SDC UKCDMAC Subgroup Paper 1

Statistical Disclosure Control (SDC) Methods Short-listed for 2011 UK Census Tabular Outputs

1. Introduction

The 2011 Census UK SDC Working Group met on the 22nd August 2007 to short-list SDC methods for 2011 Census tabular outputs. The short-listed methods will be taken forward for quantitative assessment using a risk-utility framework. This paper provides an account of the approach used to short-list and the rationale behind the short-list. Formal quality assurance has been provided by the UK Census Design and Methodology Advisory Committee (UKCDMAC), and individual Census Project Boards in the UK countries have been consulted, prior to formal sign-off by the UK Census Committee (UKCC).

2. SDC Methods considered for Short-Listing

The short-listing was facilitated by a review addressing the advantages and disadvantages of a wide range of SDC Methods which is included in the Appendix of this paper. The following pre-tabular and post-tabular methods were considered for short-listing:

1. Record Swapping
2. Over-Imputation
3. Data Switching
4. Post Randomisation Method (PRAM)
5. Sampling
6. Conventional Rounding
7. Random Rounding
8. Small Cell adjustment
9. Controlled Rounding
10. Semi-Controlled Rounding
11. Suppression
12. Barnardisation
13. ABS Cell Perturbation Method

It is assumed that table design methods will be applied alongside pre- and post- tabular SDC methods for 2011 Census outputs. The detailed design of Census outputs is yet to be determined and so further work on this issue is not possible at present. In the next stage of evaluation we will consider a wide range of different types of census tables to investigate the impact of the short-listed methods.

3. Criteria used to Short-List SDC Method for 2011 Census Tabular Outputs

Many Statistical Disclosure Control (SDC) methods have qualities which cannot be accounted for quantitatively and thus the qualitative advantages and disadvantages of the methods must be addressed. A high level qualitative evaluation of this wide range of SDC methods has been conducted to enable the short-listing of methods prior to commencing an in-depth quantitative risk-utility evaluation.

The focus here is on the protection of the main pre-defined census tabular outputs (rather than specialist outputs) whilst taking into consideration flexible user defined tabular outputs (see criterion c) and microdata samples (see criterion e).

The aim of the disclosure control strategy is to reduce disclosure risk to an acceptable level whilst maintaining as much data utility as possible.

Minimise Disclosure Risk

The most important characteristic of the SDC strategy for 2011 Census is that disclosure risk should be managed to an acceptable level, in order to respect legal and policy obligations relating to the release of census data. The privacy of individual's information must also be protected to ensure public co-operation and trust is maintained. The Registrars General have agreed the UK SDC policy position for the 2011 Census. Although an exact threshold for an acceptable level of risk is yet to be determined,` a steer has been provided towards a less conservative approach. The policy states that the key disclosure risk is attribute disclosure (i.e. learning something about an individual) as opposed to identity disclosure (i.e. identification of an individual). In addition it has been agreed that small counts can be included in disseminated tables provided that uncertainty as to whether the small cell is a true value has been created. The assumption is made that all the SDC methods can reduce disclosure risk to an acceptable level, and the impact that this will have on the utility of the statistics will be quantified in the next evaluation stage.

Maximise Data utility
Managing risk will necessarily impact on data utility. The aim will be to adopt an SDC strategy that manages risk effectively while maximising data utility, e.g.

i) Relationships between variables should be maintained as much as possible
ii) The method should be unbiased
iii) The method should have a minimal impact on the variance of the estimates
iv) The method should have a minimal impact on statistical analyses
v) Ideally the method should protect sparse tables without significantly damaging the data

The trade off between risk and utility will need to be evaluated quantitatively. In order to make this task manageable we need to reduce the number of methods for evaluation. This is achieved by short-listing SDC methods via this high level review, where we focus on other qualitative criteria.

It is proposed that the following aspects/criterion should be used:

a) Will the method provide additive and consistent tables which are a priority for users?
A key aim of the 2011 Census UK SDC Strategy is acceptance by users. The main user requirements which should be taken into account are;

a) Consistent cells across tables (i.e. the same cell in a different table has the same value)
b) All tables should be additive (i.e. rows and columns add up to row and column totals)

b) Overall, will users accept the method?
Overall user acceptance of the SDC methods needs to be considered when short-listing the methods. This will need to take into account whether the method can provide users with the outputs that they want and known perception of methods. For example, whether a method was well accepted by users in previous Censuses, the complexity of the method, and the degree of information loss resulting from the method.

c) Does the method protect against differencing? (both geographical and categorical differencing)
Research is currently being conducted amongst the user community to determine the level of requirement for flexible table generation for 2011 Census outputs. If flexible table generation is to be made available for the 2011 Census outputs then it will be vital that the SDC method selected provides protection against disclosure by differencing and linking (both for geographical and other variables). Protecting against disclosure by differencing and linking would also be advantageous in the absence of flexible table generation since it increases the flexibility of outputs in general and would remove the need for auditing ad-hoc outputs e.g. commissioned tables which can be resource intensive.

d) Is the method practical, feasible to implement and has it been used for protecting similar outputs to date?
The SDC methods selected for the 2011 Census should be practical, easy and quick to implement. This will minimise the risk of errors and facilitate the release of outputs in a timely manner to an agreed timetable. The SDC methods recommended for 2011 should be future-proof so that implementation throughout the life cycle of the census data is possible (future-proofing should also be considered with respect to dependency on any software required to implement the methods).

e) Method should not restrict microdata releases
Since all census outputs are disseminated from one dataset, they can be linked through common cells and common margins thereby increasing the chances of users being able to unpick the methodology and reveal original cell counts. The impact of the SDC methods for tables on microdata and the interaction between different types of output in terms of linking should therefore be given consideration when short-listing. Methods which leave a high proportion of true 1's and 2's in tables could impact on microdata releases, since one can use the tables to determine population uniques in microdata samples.

f) Method should be simple to understand
To achieve user acceptance it will be important to keep the SDC method as simple and as easy to understand as possible.

g) Method should be easy to account for in analyses
It will also be important to provide users with information on how the SDC methods may impact on their analyses and how this impact can be taken into account.

4. Approach Used to Derive Short-List

The proposal was made that for each of the seven criterion listed above each SDC method should be assigned a score from 0 to 2. 0 if the method does not meet the criteria, 2 if it does meet the criteria and 1 if it partly meets the criteria. It was agreed that the criteria identified to be of primary importance should be given double the weight of

criteria which are of secondary importance. This enabled an overall score to be assigned to each method to inform the short-listing process. It was also agreed that if any method failed any of the primary criteria then the method should be discounted for the short-list since it would have failed to meet the most important objectives.

The criteria deemed to be of primary importance by the working group were;

a) Will the method provide additive and consistent tables which are a priority for users?
b) Overall, will users accept the method?
c) Does the method protect against differencing? (both geographical and categorical differencing)
d) Is the method practical, feasible to implement and has it been used for protecting similar outputs to date?

The criteria deemed to be of secondary importance by the working group were;

e) Method should not restrict microdata releases
f) Method should be simple to understand
g) Method should be easy to account for in analyses

5. Short-Listing the SDC Methods

The results from this exercise can be found tables 1 and 2 below.

