follows:

(a) To describe the relationships between land use and traffic which indicate that land use forecasting is a logical basis for estimating future traffic.

(b) To describe the land use survey which is essential to develop the relationships necessary for forecasting.

(c) To describe land use forecasting techniques.

LAND USE - A BASIC MEASURE OF TRAFFIC

Land use is the name given to the activity taking place on a site. There are the factories, stores, schools, homes, etc. Taken collectively, these activities or land uses form the structure of the community.

Each site is characterized by the kind of activity or land use, the intensity of use, and a location with respect to all other sites. These characteristics largely govern traffic within the community.

The kind of land use determines the kind of people or materials which will go to a specific site. Steel manufacturing sites will attract steel workers. A shopping center will generate shopping and work trips. The intensity of land use and the number of persons it will attract are also highly related. A multi-story department store will experience heavier traffic than a single story store. Dense residential neighborhoods will generate a greater number of trips per acre than will low density suburbs.

The location of a site with respect to all other sites describes the distances which must be traveled by trip makers coming from other sites. Given the transportation channels, the location of the interacting sites will also determine, to a larger degree, the volume of traffic on the streets.

If the various activities of the community are thought of as competitors for the available sites, the most desirable sites should receive the highest bid. But the higher the cost of the site, the more intensively the successful bidder must use his site, generally resulting in multi-story structures.

The most desirable sites, typically, are those which are most accessible to other sites. In a hypothetical city with flat terrain, the central point is the most accessible to all others. If movement is restricted to roadways, and these focus on the central business district, the advantage of centrality for accessibility is increased.

Peripheral sites lacking in access to all others fall at the other end of the bidding distribution and typically are developed at lower intensities which, for residential uses, means lower densities.

There are advantages in locating centrally but the costs are higher. Certain land uses, typically, seem to be able to afford these costs better than others because of a higher return from the location.

There is a balancing of advantages derived from central siting against the lower site costs but higher movement costs. The actual factors may be numerous and complicated but, most simply stated, the process is one of competition relative for centrality in sites which by definition are limited in number. This competition results in the selection of the kind of activity which can locate profitably in a given location and it determines the intensity of use at that location.

The process also has a time dimension. All of the parameters governing the siting process may be changing in accessibility which has resulted from improvements in transportation technology. The flexibility provided by the automobile has brought a tremendous number of potential sites within easy travel range of the community. This has been associated with development of low density suburbs and the so-called "scatteration" of urban activities.

Developed sites, however, are resistant to changes in accessibility and change only gradually through time. The extremes of central land use intensity found in cities like New York and Chicago have withstood the decentralizing effects of transportation advances, but their recent suburban growth is more typical of the low density developments characteristic of such cities as Detroit and Los Angeles.

In summary, forecasting future traffic is necessary to transportation planning. While there are a variety of ways which could be and have been used to forecast traffic, the most reasonable basis is a land use forecast because traffic is movement between different land uses and land use is relatively stable through time.

In approaching the problem of forecasting the future land use distribution, it is necessary to consider the interplay of the factors of kind of land use, intensity of land use, location with respect to other land uses, and the impact of possible further reduction in the friction of movement within the structure.

A complete and accurate land use inventory is necessary to measure the current distribution of land uses, the intensity of use, and to establish the relationship of traffic to the land use structure. To fulfill these requirements the classification system, unit of measurement, collection units, and identification and processing must be considered carefully.

MEASURING THE LAND USE STRUCTURE

The two basic uses of the land use survey in transportation planning are to provide data for analysis of traffic generation and to establish a base from which to estimate the future land use structure of the area. To fulfill these requirements the following factors must be considered:

1. Classification System. The land use data should have sufficient detail to distinguish between extremes in terms of traffic generation and still be suitable for forecasting purposes. A minimum classification should include residential, manufacturing, public building, public open space, commercial transportation and utilities, streets and alleys, and vacant land. Additional detail in commercial and manufacturing is desirable.
2. Scaling Land Use. Possible measures of land use are dollar sales, employment, population location and density, land area, and floor area. Of these, net acres in use is most appropriate except in the CBD and possibly some additional commercial centers, where, because of the prevalence of multi-storied structures, floor area measurements should also be collected. Land area measures are particularly significant for the vacant land where the bulk of the future growth in activities will take place.
3. Geographic Units of Collection. The land use must be collected in the same areal

unit or units which are reconciliable with the traffic analysis zones. In addition, the O-D survey should also identify the land use of trips at the origin and destination, using the same classification scheme as the land use survey, so that trips and land use may be compared directly.

4. Identification and Processing. A field inspection generally will provide the most precise identification, but can be expensive. If a field listing operation is required to obtain the O and D samples, the land use survey may be incorporated into this operation (this is being done in Pittsburgh). The Chicago survey obtained highly satisfactory data using secondary sources such as Sanborn maps, utility meter cards, telephone criss-cross directories, etc.

For those portions of the area covered by zoning ordinances, the zoning classification of vacant land should be recorded for use in estimating future potential use.

The use of punch card techniques is essential to processing and manipulating the inventoried land use excepting in smaller communities.

The use of a coordinate system of geographic coding will permit very flexible manipulation including mechanical mapping and calculation of distances.

