An Evaluation of Land-Use and Dwelling-Unit Data Derived from Aerial Photography

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• A TRAFFIC STUDY of the Fox River Valley region in Illinois has recently been completed by the Urban Research Section of the Illinois Division of Highways. This study had several experimental aspects. Among these was a test of the use of aerial photography as a principal source of land-use and population data. This paper describes the results of this test.

Aerial photography was used because of the lack of other source material, especially for land-use data. This is typical of low-density areas such as the Fox River Valley. Extensive accuracy checks were made, not only to guarantee accuracy for this particular study, but also to establish the reliability of the method for general application. The results of the checks indicate that aerial photographic interpretation is a feasible method for areas of this kind, and possibly for more heavily urbanized areas as well.

The primary objective of the Fox River Valley Study was to develop and test a synthetic approach toward obtaining O-D data, which have heretofore been obtained from expensive and time-consuming home interview surveys. Traffic movements between zones on a road network were simulated by means of a mathematical model. Predicted zonal interchanges were then checked against O-D information collected in a screenline survey of the roadside interview type. (The results of this check will be reported in another paper by the Urban Research Station.) A primary input of the model was the estimated number of trip ends generated by each zone. The trip ends were estimated from the data obtained from aerial photography. The specific kinds of data collected for this purpose were the number of dwelling units, and land area and nonresidential building floor area classified by land-use type. Research conducted by CATS has shown residential trip generation to be related to dwelling units, when other variables are taken into account. (The relationship of residential trips per dwelling unit to net residential density and to car ownership is shown in Figures 33 and 34, (1).) Floor area has been found to be a much better indicator of nonresidential trips than land area because it more closely reflects the amount of trip-generating activity.

This is probably the first time that aerial photography has been used to collect such a comprehensive array of information. There has been considerable use of aerial photography in planning surveys, particularly to collect land area data. However, there has been little use of aerial photography to collect dwelling unit and floor area data. Furthermore, the reliability of data obtained from aerial photographic interpretation had previously been untested.

This paper briefly describes the study area the data collected from photography and the methods of collection, and the checking procedures. It also includes the results of the accuracy checks, estimates of aerial survey costs, and some tentative conclusions.

SURVEY AREA

The Fox River Valley survey area is approximately 200 sq mi in size and contains a population of about 205,000 persons and 60,000 dwelling units. It is located about 45 mi west of Chicago and includes several small cities ranging in population from 2,000 to 60,000. Figure 1 shows the area and its division by screen lines into five districts; not shown is the further subdivision into 89 zones and 2,800 blocks. The average density is 3,400 dwelling units per net residential square mile, compared with average densities of 19,000 in the City of Chicago and 3,600 in the Chicago suburbs.

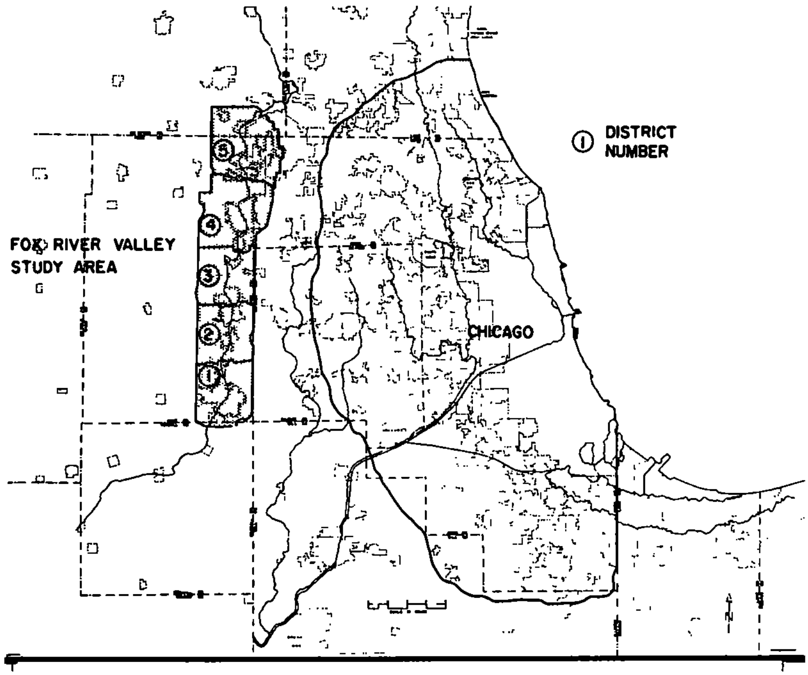

Figure 1. Fox River Valley study area.

