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Using Attribute Sampling to Assess the Accuracy of a Library Circulation System

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In the routine management of collections, librarians frequently need to make assessments about whether large numbers of items are being handled or processed correctly. For example, they may need to assess whether the circulation system is effective in reflecting books checked out, whether new items are classified correctly, or whether new items are bar coded correctly. For a librarian to determine whether all entries in a circulation system are correct is generally neither cost effective nor a reasonable undertaking. However, librarians may use statistical sampling to make an inference about the accuracy of entries in the circulation system, item classification, bar coding, or some other matter that affects the quality of library operations.

Existing library management literature presents techniques for developing descriptive statistics such as the average age of patrons, the average number of entries in a bibliography, or the average cost of a book. This literature presents equations for estimating proportions or percentages. That methodology is effective for making estimates such as average number of patrons per day and many others. However, the methodology is generally not appropriate for situations in which a librarian wants to estimate the occurrence rate of an attribute such as the portion of items misclassified. Techniques should be modified when focusing on the frequency of a single characteristic and the proportion is either very large or very small.[1] Because this process is complex, auditors have developed a methodology called attribute sampling and tables for determining required sample sizes and for evaluating the results of examining a sample.

Attribute sampling enables one to make an estimate of a maximum occurrence rate, such as the maximum portion of books shown in the records as being on the shelf that are actually not on the shelf. In addition to making an estimate, attribute sampling techniques result in one's being able to state a confidence level about the estimate. The purpose of this article is to introduce attribute sampling and illustrate how a librarian might use attribute sampling techniques in assessing the accuracy of a library's circulation system.

The Nature of Sampling

Sampling is the application of a statistical procedure to less than 100 percent of the items of some specified population for the purpose of making inferences

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about the whole population. Attribute sampling requires examining individual items to determine the existence of some preselected characteristic. For example, the objective, when assessing the accuracy of a library's circulation system, is to estimate the portion of the circulation file that is inaccurate; that is, the maximum percentage of the records in the circulation system that has the characteristic or attribute of being incorrect. The percentage of items possessing the characteristic "incorrect" is known as the deviation rate.

Certain basic requirements must apply if the inferences made from examining a sample of the circulation records are to be statistically meaningful:

- The definition of "inaccurate" or "incorrect record" must be stated, and it must be relevant to the records in the circulation system.
- Sample records should be randomly chosen so that the sample can be expected to be representative of the circulation file as a whole. This means not only that all records in the circulation file have an equal chance of being selected, but also that the sample records have a known probability of being selected.
- Results from the sample findings should be evaluated mathematically in accordance with probability theory before inferences are made about the accuracy of the circulation system. Inferences made from statistical sampling are to be distinguished from those of other sampling methods by the objectiveness and preciseness of their conclusions.
- Statistical sampling allows for the calculation of a sample reliability or a risk of reliance upon the sample.
- Given the mathematically measured risk the librarian is willing to accept, statistical sampling enables the librarian to determine an optimal sample size. This avoids examining too many or too few records.
- Statistical sampling of the circulation records enables the librarian to make objective statements about an attribute in the whole set of circulation records.

The basis for determining the number of records to include in a sample is the degree of reliability desired, where "reliability" is defined as the complement of risk (reliability is 1 minus risk). For example, a librarian willing to accept a 5 percent risk that a selected sample will not be representative of a population would achieve a reliability of 95 percent. Complete confidence can be achieved with a complete examination of all records in the circulation file. However, examining a relatively small sample can achieve a high degree of reliability so that examining additional items will make only modest improvements in reliability. Attribute sampling techniques facilitate determining mathematically the minimum level of testing necessary to meet a desired level of reliability. Stated another way, attribute sampling allows one to calculate the number of items to include in a sample given the level of risk one is willing to accept.

Sampling Risk and Nonsampling Error

When selecting a sample from a population the objective is to obtain a sample that has characteristics identical to the entire circulation record file. For example, if 3 percent of the records in the circulation system were actually incorrect, ideally one would expect to draw a sample with 3 percent of the records being incorrect. The chance that this will not be the case is called sampling risk. Sampling risk relates to the probability of the sample not being representative of the circulation file as a whole. Therefore, the risk always exists, when making inferences from the sample, that the conclusions will be different from the conclusions that would be reached if the entire circulation record file were examined. As will be shown below, sampling risk can be precisely measured and controlled.

