Gravity Model Formulation

2.20 The basic gravity model takes the following formulation, known as the combined power and exponential function:

$$F(C_{ij}) = C_{ij}^{X_1} e^{X_2 C_{ij}}$$

where *Cij* is the generalised cost between each origin and destination, and X_1 and X_2 are calibration parameters.

2.21 Generalised cost is a combination of travel time and distance, expressed as a monetary cost in pence based on DfT valuations of the cost of time for personal travel as well as fuel and non-fuel elements of travel costs. DfT guidelines recommend that generalised cost be used in preference to pure time or pure distance in transport modelling. Using generalised cost as opposed to distance means that the ease of access to more distant retail locations (such as Bar Hill Tesco Extra) can reflect the higher speeds attainable on dual carriageway or de-restricted non urban routes.

2.22 The process of the Gravity Model is as follows:

- For each origin to destination (address point to store) movement, the value of the function F given above is calculated.
- Use the Furness process[5] to refine the outputs of the function F to give a matrix of trips whose total trips per address point match the expected values and whose total number of trips to each major food store match the target values from TRICS.

2.23 This is a doubly-constrained gravity model, meaning that both the origin and destination trip end totals are matched to predetermined totals. To implement this, the Furness process is employed to calculate factors to match each origin total to its target, then match each column total to its target total, and iterate repeatedly until a converged answer is reached (i.e. each row total and each column total matches its target). However, there are often many solutions to this problem (different arrangements of numbers within the table that still give the same row and column totals), so it is important that the input function F is of a robust form. This is achieved by calibrating the parameters X_1 and X_2 to give the closest match to the Trip Cost Distribution of the GVA Grimley observed data.

2.24 The TRICS database has been built up over many years, and contains traffic survey information from thousands of sites across the UK. These sites are categorised in detail according to their purpose – including supermarkets, offices, swimming pools, places of worship and many other categories. Within each purpose category, locations are also categorised (such as town centre, edge of town, rural) as well as different geographical areas (London, rural, Scotland). For each site, rates of arrivals and departures are given by hour.

2.25 In the context of food store trip rates, the dataset can be further refined according to the size of the store, allowing different trip rates to be extracted for the different sizes of store (see paragraph 2.16) – though a careful balance needs to be struck between specifying the exact nature of the site required and maintaining a large enough sample to give accurate estimates of trip rates. In practice, the food store trip rates extracted for this study were done according to the size categorisation of the store, though there was little variance between the categories.

