Environmental Analysis of US Online Shopping

Dimitri Weideli
Master Thesis Executive Summary

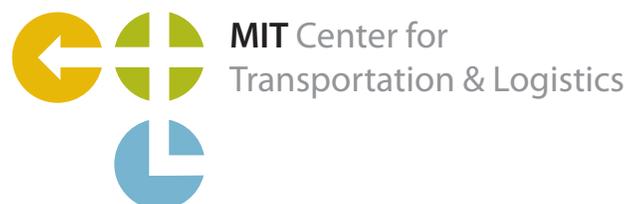Ecole Polytechnique Fédérale de Lausanne – EPFL
Lausanne, Switzerland

Research carried out at MIT Center for Transportation &
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Advisors:
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ABSTRACT: Since the advent of the Internet in the 1990s, there has been a significant increase in online shopping in the United States. As online shopping keeps growing, so does the online retail industry. Multiple players are investing either through pure online retailing or by click and mortar retailing, which also has a physical presence and a face-to face experience with their customers. While significant research has been done on the operational, marketing, branding and buying behavior dimensions of both retailing processes, there have been very limited studies on their comparative environmental impacts. This thesis attempts to estimate and compare the carbon footprint of the shopping process through ten consumer buying behaviors representing different combinations of the search, purchase and return phases of the shopping process for three representative products (electronics, clothing and toys). Using Monte Carlo Simulation, multiple scenarios of supply chain configurations, consumer transportation choices, urban density, packaging and item bundling are evaluated. Results show that online shopping is the most environmentally friendly option in a wide range of scenarios. However, as more consumers leverage traditional brick-and-mortar alternatives to their online buying behaviors, some of the environmental savings quickly erode.

1. Motivation

Online shopping is growing in the United States and represents 4.7% of the total retail trades in 2011 (US Census bureau, 2013) and might grow to 10% in 2017 with an average annual growth rate of 9% (Forrester, Mulpuru, Johnson, & Roberge, 2013). Moreover, brick and mortar retailers tend to add online retailing to their activities, people are more and more digitally connected (US Census Bureau, 2013) and find online shopping more convenient than traditional shopping.

Whereas most of the studies focus on comparing both retailing processes (Chiles & Thi Dau, 2005), only a few of them discuss their environmental impact such as Edwards et al. (2010) who analyzed the last mile delivery of non-food items, Matthews et al. (2002) who analyze the environmental impact of books retailing in the US by taking into account the differences in packaging and the return rate of unsold books, and Weber et al. (2008) who take into account the difference in packaging, transportation and buildings energy consumption. All these studies tend to conclude that under certain parameters, online shopping has a better environmental impact than traditional shopping. However, the literature fails to address the impact of the multiple steps of the buying process that define multiple shopping behaviors.

2. The Retail Supply Chain

Online and traditional retailers have different supply chains to fulfill their customer demand. Once products have been ordered from vendors, they start in a retailer central warehouse. For a brick and mortar retailer, this warehouse has to keep enough inventories to fulfill in appropriate quantity and on time multiple retail outlets. Each retail outlets also have to store enough products to fulfill the customers' needs. The products are usually transported by freight truck in large quantity, especially using pallets.

For an online retailer, the warehouse could be located anywhere as it does not have to fulfill a retail store. When a consumer purchases online a product, the information is sent to the warehouse through a data center. The product is individually packaged and shipped to the customer delivery address. According to the delivery option chosen, the delivery could either be done by truck or by airfreight. Finally, a parcel delivery carrier delivers the product, through an optimized delivery route of multiple customers.

Variations of these supply chains exist for both online and brick-and-mortar retailers (e.g. supplier direct to store, multiple tier warehouses). This study will be based the main archetype described above.

3. The Consumer Buying Process

Besides different supply chains to fulfill customer demand, online and traditional retailer affect the consumer buying process. The consumer buying process is made of five main steps (Blackwell, Miniard, & Engel, 2004).

1. *Need Recognition:* The consumer becoming aware of a lack or need that could be fulfilled by a product or service.
2. *Information Search:* The consumer collects information on existing products and services that satisfy the need.
3. *Alternative Evaluation:* The consumer evaluates the gathered knowledge, in order to chose the most appropriate product or service.
4. *Purchase:* The consumer takes action and buys the selected product or service.