Table 1: Scoring Pre-Tabular SDC methods using short-listing criterion:

Criterion for short-listing	**Record Swapping**	**Over Imputation**	**Data Switching**	**PRAM (Post Randomisation Method)**	**Sampling**
a) Additivity/Consistency	2 - Additive and consistent since pre-tabular	2 - Additive and consistent since pre-tabular	2 - Additive and consistent since pre-tabular	2 - Additive and consistent since pre-tabular	2 - Additive and consistent since pre-tabular
b) Wider User Acceptance	2 - Widely accepted in 2001	1 - User acceptance thought to be lower than record swapping due to the deletion of original data	**0** - Complexity of method likely to have a detrimental impact on user acceptance	1 **-** Complexity of method may have a detrimental impact on user acceptance but somewhat similar to record swapping	**0** - Likely to lead to users weighting tables to get realistic counts.
c) Protection offered against disclosure by differencing	2 – Yes since pre-tabular	2 - Yes since pre-tabular	2 - Yes since pre-tabular	2 - Yes since pre-tabular	2 - Yes since pre-tabular
d) Practicality, feasibility of implementation, method previously proven	2 – Implemented on 2001 UK Census data to protect tabular outputs	1 - Edit and imputation strategy required for census hence could apply variant of this. Method not proven	1 - Harder to implement than record swapping, consistency checks required after switching	**0 -** Harder to implement than other pre-tabular methods and yet to be implemented on a large scale census	2 - Very easy to implement
e) Method does not restrict the release of microdata	0 - No since households are only swapped across locations at low geographical levels	1 - Some true small cells left in tables hence some additional protection may be required for microdata	1 - Some true small cells left in tables hence some additional protection may be required for microdata	1 - Some true small cells left in tables hence some additional protection may be required for microdata	1 - May be possible to derive some small cells hence some additional protection may be required for microdata
f) Simple to understand	2 - Yes, relatively	2 - Yes, relatively	1 - More complex than record swapping and over imputation	0 - Very complex, requires probability matrices to be derived	2 - Yes, relatively
g) Easy to account for in analyses	1 - Users not told the swap rate although some information can be provided on the impact of the method on tabular outputs. Difficult to account for in analyses, but marginal distributions are preserved.	0 Difficult to account for in analysis as no indication of where the true value lies and no marginal distributions are preserved.	0 - Difficult to account for in analysis as no indication of where the true value lies and no marginal distributions are preserved.	1 - Users would not be given much information about the way in which PRAM was applied. Difficult to account for in analyses, but marginal distributions are preserved.	2 - Yes, because weights are provided
Score (criteria 1-4 are of primary importance hence score double)	**19 (rank 1)**	**15 (rank 3)**	**12 (rank 7)**	**12 (rank 7)**	**17 (rank 2)**
Fail on any primary criteria?	**NO**	**NO**	**YES**	**YES**	**YES**
SHORT-LIST	**YES**	**YES**	**NO**	**NO**	**NO**

Table 2: Scoring Post-Tabular SDC methods using short-listing criterion

Criterion for short-listing	**Conventional Rounding**	**Random Rounding**	**Small Cell Adjustment**	**Controlled Rounding**	**Semi Controlled Rounding**	**Suppression**	**Barnardisation**	**ABS Cell Perturbation Method**
Additivity/ Consistency	1 - Consistency but not additivity	**0** - No consistency and not additive	1 - Additive but not consistent	1 - Additive and consistent totals across tables but internal cells are not consistent across tables	1 - No consistency but additivity can be ensured for key statistics	1 - Consistent and additive but some additivity information missing due to suppressions	1 - Additive but not consistent	1 - Additive but not consistent
Wider User Acceptance	**0** - Users not keen on rounded cells in tables	**0 -** Users not keen on rounded cells in tables	1 - Only the small cells are rounded	**0** - Users not keen on rounded cells in tables	**0 -** Users not keen on rounded cells in tables	**0 -** High degree of information loss in tables hence low user acceptance	**0** - Not well accepted by users in 1991 UK Census	2 - Should be high due to additivity and high level of consistency which is allegedly achieved
Protection offered against disclosure by differencing	1 – Can be unpicked although some degree of work is involved	1 – Risk of unpicking through linked tables (margins rounded independently of internal cells)	**0** – No protection for differencing large cells when used on its own	2 - Yes, cannot be unpicked since no additive inconsistencies to be exploited	1 - Can be unpicked although some degree of work is involved	**0** - No protection for unsuppressed cells since they are true counts	1 - Some protection, but method is unbiased hence linked tables could be used to unpick method	2 - Yes since the lookup table is not released
Practicality, feasibility of implementation, method previously proven	2 – Very easy to implement	2 – Easy to implement, currently used on tabular census outputs by New Zealand and Canada	2 – Easy to implement, used alongside record swapping to protect tabular outputs from 2001 census in E,W and NI.	**0** - Difficulty in coping with the size, scope and magnitude of census tables. Finding an optimal solution may be very time consuming.	1 - Slightly easier to find a solution compared with controlled rounding	**0** - Very difficult to implement on linked tables	2 - Easy to implement, used in 1991 UK Census to protect tabular outputs	1 - Being implemented by ABS on 2006 Census data however implementation not yet fully completed
Method does not restrict the release of microdata	2 - Yes	2 - Yes	2 - Yes	2 - Yes	2 - Yes	2 - Yes	1 - Some cells have zero perturbation hence some additional protection may be required for microdata	1 - Some cells may have a perturbation of zero applied hence further protection may be required for microdata
Simple to understand	2 - Yes	2 - Yes	2 - Yes	2 - Yes	2 - Yes	2 - Yes	2 - Yes	1 - More complex than Barnardisation (look-up tables, probability distributions, additivity)
Easy to account for in analyses	2 - User can tell between which values true value must lie	2 - User can tell between which values true value must lie	1 - Information on how rounding was applied to small cells is not released to users	1 - Harder to account for compared with conventional and random rounding (may round cells beyond nearest base)	1 - Harder to account for compared with conventional and random rounding (may round cells beyond nearest base)	0 - Missing cells can be difficult to account for	1 - Harder to account for than rounding, exact proportion of cells modified is not revealed	1 - Harder to account for than rounding, amount of perturbation applied to tables not quantified
Score (criteria 1-4 are of primary importance hence score double)	**14 (rank 5)**	**12 (rank 7)**	**13 (rank 6)**	**11 (rank 11)**	**11 (rank 11)**	**6 (rank 13)**	**12 (rank 7)**	**15 (rank 3)**
Fail on any primary criteria?	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**NO**
SHORT-LIST	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**YES**

6. Methods which failed primary criteria

The following SDC methods were found to fail on at least one of the primary criteria and have therefore been discounted from the short-list:

- Data Switching – Failed because this method is more complex than record swapping/over-imputation and the user acceptance is expected to suffer as a result.
- Post Randomisation Method (PRAM) – Failed due to the difficulties associated with implementation. The method has not previously been used on a large scale to protect tabular outputs.
- Sampling – Failed since user acceptance of weighted tables is known to be low.
- Conventional Rounding – Failed because user acceptance of rounding methods is known to be low and users do not like tables where all values are rounded.
- Random Rounding – Failed because user acceptance of rounding methods is known to be low and the protected tables are neither additive nor consistent.
- Small Cell Adjustment – Failed because user acceptance of rounding methods is known to be low and no protection against disclosure by differencing is provided since large cell values remain unchanged by the method.
- Controlled Rounding – Failed because user acceptance of rounding methods is known to be low and the method will not cope well with the size, scope and magnitude of census tables and finding an optimal solution will in many cases be a lengthy process.
- Semi-Controlled Rounding – Failed because user acceptance of rounding methods is known to be low.
- Suppression – Failed because suppression would be very difficult to implement on linked tables and provides no protection for differencing. The method also failed on user acceptance which would be low due to the high degree of information loss.
- Barnardisation – Failed wider user acceptance because the method was not well received when used on tabular outputs from the 1991 UK Census.

7. Methods which did not fail the primary criteria

The following SDC methods were found to fully meet or at least partially meet all of the primary criteria;

- Record Swapping (score = 19)
- Over-Imputation (score = 15)
- ABS Cell Perturbation Method (score = 15)

It was agreed that these methods should be short-listed and taken forward for quantitative evaluation using a disclosure risk - data utility framework. It was also agreed that record swapping combined with small cell adjustment should also be included in the evaluation work to enable a comparison with the method adopted in 2001. Throughout the discussions the working group did consider the possibility of combining methods. The only method for which this overcomes a failure of a primary criteria is small cell adjustment if it were combined with a pre-tabular method providing protection against disclosure by differencing. This is to be included in the short list. It was agreed that the quantitative evaluation should consider combining short-listed methods where appropriate.

