



2001 CENSUS: ONE NUMBER CENSUS EVALUATION REPORT

Project Objective

The objective of the One Number Census (ONC) was to provide a methodology and process to identify and adjust for the number of people and households not counted in the 2001 Census. The extent of this underenumeration was identified using a large survey (the Census Coverage Survey – CCS) covering approximately 10,000 households. Statistical techniques were then used to produce an adjusted database from which the final Census results were produced. The One Number Census results provide a new 2001 benchmark for the annual population estimates series published by Northern Ireland Statistics and Research Agency (NISRA).

This report reviews and evaluates the methodology, processes and operations of the ONC. It also provides a preliminary overview of the wider strategic questions of whether the ONC strategy was the correct one to adopt and discusses the most and least successful aspects of the strategy.

While the ONC project was designed and implemented across the whole of the UK, this report evaluates the success of the process in Northern Ireland only. While some of the lessons common across the UK are discussed in this paper, the emphasis is on issues specific to Northern Ireland.

Background

Every effort is made to ensure everyone is counted in a Census. However, no Census is perfect and inevitably some people are missed. This underenumeration does not usually occur uniformly across all geographical areas or across other sub-groups of the population such as age and sex groups. Therefore, it is accepted best practice to assess the extent of any underenumeration, usually by means of a post-enumeration survey. Non-response to Censuses and surveys is increasing in much of the developed world so assessing the scale and type of underenumeration is becoming more important.

In the 1991 Census, the post-enumeration survey (The Census Validation Survey – CVS) suggested that overall less than one per cent of the population were missed. However, it was recognised that the survey did not identify the full extent and distribution of the underenumeration as its main focus was the accuracy of responses to specific questions. Following further work, the level of coverage achieved in the 1991 Census was retrospectively estimated at 98%. As in previous Censuses, the outputs from the 1991 Census outputs were not adjusted for under-enumeration, but the mid-year population estimates series (the MYEs) was adjusted. Differences in the published population statistics for 1991, 1.578 million enumerated in the Census and 1.607 million in the mid-year estimate, are mainly due to the final estimate of Census underenumeration.

During the extensive consultation carried out prior to the 2001 Census, users of Census data were clear that they wanted one definitive set of estimates from the Census which were adjusted for the estimated underenumeration, such that Census statistics were consistent with the MYE series. The ONC project provided a way to address this issue, incorporating methodologies to add imputed households found by the Census Coverage Survey (CCS) and adjust Census responses for estimated underenumeration. As the mid-year population estimates were directly based on these ONC population estimates, this produced a clear and simple link between Census statistics and population estimates.

Methodology

The ONC methodology was devised by ONS in consultation with experts from Southampton University. The ONC Steering Committee, which included a number of external experts and representatives, oversaw and guided the development of the methodology and management of the project, while a One Number Census Project Board oversaw the day to day progress of the project. NISRA was represented on both the project board and the steering committee. The key stages and processes used to achieve the ONC aims are summarised below, while fuller details of the methodology can be found at www.nisra.gov.uk/Census/Censusmethodology\onenumberCensus.htm. All other committee papers, detailing all the methodological research undertaken throughout the project can also be found on the National Statistics website; these include a paper specifically on the design of the ONC in Northern Ireland. There were no fundamental differences in the designs used in Northern Ireland, Scotland and England & Wales.

Key stages of One Number Census methodology

Throughout the UK, the ONC approach was applied separately in geographical areas (termed Estimation Areas) containing approximately 500,000 people. Northern Ireland was divided into three areas, namely, Belfast, west of NI and east of NI. These areas, which each composed of aggregates of Local Government Districts (LGDs), had populations of 275,000, 600,000 and 700,000 respectively.

Census Coverage Survey (CCS)

In each of these EAs, a sample of postcodes was drawn for targeted CCS interviews. The aim was to identify and interview all households within each postcode. Underenumeration has historically been observed to vary spatially with area characteristics, for example by urban / rural, level of deprivation and community background. The design of the 1997 Census Test had been stratified by these three factors and, accordingly, the CCS sample was stratified according to the response rates observed in the 1997 Census Test, with each EA divided into three strata broadly corresponding to high, medium and low expected response rates. Each stratum was analysed separately, and then the strata aggregated.