5. *After Purchase Evaluation:* The consumer reconsiders his/her purchase. It may result in keeping, returning, re-selling or throwing the item.

As the purpose of this study is to evaluate the environmental impact of the buying process, a simplified model is proposed. The first step, that is more psychological, is out of the project scope. The second and third steps are merged, since both searching and evaluation are often iterative and parallel processes. Thus, the buying process for the purposes of this study is composed by the following three main steps:

1. Search
2. Purchase
3. Return

Each step could be accomplished either online, in store, or by some combination of both. The different consumer behaviors resulting from the various combinations are shown in Table 1.

Behavior	Search	Purchase	Return
Traditional Shopper	In stores (multiple trips)	In store	In store
Traditional Shopper Impulse	In store (single trip)	In store	In store
Traditional Shopper e-informed	Online	In store	In store
Modern Shopper (Impatient)	Online - In store	Online (air delivery)	Online
Cybernaut (Impatient)	Online	Online (air delivery)	Online
Cybernaut Quick Return (Impatient)	Online	Online (air delivery)	In store
Cybernaut Pick Up	Online	Online (purchase) In store (pick up)	In store

Table 1: Selected consumer behaviors

A *Traditional Shopper* will perform all the steps of the buying process by visiting a brick-and-mortar store, including multiple trips during the search step. An "impulse" behavior indicates that the traditional shopper will only visit a store once (i.e. items are bought without additional visits to stores).

In contrast, a *Cybernaut* will perform all steps online by searching, purchasing and returning the products using the retailer website. The other behaviors are variations of these two. For instance, a *Modern Shopper* will do a search of products via store visits and online searches, but complete the rest of the steps online, while a *Traditional E-Informed Shopper* will do all the search process online but complete the rest of the buying process in a brick-and-mortar store. Other consumer variations come from choices of purchase

and return. A *Cybernaut Pickup* behavior will do all the search process online but elect to pick-up and return the products in the store, while a *Cybernaut Quick Return* will opt to do all the search and purchase steps online but return the product in a brick-and-mortar store.

All online purchase behaviors may elect regular delivery, which will heavily rely on ground shipping options, or quick delivery for impatient consumers, which include air shipping.

4. Selected Products

The carbon footprint of the buying process depends of the product being purchased. Product characteristics such as volume, weight, price and packaging directly affect the environmental impact or the allocation of emissions across the supply chain. The study focus on three products with distinct characteristics:

- Laptop, representative of consumer electronics category (higher dollar value, bulkier, more protective packaging required)
- Barbie doll, representative of toy category (low dollar value, small profile, medium packaging)
- T-shirt, representative of clothing category (low or no packaging, higher return rate)

The environmental impact of manufacturing and disposing the product themselves is not within the scope of this analysis.

5. Carbon Footprint Calculation

Carbon footprint is an estimate of emission of green house gases across the retail supply chain. As carbon dioxide represents approximately 84% of the total gases emission, results are expressed in CO_2 equivalent (CO_2e) (EPA, 2011). US average values of the emission factors of the electricity generation, the consumption of natural gas, vehicle fuels, and packaging materials were used (see Table 2).

	Emission factor	Source
Electricity	552 gCO_2e/kWh	(eGRID, 2012)
Natural gas	1926 gCO_2e/m^3	(EIA, 2011)
Car	233 gCO_2e/km	(EPA, 2008)
Bus	67 gCO_2e/km	
Parcel carrier	332 gCO_2e/km	
Road truck	0.204 gCO_2e/kg-km	
Airplane	1.057 gCO_2e/kg-km	
Corrugated cardboard	1.45 gCO_2e/g	(EPA-WARM, 2012)
EPS	4.0 gCO_2e/g	
PVC	2.45 gCO_2e/g	
Paper	0.123 gCO_2e/g	

Table 2: Main emission factors in USA

The main components included in the carbon footprint calculation are:

Packaging: Based on life cycle analysis of the different materials used, the packaging of the product (primary packaging), and the shipment packaging (secondary packaging) are estimated for each product. For brick and mortar retailing, the secondary packaging includes pallets and protective shrink wrap; whereas shipping boxes and inner packaging (e.g. foam peanuts) are assumed for online shipping.

