

# Performance of the Half-Open Interval Missed Housing Unit Procedure

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The half-open interval procedure seems to offer an inexpensive method of reducing undercoverage in housing unit frames during data collection. Interviewers check the areas near their selected cases, and, if they find any units missing from the frame, give them a chance of selection. However, the effectiveness of the method in the field has not been tested. This paper reviews how the procedure should work and presents evidence from two surveys about its performance in practice. We show experimentally that the procedure often fails to reduce undercoverage and can introduce overcoverage. We conclude with thoughts about the appropriate role for the half-open interval procedure in household surveys in the future.

**Keywords:** undercoverage, housing unit frames, half-open interval, listing, interviewers, incomplete frames

## 1 Introduction

For forty years, most large face-to-face surveys in North America used traditional listing to create housing unit frames. Listers traveled to selected areas and created a list of all housing units. Traditionally listed frames tend to undercover low-income and rural areas, as well as units in multi-unit buildings, renter-occupied units and vacant units (Subcommittee on Survey Coverage 1990; Childers 1992; O'Muircheartaigh et al. 2006, 2007). Recently, researchers have turned to dependent listing, which involves updating an initial frame in the field-adding missed units and deleting inappropriate units. The initial frame may come from an external database or from a previous traditional listing. However, dependent listing suffers from confirmation bias, a tendency to fail to correct errors on the initial frame (Eckman and Kreuter 2011).

To reduce the risk of undercoverage, surveys often use the half-open interval procedure, which instructs interviewers to check between the selected unit and the next unit on the frame for unlisted units. Any missed units found are given a chance of selection and in this way the coverage of the frame is improved. The half-open interval procedure is mentioned in many of the foundational survey sampling texts, including Deming (1960:128), Kish (1965:341-342), and Groves (1989:127-128). Ongoing surveys which use the procedure include the Health and Retirement Survey (Heeringa and Connor 1995), the National Survey of Drug Use and Health (Morton et al. 2006), the General Social Survey (Harter et al. 2010), and the National Survey of Family Growth (Lepkowski et al. 2010). To our knowledge, the half-open interval method is not used in Europe, where housing unit listing itself is rare, but Schnell (2008) recommends its use to correct

undercoverage in commercially available building frames in Germany.

Although the half-open interval procedure is well-known and commonly used, no previous studies have explored its performance. Our suspicions about the procedure's effectiveness were raised during the 2002 round of the General Social Survey (GSS), which used the half-open interval method to repair undercoverage in a ten-year-old traditionally listed frame.<sup>1</sup> Yet from the 4890 fielded cases, interviewers found only 36 missed housing units, a rate of less than one per hundred.<sup>2</sup> This finding led us to conduct a formal experiment of the half-open interval procedure's effectiveness. Before we discuss the design and results of the experiment, however, we explain in detail how the procedure should work under optimal conditions.

## 2 Mechanics of the Half-Open Interval Procedure

The half-open interval procedure asks interviewers in face-to-face surveys to check for missed units while they are in the field doing interviewing work. Each selected case is associated with another address, called the *check address*, which is usually the next unit on the frame in listing order. The interviewer checks for any missed units between the selected address and its associated check address, in two steps. The interviewer first looks for missed units within the selected address itself, for example, a basement apartment.

<sup>1</sup> NORC, which carries out data collection for the GSS, creates a national sample every ten years, after the decennial census data are released. The 2002 survey was conducted too early in the decade for the new national sample based on the 2000 census, and used the 1990 national sample, which was selected and listed in 1992 (Tourangeau et al. 1993).

<sup>2</sup> The number of found units here does not include any cases found and not selected for the survey (we explain below why subsampling of units is sometimes performed), which biases the count of found units downward slightly, but not so far that the number of found units would reach the expected level for a ten-year-old frame.

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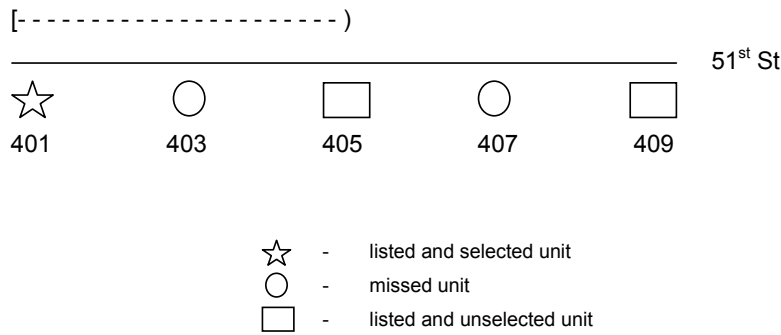