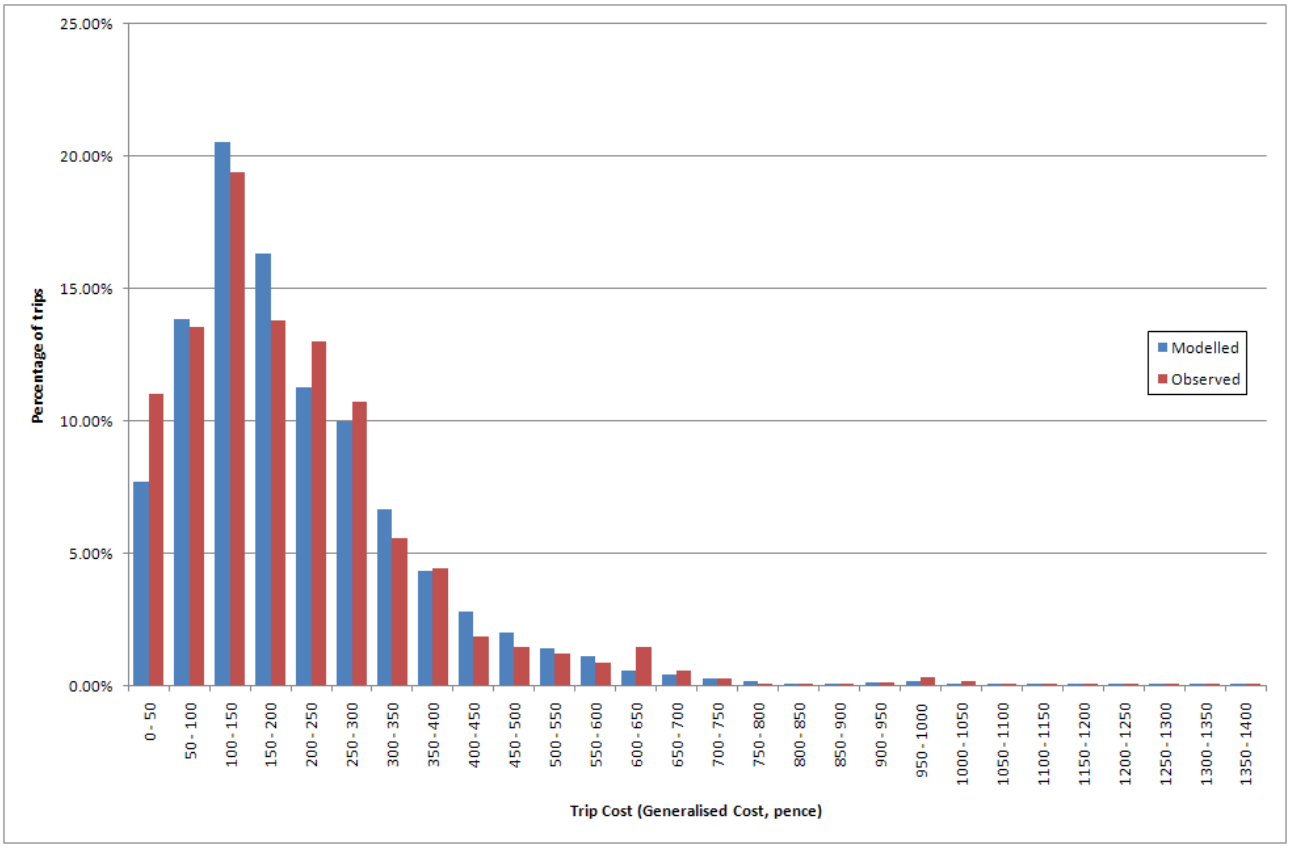
Gravity Model Calibration/Validation

2.26 Figure 2.5 shows the Trip Cost Distributions of the Observed (red) and Modelled (blue) data. The R^2 coefficient of variation is 0.971, indicating that the observed and modelled data is very well correlated. (The R^2 value is a measure of statistical fit between two sets of data: a value of 1

[5] The Furness process works by factoring each row to its target total, then factoring each column to its target total, and iterating repeatedly until a converged answer is reached.

would indicate a perfect match.) The analysis shows that a good degree of confidence can be placed on the ability of the gravity model to forecast responses to changes in the provision of major retail food stores.

Figure 2.5 – Modelled and Observed Trip Cost Distributions



2.27 Figure 2.5 shows the tendency towards longer-distance trips being recorded in the observed data, and that the Gravity Model is able to replicate this. Figure 2.5 also shows that there is a shortfall in the number of modelled lowest cost (shortest distance) trips, which causes the Gravity Model's average trip cost to be greater than that of the observed data. This means that the Gravity Model will tend to overestimate slightly the costs of trips and therefore predict a more pessimistic (high cost) outcome.

2.28 Table 2.2 displays the GVA Grimley observed data, the TRICS predictions and the Gravity Model outputs in terms of the number of trips to each major food store. The GVA Grimley observed data has been expanded from a sample of 412 interviews to a total of 61,659 trips as estimated by TRICS. A small discrepancy in the interview data can therefore cause a much larger difference when scaled by this amount. The fourth column shows the outputs from the Gravity Model, which match the TRICS estimates exactly. The final column gives an indication of the 2008 trading levels of each of these food stores (based on the GVA Grimley household survey) relative to their company average, derived from data provided in the SRS Report appendices (apart from the Cherry Hinton Tesco which is based on an NLP assessment). In this column, the = symbol means a store is trading within ±10% of its company average; ↑ and ↓ represent over and under trading by between 10% and 50%, respectively; and ↑↑ and ↓↓ represent over and under trading by more than 50%, respectively.