The CCS began three and a half weeks after Census Day. To maintain independence, CCS interviewers were not provided with the Census address lists for their areas. Maps of the postcodes selected for the CCS were supplied to interviewers and they attempted to interview every household at every address within the postcode, in effect re-enumerating the area. Comprehensive training was provided for the 100 CCS interviewers, who normally worked on the NISRA social surveys conducted by NISRA's Central Survey Unit (CSU).

The ONC method of estimation is based on an assumption of independence between the Census and the CCS, and considerable effort was made to ensure operational independence between the Census and CCS. For example,

- the sample postcodes were kept confidential;
- Census managers were not able to work on the CCS;
- CCS managers were not allowed to work on the Census; and
- CCS interviewers were drawn from NISRA's Central Survey Unit rather than Census enumerators.

Matching the CCS and Census

The returned CCS records were matched with those from the Census using a combination of automated and clerical matching. The matching process had to be as accurate as possible because the number of mismatches has a direct impact on the final estimates. The five key stages of the matching process for each unique postcode were: Exact Matching; Probability Matching; Clerical Resolution; Clerical Matching and Quality Assurance (including a double matching strategy). Further detail of the matching algorithms can be found in the ONC Steering Committee paper [SC9814](#).

Estimation of Populations for each EA and LGD

Populations for each EA, by age and sex, were estimated using a combination of

standard statistical techniques. Estimates of the total population in postcodes covered by the CCS were based on a methodology known as Dual System Estimation (DSE). It was inevitable that some households and people would be missed by both the Census and CCS. The DSE provides an estimate of the number of households and people missed by both the Census and the CCS, using - as input - the known numbers of people counted in both the Census and the CCS, those counted only by the Census and those counted only by the CCS. Linear regression models were developed to measure the relationship between the Census counts and the dual system estimates in the postcodes covered by the CCS, and these models were used to estimate underenumeration in the areas where the CCS was not undertaken. These estimates were made separately for each age-sex group in each stratum. See Steering Committee Papers [SC0003A](#) and [SC0003B](#) for more detailed methodology.

Use of the DSE requires a number of conditions to be met to ensure that error in the estimates is minimised. For an unbiased estimate, independence is required between the Census and the CCS. As described above, the Census and the CCS were made operationally independent. Simulation work was undertaken prior to the Census to examine the impact if there did prove to be some 'dependence'; these simulations demonstrated that, even for quite extreme levels of dependence, the impact on the population estimates is small provided both the Census and CCS have high response rates. Details of this research can be found in Steering Committee paper [SC0103](#).

Small area estimation techniques were then used to estimate LGD populations by age and sex, constrained to the EA populations by age and sex described above. One of Northern Ireland's EAs (Belfast) was itself an LGD and this step was necessary only in the remaining two EAs that consisted of more than one LGD. With the exception of a few large LGDs, LGDs did not contain sufficient CCS postcodes to enable accurate direct estimates of underenumeration to be made (during the development stage it had been decided that it was not practically feasible to undertake a CCS of the magnitude that would be required to provide direct estimates at LGD level). The two EAs (East of NI and West of NI) were each split into 2 sub-areas corresponding to the NUTS III areas for Northern Ireland, where each sub-area contained typically 6 or 7 LGDs. Within a sub-area, common underenumeration models were applied, and the LGD population figures flowed naturally from the analyses. The implicit assumption is that a single model applies to each LGD within the sub-area. See Steering Committee Papers [SC0003A](#) and [SC0003B](#) for more detailed methodology.

Imputation of records for households and individuals

Records for households and individuals estimated to have been missed by the Census were imputed to produce a complete set of responses for each household and person, whether directly responding or imputed by the adjustment for underenumeration. The ONC imputation process had three main stages:

- imputation of missed households (and the individuals within them); imputed households were geographically placed into either a physical property identified by Census enumerators where no Census response had been received, or into areas where similar households already existed;
- imputation of missed individuals, (i.e. individuals missed from households where the household had been counted by the Census). Donor individuals for each type were selected and used to impute individuals into the types of households that were likely to have missed people from their Census return. This process added people to real households; and
- calibration to estimates of the population. This ensured that the overall distribution of imputed individuals and households was the same as the final ONC estimates of households and individuals.