Figure 1. Example Street, Showing Listed Units and Missed Units

She then checks for units in the interval from the selected unit and up to, but not including, the check address.<sup>3</sup>

Table 1 and Figure 1 present a simple case. Table 1 shows the listed frame for this street segment, which contains three housing units, the first of which has been selected for the survey. In truth, the street segment contains five units, as shown in Figure 1. The selected unit, 401 51<sup>st</sup> Street, is indicated by a star, and the next unit on the frame, 405 51<sup>st</sup> Street, is indicated by a square. The half open interval, shown in the figure, includes all missed units at 401 51<sup>st</sup> Street, as well as all units between this address and 405 51<sup>st</sup> Street. In this figure, the interval does contain a missed unit, indicated by a circle: 403 51<sup>st</sup> Street. The interviewer should notice and record this missed unit.

Table 1: Example Frame

Order	Housing Unit Address	Selected?
1	401 51 <sup>st</sup> St	Yes
2	405 51 <sup>st</sup> St	No
3	409 51 <sup>st</sup> St	No

There is another missed unit in Figure 1, between addresses 405 and 409. This unit will not be found by the interviewer, because it does not lie in the half-open interval associated with her selected case. However, the unit does have a chance to be covered: it would be picked up via the half-open interval procedure if unit 405 were selected. In this way, both missed units are covered when the procedure is used.

The procedure can also handle more complicated situations such as multi-unit buildings and demolished units. If the selected unit is apartment 4 and the next unit on the frame is unit 5, the interviewer should check within unit 4 and between units 4 and 5 for any additional units. If the last unit in a multi-unit building is selected, she should check within that unit and between the unit and the first unit of the next building. If the check address has been torn down, its lot should still serve as the end point of the interval. If the selected unit itself was demolished, it will be marked as not eligible for the survey, but the half-open interval procedure should still be performed.

The creation of the half-open intervals themselves follows listing order: listers travel around each block clockwise,

listing the units over their right shoulders (Kish 1965:334; Survey Research Center 1969; Survey Research Center 1976). When a unit near a corner is selected, the check address will be around the corner in the clockwise direction. If the selected unit is the last unit listed on the block, the interval runs from that unit around to the first unit on the block. If there is only one address on a block, that unit must serve as its own check address, and the interviewer should check the entire block for missed units. Half-open intervals never cross block boundaries.

Of course, providing full coverage for the missed units requires not simply identifying them, but also giving them a chance of selection. When only one or a few missed units are found in an interval, all are brought into the sample, which gives the missed units the same probability of selection as the selected case with they are associated (Kish 1965:340). If the initial sample of housing units is equal probability, the units found by the procedure have this same probability of selection.

When many units are found in a given interval (for example, an entire multi-unit building), it is not practical to select them all, and the missed units are subsampled. The National Survey of Family Growth (NSFG) subsamples whenever more than two units are found in an interval (Lepkowski et al. 2010). Kish (1965:340) suggests subsampling when more than five are found. Subsampling disrupts the carefully designed housing unit selection probabilities, but has practical benefits and still provides full coverage.

The half-open interval procedure cannot handle all situations, however. Blocks with no units on the frame will never be checked for missed units, due to the block-centric nature of the procedure. Housing units that do not fall clearly in the interval associated with any one case, such as those on a new street which subdivides a block, may also not be found, even if the procedure is implemented without error. Nevertheless, if missed units such as those shown in Figure 1 are brought into the frame, but those on previously empty blocks and on new streets are not, then the procedure should repair some undercoverage. Unfortunately, our experimental evi-

<sup>3</sup> Some surveys, such as the National Health Interview Study, perform only the first step, the within-unit check (United States Census Bureau 2009).

dence suggests the procedure is not implemented correctly by interviewers.

### 3 Design of the Experiment

To formally investigate the performance of the half-open interval procedure, we conducted an experiment in conjunction with an ongoing face-to-face study at the National Opinion Research Center (NORC). We seeded missed units in the half-open intervals and observed whether the interviewers found and recorded them. We carried out this experiment in the context of the Making Connections survey, which NORC conducts for the Annie E. Casey Foundation. The foundation awarded grants to community organizations to improve the lives of families and children in disadvantaged urban neighborhoods in the U.S. NORC has conducted several face-to-face and telephone surveys in each community to evaluate the impact of the grants on the lives of residents in the neighborhoods.