RESULTS OF THE LAND USE SURVEY

The conception of the organizing influence of central location on kind of land use and intensity of land use can be examined empirically using the land use data collected for the Chicago Area. One would expect non-residential activities, and especially commercial land, to be concentrated in the CBD, with residential land occupying a greater proportion of all land as distance from the center increases.

The proportion of each of six land uses of all land in use—excluding vacant and public open space—by 2-mile rings from the center are shown in Figure 1.

The conception of a central core of specialized, non-residential activities is confirmed by the distribution of land use. The commercial category is heavily packed in the CBD, and declines rapidly to ten miles where it levels off at about 3.5 percent of the land.

Residential land is practically excluded from the central area but increases rapidly just outside the core to about eight miles from where it fluctuates around an average of 41 percent.

Another way of observing the distribution of land uses from the city center is shown in Figure 2. Here the land use data are presented in the form of ogives which give the cumulative percentage of distribution of land use, by distance. Fifty percent of the total land area of the Chicago Area Transportation Study falls within a radius of 19 miles and 50 percent beyond. In contrast, 90 percent of the manufacturing land, 85 percent of the commercial and transportation land, 75 percent of the residential land, 70 percent of the streets, 60 percent of the public open space, 66 percent of the public buildings, and only 26 percent of the vacant land are located within a radius of 19 miles.

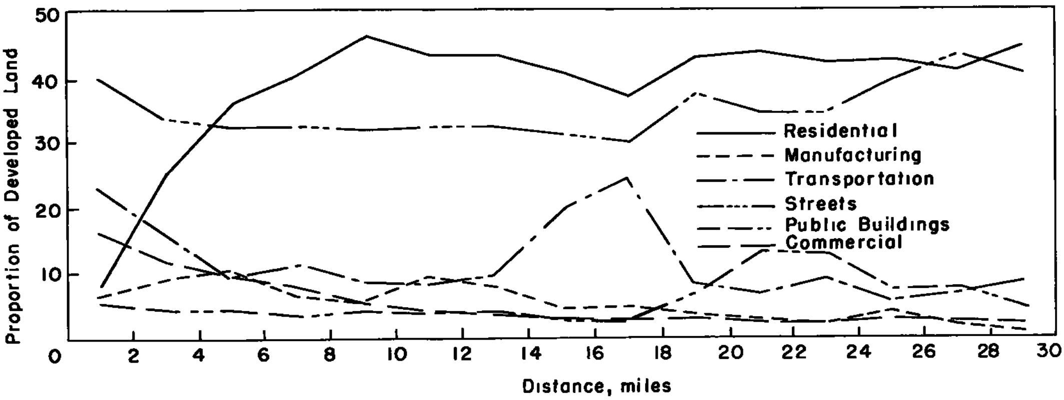

Figure 1. Land use proportions by distance from the CBD-1956.

These measures of land use proportions confirm the expected pattern of an orderly array about the city center with the non-residential uses preempting the central sites. The element of intensity of land use, however, has not been considered. Intensity is particularly important for anticipating future land use; the amount of land required by a given activity can vary significantly from place to place within the urban structure. In certain parts of Chicago a square mile of land devoted entirely to residential use will house up to 100,000 people while in other locations this figure may drop to as low as 10,000. By combining population data with the amount of residential land by