The central business districts of towns, which account for about 10 percent of the dwelling units and 30 percent of the nonresidential floor area, were excluded from the aerial photographic survey and are therefore not represented in the data analyzed in this report. The data sources were fire insurance atlas maps and field measurements for those areas that were considered somewhat too congested for reliable interpretation from photography.

SURVEY DATA AND COLLECTION PROCEDURES

All original survey data were obtained by interpretation of photography alone, using no supplementary sources. Collection was contracted to a private firm in the Chicago area which specializes in work of this type.

The specific data collected by the contractor were

1. Floor area measurements of nonresidential buildings, identified by type of specific use. Type of use was coded to 42 detailed categories which could then be grouped to more general categories—commercial, manufacturing, public buildings, public open space, vacant, and a category including transportation, communication, and utilities.
2. Land area classified by the general nonresidential use types listed and by residential and vacant. If a building was located on a land area parcel, its classification was dependent on the land-use identification of the building.
3. Dwelling unit and residential structure counts. Dwelling units were intended to approximate the census definition. Structure counts, classified as to multiple or single family, were obtained primarily to analyze dwelling unit data.

The basic collection unit for dwelling units was the block; land area and floor area were classified by land use within block. The 'block' was either the city block or, outside cities, an area with identifiable natural boundaries. Measurements were made of each nonresidential building and land parcel from photography which was enlarged to 400 ft per in. in the developed areas and 1,000 ft per in. elsewhere. Additional low altitude oblique photographs were also used. These proved to be extremely useful in determining land-use types and the number of floors in buildings. Stereoscopic interpretation was also used to some extent for these purposes.

ACCURACY CHECKING PROCEDURES

Thorough checking was conducted by the URS (Urban Research Section). To accomplish this, separate inventories were made for sample portions of the area. These data were obtained from sources other than the aerial photography. The photography used was flown in the fall of 1959; the checking was almost concurrent, and was completed in the summer of 1960.

Check Data

Nonresidential floor area check measurements were made from fire insurance atlas maps wherever they were available, and direct measurements were made in the field elsewhere. Whenever necessary, the atlas maps were brought up to date by field checking.

Two separate checks were used for the dwelling unit counts: (a) census figures for 1960 for enumeration districts in Kane County, and (b) counts obtained directly in the field by URS. The latter were made by observation, using the number of doorbells, mailboxes, and utility meters as indications of the number of dwelling units per structure. The census data were superior to the URS field counts in that they represented complete enumeration; however, the boundaries of census districts did not correspond well with study area boundaries, and there were some parts of the area, mainly rural, which the available census data did not cover. Partly for this reason, URS made the sample field counts as an additional check. Other reasons were to obtain a check on residential structure counts, and to enable a check on the field counting methods by comparison with the census figures.

Land area checking was done by remeasuring from the original photograph. This was a different procedure than that used for floor area and dwelling units, where independent sources could be used.

Sampling Procedure

A separate systematic sample of all blocks in the aerial survey was selected for checking each type of datum. The total number of blocks sampled was 272 for dwelling unit counts, 199 for floor area measurements, (only 70 sample blocks contained floor area classified as nonresidential) and 22 clusters of blocks for land area measurements. These sample blocks accounted for about 11 percent of the total dwelling units, and for about 8 percent each of the total floor area and land area which were obtained from photography.

The sample sizes were estimated in advance on the basis of data collected from photography in a small preliminary test area, which was completed by the contractor on a trial basis before proceeding with the survey. It was assumed that the amount and variability of error in the test data, as revealed by checking, would be typical of the rest of the aerial survey. A large enough sample of blocks was then selected to yield measures of aerial survey error which would be statistically reliable, at a level specified for each type of data, and for various sizes of areal units.

Stratified sampling was employed for floor area and dwelling units. This permitted a reduction in the amount of sampling necessary to obtain reliable measures of accuracy. (The actual procedure minimized the cost of sampling rather than the number of sample items, "blocks." Within each stratum, the number of blocks sampled was directly proportional to the estimated standard deviation of the error in the aerial survey, and inversely proportional to the cost of obtaining data for each block.) The floor area strata were (a) the parts of the aerial survey area checked by atlas map measurements and (b) by field measurements. Each zone was considered a stratum for dwelling unit sampling, except for the rural zones, which were grouped as a single stratum.