The experiment was conducted in the first wave face-to-face survey in targeted neighborhoods of Seattle, Washington; Providence, Rhode Island; and Oakland, California. The housing unit frame for these surveys was derived from the Delivery Sequence File (DSF) maintained by the United States Postal Service and available through third-party vendors. The lists we used in this study came from ALC. We purchased all addresses in the ZIP codes that covered the survey areas and used MapMarker GIS software to assign them to blocks. Those that fell inside the intervention neighborhoods became the surveys' frames. (For more on the assignment of addresses to Census geographies via GIS software, see Zandbergen 2008; Eckman and English 2011).

In each site, we selected a sample of blocks for additional frame construction work.<sup>4</sup> Experienced listers used dependent listing to update the DSF-derived frame, adding units that were missing and removing those that did not exist or were outside of the segment. This process resulted in a housing unit frame within these blocks that was in listing order.<sup>5</sup>

From this dependent listed frame, 918 housing units were selected for the Making Connections survey. From these, we selected 140 cases into the missed unit experiment. The cases selected for the experiment were of two types. First, all selected housing units that immediately preceded those housing units which were added during the dependent listing were selected for the experiment. For example, say 611 Elm St was on the initial address database, but 613 was not and was added by the lister during dependent listing. Then 611 Elm St (if it was selected for the Making Connections survey) was selected into the experiment. The reason for selecting all of these cases was to see if the housing units that were added to the frame by the dependent lister (such as 613 Elm St) could also be picked up with the half-open interval procedure. There were 21 such Type 1 cases selected for our experimental manipulation across the three sites. The second type of unit selected for the experiment came from the other cases sampled for the survey: 119 were selected into the experiment using systematic sampling on a

Table 2: Sample Sizes in Survey and Experiment, by Site

Site	Survey	Experimental	
	Sample Size	Sample Size	Type 1 <sup>a</sup> Type 2 <sup>b</sup>
Seattle	456	53	15 38
Oakland	200	42	3 39
Providence	262	45	3 42
Total	918	140	21 119

<sup>a</sup> True check addresses missing from the database and added by lister

<sup>b</sup> True check addresses already on the address database

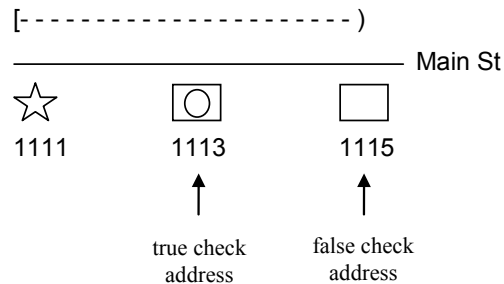


Figure 2. Illustration of Half-Open Interval Experiment: True Next Address Suppressed to Create a Missed Housing Unit (Symbols follow Figure 1)

geographic sort order within site. Table 2 gives the number of cases of each type selected in each site.

For each of the 140 cases in the experiment, we manipulated the check address to introduce a missed unit. Rather than giving the interviewers the true check address, we gave them the one after that in listing order. If the original dependent listing was correct, this manipulation should introduce a missed unit. Each true next address should have been found by the interviewers as a missed housing unit, as it should lie between the selected address and the false next address. See Figure 2 for an illustration of the suppression of the true next address. Check addresses were assigned to the 778 non-experiment cases in the usual way.

All 918 cases were fielded for the Making Connections survey. Data collection in each site was via paper and pencil face-to-face interviews in May and June of 2003 (Seattle) and August to December 2003 (Providence and Oakland).

The interviewers for the study were recruited using usual NORC methods, which at that time included advertisements in newspapers and flyers in the targeted neighborhoods. The local organization which received the grant from the Annie E.

<sup>4</sup> The number of blocks selected for dependent listing in each site was related to the availability of field staff.

<sup>5</sup> In the blocks not selected for dependent listing, the geocoded address database without field updating served as the housing unit frame, after some additional work to deduplicate the two frames. These un-updated blocks were part of the Making Connections survey but not part of the experiment we describe in this paper. We will not discuss these blocks or the cases selected from them further.

Table 3: Suppressed Units Found by Half-Open Interval Procedure, by Site

Site	Exper. Cases		Type 1 <sup>a</sup>		Type 2 <sup>b</sup>	
	Count	Found	Count	Found	Count	Found
Seattle	53	6 (11.3%)	15	0 (0%)	38	6 (15.8%)
Oakland	42	6 (14.3%)	3	0 (0%)	39	6 (15.4%)
Providence	45	3 (6.7%)	3	0 (0%)	42	3 (7.1%)
Total	140	15 (10.7%)	21	0 (0%)	119	15 (12.6%)

<sup>a</sup> True check addresses missing from the database and added by lister

<sup>b</sup> True check addresses already on the address database

Casey Foundation was also involved in the recruitment of interviewers. All applicants were subjected to standard NORC interviewer screening procedures. While we did not collect data on the interviewers, it is likely that most of them did not have previous interviewing experience, given the need for many interviewers in small neighborhoods.