Nonsampling error, on the other hand, results from the possibility that the inferences are misleading because of errors or mistakes in the execution of the sampling process. Examples of nonsampling errors that may occur in examining the circulation system are:

- Failure to include all records in the population to be sampled
- Failure to define clearly the attribute "inaccurate" or "incorrect record"
- Failure to recognize an "inaccurate" or "incorrect record" when it exists in the sample

- Failure to draw a random sample
- Failure to evaluate findings properly

Attribute Sampling

An example of how sampling works would be a librarian who wants to determine the maximum percentage of records in a circulation system that is incorrect where "incorrect" is defined as a record in the system showing a book item to be "on loan" when in fact it is not. Further, an average of seventy-five thousand items are currently circulating and that each is readily identifiable in the circulation record file. The librarian would pursue the following procedures.

Step 1. Determine the Objective of the Statistical Inference

Attribute sampling is most suitable for estimating infrequent occurrences within large populations. For the circulation records, the objective may be to estimate the maximum portion of incorrect records in the circulation file where an incorrect record is one that shows a book being on loan when it is not. The important point is that the attribute "incorrect record" is an infrequent occurrence with respect to what is generally expected of the circulation system. The attribute "incorrect record" is a characteristic of an individual record that is being examined. When the desired characteristic is not present, a deviation exists.

Step 2. Define the Population and the Sampling Unit

The sampling unit and the population are dictated by the sampling objective. The sampling unit is the individual item in the circulation system that possesses the characteristic being examined. The population is the collection of all the sampling units. The population should include all records of all books "on loan" at a given point in time when estimating the maximum percentage of all records pertaining to books "on loan" to outside borrowers. The population may not include, for example, records of books checked out to the Binding Unit if the library does not define these as "on loan." Some books, such as those on short-term loan, may be relatively easy to verify, while those on longer-term loan may entail the added inconvenience of having to be recalled. For the conclusion about the records to be valid, the population cannot exclude any records relevant to the objective of the test.

A librarian may choose to treat the circulation system as including two populations, items on short-term loan and items on long-term loan. The major reason for treating the system as including two populations would be if one were expected to have a significantly different deviation rate from the other or if obtaining evidence about the two separate groups would facilitate library management.

Step 3. Set the Tolerable Deviation Rate

Attribute sampling techniques enable one to gather evidence about the maximum occurrence rate of an attribute in a population such as the portion of items reflected on the circulation records in error. To determine sample size, one must specify a tolerable deviation rate. In specifying the tolerable deviation rate, one needs to consider the ramifications of having evidence, for example, that the deviation rate does not exceed 5 percent versus having evidence that the deviation rate does not exceed 8 percent. Normally, if a librarian specified the tolerable deviation rate for the circulation system at 4 percent, then if the evidence indicates that a maximum of 4 percent of the circulation records are deviations, that is, "incorrect," the librarian's assessment of the accuracy of the circulation records would not change.

The required sample size varies inversely with the tolerable deviation rate. As the tolerable deviation rate increases, the required sample size decreases. For example, as table 1 indicates, for a population with an expected deviation rate of 2 percent, specifying a tolerable rate of 3 percent requires a sample size of 900, while specifying a tolerable rate of 5 percent would require a sample size of 200, and specifying a tolerable rate of 8 percent would require a sample size of 80 (see table 1).

The result of attribute sampling is the computed upper deviation rate. The upper deviation rate is determined by table 2 (see table 2).