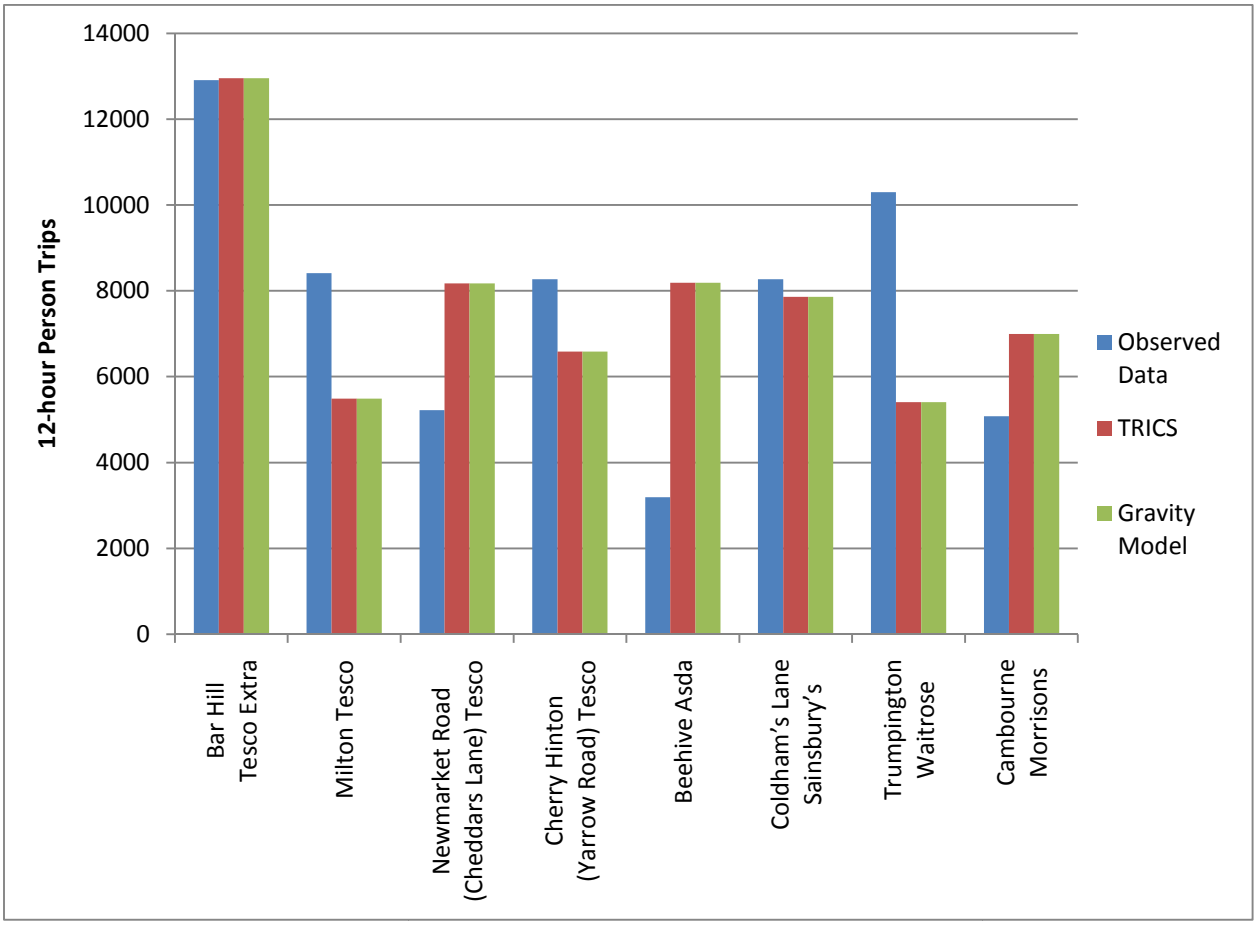
2.29 Following the table, Figure 2.6 shows the observed and estimated 12-hour person trips in a bar chart format.

Table 2.2 – Number of Trips to each Major Food Store

Store	Observed Data (Sample of 412 expanded to 61,659)	TRICS Estimated 12-hour Person Trips	12-hour Person Trips from Gravity Model	Trading Performance Relative to Company Average
Bar Hill Tesco Extra	12,912	12,956	12,956	=
Milton Tesco	8,415	5,488	5,488	↑↑
Newmarket Road (Cheddars Lane) Tesco	5,223	8,171	8,171	↓
Cherry Hinton (Yarrow Road) Tesco	8,270	6,586	6,586	↑
Beehive Asda	3,192	8,188	8,188	↓↓
Coldham's Lane Sainsbury's	8,270	7,861	7,861	↑
Trumpington Waitrose	10,301	5,409	5,409	↑
Cambourne Morrisons	5,078	6,999	6,999	↓
Total	*61,659*	*61,659*	*61,659*	

NB: The numbers displayed in this table do not add up due to rounding.

Figure 2.6 – Number of Trips to each Major Food Store



Summary of Gravity Model Performance

2.30 Figure 2.5 shows that the Gravity Model is functioning very well on overall trip cost distributions. Table 2.2 and Figure 2.6 show that the Gravity Model is also matching the TRICS estimates of the number of trips to each store, but that this does not always agree with the GVA Grimley survey data. This is particularly witnessed in the discrepancies for Milton Tesco, Newmarket Road (Cheddars Lane) Tesco, Beehive Asda and Trumpington Waitrose. Potential reasons for this are:

- The small sample size of the GVA Grimley interview data, meaning that a small discrepancy in the interviewed sample would cause a large discrepancy when scaled up to the total number of trips visiting these eight major food stores;
- Potential issues of brand loyalty and personal choice (e.g. Waitrose versus Asda), which cannot be picked up in this modelling;
- Some stores are over or under trading (as indicated in the SRS) – for example, Milton Tesco is known to be overtrading and so the GVA Grimley observed data suggests a higher number of trips to this store than the TRICS database does, while Beehive Asda is undertrading and so the observed data suggests fewer trips than the TRICS database; this cannot be replicated in the Gravity Model; and
- The method of collection of the GVA Grimley survey data – being collated by phone during the working day would impact on the socio demographics of the survey profile.