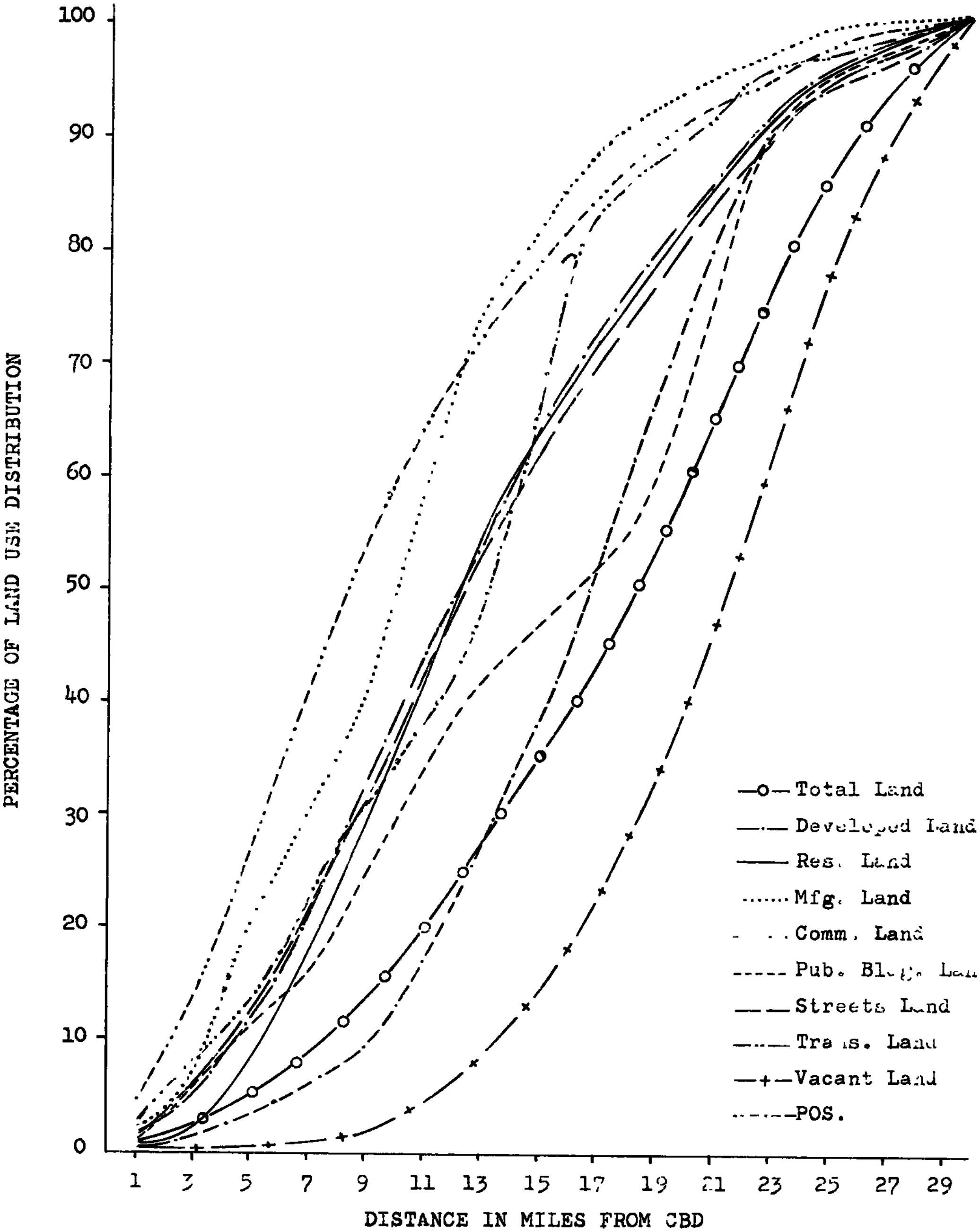

Figure 2. Cumulative percentage of distribution of land use by distance from the CBD.

successive 2-mile rings from the CBD measures of residential land use intensity are obtained (see Fig. 3). The distribution indicates that population densities decrease sharply to about nine miles from the CBD. A more gentle slope is observed from 9-18 miles with a flattening of the curve from about 18 miles continued to the edge of the survey area. The density curve exhibits striking regularity and graphically illustrates the extreme intensity of use of central land while the flattening of the curve at 18 miles to about 10,000 persons per square mile of net residential land represents about four to five dwelling units per net acre of land which is characteristic of suburban residential densities.

Figure 4 shows the gradient of industrial worker density and workers per acre of industrial land by distance rings. There is a marked similarity in the shape of this curve to the population density curve. The relationship of distance and relative intensity of land use is clearly defined and the tendency to flatten out at about 16-18 miles is present in both the worker density distribution as well as the population density distribution.

These data substantiate empirically the systematic variation of the land use distribution and land use intensity with distance from the CBD. But are these relationships a real basis for a land use forecast?

To answer this, it must be realized that distance is really a substitute measure for accessibility, and that accessibility has been changing through time.

Consider the simple example of a hypothetical city with a limited number of radial