We are confident that the short-list provides a range of different SDC methods that will meet the requirements of the UK SDC policy, particularly in terms of managing risk. We have a steer from the Registrars General towards a less conservative approach to risk management and a preference for pre-tabular methods. We have two pre-tabular methods and one post-tabular method on the short-list and the opportunity to combine different methods.

Appendix

A High Level Qualitative Review of Statistical Disclosure Control Methods for the 2011 UK Census (ONS July 2007)

Summary

This high level qualitative review of statistical disclosure control (SDC) methods for the 2011 UK Census has focused on the effects of the methods on pre-defined tabular outputs whilst considering the impact of the methods on user defined flexible tables and microdata samples.

The paper will be used to facilitate the formulation of a short-list of UK SDC methods which can be taken forward for quantitative evaluation using a disclosure risk-data utility framework (Shlomo and Young 2006). Methods discounted from the short-list will not be given further consideration for the 2011 Census UK SDC strategy.

The short-list of methods is not addressed in this paper. Short-listing was initially conducted by the 2011 Census UK SDC Working Group before being reviewed by the individual Project Boards within each UK Census Office. An Independent review of the short-listed SDC methods was also conducted through the UK Census Design and Methodology Advisory Committee (UKCDMAC) Disclosure Control Subgroup prior to formal sign-off from the UK Census Committee (UKCC). The short-list and rationale behind it will be communicated to users towards the end of 2007.

1. Introduction

In November 2006 the UK SDC Policy Position for the 2011 Census was agreed by the Registrars General of Scotland, England and Wales and Northern Ireland (ONS, GROS, NISRA, WAG, 2006). The policy outlines the decision to allow small cells in publicly disseminated tables. This means that no method of SDC (pre-tabular, post-tabular or combinations of the two) have been ruled out at this stage and all methods will be evaluated. The Registrars General have expressed a preference for pre-tabular methods, provided there is not undue damage to the data. Methods will be recommended that afford an acceptable level of protection and preserve the highest level of data utility for the outputs. Consistency and additivity across tabular outputs is a priority for users and these will be given a high priority in the assessment of the utility of SDC methods.

Many SDC methods have qualities which cannot be accounted for quantitatively and thus the qualitative advantages and disadvantages of the methods must be addressed. These will be used to inform the short-listing of SDC methods which can be taken forward for quantitative evaluation using a disclosure risk-data utility framework and include:

- user acceptance of chosen methods (particularly whether additivity and/or consistency are achieved)
- whether the methods provide protection against disclosure by differencing and linking (i.e. are suitable for flexible table generation)
- overall practicality and feasibility of implementation
- impact on the restriction of microdata releases and interaction between different types of output
- whether the method is simple to understand and is easy to account for in analyses

The final decision to determine the SDC methodology for 2011 Census outputs will be based on both this qualitative evaluation and a quantitative risk-utility evaluation.

This paper will facilitate the formulation of the 2011 Census UK SDC methods short-list for tabular outputs. The advantages and disadvantages of each method addressed in this report will be used to compare and discount SDC methods which will not suit the disclosure control requirements for 2011 Census outputs. Methods discounted at this stage will not be given further consideration with regard to the 2011 Census UK SDC Strategy.

This report begins by addressing the requirements for achieving an ideal 2011 Census Statistical Disclosure Control Strategy and concludes by discussing the advantages and disadvantages of a wide range of SDC techniques for protecting census data (both pre-tabular and post-tabular). In particular the paper focuses on pre-defined tabular outputs whilst taking into consideration their effects on flexible user defined tabular outputs and microdata samples and any issues concerned with implementation and the interactions between the outputs.

2. Requirements for achieving an ‘ideal’ 2011 Census Statistical Disclosure Control Strategy

Developing an SDC strategy for the 2011 Census which satisfies all user requirements whilst ensuring the confidentiality of the data to an agreed level of risk is likely to be a difficult task, and it is likely that compromises will need to be made. Users need to understand the potential detrimental impact on data quality that their different requirements may have.

In an ideal world tabular outputs released from the 2011 Census should achieve the following aims:

- Maximise data utility
- Minimise disclosure risk (the Registrars General have agreed that the key risk is attribute disclosure)
- Achieve user acceptance
- Be easy to implement
- Be transparent, simple to understand, and easy to account for in analyses
- Achieve a harmonised approach to SDC across the UK

There are many different aspects to achieving each of these aims - these are discussed in the following sections. In reality achieving all of these aims will be a very difficult task hence a balance of minimising disclosure risk whilst maximising data utility needs to be struck whilst taking into account user requirements and practicalities relating to implementation.

When assessing the disclosure risk of census outputs and the level of risk which is acceptable for outputs, consideration should be given to the measurement errors and the protection already inherent in the data. Errors in census data already exist for the following reasons;

i) response error
ii) non-response and coverage adjustments
iii) data processing
iv) edit and imputation procedures

Measuring the level of protection provided by these measurement errors is a very difficult task - census offices for example are unable to identify response errors unless the responses are illogical. The exact threshold of uncertainty required for 2011 census outputs has not yet been determined. The Registrars General will make this judgement at a later stage in the context of results from methodological research into the balance of protection afforded, and damage caused, by various SDC methods.

Careful deliberation will need to be given to the aims of the SDC strategy since different methods will satisfy different aims and the trade-offs will need to be considered. More detail on the ideal aims of the SDC strategy are provided below;

2.1 Maximising Data Utility

Ideally if the utility of the 2011 Census data is maximised then;

- Tables should be consistent and additive - a priority for users
- Distortion to marginal and joint distributions should be minimised and relationships between variables should be maintained
- The protected outputs should be unbiased
- The impact on variance of estimates should be minimised
- The impact on statistical analyses should be minimised

It will be important to ensure that data utility is maintained even in sparse tables. This may require giving consideration to managing disclosure risk by providing special modes of access for some outputs (e.g. under special license) rather than applying SDC methods if they cause too much damage to data utility.

2.2 Minimising Disclosure Risk

It will be crucial for the UK Census Offices to minimise disclosure risk for their census outputs to an agreed level in order to respect legal and policy obligations relating to the release of census data. The privacy of individual's information must also be protected to ensure public co-operation and trust is maintained.

In the UK SDC Policy for 2011 Outputs (ONS, GROS, NISRA, WAG, 2006) the Registrars General highlighted that the key disclosure risk is attribute disclosure (i.e. learning something about an individual) as opposed to identification of an individual. An agreement was also reached whereby small counts (0s, 1s, and 2s) could be included in publicly disseminated Census tables provided that

a) uncertainty as to whether the small cell is a true value has been systematically created; and
b) creating that uncertainty does not significantly damage the data.

The exact threshold of uncertainty required in the census outputs has not yet been decided.

When releasing the 2011 Census outputs it will be important to;

- prevent disclosure by differencing and thus enable flexible table generation (if there is a strong user requirement for flexible user defined tables)
- prevent the release of data which enables new information about an individual to be derived (this may or may not result from the identification of an individual).
- provide users with enough information about the SDC methods applied to the data so their analyses can take account of these if necessary. Care should however be taken to ensure the information provided does not allow users to determine a cells true value or the probability that a cell contains a true value.

2.3 Achieving User Acceptance

A key aim of the 2011 Census UK SDC Strategy is acceptance by users. The census is the most complete source of information about the population and it is used by central and local government, health authorities and many other organisations to target their resources effectively and plan for future requirements.

The main user requirements are;

- consistent totals for all tables
- all tables should be additive
- the SDC methods should be simple and easy to understand
- it should be relatively easy to take account of the effects of SDC when analysing data
- any impact on statistical analyses resulting from the application of disclosure control should be minimised

A good communication strategy will be vital to keep users informed about SDC developments in the lead up to the 2011 Census and will help foster a good relationship with users. Once the 2011 Census SDC methodology has been agreed a period of user education will be conducted to ensure users are knowledgeable about the effects that the SDC methods may have on the data and ensure users are educated about the best way to take account of these effects when analysing census outputs. Any last minute changes to SDC methodology should be avoided.