2.31 This shows that there is some limitation in the accuracy of the Gravity Model results, but there is no further empirical survey data that can help us refine our model to better replicate the trips for certain stores in the model.

2.32 The Gravity Model will be used to estimate the *differences* in trips to each store that are caused by the presence of a new store(s) in the future year scenarios, and therefore these discrepancies in the base year will not have a major impact in terms of the wider changes in travel patterns caused by the new store.

Future Year Construction

2.33 The Future Year Gravity Model is identical to the Base Year model in its operation. The calibrated values of X_1 and X_2 have been carried forward into all of the Future Year scenarios. The only differences between the Base and the Planned Development Only Gravity Models arise in the input data; these are:

- The list of address points has been expanded to take account of the new dwellings in NWC as accurately as possible;
- The number of dwellings elsewhere in the model has been increased in line with CSRM by increasing the assumed density of dwellings per address point: developments such as Cambridge East and Northstowe are not close enough to NWC for the exact locations of their dwellings to be required;
- An additional major food store has been included in Northstowe;
- The number of trips to major food stores has been increased to a level that is commensurate with the additional development between the Base Year and the Future Year; and
- Local centres have been included in the NWC developments as indicated in the information provided by the Districts (see Appendix A, Table A.3).

2.34 These changes are consistent with the inputs used in deriving the CSRM forecasts (see paragraph 2.11).

2.35 Each Test scenario has additional changes to reflect the situation being tested. Since there is already some level of retail provision in each location in the Planned Development Only scenario,

the number of trips to the additional stores in the Test scenarios have been calculated only from the additional retail floorspace required to make up the total size. The differences between the Planned Development Only scenario and each Test are detailed in Appendix A. The trip rates and 'gravitational pull' for each store has been calculated using its full size – only the number of trips has been reduced to account for those already modelled in the Planned Development Only scenario.

2.36 It should be noted that the trip rates used in the CSRM are not consistent with those from TRICS that have been used in the Gravity Model; the CSRM makes no distinction between food shopping trips and other shopping trips. Consequently, the number of trips in the Planned Development Only scenario is likely to be an underestimate, and this shortfall would be carried through to all Test scenarios. This would not affect the comparisons between the Planned Development Only scenario and the Tests, but it does have an impact on any absolute trip numbers.

2.37 Whenever a new store is opened, there is more competition for the existing stores in the area. The number of major shopping trips made by residents of NWC is not dependent on a major food store being provided within NWC, and therefore remains constant throughout all of the 2021 scenarios. To analyse which stores are in competition with the new store(s) in a Test, the following steps are taken:

- The Gravity Model is run with a larger total number of trips than the Planned Development Only scenario, to identify the catchment area of the new store(s). This means that each household is temporarily making more shopping trips to maintain the target levels to each store.
- Any individual movements to an existing store that have increased in size are then reset to the Planned Development Only values, as those trips do not change their destination when the new store(s) are added.
- All other movements are identified as those whose destinations are affected by the opening of the new store(s). These movements are then scaled down so that the total matrix size for the Test is the same as the Planned Development Only scenario. In this way, the model determines how the new store(s) abstract trips away from the existing stores.

Feedback to the CSRM

2.38 The Gravity Model outputs 12-hour person trips. These trips are allocated to different modes (car or non-car) according to their distance and the mode share for "Food – Superstore" trips in Cambridge derived from the SOLUTIONS study (see footnote 4 on page 7). These car mode shares are given in Table 2.3.

Table 2.3 – Car Mode Shares for Major Food Stores in Cambridge based on SOLUTIONS Study

Distance (km)	Percentage by Car
0	0%
0.5	27%
1	49%
1.5	62%
2	72%
2.5	79%
3	85%

Distance (km)	Percentage by Car
3.5	90%
4	94%
> 4.4	98%

2.39 The numbers of people travelling by car are then converted to the number of car trips using occupancy data from the DfT's WebTAG documentation. These are then split further into AM Peak, Inter Peak and PM Peak using the time of day profile from the TRICS data, to be compatible with the CSRM SATURN model.

2.40 The above procedure is carried out for the Gravity Model outputs from the Planned Development Only scenario and all Test scenarios. The difference in trips is then calculated between the Planned Development Only scenario and each Test, and this difference is applied to the CSRM SATURN highway models, replacing existing shopping trips with the new pattern of trips as predicted by the Gravity Model.