Quality of Checking

An attempt was made to obtain check measurements that could be considered equivalent to true values. Extremely accurate measurements of floor area are possible from the sources which were used. Maximum accuracy was obtained by measuring each building two or more times independently, and then reconciling the differences to arrive at a final check measurement. As a test of the consistency of this procedure, comparisons were made between two sets of measurements of selected buildings, for both atlas map and field measurements. A correlation of the two sets yielded a coefficient above 0.998, and the average difference found was nearly zero. The results were about the same regardless of the source of the measurements being compared, whether map or field. Based on these results, the error in floor area introduced by checking is assumed to be negligible.

The census data, used as the final dwelling unit check, are presumed to be exact. Any error in this check would be small, and would arise from procedures of applying the check. These are discussed later.

The land area check measurements are considered to be much less accurate than the floor area or dwelling unit checks. Variation among repeated measurements from aerial photographs is comparatively great; it usually arises from difficulties in defining land-use boundaries rather than from inexactness of measurement. Lacking a reliable and independent source, these measurements can be expected to detect only the relatively large differences.

RESULTS OF ACCURACY CHECKS

By comparing the contractor's data with check data for the selected sample blocks, the accuracy level of the entire aerial survey could be estimated. The amount of error in the aerial survey is stated in the following for each type of data collected—first, for the entire area, then by smaller geographic aggregates, so as to indicate how well accuracy was maintained on a more detailed level.

Nonresidential Floor Area

In general, measurements from photography compared well with check measurements, with a tendency on the average for the photographic survey measurements to be too low. The ratio of total check to photographic survey measurements was 1.13; in other words, the check was 13 percent higher than the survey measurements for all types of nonresidential floor area taken together, in the sample or test blocks. Statistical computations establish that the error ratio, 1.13, is reliable within plus or minus 0.01. (Differences between the check and the aerial survey have been called "errors" because the check measurements are presumed to be true. The term used in this sense is not the same as "standard error," which is a statistical measure of reliability. The chances are two-thirds that the error ratio obtained in the sample, 1.13, lies within plus or minus 0.01 of the true ratio. The true error ratio would have been obtained if all aerial survey measurements had been checked.)

There was considerable variation in accruacy of the areal subdivisions. Table 1 shows error ratios (check/aerial survey)

TABLE 1

ERROR IN NONRESIDENTIAL FLOOR AREA BY DISTRICT

District	Ratio	
	Check/ Aerial Survey	Reliability[a]
1	1.08	± 0.04
2	0.92	± 0.15
3	1.57	± 0.07
4	1.34	± 0.13
5	0.96	± 0.01
Total	1.13	± 0.01[b]

[a] Two-thirds of the time, ratio obtained in sample will differ from true ratio by amount shown.

[b] Not obtained by summing districts, which would give ± 0.04; rather obtained by summing land-use reliability figures in Table 2.

for the five districts of the Fox River Valley study area, together with the reliability of each ratio. Good accuracy is indicated for Districts 1, 2, and 5, where the ratios are 1.08, 0.92, and 0.96, respectively. Furthermore, the reliability ranges for these figures indicate that the true errors could be close to zero (or, ratios of 1.00). On the other hand, Districts 3 and 4 have high error ratios, 1.57 and 1.34, which cannot be explained by sampling variability. These districts presented no unusual measurement problems. The most plausible explanation for this variation lies in the fact that different personnel performed the photographic interpretation for these areas.

Despite the errors mentioned, there was a fairly high over-all correspondence between individual blocks, as evidenced by the correlation coefficient obtained, 0.98, as shown in Figure 2, where block data are plotted. This probably can be explained as a tendency for errors in the two groups of districts to be consistently high or low.

Rates of error by generalized land-use categories for the aerial survey as a whole are given in Table 2. The figures indicate a significant understatement of floor area by the survey in the manufacturing and "other" land-use categories. By contrast, agreement is very high in the commercial and the public building categories. Manufacturing is the largest source of error, most of which is caused by building omissions.

For some purposes it may be more important to know the correct proportional distribution of floor area by land-use type rather than the absolute amounts. The aerial survey distribution is compared with the check distribution in Table 3. This is equivalent to adjusting the aerial survey floor area in each land-use class by applying a correction factor based on the average error for total floor area. (Two correction factors were actually used for Table 3, based on the average errors for each of two portions of the survey area. The wide difference between the two average errors, 32 percent as compared with 2 percent, allowed a better adjustment than the use of one over-all average.) The resulting error ratios in Table 3 show that a fairly good adjustment could be made without correcting each land use separately. Manufacturing and commerical, the largest categories, compare quite closely.

