CARBON AUDITING THE "LAST MILE": MODELING THE ENVIRONMENTAL IMPACTS OF CONVENTIONAL AND ONLINE NON-FOOD SHOPPING

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Introduction

The last link in the supply chain (from retailer / supplier to consumer), the so called "last mile", is not only the most visible, but can also be the most energy intensive part of the supply chain. Several authors (Browne *et al.* 2008; Weber *et al*. 2008; Jespersen, 2004) note that in the case of conventional shopping, personal shopping trips can use more energy than the entire upstream supply chain, even when production is included. Therefore, an assessment of the relative carbon intensity of the so called "last mile" delivery (i.e. the final home delivery to the customer) compared with the customer collecting goods from physical stores is of vital importance in identifying the overall impact of the two retail channels. While previous studies have also examined this last mile delivery (Abukhader & Jönson, 2003; Farag *et al.*, 2006), to date, no study has systematically compared conventional consumer travel with freight delivery in terms of energy expenditure per delivery drop / item bought.

This paper, taking into account the intricacy of consumer behaviour, attempts to model the carbon emissions associated with receiving non-food goods delivered to the home by parcel carrier, compared with consumers making a trip to the shops to buy the products in-store. Several last mile scenarios are proposed based on publicly-available data, discussions with practitioners in industry and realistic assumptions derived from the literature. Sensitivity analyses are then performed.

Literature Review

Online shopping: Environmental impact

Online retailers claim that shopping online is more environmentally-friendly than travelling to the shops to purchase goods (Smithers, 2007). Consumers tend to agree (IMRG, 2008; Royal Mail, 2007). Yet, the environmental balance favouring freight transport to the home over traditional shopping methods is not as straightforward as it may first seem as, there are direct effects and indirect (or complementarity) effects that may off-set any initial environmental gains. These include:

- Frequent purchases of small quantities generating numerous, relatively inefficient home deliveries (Kröger *et al.*, 2003; Mokhtarian, 2004);
- Customers' tendency to purchase separate items from several different web-based companies (each requiring separate delivery). Previously, goods would have been bought on one trip to the shops;
- Additional sortation requirements to combine multiple customers' orders prior to delivery. Some companies do not deliver the whole of a customer's multi-order in one trip because of the timing of the picking process;
- Internet-browsing encouraging people to go shopping for additional and/or supplementary purchases (Skinner *et al.*, 2004);
- Minimal travel savings for online shopping, when goods, if purchased via the conventional channel, would have been bought as part of an overall multi-activity trip;
- Additional freight movements being created in cases where customers previously walked or cycled to the shops;
- The treatment of failed deliveries when no-one is at home and the return of unwanted goods; and
- Lower prices for internet purchases encouraging consumers to buy more.

In recognition of these issues, the present study models several different consumer trip scenarios.

Conventional shopping: Consumer behaviour complexities

Equally, when it comes to conventional shopping, there is no such thing as a 'typical' high street shopper, and compiling accurate shopper profiles is difficult owing to a lack of behavioural data at the consumer level (Rotem-Mindali & Salomon, 2007). Further complexity arises because shoppers often multi-task (referred to as trip chaining) when they combine shopping with other non-shopping activities, such as travelling to work or dropping the children at school. The appeal to the consumer is that the marginal costs associated with the shopping segment of their journey can be negligible (Mokhtarian, 2004). Studies in this area are limited.

We cannot assume that consumers *only* make single-purpose, single-stop visits to high street stores (Dellaert *et al.*, 1998; Thrill, 1986). Popowski Leszczyc & Timmermans (2001) found that in New Zealand, a third of grocery shopping trips were multi-purpose trips (consumers still embark on a main weekly grocery shop, although they increasingly supplement this with top-up visits to stores (Future Foundation, 2008)). In contrast, when clothes shopping (a good example of a high-order discretionary purchase), consumers are found to be less sensitive to opportunities for reducing travel costs by trip chaining (Dellaert *et al.*, 1998). Brooks *et al.* (2008) speculated that purchase frequency (and associated factors such as expense and perishability) is linked to the perceived enjoyment or importance of the trip type or destination. In other words consumers are more prepared to make shopping for expensive goods the main reason for a trip (and to travel further in order to purchase those goods) than they are for the purchase of lower order goods; shopping for clothes, for instance, is often the sole purpose of a trip. In this paper, we examine several different conventional trip chaining scenarios with CO_2 emissions apportioned according to trip purpose.