User consultation work to determine high level requirements for 2011 Census outputs is currently being undertaken This work will feed into the development of the UK SDC strategy.

2.4 Ensuring Methods are Easy to implement and are 'Future-Proof'

The SDC methods selected for the 2011 Census should be easy and quick to implement. This will minimise the risk of errors occurring and facilitate the release of outputs in a timely manner to an agreed timetable. The SDC methods recommended for 2011 should be future-proof so that implementation throughout the life cycle of the census data is possible (future-proofing should also be considered with respect to dependency on any software required to implement the methods).

2.5 Ensuring Transparency of Methods

Lack of transparency in SDC methods can result in a perceived risk of disclosure. For example record swapping may not be seen as transparent since the data is not visibly perturbed, however, this lack of transparency can be overcome with user communication.

Prior to the release of outputs from the 2011 Census it will therefore be important to conduct user communication and education sessions. These will help to eliminate the perceived risk of disclosure which can result if small cells appear in tabular outputs. A good communication strategy should be adopted to ensure that all users of census outputs are aware that disclosure control methods have been applied and that the risk of disclosure has been reduced to an acceptable level whilst maintaining the highest level of data utility possible.

2.6 Achieving a Harmonised approach to SDC across the UK

The aim for the 2011 Census is to develop a common SDC methodology for all UK outputs. Tabular outputs from the 2001 Census were subjected to different methods of disclosure control across the UK due to late concerns that record swapping did not provide sufficient protection. The post-tabular method of small cell adjustments was therefore applied to tabular outputs in England and Wales and Northern Ireland after record swapping. In Scotland small cell adjustments were only applied to Work Place tables since record swapping did not provide any protection for these outputs. This late change in disclosure control methodology and the resulting lack of harmonisation across the UK caused a great deal of dissatisfaction among the user community. It should be noted that there have been no known cases of disclosure from the 2001 Census outputs across the UK.

In the 1991 Census all UK Census Offices used the same threshold rule of 50 residents at Output Area[1] level. Prior to 2001 ONS conducted a qualitative review of disclosure risk for 2001 Census outputs and perceived that there would be an increase in disclosure risk for the following reasons:

1) The 2001 Census results would be very widely disseminated via the internet. The increased accessibility also increased the risk of misuse of census data. The increased risk from attempts to break any confidentiality protection provided needed to be managed.
2) The 2001 Census would have greater flexibility of census output and the production of information would be more detailed than published for previous censuses. Data for output areas would be provided which were considerably smaller in geographical size than the lowest geographical level provided in 1991.
3) All questions from the 2001 Census would be fully coded. Previous censuses had coded only 10% of the responses for some key variables and that had added a level of uncertainty to published results.
4) Advances in technology including capabilities for storage and processing of information meaning increased risk from data linkage.

[1] The target size for Output areas in 1991 was 50 households.

New Output Areas were introduced in England, Wales and Northern Ireland at the 2001 Census. Due to the perceived increase in disclosure risk between 1991 and 2001, census Output Area thresholds[2] in England and Wales and Northern Ireland were doubled. Scotland however decided that the increased protection gained by raising their geographic thresholds did not outweigh the damage to the continuity between 1991 and 2001.

In an ideal world the same geographical threshold rules should be adopted across the UK for the 2011 Census. Due to the effects on stability and the resource required to resize output areas, the harmonisation of output areas in 2011 is far from guaranteed. Following a public consultation on geography for National Statistics an interim policy position has been agreed (link when available) that focuses on stability.

3. Comparing Pre-Tabular and Post-Tabular Disclosure Control Methods

Disclosure control methods for tabular outputs can either be pre-tabular (applied to microdata prior to tabulation) or post-tabular (applied to tables). Pre-tabular methods are particularly attractive because they only need to be applied once to the microdata and all tables are disseminated from the perturbed microdata. Pre-tabular methods provide some protection against disclosure by differencing. In the UK SDC Policy for 2011 Census Outputs which was released in November 2006, the Registrars General of the UK Census Offices expressed a preference for pre-tabular methods of disclosure control for the 2011 Census provided there is not undue damage to the data.

Table 1: The Advantages and Disadvantages of Pre-tabular Methods of Disclosure Control

Advantages	Disadvantages
A1. Tables will be consistent and additive since all tabular outputs are created from protected microdata. **A2.** Pre-tabular SDC methods by definition only need to be applied once to the microdata. **A3.** Some protection against disclosure by differencing. **A4.** Flexible user defined tables possible provided microdata sufficiently protected against disclosure by differencing. **A5.** Generally Flexible – parameters can often be easily changed to determine amount of perturbation in the data.	**D1.** Data can appear as if not visibly perturbed. **D2.** Likely to be more difficult for users to understand and account for in their statistical analyses compared with post-tabular methods such as rounding.

Post-tabular methods of disclosure control work by perturbing cells which occur in tabular outputs. These methods need to be applied to each table disseminated and do not provide any protection for microdata.

Table 2: The Advantages and Disadvantages of Post-tabular Methods of Disclosure Control

Advantages	Disadvantages
A1. Generally clear and transparent to users. **A2.** More likely that post-tabular methods protect high risk records (cells within which risky records fall in the table can be easily located and protected). **A3.** Generally easier for users to understand and account for in their analyses than pre-tabular methods. **A4.** Generally flexible – parameters can be easily changed to determine amount of perturbation in the data. **A5.** Some post tabular methods are clearly visible to users e.g. rounding.	**D1.** Tables unlikely to be consistent and additive. **D2.** Generally post-tabular methods need to be applied to every table separately. **D3.** Post tabular methods could be considered to be at greater risk of unpicking compared with pre-tabular methods. **D4.** Some methods are at high risk of disclosure by differencing and will therefore be unsuitable for user defined tables. **D5.** Data may not appear to be visibly perturbed with some post-tabular methods e.g. Barnardisation and ABS Cell Perturbation Method.

[2] 2001 Output Areas in England and Wales and Northern Ireland were designed using a target size of 125 households. and the threshold rule applied was 100 residents and 40 households. In Scotland the 2001 target Output Area size was 50 households and the threshold rule applied was 50 residents and 20 households.

4. Pre-Tabular Methods of Disclosure Control

The following pre-tabular disclosure control methods are being considered at this early stage in the development of the 2011 Census UK SDC Strategy;

4.1. Record Swapping

With Record Swapping a small percentage of household records have geographical identifiers swapped with other records matching on specific control variables (e.g. age, gender, Hard to Count (HtC) index[3], household size). Swapping only records which match on control variables helps to minimise bias.

A small percentage of individual records within communal establishments can also be swapped using similar control variables but replacing household size by communal establishment type.

Record swapping is typically carried out within a higher level geographical area e.g. Local Authority[4] and households / persons in communal establishments are swapped in and out of smaller geographical areas e.g. Output Areas. Record Swapping therefore ensures that Local Authority marginal distributions remain unaffected.

With record swapping the level of uncertainty is not known to the user (the percentage of records swapped remains confidential). This can be advantageous to the Census Offices since it can provide an added level of protection to the outputs because users are unaware of the probability that a cell contains a true value. This can however be frustrating to users.

[3] The Hard to Count (HtC) index was constructed in the 2001 UK Census as a measure of enumeration difficulty. It was constructed from the following 1991 Census variables; Multi-occupancy, unemployment, language difficulty, private rented accommodation, number of household imputed in 1991. Scotland also used ethnic group.

[4] In 2001, Output Areas could be combined to form Local Authorities.