2.41 The highway structure of the SATURN models does not change between the Test scenarios; the basic access to each site is not affected by the inclusion of a food store. As discussed in paragraph 2.5, the highway representation of each development site has the main infrastructure coded as 20mph roads.

2.42 The highway model then enables analysis of vehicle kilometres, carbon impacts, junction performance, etc. to be undertaken for each Test and the Planned Development Only scenario. For each Test scenario, the impact of the additional food store related car trips on the network is examined, highlighting issues of congestion and network performance in the wider modelled area.

Summary of the Technical Approach

2.43 In summary:

- None of the existing transport models were found to be suitable for the purposes of this study for a variety of reasons (for example, inconsistent modelling approaches across the different sites, or lack of detail in the NWC quadrant). Whilst CSRM has a land use model attached to it, it does not provide detailed enough coverage of NWC and thus it was necessary to construct a gravity model which would take information from the CSRM land use model and in turn inform testing of the various scenarios using the CSRM SATURN highway models for the future forecast year.
- A bespoke Gravity Model has been developed for this study using information supplied by the districts and that acquired by GVA Grimley in their survey of shoppers. The base year (2008) model has been shown to accurately replicate the spread of retail trips found in the survey, although at a individual store level there are some discrepancies resulting from wider factors including sample sizes of the data, brand loyalty and personal preferences, actual over/under trading of the stores, and the socio-demographic survey profile.
- The Gravity Model has been used to forecast the situation in 2021, taking into account planned development across the county including expected retail provision within the NWC sites' planning policy as well as a new major food store at Northstowe. The model has then been used to inform changes to the future 2021 highway models in the CSRM so that the impacts of each scenario can be analysed at a more detailed network level and produce forecasts of travel distance, time and emissions.

3. Gravity Model Forecasts

Introduction

3.1 Chapters 3 and 4 provide information on the outcome of the testing of the six scenarios for locating a major food store in NWC (and including information on the 'Do-Nothing' case where no additional major food store is provided). This chapter concentrates on analysis of the Gravity Model outputs, while Chapter 4 provides more detailed transport related information extracted from the SATURN highway model. A qualitative discussion of the implications of these results can be found in Chapter 5.

3.2 The six test scenarios, plus the Planned Development Only scenario, are detailed in Appendix A. In summary, these are:

- **Planned Development Only:** Defined as being all development sites as currently planned including provision of local stores but no new major food store. This provides our 'baseline' traffic networks for 2021 against which each of the tests below have been appraised; the SATURN models are unchanged from those produced by CSRM.
- **Test 1:** Minor store on University site upgraded to a major store (5,500 m^2 GFA)[6] and included in Gravity Model with appropriate adjustments made to the SATURN models; other sites unchanged.
- **Test 2:** Minor store on NIAB site upgraded to a major store (5,500 m^2 GFA) and included in Gravity Model with appropriate adjustments made to the SATURN models; other sites unchanged.
- **Test 3:** Minor store on Orchard Park site upgraded to a major store (5,500 m^2 GFA) and included in Gravity Model with appropriate adjustments made to the SATURN models; other sites unchanged.
- **Test 4:** Minor stores on University and NIAB sites upgraded to (smaller) major stores (3,000 m^2 GFA each)[7] and included in Gravity Model with appropriate adjustments made to the SATURN models; Orchard Park store remains unchanged.
- **Test 5:** Minor stores on University and Orchard Park sites upgraded to (smaller) major stores (3,000 m^2 GFA each) and included in Gravity Model with appropriate adjustments made to the SATURN models; NIAB store remains unchanged.
- **Test 6:** Minor stores on NIAB and Orchard Park sites upgraded to (smaller) major stores (3,000 m^2 GFA each) and included in Gravity Model with appropriate adjustments made to the SATURN models; University store remains unchanged.

3.3 Figure 3.1 shows the locations of the 2021 modelled major food stores for the Planned Development Only and Test scenarios and the locations of the proposed new major food stores. Figure 3.2 shows the locations and sizes (m^2 GFA) of the stores in NWC that are modelled in the Planned Development Only scenario: these are all minor stores and are not included in the Gravity Model as they are present in the CSRM forecasts. Figure 3.3 shows the locations and sizes of stores in each Test scenario. Note that the store on the Orchard Park site changes location, depending whether it is minor or major: these two locations are labelled C1 and C2, respectively.

[6] 5,500 m^2 GFA is equivalent to approximately 3,800 m^2 RFA or 2,500 m^2 net convenience floorspace.
[7] 3,000 m^2 GFA is equivalent to approximately 2,000 m^2 RFA or 1,500 m^2 net convenience floorspace.