Methodology, data sources and assessed scenarios

Using an Excel spreadsheet, and the carbon audit model outlined by Edwards *et al*. (2009a), the emissions factors for home delivery operations by diesel- and petrol-fuelled vans were obtained from four statistical sources (Defra, NAEI, RHA and FTA) and averaged. Emissions for personal travel (car and bus journeys) were derived from Defra (2007), and E4Tech provides the emissions factor for electric vehicles (E4Tech, 2007).

Online shopping: delivery rounds / drop characteristics, failed deliveries and returns

The vast majority of online purchases result in the physical movement of goods to an individual address (typically a consumer's home) by parcel carrier (RAC Foundation, 2006). In general, these deliveries are distributed from local parcel carrier depots, and consist of mixed loads in the back of vans. Volumes delivered are high: IMRG (2008) estimates that 820 million parcels were delivered to UK online shoppers in 2008.

Traditionally, vehicle load factors have been measured with respect to weight. For vans in the home delivery sector, the number of drops per round is more representative of vehicle utilisation than the total weight of the consignments, as parcel delivery companies are concerned with achieving high drop density rates. Therefore, all delivery drops are treated equally, regardless of their physical shape and at what point in the round they are delivered.

Another important consideration is the incidence of failed delivery, as increasingly people are not at home to receive deliveries during the working day, when most home delivery companies operate. We use two failed delivery ratios. First, a first-time failure rate of 25% of deliveries, after McLeod & Cherrett (2006) and Song *et al*. (2009); and second, a 12% failure rate (assumed by Weltevreden & Rotem-Mindali (2008), and similar to IMRG (2008)).

The return of unwanted goods is a further issue. Typically, between 25-30% of all non-food goods bought online are returned compared with just 6-10% of goods purchased by traditional shopping methods, although this varies widely among product groups (Nairn, 2003; Fernie & McKinnon, 2009). The environmental implications of these online returns are strongly influenced by both parcel carriers' returns policies and consumers' preferred habits. For instance, parcel carriers who collect returned items as part of their usual delivery round, and courier networks that offer to take back items when their representatives are next delivering in that area, generate very little additional mileage. Alternatively, for retailers with a high street presence, customers may choose to return items to a physical store, or otherwise send them back through the standard postal service. The modelling undertaken for this stage takes account of these different returns options.

The home delivery calculations relate to typical conditions, with the underlining assumptions based on information derived from discussions with leading parcel delivery companies. As a result, we apply the following criteria to the calculations:

- *An average home delivery round*: 50-miles and 120 drops;
- *A city centre round*: an average of 25-miles and 110 drops;
- *A rural round*: typically 80-miles round trip, with approximately 70 drops;

- *A personal courier delivery*: 40 drops and 25-miles (either with a local delivery to a courier's home first or the courier collecting deliveries from a local depot);

In addition, we assume a range of items per drop, from a single item per drop to 1.4 items in the case of deliveries containing books / DVDs / CDs and 2.5 items for other non-food goods (clothes, household items) (Beveridge, 2009). Some online retailers have a dispatch policy where they delay distribution until all items purchased are available for delivery, while other online retailers prefer to send one item per package regardless of the number of goods ordered at the time of transaction. For direct comparison with conventional shoppers' behaviour, per item delivered is the preferred variable.

Conventional shopping: Personal travel

Our analysis has relied mainly on government statistics available at the national level. The National Travel Survey, undertaken by the DfT, collects data on personal travel and travel behaviour over time, with the average car driver making a round-trip of 12.8-miles for non-food shopping and bus passenger 8.8-miles per trip (DfT, 2009c). We also assume average bus patronage (9.2 passengers per bus). By restricting our analysis to these two motorised transport modes we cover the majority (72%) of shopping trips (DfT, 2007). Those trips undertaken on foot or by bicycle have been excluded from the calculations, in line with typical life cycle assessments.