Table 3: The Advantages and Disadvantages of Record Swapping in General

Advantages	Disadvantages
A1. Swapping rates are flexible. **A2.** Marginal distributions preserved at a higher geographical level and within control strata. **A3.** Given household characteristics (used as control variables), other census variables are likely to be independent of geography therefore less bias will occur. **A4.** Maintains internal consistencies within households. **A5.** Control variables (variables upon which swapped records must match) can be determined according to requirements. **A6.** Swapping geographies will not necessarily result in inconsistent and illogical records i.e. less edit failures. **A7.** Provides some protection against differencing (geographical and variable differencing). User defined flexible table generation possible provided record swapping provides enough protection or used in addition to other suitable SDC methods. **A8.** Previous experience of using record swapping in 2001 Census.	**D1.** Users cannot be provided with the swap rate hence no measure of whether a value in a table is the true value - Difficult for analysts to properly account for its impacts at levels below Local Authority. **D2.** Rare combinations of variable characteristics are still disclosive (i.e. special uniques). **D3.** Using current methods all geographic fields such as workplace are swapped hence work place tables not protected. **D4.** Generally introduces bias into the results at geographical levels below Local Authority and causes lower level characteristics to become more homogeneous.

Record swapping can take several different forms including random record swapping and targeted record swapping. These different record swapping methods can also be performed using all records or just the records which have not been imputed or had a variable imputed (see section 4.1.3). The additional advantages and disadvantages of random and targeted record swapping are now discussed.

4.1.1 Random Record Swapping

Random record swapping involves selecting at random households and individuals within communal establishments for swapping. Random record swapping results in a percentage of records having their geographic identifiers swapped with other records which match on a set of key variables. Random record swapping was used to protect Scottish tabular outputs from the 2001 Census (with the exception of work place tables). In England and Wales and Northern Ireland random record swapping was used alongside small cell adjustments to protect tabular outputs from the 2001 Census. Random record swapping was also used to protect tabular outputs from the 1991 US Census.

Table 4: Additional Advantages and Disadvantages of Random Record Swapping

Advantages	Disadvantages
A1. Higher data utility generally expected to be maintained with random swap compared with targeted swap at the same swap rate since perturbation is carried out on all records at random and not just on uniques and risky records.	**D1.** Can leave a high proportion of risky (unique) records unperturbed if a low swap rate is used. Using a higher swap rate introduces a greater degree of information loss. **D2.** Higher risk of disclosure expected for random swapping compared to targeted swapping using the same swap rate. **D3.** Errors (bias and variance of estimates) due to perturbation, joint distributions are particularly affected at lower levels of geography. **D4.** All records (risky or not) have the same probability of being perturbed.

4.1.2 Targeted Record Swapping

Targeted record swapping involves selecting a random sample of the potentially unique/ risky records for swapping. This may involve flagging records which are expected to be risky based on particular characteristics. The records actually chosen for swapping can then be selected from these flagged records. The records are then paired for swapping with other flagged records which match on control variables. For records where no match can be found within the flagged records, a match is found using non-flagged records which match on control variables.

Targeted record swapping results in a percentage of potentially unique records having their geographic identifiers swapped with other potentially unique records which match on a set of key variables. Targeted record swapping was used to protect tabular outputs from the 2001 US Census.

Table 5: Additional Advantages and Disadvantages of Targeted Record Swapping

Advantages	Disadvantages
A1. Targeted swapping lowers disclosure risk compared with random swapping - Unique/risky records are more likely to be perturbed.	**D1.** Larger errors (bias and variance of estimates) since perturbation carried out on uniques and outliers joint distributions particularly affected i.e. lower levels of data utility for targeted swap compared with random swap using the same swap rate. **D2.** Success in protecting against disclosure is largely dependent on the way the risky records are defined. **D3.** For a small swapping rate, can be difficult to decide which records are most risky for swapping. **D4.** Small cell values are more likely to be perturbed to a greater degree by targeted swapping.

When performing targeted record swapping the perceived risk of attribute disclosure may however be greater compared with random record swapping. This result may occur because swapping only risky records may cause the number of zero cells in tabular outputs to increase to a greater extent compared with swapping records at random.

4.1.3 Random and Targeted Record Swapping: Imputed records eliminated from swapping process

Both random and targeted record swapping can be performed on just those records with no imputation either for missing items or census non-response. This method assumes that imputed records are protected records and hence do not need to be swapped. The advantage of selecting only non-imputed records for swapping is that an additional level of protection may already be provided as a result of the imputation. The disadvantage to this method is that the imputation may be exact and hence the records are not protected and therefore the risk of disclosure is higher than expected. Imputing only one variable in a record may also not be sufficient to protect against disclosure.

If random or targeted record swapping is performed on only the non-imputed records then the disclosure risk should be at least as low as when the method is performed on all records and actually has the potential to be reduced at no extra cost to data utility.

4.1.4 Local Density Swapping (Geographical Perturbation)

Other forms of modifying household location can be considered as an alternative to record swapping and can all be defined in the framework of ‘geographical perturbation’ methods (Young, Martin, Skinner, 2007). These new approaches include ‘Displacement’ which can be performed in a geographical information system (GIS) where a subset of household locations are randomised by adding random offsets according to some rule controlling for risk-utility. ‘Local Density swapping’ is an alternative approach to record swapping which is applied independent of geographical boundaries and therefore aims to offer greater protection against geographical differencing. Disclosure by differencing can arise when geographies are published that overlap and can be differenced to produce slivers which contain small numbers of people (particularly the case in rural areas). Local density swapping perturbs household location according to local population density which may be considered a predictor of disclosure risk. Empirical work on synthetic census data (Young, Martin, Skinner, 2007) shows some improvements of local density swapping over random record swapping in terms of some risk-utility indicators.

Table 6: The Advantages and Disadvantages of Local Density Swapping

Advantages	Disadvantages
A1. Swaps are 'local' so plausibility of records is generally maintained (i.e. do not swap a person in a high rise city flat to a rural area with no flats). **A2.** Takes into account the spatial dimension of risk by sampling household distance (instead of a distance at random) and therefore less noise is added to households in urban areas. **A3.** Distance between swaps is controlled by sampling from a distribution which is flexible and parameters can be varied. **A4.** Can provide greater protection against geographical differencing since swaps are independent of geographical boundaries. **A5.** Maintains internal consistencies within households.	**D1.** Rare combinations of variable characteristics are still disclosive (i.e. special uniques). **D2.** Assumes disclosure risk is correlated with population density. **D3.** Only recently developed and its impact on data utility and disclosure risk are still being assessed. **D4.** Introduces bias into the results at low geographical levels. **D5.** Difficult for analysts to properly account for its impacts at low geographical levels. **D6.** Work-Place tables not protected.

4.2 Over-Imputation

Over-Imputation involves randomly selecting a percentage of microdata records which then have certain variables erased. Standard imputation methods are then applied by selecting donors matching on control variables and the erased variables are then imputed.

Table 7: The Advantages and Disadvantages of Over-Imputation

Advantages	Disadvantages
A1. Imputation software already required for census programme. **A2.** Can target over-imputation towards risky variables and risky geographical areas. **A3.** Could be used to protect work place tables if imputation includes geographical fields. **A4.** User defined flexible table generation possible since provides some protection against disclosure by differencing as long as some fields in set of overlapping records include imputed information.	**D1.** Marginal distributions at higher aggregations not preserved (can create bias at levels of geography higher than Local Authority). **D2.** Increased variance of cell counts due to the deletion of data. **D3.** Errors (bias and variance of estimates) due to imputation, particularly the case for mis-specified models. **D4.** Difficult for analysts to properly account for its impacts e.g. the standard errors at high levels of geography. **D5.** Over Imputation can alter the association between characteristics of members within the same household.

Research conducted prior to the 2001 Census illustrated that there was little to choose between over-imputation and record swapping in terms of the impact on statistics at smaller areas of geography. At the Local Authority level record swapping maintains the marginal distributions however this is not true for over-imputation. ONS excluded imputation as the disclosure control method for 2001 census outputs for the following reasons;

i) Over-imputation can create bias at levels of geography higher than LAD.
ii) Over-imputation inflates variances due to the deletion of data.
iii) Over-imputation was less transparent to the data analyst in terms of how the data was perturbed. In particular, analysts would not be able to properly allow for its impacts (e.g. the standard errors at high levels of geography). It was noted that analysts would not be able to tell how record swapping had affected analyses at the small area level.