Table 1 Determination of Sample Size: 5% Risk of Concluding the Deviation Rate Is Lower Than It Actually Is

Expected % Rate of Occurrence	Tolerable Rate: % Rate of Occurrence									
	1	2	3	4	5	6	7	8	9	10
0.25	650	240	160	120	100	80	70	60	60	50
0.50	*	320	160	120	100	80	70	60	60	50
1.0		600	260	160	100	80	70	60	60	50
1.5		*	400	200	160	120	90	60	60	50
2.0			900	300	200	140	90	80	70	50
2.5			*	550	240	160	120	80	70	70
3.0				*	400	200	160	100	90	80
3.5				*	650	280	200	140	100	80
4.0					*	500	240	180	100	90
4.5					*	800	360	200	160	120
5.0						*	500	240	160	120
5.5						*	900	360	200	160
6.0							*	550	280	180
6.5							*	1000	400	240
7.0								*	600	300
7.5								*	*	460
8.0									*	650
8.5									*	*
9.0										*
9.5										*

*Sample size more than 1,000.

Audit Sampling (New York: American Institute of Certified Public Accountants, 1983). Used with the permission of the American Institute of Certified Public Accountants.

Step 4. Set the Acceptable Risk of Concluding That the Deviation Rate Is Lower Than It Actually Is

The sample a librarian selects may be representative of the population, or it may not be. If the sample is not representative of the population, the computed upper deviation rate may be higher or lower than it actually is in the population.

When sampling, the librarian must accept some risk that the computed upper deviation rate is incorrect. Because knowing that the circulation system is ineffective is more important than knowing it functions effectively, the librarian will wish to avoid concluding that the population occurrence rate is lower than it actually is. Auditors often specify an acceptable risk of either 1 percent, 5 percent, or 10 percent, depending on the nature of the attribute being examined, and maintain statistical sampling tables that reflect these levels of risk. Table 1 is a table for determining sample size for attribute sampling for a 5 percent level of risk. The amount of risk accepted affects the sample size. The greater the risk accepted, the smaller the sample size.

Risk is related to reliability or confidence level. When specifying a 5 percent risk of concluding that the deviation rate is lower that it actually is, the librarian is accepting a 5 percent chance of concluding that the deviation rate is lower than the tolerable rate when it is not. Conversely, when specifying a 95 percent reliability level, the chance of being right is 95 percent.

Another way to conceptualize this is to assume that for a 95 percent reliability

Table 2 Table for Computing Upper Deviation Rate: 5% Risk of Concluding Deviation Rate Is Lower Than It Actually Is

Sample Size	Number of Observed Deviations																				
	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	35	40	45	50
10																	0		1		
20												0				1	2	3		4	5
30										0			1		2	3	4	5	7	8	10
40								0			1		2		3	5	6	8	10	12	14
50						0				1		2	3	4	5	7	9	11	13	16	18
60					0			1			2	3	4	5	6	9	11	14	17	20	23
70					0		1		2		3	4	5	7	8	11	14	17	20	24	27
80				0		1		2		3	4	5	7	8	9	13	16	20	24	28	32
90				0		1	2		3	4	5	6	8	9	11	15	19	23	27	32	36
100			0		1		2	3	4		6	8	9	11	13	17	22	26	31	36	41
120			0	1		2	3	4	5	6	8	10	12	14	16	21	27	33	38	44	50
140			0	1	2	3	4	5	6	7	10	12	14	17	19	26	32	39	46	52	59
160		0	1	2	3	4	5	6	8	9	12	14	17	20	23	30	38	45	53	61	69
180		0	1	2	3	5	6	8	9	11	14	17	20	23	26	35	43	52	60	69	78
200		0	1	3	4	6	7	9	11	12	16	19	23	26	30	39	48	58	68	77	87
220		0	2	3	5	7	8	10	12	14	18	22	25	29	33	44	54	64	75	86	97
240		1	2	4	6	8	10	12	14	16	20	24	28	33	37	48	59	71	83	94	106
260		1	3	4	7	9	11	13	15	17	22	26	31	36	41	53	65	77	90	103	116
280		1	3	5	7	10	12	14	17	19	24	29	34	39	44	57	71	84	98	111	125
300	0	1	3	6	8	11	13	16	18	21	26	31	37	42	48	62	76	91	105	120	135
320	0	2	4	6	9	11	14	17	20	22	28	34	40	45	51	66	82	97	113	128	144
340	0	2	4	7	10	12	15	18	21	24	30	36	42	49	55	71	87	104	120	137	154
360	0	2	5	8	10	13	17	20	23	26	32	39	45	52	59	76	93	110	128	146	163
380	0	2	5	8	11	14	18	21	24	28	34	41	48	55	62	80	98	117	135	154	173
400	0	3	6	9	12	15	19	22	26	29	37	44	51	59	66	85	104	123	143	163	183
420	0	3	6	9	13	16	20	24	27	31	39	46	54	62	70	90	110	130	151	171	192
460	0	4	7	11	15	18	22	26	31	35	43	51	60	68	77	99	121	143	166	188	211
500	1	4	8	12	16	21	25	29	34	38	47	56	66	75	84	108	132	157	181	197	221
550	1	5	9	14	18	23	28	33	38	43	53	63	73	83	94	120	146	173	200	227	255
600	1	6	10	15	20	26	31	36	42	47	58	69	80	92	103	132	161	190	219	249	279
650	2	6	12	17	23	28	34	40	46	52	64	76	88	100	112	143	175	207	239	271	303
700	2	7	13	19	25	31	37	43	50	56	69	82	95	108	122	155	189	223	258	292	327
800	3	9	15	22	29	36	43	51	58	65	80	95	110	125	141	179	218	257	296	336	376
900	4	10	18	26	34	42	50	58	66	74	91	108	125	142	159	203	247	291	335	379	424
1000	4	12	20	29	38	47	56	65	74	84	102	121	140	159	178	227	275	324	374	423	473