Some shopping trips do not result in a purchase, though this 'browsing' category has been largely ignored by researchers owing to a lack of data (Moe & Fader, 2001). Nevertheless, frequently a fact-finding trip results in a later purchase (often online) (Skinner *et al.*, 2004). RAC (2006) reported that almost four out of five internet shoppers (78%) go to stores to look at goods before buying online, and DfT (2009a) recently reported that in almost a fifth of deliveries, a household member had visited an outlet prior to purchasing the item online. The converse is also true, where people research the market online prior to the shopping trip. This permits some rationalisation of the shopping activity and related travel.

Results and discussion

An average home delivery round (50-miles) produces 181gCO_2 per drop assuming 120 drops (or 21,665gCO_2 over the course of the round). This can be compared with an average shopping trip by car (12.8-miles) generating 4,274gCO_2 (all of which is assigned to the number of items purchased by the individual shopper). If only one item is purchased conventionally then the entire trip emissions are allocated to that one item. In other words the CO_2 from personal car-based travel is 24 times greater than the CO_2 produced by a delivery drop as part of a typical freight round when only a single item is purchased in each case.

An alternative interpretation is that a consumer would need to buy 24 non-food items in one standard car-based trip for this method of shopping to be less CO_2 intensive than having one non-food item delivered (on the first attempt) to their home by a parcel carrier. For an average bus passenger, 7 or more non-food items would need to be purchased to compete favourably with a home delivery.

The above calculations assume one item per drop for home delivery and only one item per shopping trip. When we increase the number of items per home delivery to a more realistic 1.4 items per drop (for a typical book order) and 2.5 items per drop (for clothes and other household goods) the CO_2 per *item* is reduced to 137g and 72g respectively or the equivalent of a conventional car-based shopper needing to buy 32 or 59 non-food items in one trip. For bus travel a shopper would have to carry 10 or 18 non-food items respectively.

Delivery / collection method	Total gCO_2 per trip	gCO_2 per item delivered / collected
Standard delivery van (<3.5-t) (120 deliveries per 50-mile round trip)	21,665g	181g (per drop) 137g (1.4 items) 72g (2.5 items)
Car (dedicated shopping trip of 12.8-miles)	4,274g	4,274g (single item)
Bus passenger (dedicated shopping trip of 8.8-miles, assuming average patronage)	11,641g	1,265g per passenger (single item)

Table 1: CO_2 per average trip and per drop/item (parcel carrier / car / bus)

The above investigations compare theoretical trips based on average values, yet home deliveries vary by delivery vehicle, drop density (the number of delivery drops per round); failure rates (the number of failed first-time deliveries); distances covered (including type of road network), and the method by which unwanted items are returned.

Online shopping considerations

Delivery vehicle and drop characteristics: Deliveries in central urban areas are characterised by relatively high drop densities and relatively short delivery rounds. A city centre delivery round is defined as 25-miles and a 110 non-food drops (these figures are based on typical values for a leading parcel delivery carrier in the UK). Using these values the gCO_2 emissions per drop (containing only a single item) average $98gCO_2$ compared with a typical value of $181gCO_2$ for an average round (Table 1). To date, only a few companies use electric vehicles for non-food delivery. Employing this technology a city centre delivery drop by electric vehicle would be apportioned $28gCO_2$. Similarly, assuming the average item content is increased to 1.4 items per drop, a standard urban delivery would generate $70gCO_2$ per drop and an electric vehicle $20gCO_2$ per drop.