The result was an individual level database that represented the best estimate of what would have been collected had the 2001 Census not been subject to underenumeration. Tabulations derived from this database automatically include compensation for underenumeration measured by the CCS, for all variables and all levels of geography. The detailed methodology can be found in Steering Committee Paper 'A Donor Imputation System to Create a Census Database Fully Adjusted for Underenumeration' [SC9908](#).

EA/LGD Quality Assurance

An extensive quality assurance process was undertaken to ensure the overall ONC population estimates were coherent, consistent with other relevant sources, and of the right overall magnitude. This involved a series of quality checks at LGD, EA and Northern Ireland levels aided by data, grouped by age, sex and geography, drawn from the annual mid-year population estimates produced by NISRA and aggregate level administrative data. The administrative data sources and those supplying them were: state pension and child benefit (Department of Social Development); children at school (Department for Education); students in further and higher education (Department for Education); NI Central Health Index (NI Department of Health and Social Services and Public Safety).

The various data sources were used to calculate a range of plausible values for the number of people of each sex within five-year age groups in each geographical area. The ONC population estimates were compared with these 'diagnostic ranges'. A range of descriptive information was also gathered to give a fuller picture of the area under consideration, for example information about the fieldwork for the Census and the CCS. Demographic ratios such as the number of males to females were also calculated. All of this information was presented to Quality Assurance panel meetings consisting of specialists from NISRA, GROS, ONS and Southampton University. They considered the evidence for each EA and LGD before either accepting or rejecting the estimates. Each Census Office

had its own QA panel, with representatives of the different offices sitting on each other's panels to ensure consistency.

There was a predetermined contingency strategy in the event of the ONC estimate for any EA or LGD being rejected. Information from similar LGDs which had already passed the QA process was used to make adjustments. This process is called 'borrowing strength'. The similar LGDs, or borrowing strength areas, for each LGD were set out and agreed as part of the ONC consultation. These strategies are covered in detail in the paper 'ONC Quality Assurance and Contingency', but they were not required or used for Northern Ireland EAs.

The administrative sources were not used to replace or adjust Census estimates. Rather, the role of the administrative sources was to confirm that the Census estimates were plausible.

National Quality Assurance and Dependency

As outlined earlier, underpinning the ONC methodology is the assumption of independence between the Census and CCS. For the ONC to work optimally, there should be no systematic relationship between the chance of a household or individual being enumerated in the Census and of being captured by the CCS. The national quality assurance indicated a degree of dependence sufficient to warrant adjustment. There was a predetermined UK contingency strategy to be used for such an eventuality, adjusting the Dual System Estimator with plausible target sex-ratios, or other demographic information. However, the quality assurance process had shown changes in the observed sex ratios over time in the Censuses of 1971, 1981, 1991 and 2001, so that it was concluded that it would not be appropriate to base an adjustment on an assumed sex ratio. Alternative methods of adjustment were investigated and a method, using a household-level count, was developed and implemented. The data sources used to estimate dependence varied in quality across the UK and slightly different methods were used by the three Census Offices. A paper outlining the Northern Ireland analysis can be found here.

Consultation

It is important that users of Census data have confidence in the estimates of the population produced by the One Number Census. In arriving at the ONC methodology and processes, acceptance was sought in a number of ways, including:

- the Steering Group which included key representatives from the academic and user community and interested experts;
- the consultation process with Census user groups;
- a 'Series A' Royal Statistical Society (RSS) paper (Brown et al, 1999);

- several RSS seminars;
- the Spring 1998 Census Consultation paper '2001 A One Number Census';
- the Spring 1999 Consultation paper 'A Guide to the One Number Census';
- a workshop hosted by ONS devoted to the One Number Census project in May 1998; and
- special workshops held in conjunction with ONS Census Output Consultation Roadshow meetings.