Audit Sampling (New York: American Institute of Certified Public Accountants, 1983). Used with the permission of the American Institute of Certified Public Accountants.

level and a given tolerance rate, one hundred samples were drawn from the circulation file. Statistically, ninety-five of these one hundred would be representative of the records in the circulation file. One sample drawn from the circulation file would have a 95 percent chance of being representative.

Step 5. Estimate the Expected Population Deviation Rate

The expected population deviation rate, also known as the expected occurrence rate, is an estimate of the actual frequency of the attribute being investigated. For example, a librarian may believe that 2 percent of the records in the circulation file are incorrect. The estimate of the expected population deviation rate is a matter of judgment. It may be based on results of previous samplings, familiarity with deviation rates in similar situations, preliminary samples of the circulation system, or some other factor. Estimating the deviation rate incorrectly may cause the initial sample size to be incorrect and require additional sampling. Fortunately, an incorrect estimate does not increase the risk of concluding the deviation rate is lower than it actually is.

The size of the expected population deviation rate in relation to the tolerable deviation rate affects the required sample size. The closer the expected population deviation rate is to the tolerable deviation rate the larger the required sample size.

Step 6. Determine the Initial Sample Size

After estimating the number of incorrect records in the circulation system (the expected population deviation rate) and setting a tolerable deviation rate for the circulation records, the librarian may use table 1 to determine the initial sample size. The sample size is called the initial sample size because the deviation rate in the actual sample determines whether the sample size is large enough to substantiate the expectation that 2 percent of the records are incorrect.

Suppose the librarian is willing to assume that the accuracy of the circulation system is such that no more than 4 percent of the records are incorrect (the tolerable deviation rate) and expects the number of incorrect records to be 2 percent (expected population deviation rate).

To determine sample size, locate the 4 percent tolerable deviation rate along the top row and the 2 percent expected deviation rate down the column to the left. The initial sample size is 300, determined by the intersection of the appropriate row and column. This particular sample size corresponds to a reliability level of 95 percent. Tables similar to table 1 are available for reliability levels higher or lower than 95 percent.

Step 7. Select the Sample

Determine the number of records to be examined and select a sample of these records randomly from the circulation file. The primary requirement in selecting the sample is that each record in the circulation file have an equal chance of being included in the sample. For most academic libraries the circulation system is maintained in a computer database, and generally the records are consecutively numbered. For example, record numbers may be from 1 to 840,992, or the records may be numbered from 100,948 to 941,940. Lotus 1-2-3, Excel, and other computer software programs have the capacity to generate a listing of random numbers. Some programs allow the user to enter the number of the first and last record, and others assume the records are numbered beginning with zero. Alternatively, a librarian may use systematic sampling. Systematic sampling is a method of selecting a sample in which every nth item in the population is selected from one or more random starting points. A librarian using systematic sampling must ensure that the items in the population are in random order.