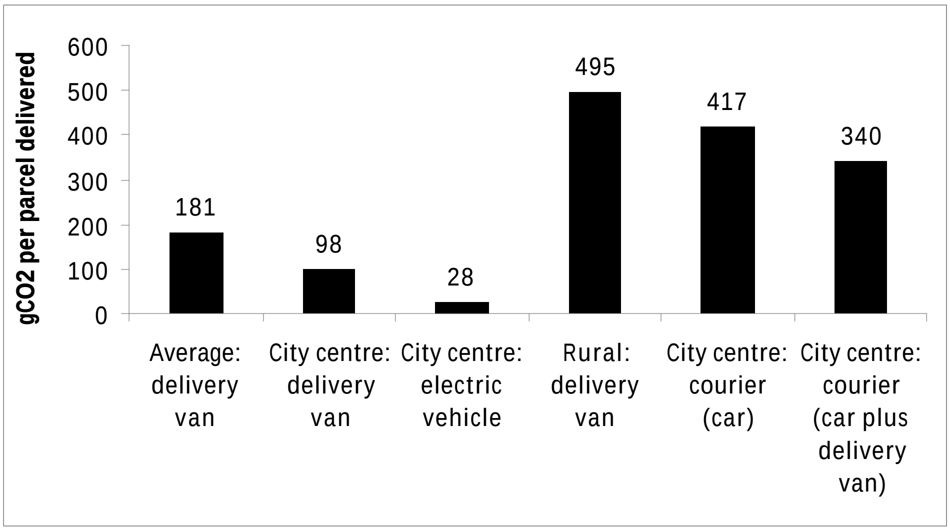

Figure 1: gCO_2 per drop for average deliveries by round type

In rural areas typical delivery distances are greater (80-miles) and deliveries per round fewer (70 drops). As a result, a typical non-food drop (containing a single item) delivered to a rural address by standard delivery van would be allocated $495gCO_2$ (Figure 1), or five times the typical emissions for a city centre delivery. Parcel delivery carriers are far less likely to deploy electric vans to these outlying areas, owing to greater round distances and few recharge opportunities while away from the depot. In summary, it appears that standard city centre deliveries produce just 20% of the CO_2 per drop that rural deliveries generate (when vans are the means of delivery).

Similar analysis is now performed for car-based or 'courier' deliveries. Courier home deliveries (using a private car) have become increasingly popular among online retailers in recent years (Beveridge, 2007), yet with lower drop densities (of approximately 40-deliveries per 'round') and the use of relatively inefficient private vehicles, their CO_2 emissions per standard delivery (of 417g) are six-times the emissions of a city centre van-based delivery, *and* higher than typical emissions per delivery to rural areas. This assumes that couriers use their cars to collect deliveries in person from their local depot. When a delivery van undertakes part of the route first to the courier's home, the CO_2 is reduced to 340g per drop. The relative inefficiency of car-based couriers for home delivery has not been highlighted previously. Nevertheless, courier-style deliveries are popular among both clients and carriers, as they achieve relatively high first-time delivery rates (couriers often have a regular customer base and therefore, become familiar with their customers' availability to receive deliveries). Additionally, couriers often combine deliveries with other activities, e.g. supermarket shopping or performing the 'school run' (Beveridge, 2009), thereby partly off-setting the relatively high emissions per courier drop.

Failed delivery rates: Failed delivery is both inconvenient and uneconomic. We take two first-time failure rates for both urban and rural areas. Various failed delivery scenarios are considered for both urban and rural areas, based on the following:

- a 12.5% deliveries failure rate (considered to be an average to good failure rate for deliveries); and
- a 25% first-time failure rate (similar to failure rates noted by McLeod & Cherrett, 2006) and Song *et al*. (2009), and often experienced by those carriers requiring proof of delivery signatures.

	100% successful first-time delivery	**12.5% failure rate**	**25% failure rate**
Urban deliveries: gCO_2 per item	98g	110g	123g
Rural deliveries: gCO_2 per item	495g	557g	619g

Table 2: Emissions (gCO_2) per item including failed delivery rates

Emissions of CO_2 per average city centre drop may increase from 98g for 100% first-time delivery to the worse-case scenario of 123g when one-in-four deliveries fail. Similarly, in rural areas CO_2 per drop increases from the standard 495g for no failures to 619g for a 25% failure rate (Table 2).

Most delivery companies automatically schedule the re-delivery attempt for the next working day after the first-failed attempt, and as a result a high percentage of second attempts also fail, compounding the effects of the initial failed delivery. After a second failed attempt non-delivered goods are held at the local depot, and 'carded' customers (those receiving a failed delivery slip through the letterbox) have to visit the depot in person to collect the item. Around 3% of all home delivery recipients make a trip to collect an item left at a post-office, depot or outlet (DfT, 2009a). The CO_2 implications of these failed deliveries is the focus of Edwards *et al*. (2009b).