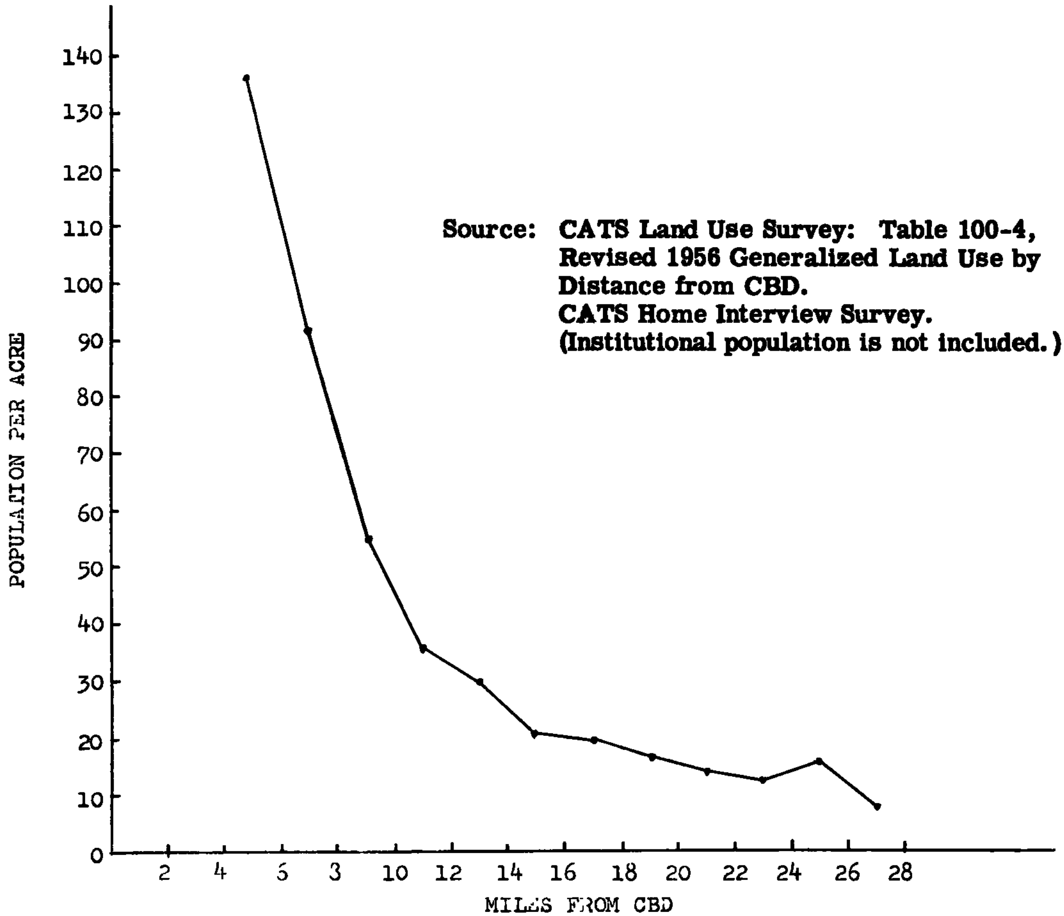

Figure 3. 1956 Chicago area population densities by 2-mile distance rings from the CBD.

transportation routes to the center with equal speed, Sr, on all sections of the routes. Consider also that non-radial movement travels at a speed So. Accessibility in terms of time to the CBD could be computed as the sum of the time required to reach the radial or the CBD plus the time traveled on the radial, if used.

$$\text{Time} = \frac{Do}{So} + \frac{Dr}{Sr}$$

Where: D = Distance
S = Speed

Assuming that the settlement pattern is a function of the time distance from the city center as the speed of travel on non radial routes approaches pedestrian speeds or slower, a stellate pattern of development would emerge. If the two speeds are equal, all other things assumed equal, a concentric ring growth shape would result.

The evidence on land use displayed a fairly smooth gradient with distance. But radial distance from the CBD averages the characteristics of developed corridors along major transportation routes with those of the largely vacant interstitial areas. The actual pattern is star shaped.

Super highways might therefore be expected to continue the star shaped pattern of settlement found in the Chicago area. Actually a system of expressways and rapid transit facilities, combined with rising rates of car ownership, could increase interstitial area accessibility relative to more distant sites, provided that feeder roads and ramps are made available.

The settlement pattern, in any case, will result partly from the very transportation facilities which are to be planned on the basis of the land use projection. The circular effect is minimized to the extent that the future facilities do not create severe sectoral distortions in accessibility at given distances from the center.

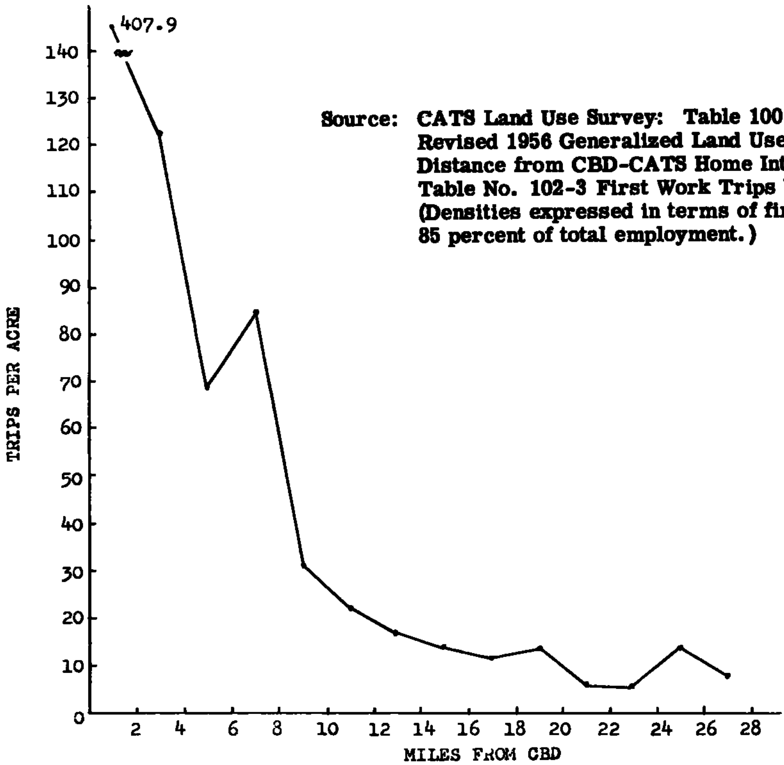

Figure 4. 1956 Chicago area manufacturing worker densities by 2-mile distance rings from the CBD.

Another difficult problem involves the effect that increases in speed of travel will have on intensity of land use. While time series data on land use are not available, the density patterns by distance are a kind of crosscut through time since the central areas are oldest and the peripheral development is most recent. These gradients have been assumed to flatten out at about 18 miles for the forecast period.

A further difficulty involves the fact that as speed of travel, or more accurately as the cost of travel declines, development may become discontinuous and developments can jump over large tracts of land. This effect is expected to be cancelled out as the skipped areas would eventually be filled in unless cost of travel approaches zero, at which time all concepts of locational advantage lose meaning.