GROS preferred over-imputation to record swapping for the 2001 Census but found that the costs of including this method in the proposals to the edit and imputation software provider were too high. The record swapping code was written in-house by ONS but the method had the disadvantage that it did not protect the Work place tables and did not protect the census microdata samples.

4.3 Data Switching

Data switching involves swapping the values of one or more variables in one record with the values for the same variable in another record. Switching occurs within similar households in different geographical areas which are within close proximity. Data Switching is similar to record swapping but unlike swapping it does not maintain relationships within households.

Table 8: The Advantages and Disadvantages of Data Switching

Advantages	Disadvantages
A1. At the level of geography at which switching occurs the structure of the data is perfectly preserved. **A2.** Can target risky variables. **A3.** Can protect work place tables if geographical fields are switched.	**D1.** Switching only selected fields can causeinternal inconsistencies because characteristics between variables within the household are not maintained. **D2.** Introduces bias at geographies below the level at which switching conducted. **D3.** Consistency checks required after editing. **D4.** Errors (bias and variance of estimates) due to switching, joint distributions are particularly affected.

Data switching was discounted from use on 2001 Census outputs because of the inconsistencies it can introduce into the relationships between census variables.

4.4 Sampling

Sampling may be used as a disclosure control method because ambiguity is given to the frequencies depending on the chances of a respondent being in the sample. It is not known whether a cell count of one is actually a population unique for example. The smaller the sampling fraction, the more protection is given.

Table 9: The advantages and disadvantages of Sampling

Advantages	Disadvantages
A1. Integrity of data is maintained (people aren't added in to the population). **A2.** May be more acceptable to users as data is not changed. **A3.** Simple and straightforward to carry out. **A4.** Easy for users to understand.	**D1.** A high sampling fraction leads to a high potential for disclosure. **D2.** Totals and subtotals will be incorrect. **D3.** Sampled data will inevitably lead to users weighting tables to get realistic counts. The error between the true values and the sampled values will be largest for small sampling fractions. **D4.** Users may be concerned about some of the data being 'thrown away'. **D5.** Using random sample may end up biasing the data if many respondents happen to be removed with certain characteristics.

4.5 Post-Random Perturbation Method (PRAM)

Post-randomisation method (PRAM) is a perturbation method which adds noise to categorical variables by changing values of fields for a small number of records according to a prescribed probability matrix and a stochastic process based on the outcome of a random multinomial draw. PRAM is a generalisation of record swapping and data switching and therefore shares many of their advantages and disadvantages but due to its nature, record swapping is less likely to give rise to illogical records. An adaption of PRAM was used to protect both the individual and household Sample of Anonymised Records[5] (SARS) from the 2001 UK Census but has yet to be implemented on a large scale census for tabular outputs. Since the probability mechanism used to apply PRAM is known characteristics of the original data can be estimated from the perturbed data and the perturbations can be taken into account in statistical analyses. This may be seen as advantageous for the user but the Census Offices may be concerned that this could increase the risk of the perturbations being unpicked. The resulting perturbed file may retain some unusual or high risk combinations, but there will be uncertainty over whether these have been created through the perturbation process or are original values from a respondent

[5] Microdata samples produced from 2001 Census data

Table 10: The Advantages and Disadvantages of Post-Random Perturbation (PRAM)

Advantages	Disadvantages
A1. Method can be targeted to risky records or sensitive variables. **A2.** Invariant PRAM is unbiased conserving the expected frequency distributions within the total population. **A3.** The ONS adaption of PRAM used on the 2001 Census microdata samples was designed to maintain the exact univariate distributions not just the expected distributions. Some joint distributions were also maintained by carrying out PRAM within strata.	**D1.** Errors (bias and variance of estimates) due to perturbation. **D2.** Need for re-editing and further imputations to remove inconsistencies in data resulting from PRAM. **D3.** Yet to be implemented on a large scale census (Only used for 2001 microdata samples in UK). **D4.** Harder to implement than record swapping. **D5.** Generally all records (risky or not) have the same probability of being perturbed unless records with unique combinations are flagged which is time consuming. **D6.** If PRAM is applied to individual records then two individuals may end up with different values for a household variable. PRAM can therefore not be applied independently to all records. **D7.** A consequence of using PRAM to protect 2001 microdata was that transition matrices were not released with the microdata samples to counteract the reduced protection from the ONS adaption of PRAM. ONS focused on making risky records safe (outflow) thus little protection was provided in the file by inflow (records being perturbed to risky combinations) and perturbed values were controlled to avoid creating unusual/potentially risky combinations.

4.6 Discussion of pre-tabular methods

Pre-tabular methods are advantageous because they only need to be performed once on microdata. This means that all tables produced are consistent and additive. Pre-tabular methods however are not as transparent to users as post-tabular methods since it appears as if no disclosure control has been applied. Pre-tabular methods applied in a way which minimises information loss may not sufficiently protect the data hence additional methods of disclosure control may need to be applied.

Using pre-tabular methods which target risky records reduces the disclosure risk but also increases the information loss to a much greater extent compared with methods which perturb records at random.

Data switching and over-imputation can cause internal inconsistencies in the data and damage household relationships. When applying record swapping or geographical perturbation there is no damage to household relationships because entire households simply change location. Geographical perturbation and record swapping however do not provide protection for work place tables since geographical fields are not swapped. The record swapping conducted for the 2001 Census outputs was also unable to protect the microdata samples because the level of geography contained in the microdata was higher than the geographical level within which swapping was conducted.

5. Post-Tabular Disclosure Control Methods:

The following post-tabular disclosure control methods are being considered at this early stage in the development of the 2011 Census UK SDC Strategy;

5.1 Rounding

There are a number of alternative methods that can be used for rounding cells. These are outlined below. The base to which cells are rounded can be altered depending on the level of disclosure control that is required. The following table outlines the main advantages and disadvantages of using rounding procedures as a method of disclosure control.

Table 11: General Advantages and Disadvantages of Rounding Procedures

Advantages	Disadvantages
A1. Easily understood. **A2.** Generally simple to implement unless using some form of controlled rounding. **A3.** Flexibility in rounding base. **A4.** Generally clear and evident to users since data is visibly perturbed. **A5.** Provides a small amount of uncertainty around all cell values. **A6.** Introduces ambiguity into the zeros which exist in the table.	**D1.** Only controlled rounding ensures that rounded cells will add up to table totals. **D2.** Where tables are combined to create user-defined areas, cells could be significantly altered by the rounding process (rounding errors can accumulate substantially at higher levels). **D3.** Affects the level of association between variables as a result of rounding entries. **D4.** Increase the variance of cell counts. **D5.** Greater distortion to distributions when compared with record swapping. **D6.** Caution required if user defined tables made available - rounding methods do not generally provide 100% protection against disclosure by differencing. **D7.** Can cause the number of zero's in the table to increase hence increasing the risk of perceived attribute disclosure.

The advantages and disadvantages of each of the different rounding methods are now discussed below and these should be considered alongside the advantages and disadvantages of rounding methods in general.

5.1.1 Conventional Rounding

When using conventional rounding, each count is rounded to the nearest multiple of a fixed base (usually base 3 or base 5). The marginal totals and table total are rounded independently from the internal cells.

Table 12: Additional Advantages and Disadvantages of Conventional Rounding

Advantages	Disadvantages
A1. Users know that the true value has been rounded to the nearest multiple of the base. **A2.** Cells in different tables which represent the same records will always be the same. **A3.** Consistent table totals within the rounding base because totals rounded independently from internal cells.	**D1.** Less protection than controlled/random rounding. **D2.** Can be unpicked. **D3.** Tables not additive – totals rounded independently from internal cells. **D4.** Not suitable for flexible table generation, it can be easily unpicked when differencing and linking tables. **D5.** Biased if counts not uniformly distributed.

5.1.2 Unbiased Random Rounding

With unbiased random rounding, all cells in tables are rounded up or down to one of the nearest multiple of the base according to an unbiased prescribed probability scheme. The probabilities are assigned so that the expected rounded value is the original value.