Accuracy in identifying detailed land-use types from aerial photography would be expected to be much lower. Table 4 gives the ratio of error for each of 42 detailed use categories, which are subdivisions of the generalized types previously discussed. These figures, as in Table 3, have been adjusted for the total percentage error by converting amounts of floor areas to proportions. Table 4 also gives an intermediate breakdown of the commercial category into retail, service, and wholesale; the errors

TABLE 2

ERROR IN NONRESIDENTIAL FLOOR AREA BY TYPE OF LAND USE

Land Use	Ratio: Check/ Aerial Survey	Ratio: Reliability[a]
Manufacturing	1.26	± 0.05
Commercial	1.04	± 0.05
Public Bldgs.	1.05	± 0.03
Other	1.37	± 0.26
Total	1.13	± 0.01[b]

[a] Two-thirds of the time, ratio obtained in sample will differ from true ratio by amount shown.

[b] Obtained by weighting and summing reliabilities of types of land use.

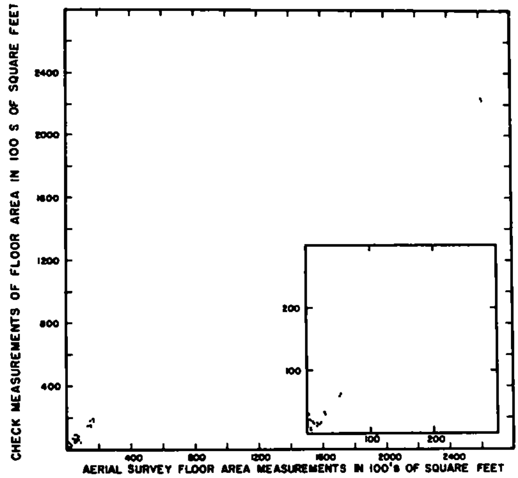

Figure 2. Aerial survey and check measurements of total nonresidential floor area by sample block.

TABLE 3

CHECK AND AERIAL SURVEY NONRESIDENTIAL FLOOR

Land Use	Check	Aerial Survey	Check/ Aerial Survey
Manufacturing	0 401	0.374	1.072
Commercial	0.362	0.367	0.986
Public Bldgs.	0 214	0.237	0 903
Other	0 023	0.022	1 045
Total	1.000	1.000	1.000

for retail and service (5 and 25 percent) show a fair ability of the photo-interpreter to distinguish between kinds of commercial activities. But most detailed types have large errors, 40 percent or more, with the exception of the public building categories. The high sampling variability of such small groupings, however, prevents a definitive statement as to detailed accuracy.

Improvements in the photographic survey procedure depend on finding out why errors occurred. Errors in nonresidential floor area have the following major components:

1. The measurements of buildings can be incorrect either because of inaccuracy in (a) the ground floor measurement or (b) the number of floors counted. The second is usually the more serious.
2. The land-use type of identification of buildings can be wrong. This reflects an inability either to distinguish nonresidential buildings from residential or to identify the particular nonresidential type.
3. Nonresidential buildings can be omitted, not because of faulty identification as residential, but because of inadequate control of building coverage. In certain cases, for example, large factory buildings were not recorded at all.

Of these three classifications, the last (building omissions) was the most important. Classification of error in floor area totals for the entire survey in order to measure the relative importance by type are given in Table 5, where net differences between check and survey totals are shown. It may be seen that of the 13 percent error, the omissions accounted for 12 percent, other types of errors adding only small amounts. This resulted because plus-and-minus errors, except for building omissions, tended to cancel for the total area; it would not be true for small areas. Thus correcting for omissions alone would have resulted in an over-all error close to zero.

The kinds of error in floor area were a result either of lack of care in obtaining data or of limitations of aerial photographic interpretation itself. More efficient control procedures probably would have solved the building omission problem to a great extent. Measurement and identification accuracy on a detailed level probably could be improved by further enlarging the photography and by using supplementary materials. If greater accuracy is needed the user of the data must decide whether the added expense would be justified.

Land Area

Remeasurements of land area for checking purposes do not have the same validity as those of floor area because no source superior to the original aerial photography itself was available. Furthermore, definitions of land-use boundaries are necessarily inexact (with the exception of gross total land area). The various nonresidential land uses, except for vacant land, were therefore treated as a group for checking purposes.