FORECASTING THE FUTURE LAND USE

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. Most simply, upper limits to population and industrial workers are set by small areas, these areas are rated in terms of desirability, and aggregate forecasts of total population and workers are assigned to each zone.

The procedure for estimating future land use by analysis zone required the following:

1. A complete inventory of current land use by zone.
2. Estimation of the future population density and worker density by zone.
3. Plans for redevelopment projects, the CBD, and other local plans.
4. Estimation of the future use of land in each zone assuming no land to be vacant.
5. Development of population and worker holding capacities by zone. Calculation of the ratio of 1956 population to the capacity population and 1956 workers to the capacity workers by zone.
6. Estimation of aggregate population and worker increase for the study area by 1980.
7. Distribute the forecast increases in population and workers to zones on the basis of holding capacity and relative accessibility.
8. Estimation of remaining land uses by zone on basis of predicted future population.
9. Review for reasonableness.

THE CENTRAL AREA AND REDEVELOPMENT PROJECTS

Local agencies were contacted and their plans for redevelopment were obtained. A clipping file of planned shopping centers was also maintained.

The recent plan for the central area of Chicago was scaled in terms of proposed added floor area and activities, and is currently being reviewed.

SETTING FUTURE POPULATION AND WORKER DENSITIES

The 1956 inventory of land use has been described. Analysis of population density patterns indicated that there was a systematic decline in net residential density as distance or place of residence from the CBD increased. This pattern was regular enough to suggest the use of norms based on location with respect to the CBD. In order to decide which zones would be set at the norms and which zones would continue at their current density, and 582 CATS analysis zones were grouped according to the percent of current used land to total usable land. This procedure resulted in three basic groupings:

1. Zones which were over 75 percent developed in 1956 continued at the same residential density as in 1956. The majority of these high developed zones (256) were in the city of Chicago.
2. For zones which were between 75 percent and 50 percent developed, a normative density was estimated by using the appropriate sector regression curve of density on distance. This estimated density was compared to the current density and if there was less than ten percent difference, the existing density was continued. Careful inspection

of the aerial photography and existing development were the basic references for setting the future densities for the remaining zones.

3. For the 90 zones which had less than 10 percent of their land developed, the sector distance norms were used to estimate future densities. In the main, these zones had densities which varied between 8 and 10,000 persons to the square mile of residential land.

The estimation of the future worker densities by zone was less precise than the estimation of the population densities. The regular declines which have already been examined served as the base for the estimation of future worker densities.

The bulk of all future industrial expansion is expected to fall beyond a radius of nine miles from the CBD. Worker densities for zones between 9 and 12 miles were set at 29 workers per net acre of manufacturing land. For zones between 12 and 18 miles, densities were set at 20 workers to the acre and for zones beyond 18 miles, the density assumed was 17.5 workers to the acre.

DESIGNATION OF LAND USE

With future densities estimated, the question of the rate of utilization land use for population and workers is resolved. Next, the problem of how much land is available for different activities by zone must be answered. It was assumed that currently developed land would continue in that use until the target year 1980, except for planned redevelopment projects, the CBD, and committed demolitions for highway construction. Zoning regulations were used to divide vacant land into residential, industrial, and commercial.

Additions to the major park system were estimated after contacting the Forest Preserve officials and reviewing the current ratios of open space and population in the study area. This land was subtracted from vacant zoned residential land by zone.

Records of industrial land on the market but not currently zoned for industrial land are maintained by the Commonwealth Edison Company. These sites were obtained, reviewed and in some cases added to vacant industrial land and then subtracted from vacant residentially zoned land.

Street area was considered constant for zones with less than ten percent of their total area vacant in 1956. For zones having a large amount of vacant unplatted land, streets were added at a variable rate according to the distance from the CBD.

Potential increase in public building land was obtained by multiplying the vacant residentially zoned land by .06, which amount was deducted from vacant residential.

Commercial land was obtained by multiplying the remaining vacant residential land by the estimated future residential density to obtain the additional population which could be absorbed by the zone. This population was added to the current population to obtain the zone's population holding capacity. If the sum of the current commercial and zoned commercial land fell below the ratio of two acres per thousand population, the commercial acreage was increased to meet this minimum and the residential area adjusted accordingly.

Vacant residential land is thus a residual of the above operations. These operations resulted in estimates of potential land by land use type and permitted the calculation of population and manufacturing-worker capacities by zone.

CATS AREA POPULATION CAPACITY

Population holding capacity by zone is obtained by multiplying the designated residential land by the estimated residential density for each zone and adding this to current population. On the basis of these calculations, if all of the vacant land in the CATS Study Area were developed, the area could accommodate about 9,200,000 persons. The 1956 population was 5,200,000 or 57 percent of the capacity.

Figure 5 illustrates the distribution of "percent population capacity" by 2-mile rings from the CBD. The percent of population capacity declines shartly from nine to 19 miles and then less rapidly to ten percent at 29 miles distance from the CBD.

Figure 6 shows the comparable gradient for manufacturing workers. Here again the sharp decline with a flattening at the edges of the study is apparent.