This method is easy to apply and is clear and transparent to users. Unbiased random rounding has been used to protect tabular outputs from the 2006 censuses of New Zealand and Canada.

Table 13: Additional Advantages and Disadvantages of Unbiased Random Rounding

Advantages	Disadvantages
A1. Consistent table totals within the rounding base because totals rounded independently from internal cells. **A2.** Removes all 1s and 2s from tables, and so removes cases of perceived disclosure as well as actual disclosure. **A3.** Unbiased. **A4.** Provides good protection against disclosure by differencing (although not 100% guarantee). **A5.** Feasible, since rounding is already available in Supercross software. **A6.** Easy to justify, since it is already in use in many NSIs (although usually with high thresholds on mean frequencies in cells). **A7.** Users able to take into account effect of rounding in their analysis and can easily determine between which values the true value must lie. **A8.** Flexible table generation possible although full protection from disclosure not guaranteed – tables would need auditing before release.	**D1.** Rounds all cells, including safe cells hence increased information loss when compared with small cell adjustment. **D2.** Tables not additive - totals rounded independently from internal cells. **D3.** Can be unpicked in a proportion of cases through linked tables due to internal cells of the tables and the margins being rounded independently. Risk of unpicking less when rounding to base 5 but this involves greater damage to the data.

5.1.3 Small Cell Adjustments

Applying small cell adjustments involves randomly adjusting small cells upwards or downwards to a base using an unbiased prescribed probability scheme. Marginal totals are obtained by summing perturbed and non-perturbed cells.

Small cell adjustments were used in addition to random record swapping to protect 2001 census tabular outputs for England and Wales and Northern Ireland. In Scotland, only the work place tables from the 2001 Census used small cell adjustments to protect against disclosure because record swapping did not provide any protection for these outputs. Small cell adjustments were also used by the Australian Bureau of Statistics to protect their tabular outputs from the 2001 Census.

Table 14: Additional Advantages and Disadvantages of Small Cell Adjustments

Advantages	Disadvantages
A1. Tables are additive since totals calculated from summing rounded and un-rounded cells. **A2.** Eliminates all small cells in the table and therefore disclosure risk is minimal with respect to identity disclosure. **A3.** Removes all 1s and 2s from tables, and so removes cases of perceived identity disclosure as well as actual disclosure. **A4.** Unbiased. **A5.** Protects the risky (unique) records against identification. **A6.** Only small cells are rounded hence lower loss of information for standard tables. **A7.** Additional protection for the high-risk (unique) cells **A8.** Available in Supercross.	**D1.** Table totals not consistent since margins calculated using perturbed internal cells - Inconsistency of margins between linked tables. **D2.** Margin totals can be affected by large errors. **D3.** Marginal totals are not rounded hence tables are easier to unpick. **D4.** The availability of several linked tables can increase risk of tables being unpicked. **D5.** Little protection against disclosure by differencing hence only one set of geographies and other variables can be released. **D6.** Implementation problems (high information loss) for sparse tables (e.g. origin-destination tables). **D7.** Bias may result if sum of perturbations going up does not equal the sum of perturbations going down. **D8.** Rounding errors can accumulate substantially at higher levels of geography. **D9.** Not suitable for flexible table generation. **D10.** Reliant in 2001 Census on Supercross software package which required a licence

	from the ABS.

5.1.4 Controlled Rounding

Controlled rounding is a method for rounding the cells of a statistical table that maintains its additive structure. The procedure uses linear programming techniques to round table entries up or down and in addition ensures that all rounded entries add up to the rounded totals.

Table 15: Additional Advantages and Disadvantages of Controlled Rounding

Advantages	Disadvantages
A1. Tables are additive – rounded entries are conditioned to add up to rounded totals. **A2.** Consistent totals across linked tables - totals rounded independently from internal cells. **A3.** Cannot be unpicked because there are no additive inconsistencies to be exploited. **A4.** Available in Tau-Argus. **A5.** Method can be used to protect flexible tables but time taken may result in method being unsuitable for this purpose. **A6.** Rounded table is as close as possible to the original table.	**D1.** Difficult to find control-rounded solutions to sets of linked tables. Cells may be rounded beyond the nearest rounding base as a result. **D2.** Difficulty in coping with the size, scope and magnitude of census tabular outputs. **D3.** Different values for the same internal cell in different tables. **D4.** Complicated to implement. **D5.** Takes time to find optimal solution and needs to be implemented on every table.

5.1.5 Semi-Controlled Rounding

Semi controlled rounding also uses linear programming to round table entries up or down whilst controlling for the overall total in the table or controlling for each separate output area total. i.e. semi-controlled rounding ensures that either;

a) the overall total of the tables is preserved
b) the output area totals are all preserved

Table 16: Additional Advantages and Disadvantages of Semi-Controlled Rounding

Advantages	Disadvantages
A1. Consistent table totals across linked tables. **A2.** Some table additivity preserved and therefore utility increased compared to conventional and random rounding. **A3.** Unbiased. **A4.** Method can be used to protect flexible tables but time taken may result in method being unsuitable for this purpose.	**D1.** Tables not fully additive. **D2.** Difficult to find an optimal solution. **D3.** Takes time to find optimal solution and needs to be implemented on every table.

5.2 Suppression

A method of protecting unsafe cells in tables is cell suppression. This means that unsafe cells are not published – they are suppressed and replaced by a special character, such as an ‘X’ which should differ from the symbol used to denote missing values. Such suppressions are called primary suppressions. To make sure the primary suppressions cannot be derived by subtractions from published marginal totals, additional cells are selected for secondary suppression. The selection of secondary suppressions can be done either by hand or by software. Determining a pattern of complementary suppressions that minimizes the overall loss of information results into a difficult optimization problem. A method of partial cell suppression has recently been developed which consists of replacing some table entries by appropriate intervals containing the actual value of the unpublished cells. Partial cell suppression has the important advantage of reducing the overall information loss needed to protect the sensitive information.

Table 17: The Advantages and Disadvantages of Suppression

Advantages	Disadvantages
A1. Cannot be unpicked provided secondary cell suppression is adequate and same cells in linked tables are suppressed. **A2.** Easy to implement on unlinked tables. **A3.** Highly visible. **A4.** Remaining cell values unchanged. **A5.** Primary suppressions easy to apply. **A6.** Able to target risky records.	**D1.** A large number of cells would need to be suppressed resulting in a high degree of information loss. **D2.** Non-confidential information must also be suppressed. **D3.** Difficult to implement on linked tables. **D4.** Difficult to optimise secondary cell. suppressions to protect risky cells. **D5.** Very difficult to protect against differencing. **D6.** Care needs to be taken to ensure same cells in linked tables are always suppressed. **D7.** Not suitable for flexible table generation.

5.3 Barnardization (UK 1991)

Barnardisation is a form of cell perturbation which modifies each internal cell of every table by +1, 0 or -1, according to the probabilities (p/2, 1-p, p/2). Zeros are not adjusted. Table totals are added up from the perturbed internal cells resulting in inconsistent totals between tables. Typically, the probability p is quite small and therefore the majority of cells are not modified. The exact proportion of cells modified is not revealed to the user. A further form of cell perturbation has recently been developed by the Australian Bureau of Statistics for protecting outputs from their 2006 Census (see section 5.4).

Table 18: The Advantages and Disadvantages of Barnardisation

Advantages	Disadvantages
A1. Some protection against disclosure by differencing. **A2.** Unbiased. **A3.** Previous experience of using Barnardisation in 1991 Census.	**D1.** High proportion of risky (unique) records unperturbed. **D2.** Totals not consistent between tables since margins calculated by perturbed internal cells. **D3.** Difficult to implement for flexible output. **D4.** Difficult to ensure overlapping tables are altered in the same way. **D5.** Tables may not sum correctly to larger geographies. **D6.** Where tables are combined to create user-defined areas, cells could potentially be changed by more than 1.