Returns: When unwanted items are collected by the parcel carrier as part of the outbound delivery round, the gCO_2 per collection / item is effectively the same as per delivery. However, when alternative arrangements are made (either on the part of the consumer or the carrier) more complicated calculations are necessary, and these are examined next.

Conventional shopping considerations

Dedicated trips (solely for the purpose of shopping)

Table 1 illustrates the emissions produced by average non-food shopping trips by car and bus, when fossil fuels are the standard energy source. When a car powered by electric means is the mode of travel, the shopping trip would be responsible for 1,586gCO_2 (or approximately a third of the emissions produced by a standard car). Many such non-food trips are much shorter in distance. Even so, a local 2-mile shopping trip by car still generates 1,336gCO_2 (to be distributed equally among the items bought), and a similar trip by urban bus 317gCO_2 per passenger.

In the case of longer, dedicated shopping trips of some 40-miles return, for example, when a conventional shopper makes a trip to a neighbouring large town / city other than where they usually shop or someone in a rural area travels to their main town centre, using a car is over 70 times less efficient in carbon terms, at 13,358 gCO_2, than having an item delivered first-time to a consumer's home (181gCO_2), assuming the item is kept by the online customer. An express bus service and rural bus would produce 5,751gCO_2 and 4,198gCO_2 per passenger respectively and therefore is between 23 and 30 times less efficient. These comparisons assume only one conventional shopping trip is required to make the purchase.

Browsing (a shopping trip involving no purchases):

A certain number of shopping trips end in no purchase, and in these cases, the unsuccessful trip needs to be factored into the calculations. On the assumption that one in ten shopping trips for a particular product results in no purchase, the gCO_2 in each of the above dedicated shopping trips would increase by a factor of 1.1. Nevertheless, at a *personal* level, a shopper's CO_2 trip-related footprint would double to take account of a second journey to the shops. So while total emissions for a 'browsing plus purchase' average car trip would be 4,701gCO_2, (4,274gCO_2 x a factor of 1.1, as we assume one in ten conventional shopping trips is for browsing only), for the individual undertaking the second journey it would be 8,548gCO_2 as they make the journey twice.

Trip chaining

Trip chaining is a further consideration. Rather than making dedicated visits to shops solely to buy a product, a consumer may choose to acquire the item as part of a larger shopping expedition when many items are bought, and / or to combine the shopping trip with other activities. Some possible emissions consequences (for the high street shopper) are illustrated in Figure 2. The combined trip assumes that shopping-related mileage is a quarter of the overall trip mileage (25%).