Figure 3.1 – Major Food Store Location Plan

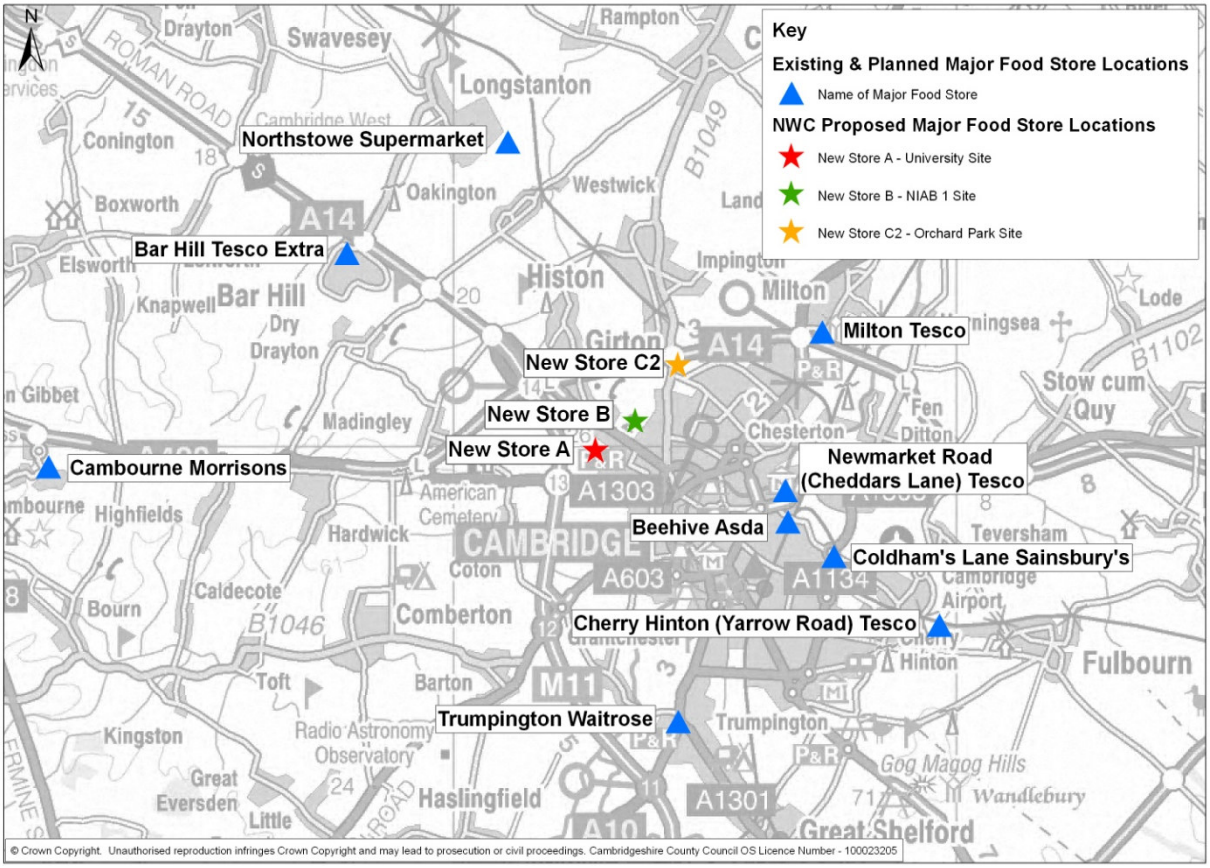


Figure 3.2 – Food Store Locations and