5.4 Cell Perturbation (e.g. ABS Method)

This new cell perturbation method is essentially a post tabular approach which takes into account pre-tabular information. The method involves adding small perturbations to all cells in a table using a two stage process;

Stage one results in a consistently perturbed non additive table. To achieve this, all microdata records are assigned a record key. When creating a table the record keys for all records contributing to each internal cell are summed and a function is applied to this sum to produce the cell key. Lookup tables (determined by the organisation) are then used where the true cell value and the cell key are used to determine the amount by which the cell should be perturbed. This means that the same cell is always perturbed in the same way. The perturbation can be set to zero for a pre-determined set of key outputs (e.g. age by sex population counts). Table margins are perturbed independently using the same method.

At the second stage another perturbation is added to each cell (excluding the grand total) to restore table additivity. The stage two perturbations are generated using an iterative fitting algorithm which attempts to balance and minimise absolute distances to the stage one table, although not necessarily producing an ‘optimal’ solution.

The ABS cell perturbation method is very dependent upon the lookup table used. For example a lookup table could be designed which could model the post-tabular methods of small cell adjustments or random rounding.

Table 19: The Advantages and Disadvantages of Cell Perturbation

Advantages	Disadvantages
A1. Tables are additive after the additivity module is applied. **A2.** Provides protection for flexible tables. **A3.** Perturbation noise distributions can be set in such a way that they are approximately unbiased with small variances. **A4.** Efficient – allegedly has a quick run time. **A5.** Able to produce perturbations for large high dimensional hierarchical or cross classified tables. **A6.** Protects against differencing since it is not known how the cells are perturbed. **A7.** Flexible method – lookup table can be specifically designed to suit needs.	**D1.** Tables not consistent (consistency is maintained during the first stage of the perturbation process but is lost when the additivity module is applied). The ABS claim that the loss in consistency between tables is low. **D2.** May require careful specification of look-up tables for different types of data / output, particularly sparse tables.

If the second additivity stage is not used then same cells in linked tables will have consistent values since the same perturbation will be applied to all cells which represent the same group of individuals. Table totals will also be consistent but the tables will not be additive.

5.6 Discussion of Post-Tabular Methods

The main disadvantage of post tabular methods is that they need to be applied to every table compared with pre-tabular methods which only need to be applied once to microdata. Post-tabular methods often destroy the consistency of totals between tables and additivity within tables. If post-tabular methods maintain additivity by calculating marginal totals from perturbed internal cells, a large degree of error can be introduced to the totals. Controlling post-tabular methods to ensure internal cells add up to output area totals or table totals is more complicated and finding an optimal solution can be a lengthy process. Controlled versions of rounding however maintain greater data utility compared with conventional and random rounding.

6. Disclosure Control using Table Design Methods

Table design methods can be applied alongside post-tabular or pre-tabular disclosure control methods as well as being applied on their own. Methods used to reduce the risk of disclosure include;

- Aggregating to a higher level geography or to a larger population subgroup
- Applying table thresholds
- Collapsing categories of variables (reducing the level of detail in the table)
- Applying a minimum average cell size to released tables.

Any tables not meeting the criteria for public release could be made available via some form of a special licence. Table design methods have been used in past UK censuses to supplement the pre-tabular and/or post-tabular disclosure control methods applied to the data. It is almost inevitable that some form of table design methods such as table thresholds will be used on 2011 Census outputs to the same effect – acting as a final safeguard to ensure the detail of the data is fitting for the method of release.

Table 20: The Advantages and Disadvantages of Table Design Methods

Advantages	Disadvantages
A1. If table design methods are used on their own then only true data is released. **A2.** Tables are additive. **A3.** Consistent totals in tables. **A4.** Easy to apply. **A5.** Easy to explain. **A6.** Thresholds can prevent sparse tables from being released where risk of attribute disclosure is high.	**D1.** Large amount of information lost. **D2.** Many tables may not pass release criteria. **D3.** User discontent at amount of data unable to be publicly released.

7. Conclusion

When compiling the short-list of SDC methods to be considered further in a quantitative risk–utility evaluation the following criteria for the 2011 UK SDC Strategy were taken into account:

- whether the method provides additivity and consistency
- user acceptance of the chosen method
- whether the method protects against differencing
- the overall practicality and feasibility of implementation
- the interaction between different types of output
- ease in understanding the method
- whether the method is easy to account for in analyses

The strength of user requirement for the availability of user defined flexible tables will not be known until 2008, hence there needs to be a working assumption that this option is likely to be made available in 2011. If flexible user defined tables are made available it will be vital that the SDC strategy provides full protection against disclosure by differencing. Specially commissioned tables from the 2001 Census were often subject to a long delay due to the auditing required to assess disclosure risk resulting from linked tables since small cell adjustments provided little protection against disclosure by differencing. This experience in 2001 suggests that whatever the output policy in 2011 (pre-defined tables or some pre-defined and the facility for user-defined flexible tables), ensuring that the disclosure control method protects against differencing is important due to the large amounts of tabular outputs on differing geographies which are likely to be released / requested. If flexible table generation was not provided for 2011 Census outputs then an SDC strategy which protects against differencing would still be preferable making the Census Offices duty to provide commissioned tables more efficient by removing the need to audit every table to prevent disclosure by differencing.

Mixed strategies can be used to protect against disclosure. This could involve pre-treating the microdata using a pre-tabular method of disclosure control and treating the resulting tabular data using a post-tabular disclosure control method. Previous research (Shlomo, 2006) has illustrated how the combination of record swapping and rounding can to some extent balance the opposing effects that the methods have on the utility of tables. The effects on data utility of combining pre and post-tabular disclosure control methods will be addressed when the methods are evaluated quantitatively using a risk-utility framework.

Pre-tabular methods have the advantage that they provide some protection to microdata as well as tabular outputs. The microdata may however require further protection to ensure the risk of disclosure is acceptable. In the UK SDC Policy Agreement the Registrars General expressed a preference for a pre-tabular method of disclosure control for 2011 Census outputs provided there is no undue damage to the data. A pre-tabular method of disclosure control would also satisfy the user requirement for consistent and additive tables. If a pre-tabular method of disclosure control is selected for the 2011 Census UK SDC Strategy then any perturbation of the microdata will need to take place in the Downstream Processing (DSP) schedule and would need to satisfy any requirements of the schedule. Any post-tabular perturbation of the data would take place during output production.

Throughout the development of the SDC strategy it will be important to consider the level of protection already inherent in the census data from error sources such as data processing, coverage adjustments, non response and edit and imputation procedures, although much effort is devoted to minimising these errors. This will ensure that the acceptable level of disclosure risk is suitable and the utility of the data is not damaged beyond what is necessary. Due to the problems encountered with sparse 2001 census tables (e.g. origin and destination tables) being significantly damaged after applying disclosure control, consideration will be given to releasing under a special licence any 2011 outputs whose utility is decreased by a significant amount.

Across the UK 2001 Census tabular outputs were subject to different threshold rules. Scotland adopted a minimum threshold for Census Area Statistic (CAS) tables of 20 households and 50 residents and OA's were designed to have a target size of 50 households. In England and Wales and Northern Ireland the threshold adopted for CAS tables was 40 households and 100 residents and the OA target size was 125 households. The harmonisation of output areas in 2011 is far from guaranteed. Following a public consultation on geography for National Statistics an interim policy position has been agreed that focuses on stability.

The Registrars General of England and Wales, Scotland and Northern Ireland have agreed to aim for a common SDC methodology for 2011 Census outputs. All UK Census Offices are working closely to achieve this aim. As outlined in this paper, the Census UK SDC working group, which has representatives from all UK Census Offices, has developed a short-list of SDC methods for the 2011 Census that will undergo a full evaluation over the next year. Formal quality assurance has been provided by the UKCDMAC, and individual Census Project Boards in the UK countries have been consulted prior to formal sign-off by the UKCC. The short-list will be communicated to users via a series of Census Advisory Groups in November, an RSS meeting in December, and an information paper which will be made available on the internet.

References:

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