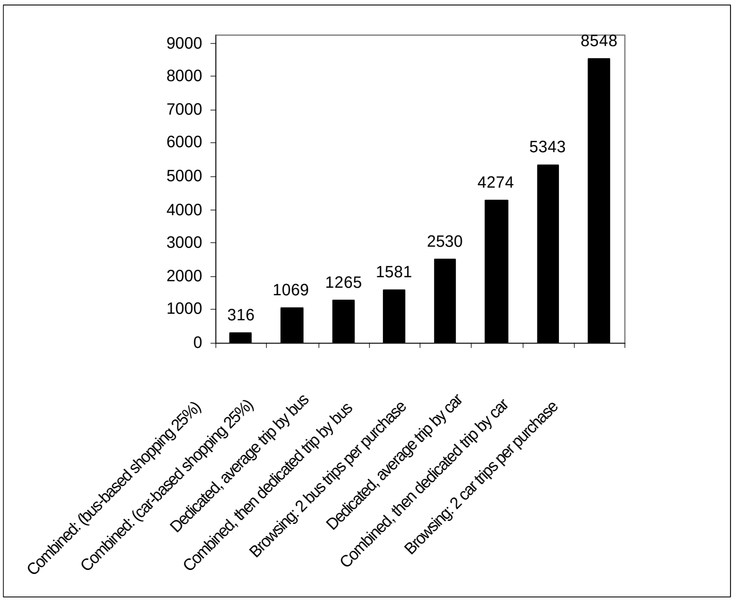

Figure 2: Implications of shopping trip type on CO_2 emissions

The consolidation of shopping activities is to be encouraged, as the most efficient ways to purchase shopping are either by car as part of a bulk shopping trip or when the shopping activity is part of a combined trip (trip chaining) or by bus, travelling at peak times in the company of lots of other passengers. In fact, bus travel can compete with home delivery in terms of CO_2 efficiency during high-occupancy periods. For example, when a shopper travels an average distance (8.8-miles) by bus, in the company of 29 other passengers, and buys 5 items, each purchase would be allocated a share of just 78g$CO_{2,}$ less than that for a city centre home delivery (98gCO_2).

Returns

The actual gCO_2 per online order will very much depend on not only the number of delivery attempts but also the method by which unwanted items are returned by the customer to the retailer. The most efficient returns method is when a parcel carrier modifies their outbound schedule to collect returns as part of the standard delivery round. In this case the integrated returns collection is allocated 362gCO_2 (twice the CO_2 of an outbound drop), as the unwanted item has the combined emissions of an outbound and return trip (in effect two outbound deliveries).

When the customer returns the item directly to the retailer's high street store, the CO_2 would be 4,455gCO_2 (181gCO_2 plus 4,274gCO_2), calculated on an average car-based round trip (12.8-miles). Owing to convenience many shoppers opt for this method, although ideally the returns trip should be undertaken at the same time as other activities, as part of an overall trip chain, or alternatively, the item should be returned when the shopper intended to shop at those premises anyway.

Discussion and summary

The calculations in this study and available published evidence (Jespersen, 2004; Browne *et al*., 2006; Weber et al., 2008) suggest that emissions from car-based shopping trips can far exceed those from distribution operations back along the supply chain. It is likely therefore that the environmental comparison of online and conventional shopping channels will be dominated by what happens at the local level. Differences in CO_2 emissions between car-borne shopping trips and home deliveries are likely to be much more important determinants of the respective carbon footprints of online and conventional shopping than differences in upstream logistical operations as far back as the point at which the two distribution channels diverge.

Numerous factors influence emissions from home deliveries. They include: drop densities (the number of drops per delivery round); the distance and nature of the delivery round; the type of vehicle used; and the treatment of failed deliveries and returns. On average, when considering only the last mile stage and assuming a dedicated conventional shopping trip, a customer has to buy 24 items or more per trip (or 7 or more items for bus users) for the conventional shopping trip to be as carbon efficient as a home delivery.

This assumes a successful, first-time home delivery, yet emissions per drop or per item are obviously affected by drop density and vehicle use. In urban areas van-based deliveries within city centres were found to produce half the CO_2 emissions of an average, geographically non-specific round, owing to the compact nature of the area served and the relatively high drop densities, while emissions from deliveries to rural areas were more than twice the average (at 492gCO_2). Dedicated deliveries by courier in urban areas emitted surprisingly large amounts of CO_2 per drop (417g) indicating the environmental inefficiency of using a car as the delivery mode (though it is acknowledged that car-based couriers have the opportunity to combine deliveries with other trip chaining activities). Overall, when the incidence of failed deliveries was factored in, emissions per drop rose by as much as 25% for this type of delivery.

For any length of conventional shopping trip it is always better to maximise the number of purchases at any one time, though for longer shopping trips, home delivery by van is almost always the most efficient method of acquiring non-food goods. This holds true even when the relatively high rates of online parcel returns are factored into the calculations, as long as the unwanted returns are collected by the parcel carrier. Importantly, when a shopper travels by bus at busy times and makes several purchases, the emissions per item are lower than when a home delivery van delivers just one item to a consumer's home. Consequently, the use of public transport needs to be promoted wherever practical, especially for shorter trips.

The relative carbon intensity of the different forms of retail distribution depends on their particular circumstances. Neither has an absolute environmental advantage. Some forms of conventional shopping behaviour emit less CO_2 than some home delivery operations. On average, however, in the case of non-food purchases, the home delivery operation is likely to generate less CO_2. This environmental advantage can be reinforced in various ways if online retailers and their carriers alter some of their current operating practices.

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