Sizes (m^2 GFA), Planned Development Only

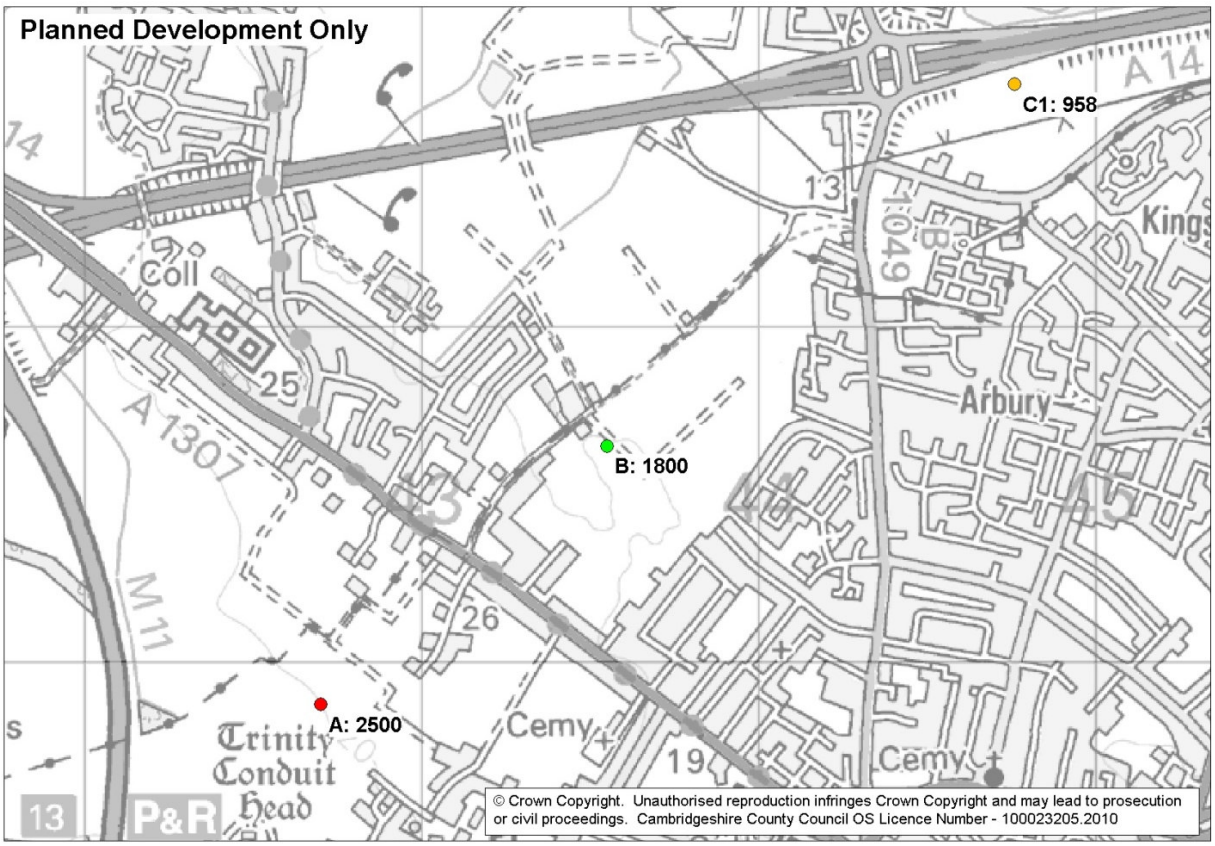
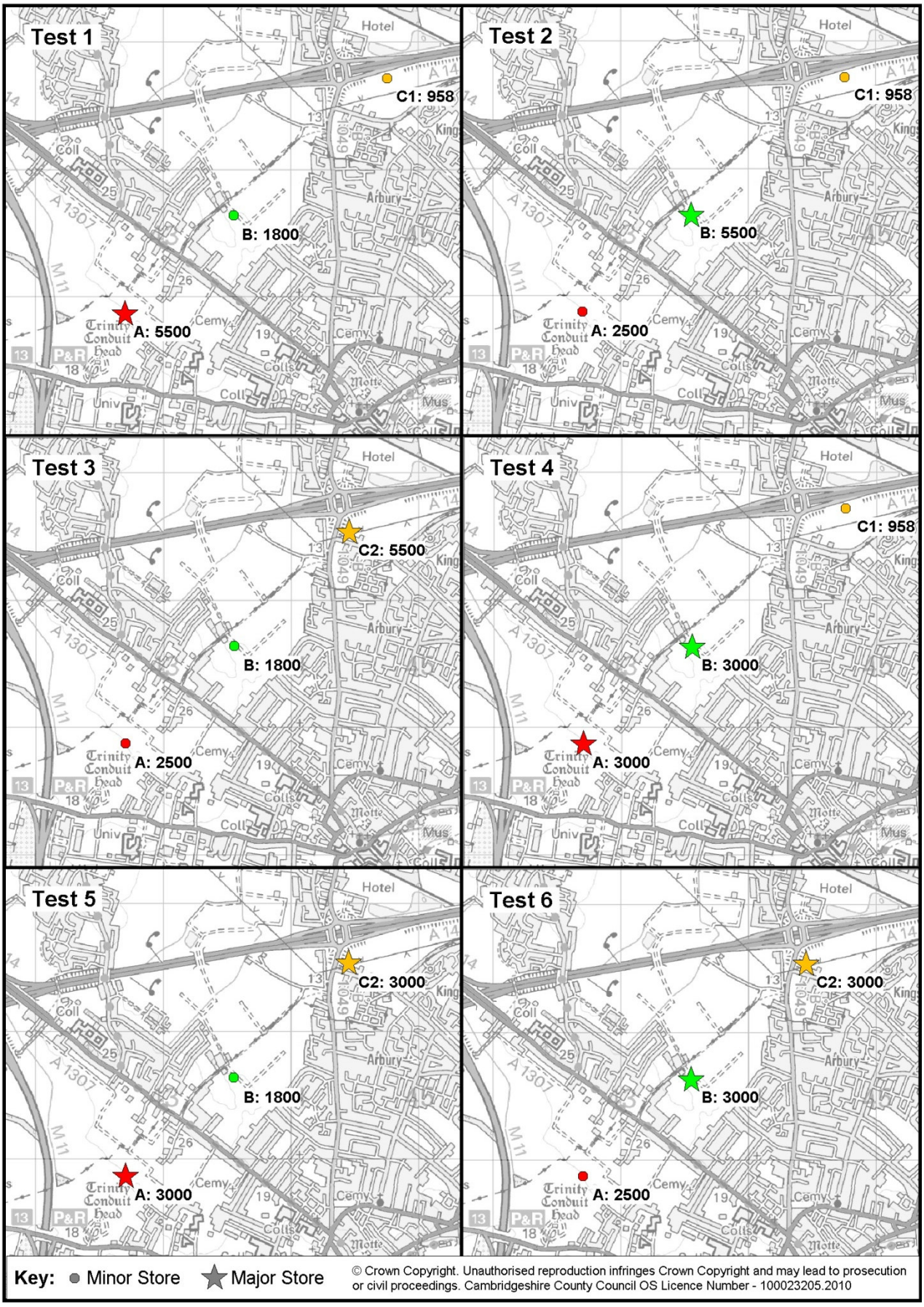