The ratios of error (check divided by aerial survey measurements) that appear in Table 6 are based on a repetition of the same process used in the original measurements, which would be likely to produce sizeable errors due to differences in land area definition. Nevertheless, the results of the comparisons were close. The aerial survey measurements of gross totals which include all land area within sample blocks, and net totals, which include everything except streets, each differed by a negligible amount from the check measurements. Vacant land area also showed a negligible difference, probably because most of it is found in large, unbroken areas. Original survey mea-

TABLE 4

CHECK AND AERIAL SURVEY NONRESIDENTIAL FLOOR AREA PROPORTIONS COMPARED BY DETAILED LAND-USE CATEGORY

Land Use	Check	Aerial Survey	Ratio of Check to Aerial Survey[a]
Commercial retail or service, type unknown	--	0.007	NC
Commercial retail			
Type unknown	0.226	0.244	0.926
Food and drugs	0.007	0.004	1.750
Eating and drinking places	0.019	0 012	1.583
Department stores, furniture, and appliances	0.006	0.003	2.000
Other	0.051	0.030	1.700
Total	0.309	0.294	1.051
Commercial services			
Type unknown	--	0.018	NC
Finance, insurance, real estate	--	--	NC
Personal services	0.003	0.005	0.600
Medical, dental, legal	0.003	0.005	0.600
Offices, general	0.002	--	NC
Other[b]	0.039	0 035	1.114
Total	0.047	0 063	0.746
Commercial, heavy			
Type unknown	--	--	NC
Wholesalers, distributors	--	0.002	NC
Junk and salvage yards, used car lots	0.003	0.001	3 000
Other heavy commercial[c]	0.003	--	NC
Total	0.006	0.003	2 000
Manufacturing			
Type unknown	--	0.091	NC
Primary metals	--	--	NC
Other	0.400	0 283	1.413
Total	0.400	0.374	1.070
Transportation, utilities, communications, and other non-manufacturing industrial			
Type unknown	--	--	NC
Trucking terminals, warehouses	0.017	0 004	4.250
R R. stations and bus depots	0.001	--	NC
R. R. right-of-way	--	--	NC
Airports	--	--	NC
Mines, quarries, oil wells, etc.	--	--	NC
Other utilities, transportation, and sanitary services	--	--	NC
Total	0.018	0 004	4.500
Public Buildings			
Type unknown	--	--	NC
Government and public buildings	0.004	0.006	0.667
Schools	0.145	0.180	0.806
Hospitals and sanitariums	0.021	0.027	0.778
Military installations	--	--	NC
Other public buildings	0.044	0.024	1.833
Total	0.214	0.237	0 903
Public Open Space			
Type unknown	--	--	NC
Parks and beaches	0.001	0.016	0 063
Golf courses	--	--	NC
Cemeteries	--	--	NC
Other[d]	--	--	NC
Total	0.001	0.016	0.063
Vacant land and floor area			
Vacant usable land	--	--	NC
Vacant unusable land, and water	--	--	NC
Vacant floor area	0.005	0.002	2.500
Parking lots	--	--	NC
Total	0.005	0.002	2 500
Total floor area	1.000	1 000	1 000

[a] NC = ratio not computed, either check or aerial survey, or both, had no floor area in category.

[b] Including other professional services, repair, indoor recreation, indoor nonprofit organizations.

[c] Including new construction.

[d] Including outdoor theatres, racetracks, stadiums, zoos, and all other outdoor recreational services.

TABLE 5

TOTAL NET DIFFERENCE BETWEEN CHECK AND AERIAL SURVEY, NONRESIDENTIAL FLOOR AREA BY TYPE OF ERROR

Error	Difference: Aerial Survey Less Check	Difference: Percentage of Total Aerial Survey
Measurement:		
Ground floor	-402[a]	-3.5
No. of floors	98	0.8
Identification[b]	199	1.7
Omission	-1,368	-11.9
Total	-1,473	-12.8

a In hundreds of square feet.

b Of residential as nonresidential. Errors by generalized nonresidential type of use (manufacturing, commercial, etc.) not included. These errors were very small, indicating identification as to generalized type was accurate.

surements for nonresidential land in use exceeded check measurements by a small amount, whereas they were slightly low for residential land, the error ratios being 1.08 and 0.93, respectively. (The latter figure agrees closely with previous checking on fire insurance atlas maps in the pretest area and is likely to be nearly correct.)

Not all this error was the contractor's. By performing two or more check measurements and measuring the variation between them, the amount of checking error for land area was approximated; this indicated that on the average about 20 percent of the differences between check and survey measurements could be considered an error in checking.