Both of these distributions illustrate the tremendous organizing impact of the central area on the distribution of population and workers and hence, the development of land. While there are sectoral effects present, these are thought simply to be the distortions of a purely concentric ring growth based on equal distances instead of equal times. If adequate measures of the friction of travel during the time these sectors were experiencing their heavy growth were available, sectoral variations might be largely explained.

FORECAST OF 1980 POPULATION AND WORKERS

For the CATS study area, the 1980 population estimate was 7,752,000. This would be an increase of about 48 percent and is well within the estimated population capacity of the area (see Table 1). The 1980 estimated population amounts to 84 percent of the estimated capacity which leaves room for about 1.5 million persons or about 16 percent of the area's holding capacity.

The forecast of manufacturing workers was obtained from an economic analysis using an "input-output" technique. The 1980 forecast of manufacturing workers was 1,098,000 as compared to 857, 000 in 1956. This is an increase of 28 percent compared to a 48 percent increase in population (over-all increase in employment was 52 percent). The lower rate for manufacturing results from a relatively greater increase in productivity (1). The relation to capacity is shown in Table 1, which indicates that on aggregate basis, there is ample manufacturing land in the study area.

POPULATION AND WORKER DISTRIBUTION

The spatial distribution of 1956 percent of population capacity displayed a distinct pattern of gradual build up to a peak of 96 percent at seven miles with a sharp decline

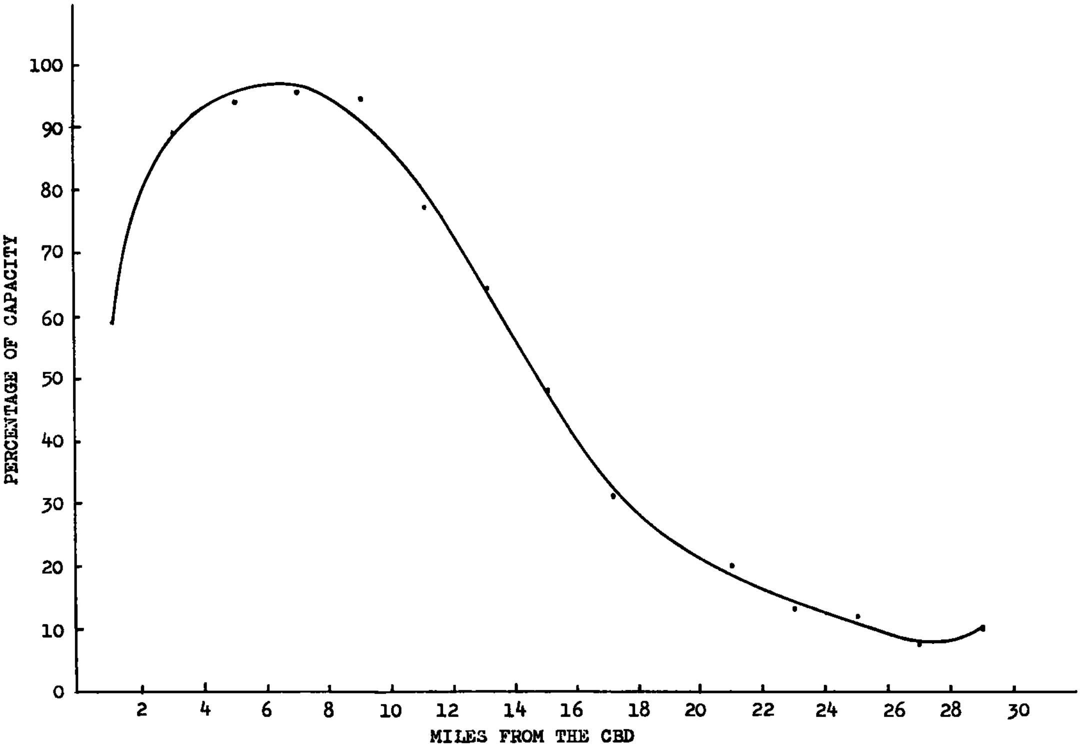

Figure 5. Percentage of population capacity by distance from the CBD-1956.

TABLE 1
COMPARISON OF 1956, 1980, AND CAPACITY POPULATION

Year	Population	Percent Capacity	Mfg Workers	Percent Capacity
1956	5,201,000	57	857	54.9
1980	7,752,000	84	1,098	70.4
Capacity	9,188,000	100	1,560	100.0

to 19 miles and then a gradual decline to the edge of the study area. Analysis of trends for the city of Chicago based on census tract data revealed much the same pattern. Successive time cuts show that the ring with the highest percent population capacity to be moving slowly outward and the inner rings, which were previous highs, to be declining.

The procedure for estimating the 1980 distribution of percent of population capacity by distance ring from the CBD centered on estimating (a) the 1980 peak, (b) the amount of decline for the rings closer to the CBD and (c) the slope of the curve from the peak to the edge of the study area. The curve resulting from these components must also satisfy the aggregate population estimate for the target year.

The 1980 peak population capacity was set at 11 miles from the CBD which represents a rate of movement of 1.6 miles per decade. This is the approximate rate of movement which was experienced from 1920 to 1956.