Interviewers were trained in-person in all aspects of the survey protocol over three days by experienced NORC field supervisors and central office staff, most of whom did not know about the experiment. The training contained one 30-minute module on checking for missed housing units in the half-open interval.<sup>6</sup> The interviewers were told that the cases they found in the intervals would be sampled and some would be returned as additional cases to work. They were not informed about the experiment or the manipulation of the check address.

Usual NORC protocol calls for interviewers to immediately add housing units that they find inside the half-open interval to their assignment (unless more than three are found, in which case three are selected in consultation with the central office). In this study, however, interviewers simply informed their supervisors, via paper forms, when they found missed units in the half-open intervals. This change in procedure was necessary to guarantee that the units we had suppressed, the true check addresses, were not selected by the interviewers and brought into the sample, which would have given them two chances of selection.

#### 4 Results of the Experiment

Of the 140 cases selected for the experiment, interviewers found missed units associated with only 15 (10.7%) of them, as shown in Table 3. Interviewers found the highest percentage of suppressed units in Oakland (14%) and the smallest in Providence (7%). In none of the sites did the interviewers find missed units associated with any of the Type 1 experimental cases, despite the fact that a lister using dependent listing had found and added those same units just a few weeks previously.

To ensure that nothing had gone wrong with the experiment, we performed a manipulation check in the Seattle site. One interviewer returned to each of the 47 experimental cases where no missed unit was reported to check whether the selected address, the true next address and the false next address all existed and were in the expected order: that is, whether the truth on the ground looked like Figure 2, as

intended. This check was performed immediately after the close of data collection.

Table 4: Results of Manipulation Check on Experimental Cases Where Suppressed Unit Not Found, Seattle Only

Result of Check	Count	Percent
All housing units in order	37	78.7%
Additional missed units in interval	4	8.5%
False check address not found	6	12.8%
Total	47	

The results of the manipulation check are in Table 4. In the majority of the cases in which the interviewer did not report a missed housing unit, the units were in the expected order, and the true next address should have been reported as a missed unit. In four cases, there were additional missed units in the interval, in addition to the true check address, that the interviewers should have reported. In six cases, the false check address could not be located.

To better understand why some suppressed units were found and others were not, we can look at the available characteristics of the selected cases at the closed end of the half-open interval.<sup>7</sup> Although the sample sizes are very small, interviewers were more likely to successfully conduct the half-open interval procedure when the selected case with which the interval is associated was itself an eligible housing unit and when it completed the interview. There are no meaningful differences in the share of the found and unfound cases that are in multi-unit buildings (data not shown).

The experimental design required that interviewers report the units they found to a supervisor, who passed the data on to the central office. To hide the experiment from the interviewers and supervisors, they followed this procedure for all cases selected for the survey, whether part of the experiment or not. Because of this process, we were also notified of units

<sup>6</sup> Thirty minutes of training on the half-open interval procedure is standard for NORC surveys. The National Survey of Family Growth also provides 30 minutes of training on this topic to new interviewers and follows up soon afterwards with refresher training by phone (personal communication with Nicole Kirgis, Survey Research Center).

<sup>7</sup> Unfortunately, we do not have data about the suppressed units, the true check addresses, themselves.

Table 5: Missing Units Found by Half-Open Interval Procedures Outside of Experiment, by Site

Site	Non-Experimental		Duplicates with Frame	
	Cases	Units Found	Count	Percent of Found
Seattle	403	9	5	55.6%
Oakland	158	15	10	66.7%
Providence	217	31	30	96.8%
Total	778	55	45	81.8%

found by interviewers in the half-open intervals associated with the cases which were not selected into the experiment. We deduplicated all of the missed units reported by the interviewers against the frames to make sure no units which had already had a chance of selection were reported as missed. This step is usually not possible when interviewers select the missed units in the field, without central office involvement. We are not aware of any previous studies that have performed this deduplication check.