Dwelling Units and Residential Structures

Census data for 1960 were the basis of final dwelling unit count comparisons for accuracy checking. Comparisons were made with (a) original aerial survey counts and (b) corrected aerial survey counts. (The latter are equivalent to the field sample counts made by the URS, weighted by the total number of dwelling units in each zone.) Inasmuch as census data can be assumed to be accurate, a direct check could then be made of the sampling procedures and of the accuracy of field-counting methods used to obtain factors. Census comparisons were made for the total survey area, for each of the five districts, and for 84 of the 89 zones outside the central business districts where counts were obtained from photography.

Because census counts were available in units no smaller than enumeration district, a direct comparison of blocks in the field sample could not be made. Instead, a procedure was followed that allowed a comparison of census, original survey, and corrected survey counts by a common unit—the zone. It was recognized that census counts by zone resulting from this procedure, having been arrived at by applying successive factors, would vary from the true totals, but these discrepancies were thought insignificant, especially where comparisons were made by units larger than the zone.

The total corrected aerial survey dwelling unit count for the area where photography was used differed from the census count by only 0.4 percent. This percentage difference is negligible and is reliable within 1.0 percent. (Statistical reliability for dwelling units has the same meaning, as for floor area, described earlier.) Because any problems arising from noncomparable Fox River Valley and census areal units become extremely minor at this scale, this comparison should be considered adequate evidence of high accuracy. The results demonstrate that dwelling units as defined by the census can be counted accurately in the field using methods described earlier, and therefore that sample field counts can provide reliable correction factors on an overall basis.

The original aerial survey counts, on the other hand, were about 10 percent less than census counts for the total area. This is to be interpreted as a necessary shortcoming of photography itself as a source rather than as deficient workmanship, because dwelling unit counts from photography are estimates based on the size of residential structures, character of the area, etc., and cannot be made exact by the exercise of greater care.

Table 7 shows the variation in accuracy of both types of counts by district, where

TABLE 6

ERROR IN LAND AREA MEASUREMENTS BY LAND-USE TYPE

Land Use	Ratio of Check to Aerial Survey
Total:	
Gross (including streets)	1.00
Net (excluding streets)	1.00
Nonresidential in use	1.08
Residential in use	0.93
Vacant or unusable	1.00

TABLE 7

RATIO OF CENSUS TO FRV SURVEY OCCUPIED, DWELLING UNIT COUNTS BY DISTRICT

District	Ratio	
	Census to Corrected Aer. Survey	Census to Uncorrected Aer. Survey
1	1.02	1.15
2	1.01	1.07
3	1.00	1.03
4	0.99	1.20
5	0.99	1.01
Total	1.004	1.120

error is again expressed as the ratio of census counts per survey count. The table shows that, although corrected districts were in error by very small amounts, 1 to 2 percent, census counts were higher than uncorrected counts by amounts which varied from -1.0 to +17.0 percent. Districts 1 and 4, which contain cities with populations of 53,000 and 64,000, large enough to have a large number of multi-family structures where estimation is difficult, had errors of 12 and 17 percent. The other districts are predominantly single-family and had small errors.

Zones, as much smaller units (the average size is about 600 dwelling units), had correspondingly larger errors. Even so, the frequency distributions of zone errors which appear in Table 8 show that the accuracy of corrected zones was more than adequate, 86 percent being within ± 5 percent of the census counts. This compares with only 21 percent within this range for the uncorrected zones. These data are presented in graphic form in Figures 3 and 4 in which the degree of correspondence with census counts may be compared for both sets of survey counts.

Accuracy of unfactored dwelling unit counts from photography was quite high in single-family home areas, but low in multiple-family structure areas. Table 9 shows the relationship of dwelling unit count error to dwelling units (families) per residential structure, demonstrating the regular increase in percentage error from 5 to

TABLE 8

FREQUENCY DISTRIBUTION OF ZONES BY PERCENTAGE ERROR FOR CORRECTED AND UNCORRECTED AERIAL SURVEY DWELLING UNIT COUNTS

Plus or Minus Error as Percent of Census DU's	Percentage Frequency Distribution of Zones	
	Corrected Aerial Survey	Uncorrected Aerial Survey
0 to 5	85.7	21.4
6 to 10	8.3	42.9
11 to 15	4.8	10.7
16 to 20	--	9.5
21 and over	1.2	15.5
Total	100.0	100.0

TABLE 9

RATIO OF CENSUS TO UNCORRECTED AERIAL SURVEY, OCCUPIED DWELLING UNIT COUNTS BY DWELLING UNITS PER STRUCTURE

Dwelling Units Per Structure[a]	Ratio of Census to Uncorrected DU Counts
1.14 or less	1.05
1.15 to 1.24	1.27
1.25 to 1.34	1.31
1.35 to 1.44	1.31
1.45 and over	1.55

[a] Obtained in field sample.