In Northern Ireland, the ONC process was publicised through, among other events, a Census roadshow, a meeting of the local group of the Royal Statistical Society and a presentation at the annual Conference on Applied Statistics in Ireland (CASI).

Assessment and Lessons Learnt

Operational and Organisational

Operationally the ONC was a major success. A new and ground-breaking methodology was successfully implemented and for the first time (both here or anywhere in the world) all Census results were successfully adjusted for measured underenumeration. Three key statistical elements (matching, estimation and imputation) were developed and operated to a high degree of professionalism.

Operational difficulties with other aspects of the Census, such as the outbreak of Foot and Mouth disease and delays in receipt of postback forms, are described in the other relevant evaluation reports.

It is estimated that 95 per cent of the population were covered in completed Census returns. It has been estimated, approximately, that a crude adjustment based on populating dummy forms for households believed by enumerators to be occupied households, might have increased coverage to around 98 per cent of which 3 per cent were estimated. Without the ONC, this additional 3 per cent would have been estimated by simply factoring up the enumerated population and not taken account of the likely differences between the enumerated and non-enumerated populations. It is clear that the ONC has enabled a more accurate population count giving a more representative picture of the characteristics of the population.

There is a perception amongst some users that the ONC led to a much longer timetable and to the results being delayed. The ONC process added around two months elapsed time to the original timetable. The overwhelming view from users

during the consultation phase was that this was an acceptable length of time to wait for the higher quality data afforded by the ONC process.

However, there were unforeseen delays within the ONC process. In implementing any major innovation, there is always a greater risk of the unexpected cropping up and there were two such major occurrences on the ONC. One was when the imputation method caused inappropriate 'spikes' which had to be eradicated, and the other was the need not just to adjust for dependency but to develop an alternative adjustment method when the contingency strategy proved unsuitable. Both of these took significant time and resource to resolve. Although they did not cause additional delays (because of staff's commitment and willingness to work many extra hours to make the innovative methods a success), the former resulted in data already issued (Key Statistics at Ward level) to be marginally revised and reissued. Two unexpected major hitches is probably less than might be expected for the level of innovation involved but it does illustrate the need to build significant contingency into the timetables for innovative processes, to a greater extent than in this case. In hindsight, it may be that the additional two months in the timetable was not long enough to allow sufficient contingency time for the unexpected.

A related lesson is that the ONC system development was carried out too late because the methodology was not finalised until a late stage - often the case with new, innovative methodologies. The consequence was insufficient time to develop and test the system fully before live running began. The resources that had been estimated to be needed for live running (at ONS) were not enough; staff were seconded from other areas to address this. The seconded staff had to be trained but were generally able to pick up the procedures quickly, due to the clarity of the system and the knowledge of the core team. Within NISRA, the small numbers of statistical staff struggled to cope with the peak flow of results when at some stages all three EAs were going through the ONC process. More fully defined and developed processes earlier in the cycle would have enabled the statistical staff to plan further ahead and prepare for the required analyses.

The Matching team (matchers and expert matching quality assurers) was all NISRA staff. Using NISRA staff gave the flexibility to increase or change the staffing levels at short notice, but on occasions moving staff to matching took resources away from other processes. On occasions, NISRA was critically reliant on using spare capacity at ONS. This became important as the timetable became compressed due to changes in the EA processing order.

Organisationally, the project management of the whole ONC at ONS was successful and was well integrated with the rest of the Census operations. Relations with both the research team at ONS and the academic team at Southampton were extremely good and created an excellent partnership which helped to develop skills among those at NISRA.

Statistical

In statistical terms, the ONC was the right strategy to adopt. It was a natural progression from the introduction of the Census Validation Survey in 1991 to the addition in 2001 of imputed households estimated by the ONC. There would have been much bigger question marks about the Census results in 2001 if they had not been adjusted for the 80,000 people that the ONC estimated, especially if the estimate of under-enumeration had followed the publication of Census results after a time lag.