Very slight decreases were forecast for rings within ten miles with the exception of a 0-2 mile ring.

For distance rings beyond the 10-12 mile ring, a semi-logarithmitic relation between

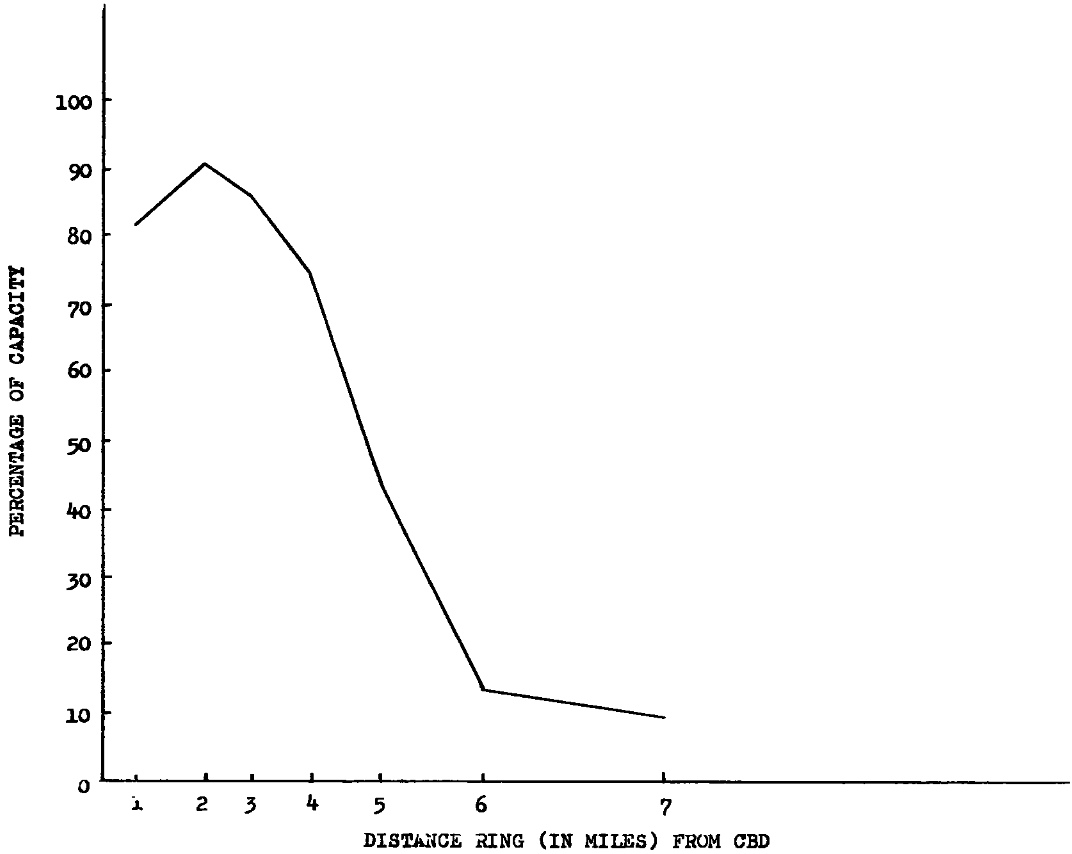

Figure 6. Percentage of manufacturing worker capacity by distance ring from the CBD-1956.

distance and percent capacity was assumed and the slope adjusted so that the over-all shape of curve of percent population capacity for 1980 resulted in a total area population of 7,752,000 persons. The resulting distribution by distance is shown in Figure 7.

Within this major control of distance on the distribution of future 1980 population, sector and then zonal estimates were made on the basis of the present capacity, the proximity of each zone to an expressway and/or to an incorporated area which could provide needed services. The results were then mapped and reviewed on the basis of reasonableness.

Over all, the population forecast recognizes a tendency for close in areas to develop sooner than more distant areas. At the same time, on a small area basis, individual variations reflecting transportation facilities and past trends are allowed. Within the limits of present knowledge, this appears to be a most reasonable estimate of the future population distribution.

MANUFACTURING WORKER DISTRIBUTION

The manufacturing worker distribution procedure parallels the distribution of population in many respects. An over-all estimate of future manufacturing workers was obtained, the land available for future industrial growth was inventoried and reviewed, the present distribution including worker densities was examined, and finally, a successive distribution of growth by major geographic units, down to traffic analysis zones, was prepared.

ZONAL ESTIMATION OF LAND USE FOR 1980

With the zonal estimates of manufacturing workers and resident population and their respective densities, the amount of land devoted to residential and manufacturing