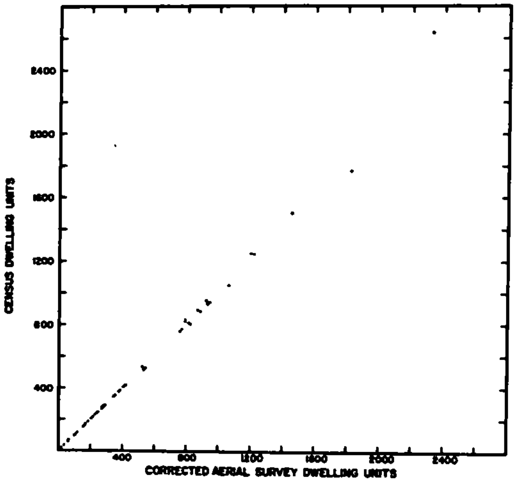

Figure 3. Census and corrected aerial survey dwelling units by zone.

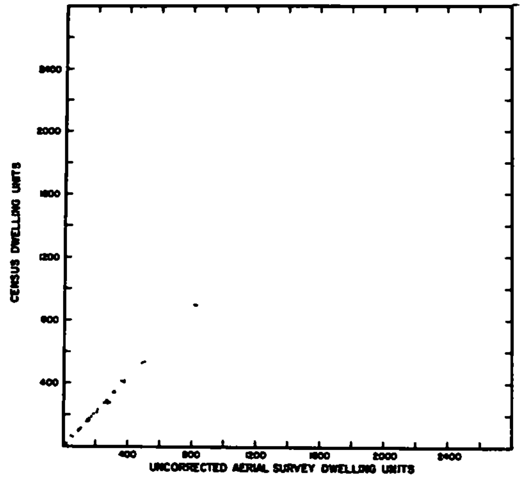

Figure 4. Census and uncorrected aerial survey dwelling units by zone.

55 percent in areas where dwelling unit structures were less than 1.15 and more than 1.44, respectively. Also, the variation in error among individual zones was comparatively small in areas with low dwelling unit per structure rates, where most zones were within ± 5 percent of the 5 percent mean error rate. Where the mean error rate was high, individual zone errors differed widely; one-half the zones varied by more than 25 percent from the mean error in areas with dwelling units per structure rates of 1.45 and over. These areas, therefore, require much heavier sampling than do areas of single-family homes to obtain equally reliable correction factors.

SURVEY COSTS

The approximate total cost of data collection, including both the aerial survey data and the data used for checking, was $10,000. Expressed in unit costs this is about $0.18 per dwelling unit, or $51 per sq mi. (Central business districts are not included.) These figures represent only costs directly concerned with data collection itself, and exclude the cost of planning the project, designing the sampling, analyzing, and tabulating data, etc. The costs are itemized in Table 10 by type of data and checking method where possible. Unfortunately, a breakdown by type of data of the cost of the original photographic work, which was done by the contractor, was not available.

TABLE 10

COST OF DATA COLLECTION

Type of Data	Cost ($)
Aerial survey	7,000
Check	2,850
Dwelling units (field counts)	900
Floor area measurements:	
Field	1,300
Atlas map:	
Measurements	400
Rental	200
Land area (photo measurement)	50
Total	9,850

CONCLUSIONS

An evaluation of the accuracy achieved depends on the use made of the data. The FRV study required sufficient accuracy to make trip estimates by areal subdivision. In general, these standards were met, but only after correction factors obtained by independent sample checking had been applied. The over-all errors of 12 and 13 percent for uncorrected dwelling units and floor area, and especially the large variation by district and by zone, prevented the use of these data as they came from the contractor.

The most important data for trip generation purposes in this study were dwelling unit counts and commercial floor area, which typically generate 55 and 25 percent, respectively, of total vehicle trips. Accuracy (after corrections) was high for both these items, especially for dwelling units, by areal subdivision as well as for the totals. The other floor area data were adequate, as were land area measurements used. It is estimated that trips generated by the average zone (about 4,000 vehicle trips) would be in error due to data inaccuracy by about 15 percent or less, two-thirds of the time. Districts would have much smaller errors—about 3 percent.