The estimates of underenumeration, and thus the Census results, are based upon a sample survey (the Census Coverage Survey) and are therefore subject to sampling error. Standard statistical techniques have been used to calculate these error levels and produce confidence intervals for the One Number Census results. The error levels associated with the ONC estimates are mainly driven by the magnitude of the estimated underenumeration and the sample size of the CCS. The resulting 95 per cent confidence interval for the Northern Ireland population is +/- 0.7% or about +/- 12,000.

There has been some debate about the publication of this figure. It solely reflects the sampling nature of the CCS, and quantifies how if a different CCS sample had been drawn, the ONC population estimate would have differed. In statistical terms, the confidence interval was determined using jack-knife techniques whereby the ONS estimation process was repeated using sub-samples of the CCS sample and quantifying the variability in the resulting population estimates. This is standard statistical practice. However, the confidence interval takes no account of the non-sampling errors that may exist such as those introduced by the estimate of dependence, the possible misunderstanding that the public have had about the concept of usual residence and universal sources of survey errors such as incorrect form completion.

Quality Assurance and Dependence

Operationally, the quality assurance process at LGD level or higher was successful: nothing on its scale had been done before in any other country and international experts have commented on its thoroughness and professionalism. There are however issues of the ever-present time/quality balance and the inevitable pressure to produce Census results can conflict with the need for in-depth demographic analysis. While all that was possible in the time was achieved, allowing more time to explore every issue more fully may have been beneficial - achieving the right balance is difficult.

The problem of the inappropriate spikes and the necessary revision to published Ward level Key Statistics mentioned earlier illustrates the time/quality conflicts. In essence the problem was caused by the ONC process assigning incorrect

geographical references to a small number of cases and was discovered by NISRA during the quality assurance of output area level statistics. Had the release of the original ward level data been delayed until this detailed quality assurance work had been completed at the lower geographical of output area, revision would not have been necessary, but the release of the original ward statistics would have been delayed. NISRA took the view that the ward level statistics required revision but, as quantified at the time, the conclusions drawn from analyses of the original ward statistics would have differed little from analyses of the final estimates.

The ONC relied completely on the CCS as the sole source of information on underenumeration and subsequent work in England has shown this to be a shortcoming, in particular where the coverage of the Census is exceptionally low. In practice there was little alternative; investigations during the development found that none of the other sources which might have been used in a triple system estimator (Census, CCS and a third national population source), was reliable across the country as a whole. The CCS was designed as carefully as possible to be independent and the operational measures put in place to achieve this were successfully implemented. The CCS also achieved high response rates in the majority of areas. However dependence was found. Intuitively it does seem likely that the chance of being missed by the CCS is higher if the person in question was missed by the Census. The measurement of such 'dependence' is extremely difficult; internationally there has been some theoretical work but nobody else, to our knowledge, has attempted the practical application of measuring 'dependence'. In hindsight, NISRA should have done more in contingency planning to consider the impact on the ONC of the lack of any third national data source of adequate quality.

The ONC and the mid-year Population estimates

One of the main drivers for the ONC approach was the desire to place Census counts and the population estimates on similar bases and this has been achieved. As described earlier, in 1991 the Census count and the MYE differed by about 30,000 mostly attributable to under-enumeration in the Census. In 2001 the difference between the Census count (1.685 million) and the MYE (1.689 million) is only 4,000. This is attributable to 2 sources. Firstly, about 1,500 members of the armed forces stationed here (and counted in the MYE) were counted in the Census in GB; this referred to persons who had a home and family in GB and they were counted in GB Censuses to ensure that household structures were reported as accurately as possible. The remaining gap reflects births, deaths and migration between Census Day (29 April) and MYE day (30 June).

As well as making the Census / MYE link clearer, the ONC has also made the age distributions within the two data sets more similar. The ONC demonstrated again the previously observed phenomenon that under-enumeration is

concentrated in certain age-groups, particularly young adults and the ONC adjustment ensures that age distributions in the Census and the MYEs are similar.

Conclusion

It was a huge achievement to carry out the ONC, particularly in view of the Census Operation that actually took place and what was accomplished in the timescales. While there are some lessons to be learnt and some further studies to be undertaken, as detailed above, the ONC approach provides a platform on which to build for the future.