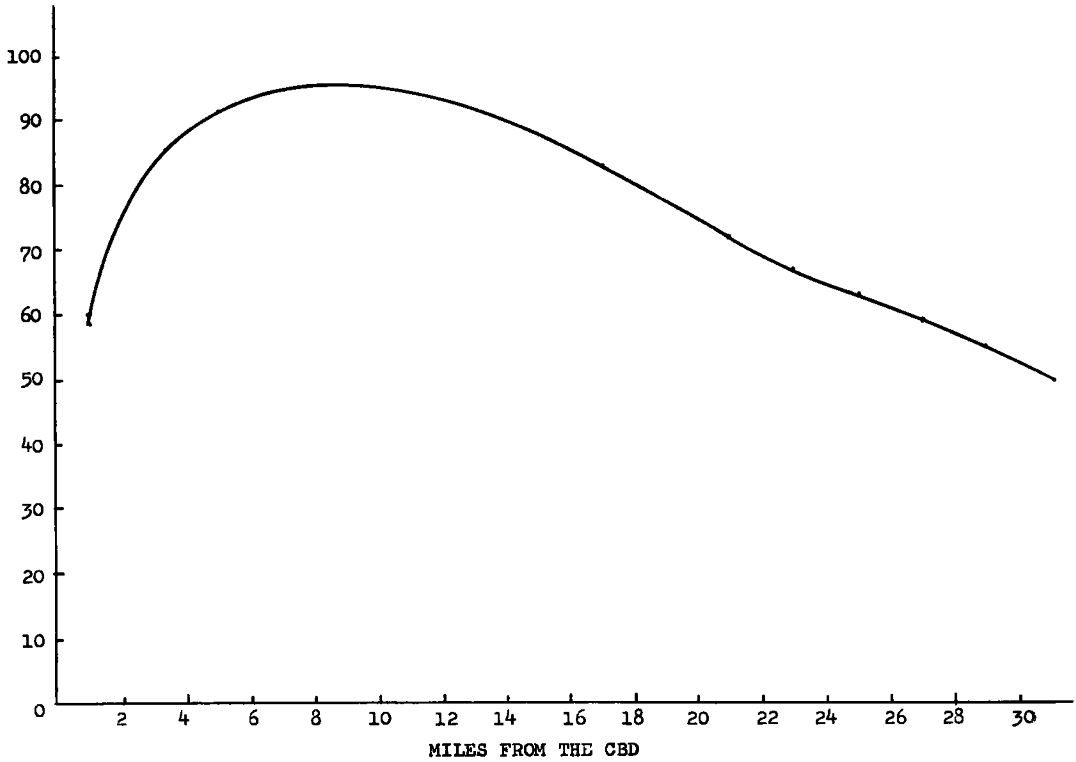

Figure 7. Estimated percentage of population capacity by distance from the CBD-1980.

activities is set. The exact amount of the remaining land uses has still to be estimated although the "capacity" has been designated.

For commercial, and public building uses, the amount estimated to be in use as of 1980 derived population and residential land norms. Planned regional shopping centers can be inserted into the forecast.

CONVERSION TO TRAFFIC

The land use projection provides estimates of the amount and kind of land use in each traffic analysis zone for the forecast year. The land use has been tied directly to forecasts of workers and population so that the estimation of residential and manufacturing destinations is a relatively easy conversion.

The calculation of trips to commercial and public buildings employs the generation rates of these land uses as measured by the 1956 surveys of land use and traffic.

By estimating the total traffic which the forecast population would be expected to make and estimating the distribution of that traffic by land use of destination, excellent checks are available for reviewing the traffic estimates made directly from the land use.

SUMMARY

The estimation of future land use by geographic location is a prerequisite to planning future transportation facilities because traffic results from the interaction of spatially separate specialized land uses.

A detailed land use survey provides the basic data from which current patterns emerge and also gives measures of the location of present vacant land and current zoning.

Analysis of the present distribution of activities and intensity of land use reveals a pattern which is heavily organized around the CBD.

Land use holding capacities can be estimated by setting the future land use intensity by zone and multiplying by the probable amount of land that could be in that use if all land in a zone were used.

A population forecast and an economic forecasting model are used to obtain the future aggregate population and manufacturing workers. Knowing the holding capacity of each zone, and the aggregate number of persons estimated to be living in the area by 1980, the zonal forecast becomes a distributional problem. Modification of the current pattern of percent population capacity on a distance gradient provides basic controls within which reasonable sectoral variations can be continued. The future manufacturing workers can be distributed in an analogous way.

Land to serve the population and workers is reserved on a normative basis. The entire land use pattern is then reviewed to insure that a reasonable pattern has resulted.

With future land estimated, the number of trip destinations to any zone can be estimated by using traffic generation rates by land use type and the amount of land for the corresponding use. An independent estimate of the total trips which the future population would make can be made and compared to the estimate based on land use and traffic generation.

The kind of forecasting procedure herein described should not be confused with a typical "master plan." While known planning projects have been incorporated, the forecast represents an attempt to anticipate the pattern of future land use if current trends are continued. It is an attempt to scale the dimensions of future land use rather than to say what future land use "ought" to be.

The projections should be considered as a basic framework within which detailed local land use plans and exceptions—where local considerations indicate deviations are in order—should be worked out.

Some of the areas in which further research should be very rewarding would be in developing better measures of accessibility, land use classifications and, most important, review and reformulation of theory relative to the spatial characteristics of growth of population and non-residential activities in regions.

In spite of the many shortcomings, land use projections should provide a basis for integrating land use planning and transportation planning which should result in a more nearly balanced relation between urban growth and construction of transportation facilities.

REFERENCE

1. Hoch, Irving, "Forecasting Economic Activity for the Chicago Region." HRB, (1959).