Essential Procedures and Indicated Improvements

Careful workmanship is the main element necessary in aerial photographic interpretation. Much greater care is required than when data are obtained from other sources, such as fire insurance atlas maps or from direct field surveys. This is particularly true for floor area data. On the whole, the quality of work from photographs in the FRV survey appeared to be good, and much of the error found was probably due to limitations in the technique itself.

An important finding of the study is that sample checking is essential to obtain measures of accuracy and correction factors, for all types of data. Because of the variation in error possible, a preliminary testing should be done, from which sample sizes can be estimated large enough to produce statistically reliable measures. The FRV sample sizes that were estimated by this method proved to be large enough to produce adequate correction factors. Dwelling units in fact were oversampled; one-third the number of blocks checked would have given a standard error for the total of 3 percent. Sampling should be stratified by areal unit, by land-use type, etc., because of the different rates of error which are likely among the groupings.

Certain improvements are possible in dwelling unit sampling. As was shown previously, single-family homes were counted from photography within 5 percent of census counts. Sample sizes should therefore be very small in areas of this type and much larger where the dwelling unit per residential structure ratio is high. This would allow a reduction in total sample size.

Controls on procedure proved to be important. These include setting up forms for recording data, lists of blocks to be covered, etc., so as to insure completeness of coverage and prevent duplications. The building omissions problem discussed, which accounted for most of the error in total floor area, might have been controlled by better procedures; each building could have been numbered on the photographs, recorded on forms, and then rechecked for coverage. Forms were also designed to allow checking on computations, illogical entries, and other clerical errors. Some zones were thus corrected by 20 percent or more as a result of checks made for these contingencies.

Oblique photography was found necessary for floor area data, to determine the number of floors and to aid in land-use identification. It also made much better identification of land area possible. Other supplementary sources would also be desirable.

Comparison with Other Methods

Based on the experience in this study and elsewhere (the Chicago Area Transportation Study used atlas maps to collect floor area and land area data), aerial photography as a source of floor area and land area data still appears to be definitely inferior to fire insurance atlas maps. Better accuracy can be obtained more easily from atlas maps, especially for detailed land-use identification, at roughly one-half the cost.

Comparative costs and accuracy for dwelling unit counts by field survey and counts from photography are closer. Although it is true that field surveys can be as accurate as desired, the FRV photo counts, corrected by field sampling, are also accurate enough for most purposes. The accuracy of field surveys is not necessarily higher than uncorrected photo counts. For instance, it was necessary to correct for an 8 percent error in the field survey of dwelling units made for the Pittsburgh Area Transportation Study (2). At high densities, all types of surveys are more difficult. Experience in this study has shown that costs for field surveys would be about the same as the FRV combination photo and field sample method, and might be considerably more in areas of single-family homes.

General Applicability

Whether to use aerial photography as a data source depends on the type of area in which data are to be collected, type of data needed, accuracy needs, availability of other source materials, capability of personnel, and other factors such as cost limitations.

Aerial photography is best suited for areas of relatively low density—suburban areas, small cities, or rural areas. No other source is usually available for either floor area or land area data in these areas except sometimes in central business districts. Densities in the Fox River Valley, for instance, range from 1,000 to 10,000 dwelling units per square mile of residential land in use, excluding central business districts. These densities are also typical of Chicago suburban densities. Such areas have a predominance of single-family homes where dwelling unit counts may be made most accurately. Land-use identification of floor area and land area is also most feasible at low densities because land-use types are usually not mixed in a structure. However, measurement of total floor area without identification probably would be as accurate at high densities. In these areas, a technique combining photographic measurement with identification in the field would probably produce good results, but, of course, would add to the cost.

Where other sources are available for floor or land area data (such as fire insurance atlas maps) aerial photography should not be used, even if the other source covers only part of the area. Increasing the accuracy of measurements from photography beyond that obtained in the FRV study would probably result in sharply increased costs.

In conclusion, the FRV study shows that aerial photography can provide satisfactory data if used where it is best adapted and if proper precautions are taken. Although the testing summarized in this report was thorough, applications in other types of areas and with changes in techniques would add useful information.

REFERENCES

1. "Final Report." Chicago Area Transportation Study, Vol. 1 (1959).
2. Wegener, B.H., "Home Interview Sample Selection." Pittsburgh Area Transportation Study Research Letter, p. 5 (May 1959).