Figure 3.3 – Food Store Locations and Sizes (m^2 GFA), Test Scenarios



3.4 The remainder of this chapter deals with the analysis of the Gravity model forecasts of changes in trip patterns arising from the inclusion of a major new food store in each of the six scenarios. This includes:

- Mode share by car for each major food store location for all scenarios;
- Analysis of changes in the generalised cost of shopping trips (giving an indication of changes in travel time and distance across the County);
- How a new store in NWC will abstract retail trips from other major food stores in the modelled area;
- The level of internalisation achieved in the various scenarios; and
- The shopping destinations of trips from all wards in the Gravity Model catchment area, giving an indication of how far people are drawn to the modelled major food stores.

3.5 All results from the Gravity Model are presented in terms of 12-hour person trips, across the whole catchment area of the Gravity Model. They are converted later to car trips by time period for input into the CSRM SATURN model – this is addressed in the following chapter.

Mode Share

3.6 Mode shares were applied to each trip according to its distance, using the information derived from the SOLUTIONS study for main food shopping trips in Cambridge (see Table 2.3). The resulting mode share to each store is therefore determined by the distribution of short- and long-distance main shopping trips to that store.

3.7 Table 3.1 shows the percentage of trips to each major food store that are made by car, for main shopping purposes (not top-up shopping). A lower percentage indicates that fewer car trips, and therefore more trips by other modes (such as walking and cycling) are taking place. In addition, for the stores in NWC only, the number of people travelling in cars is provided (referred to as car-person trips). These are for a 12 hour day which has been generated by the additional food store provision over and above that contained in the Planned Development Only scenario.

3.8 For the existing stores, there is very little variation between the Planned Development Only scenario and any of the Tests. The results for the Northstowe supermarket are affected due to a less accurate distribution of the future year dwellings in that area, resulting in a decreased potential for short-distance non-car trips which would not be the case in practice.

3.9 The car mode share is clearly lower in areas that have greater population close by. The new store locations are all situated close to major housing developments, giving them all favourably low car mode shares. New Store A, on the University site, achieves the lowest car mode share since it has the densest population nearby; particularly the inclusion of student accommodation. It has since been noted that too many student accommodation units (see Appendix A) were included, but even when this number is reduced to the correct level, the University site still has the highest number of dwellings.

3.10 In Tests 4, 5 and 6, where there are two smaller stores, the car mode shares are lower (and therefore the non-car mode shares are higher) than when there is a single larger store as in Tests 1, 2 and 3. This is partly due to the better penetration of stores into the populated areas when the retail provision is split over two sites. The size of the store also plays a part in its mode share, since a smaller store has a smaller 'gravitational pull' and therefore draws its trips from shorter distances, which have lower car mode shares (see Table 2.3).

3.11 Note that this modelling covers only a household's main food shopping trips, not any top-up shopping. It is reasonable to expect that any top-up shopping that takes place at the new store(s) would also be sourced from the local area or from pass-by trips (see paragraphs 4.19 to 4.22).