Step 8. Examine the Items in the Sample

In this example, the objective of attribute sampling is to assess the effectiveness of the circulation system by determining the maximum portion of the circulation records that are incorrect. Each record in the sample should be examined individually to determine if it is represented by a book item "on loan" rather than on the shelf. If the record incorrectly indicates that a book is "on loan" when in fact it is not, then a deviation has occurred.

Since items "on loan" are not readily available for examination, the librarian must necessarily either wait until the

item is returned on the due date or recall the item for examination. This decision depends on the duration of the loan period. For example, recalling all items with loan periods exceeding three weeks may be expedient, while allowing those with shorter periods to continue circulating until the appointed due date. Holds can be placed on the sample items so they can be readily identified upon return.

Step 9. Evaluate the Sample Results

To estimate the population occurrence rate, divide the number of incorrect records found in the sample by the sample size. If 1 incorrect record were found in the sample of 300, the sample occurrence rate would be 0.33 percent (1/300). Tables are available to estimate the population's upper deviation rate. Table 2 presents data for estimating the sample results with 95 percent reliability. Tables for evaluating results at 90 and 99 percent reliability are also available.

By locating the actual sample size (300) at the left of table 2 and looking across the row to the column indicating the number of deviations found in the sample (1), the librarian may then find the computed upper deviation rate (2 percent) at the top of this column. The librarian may conclude with 95 percent confidence that maximum percent of incorrect records in the circulation file is 2 percent.

Comparing the computed upper deviation rate (2 percent) with the tolerable deviation rate (4 percent) indicates that the sampling exercise substantiates the prescribed expectation that no more than 4 percent of the records are incorrect. If the computed upper deviation rate is less than or equal to the tolerable deviation rate, the librarian may conclude that the circulation system is performing satisfactorily. If, on the other hand, 4 incorrect records had been found in the sample, using table 2, the computed upper deviation rate would be 5 percent, which is in excess of the tolerable rate.

Conclusion

Knowing the accuracy of the circulation system can have a major impact on collection development decisions. If, for example, a library is conducting an inventory audit of the collection, some books would necessarily be found to be out "on loan." If the circulation system has been verified to be of sufficient accuracy, then those books "on loan" can be accepted as accounted for without having to verify each individual item. Dougherty and Heinritz have indicated how attribute sampling might be useful for analyzing characteristics of "books that have been in circulation for 14 days or more," thereby suggesting that attribute sampling procedures can be profitably applied to collection management issues.[2] Attribute sampling, like any statistical method, has many dimensions, but it is particularly well adapted to analyzing the kinds of large populations frequently found in libraries.

References and Notes

1. As discussed in Donald M. Roberts, "Sample Size Determination for Attributes," *Journal of Accountancy*, June 1975, 46–47, the binomial distribution is appropriate for estimating proportions when the frequency is very large. The methodology assumes a normal distribution.
2. Richard M. Dougherty and Fred J. Heinritz, *Scientific Management of Library Operations* (Metuchen, N.J.: Scarecrow, 1982), 212.

Suggested Readings

Dougherty, Richard M., and Fred J. Heinritz, with Neal K. Kaske. *Scientific Management of Library Operations*. Metuchen, N.J. and London: Scarecrow, 1982.

Guy, D. M., and D. R. Carmichael. *Audit Sampling: An Introduction to Statistical Sampling in Auditing*. New York: Wiley, 1986.

Powell, Ronald R. *Basic Research Methods for Librarians*. 2d ed. Norwood, N.J.: Ablex, 1991.

Roberts, D. M. *Statistical Auditing*. New York: American Institute of Certified Public Accountants, 1978.

Simpson, I. S. *Basic Statistics for Librarians*. 3d ed. London: Library Association, 1988.