Table 5 presents the results of this check. Overall, interviewers found 55 missed units associated with the 778 cases not selected into the experiment. However, 81.8% of the units that the interviewers reported as missed were already on the housing unit frame.<sup>8</sup> Had the interviewers selected these units, they would have introduced overcoverage.<sup>9</sup>

## 5 Discussion and Conclusion

This experiment resulted in two main findings. The first is that interviewers do not find missed housing units with the half-open interval procedure that they should find (Table 3). The second is that when they do report missed units, they are often making errors of overcoverage (Table 5).

The interviewers' low rate of success in finding the planted missed units suggests that they simply fail to conduct the half-open interval procedure. However, the evidence that they do find units which were not missed does not fit this interpretation. One explanation that can account for both findings is that interviewers strategically report missed units when it is in their interest. Reporting missed housing units leads to a larger workload for interviewers, and may increase their pay, especially if they are paid by the hour. However, finding these units also adds to their response rate targets, and may increase pressure from their supervisors to complete interviews. When conducting the half-open interval procedure, interviewers can observe the missed housing units before they report them, and can form expectations about the cases' likelihood to respond. Cases that seem more cooperative may be more likely to be added, and vice versa. Interviewers may be using the eligibility and response behavior of the selected case as a proxy for the missed case, which would explain the tendency to find the planted missed units when the selected case is itself eligible and a respondent. We cannot test this hypothesized mechanism with the data at hand, but such correlations between coverage propensity and response propensity have been reported in other studies (Manheimer and Hyman 1949; Boyd and Westfall 1955; Hainer 1987; Eyerman et al. 2001; Eckman 2010).

Additional training on the half-open interval procedure may be able to overcome the poor performance we detected in this study. However, additional training should be justified by a total survey error and cost perspective. This training time would come at the expense of other modules or would add to total training time and costs. It is not clear that the housing units interviewers would add to the sample, if they conducted the procedure more thoroughly, would be different enough, and numerous enough, to affect survey estimates. Because so few cases are added to the sample via the half-open interval procedure, we do not have enough data to evaluate its effects on total survey error.

We recognize several shortcomings of the research presented here. Our experiment involved only three sites, all disadvantaged urban neighborhoods, and small sample sizes. It is possible that a larger nationally-representative study would come to different conclusions. This experiment also used mostly new interviewers. Though they received standard training on the half-open interval procedure, it is possible that experienced interviewers would have found more of the suppressed units. However, our experience with the 2002 GSS, a national survey using many experienced interviewers, partially addresses both of these concerns.

Many large U.S. face-to-face surveys are responding to cost and time pressures by moving to frames derived from the Postal Service's DSF without in-field updating via dependent listing. A good deal of recent research has explored the coverage of these frames, and the evidence points to systematic undercoverage of rural areas and new construction (Iannacchione et al. 2003; O'Muircheartaigh et al. 2002; Staab and Iannacchione 2003; Dohrmann et al. 2006; O'Muircheartaigh et al. 2006; Dohrmann et al. 2007; Iannacchione et al. 2007; O'Muircheartaigh et al. 2007; Montaquila et al. 2009; English et al. 2010). These frames could also benefit from a procedure to find and cover missed housing units. Unfortunately, the only ordering on the DSF is the carriers' delivery routes, the sequence in which the mail is delivered. These routes are not in listing order and may con-

<sup>8</sup> The Providence row in Table 5 is a bit of a special case. In this site, an interviewer found 30 missed housing units in the interval attached to one selected case, all in one apartment building. This building was already on the frame and these units were removed by the duplication check. Thus the rate of finding missed units is high in the Providence site, and the duplicate rate is also high, due to just this one anomalous situation.

<sup>9</sup> Note that the ten cases which survived the deduplication check may also have been overcovered, if they were not truly inside the assigned half open intervals. We were not able to perform this check.

tain discontinuities. McMichael et al. (2008) discusses practical difficulties in implementing a half-open interval procedure in the field with a DSF-based frame. Given the errors of overcoverage and undercoverage we detected in this study using well-ordered frames, we are not optimistic about the use of the half-open procedure with DSF frames.

We do not find the performance of the half-open interval procedure satisfactory. Its failure to repair undercoverage is one problem, but its introduction of overcoverage is another serious concern. We recommend that surveys not use the procedure unless working from a frame with a good deal of undercoverage which is believed to lead to undercoverage bias. In such cases, surveys should incentivize interviewers to find missed units, perhaps by planting missed units that interviewers can be expected to find. We also strongly recommend that any use of the half-open procedure include a deduplication step, such as the one we used here, to prevent interviewers from adding units to the sample that are already on the frame and had a chance of selection. These two steps add to the complexity of the half-open interval procedure, but should address the concerns raised in this study.

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