Transportation: US average fuel consumption values of all vehicles are used combined with approximated freight distance traveled in trucks, airplanes, parcel carrier delivery vehicles and customer vehicles (with trip chaining).

Energy consumption: In the US (EPA, 2011), electricity and natural gas are the main sources of energy used for heating, lighting and buildings' across the supply chain. For each building type, different allocation methods were used to assign the emissions to products, when needed:

- *Warehouse, sorting and collecting centers:* according to the storage time in the building
- *Retail store:* according to the annual number of customers entering the building for searching, purchasing and returning products.
- *Computer use:* Electricity consumption of personal computer use during the buying process.
- *Data center:* Approximation of the carbon footprint of the use of the Internet, according to the average number of servers in use in the US, and the global internet traffic [1.7 kWh/GB in 2012] (Koomey & Taylor, 2008)

Information flow: In addition to electricity used to transmit information, estimation of emissions of printed labels necessary to trace the product through the supply chain.

The collection of data included official US statistics and assumptions made in the literature. In order to take into account the variability of the different parameters, a Monte Carlo analysis has been applied to each consumer behavior, with 10000 samples (see Table 3).

		min	max	source
Online time of	Search	30 min	2h	-
	Purchase	10 min	18 min	
	Return	10 min	15 min	
Distance [km]	Freight brick and mortar	50	400	(walmart, 2013) approximation
	Freight online	50	1500	(amazon.com, 2013) approximation
	Customer	1	8	(US department of Transportation, 2009)
	Parcel carrier	0.1	1	-
Internet	Computer power [W]	30	120	(Pickavet & et al., 2008)
	Data center gCO_2e/h	17.3	101.2	(Koomey & Taylor, 2008) 2012 approximation
other	Trip chaining	20%	100%	-
Building's energy	Warehouse $[gCO_2e/m^2\text{-}day]$	38	162	(EIA U., 2007)
	Retail store $[kgCO_2e/m^2\text{-}year]$	35	148	

Table 3: Main parameters' assumptions

Finally, estimation of return rates have been applied to each consumer behavior, with the assumption that there are more returns with an online purchase, than in a traditional store purchase (Edwards, McKinnon, & Cullinane, 2010).

6. Results

Results are shown for the buying process of a toy, for customers living in an urban area. Figure 1 shows the carbon footprint of online and traditional shopping, when only the purchase step and the appropriate return rate are considered.
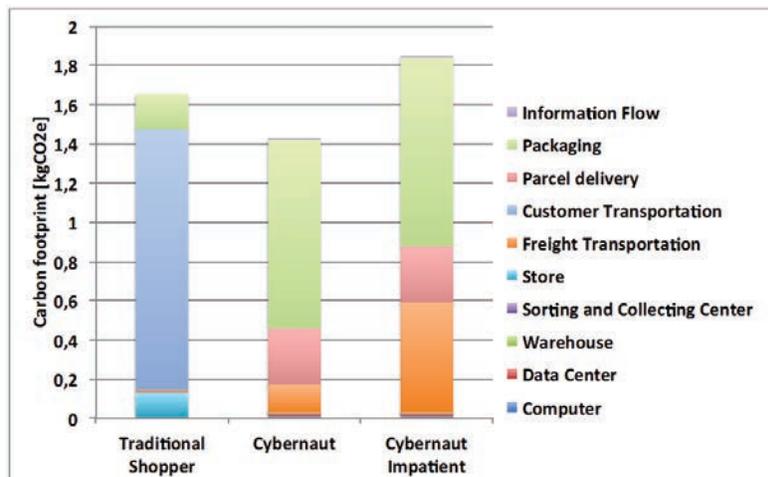
Figure 1: Carbon footprint comparison (without search step)

The Cybernaut tends to have a lower environmental impact than the Traditional Shopper, as long as he does not use speed delivery.

Figure 2 shows the average carbon footprint of each consumer behavior, along the entire buying process (search-purchase-return) of a toy.

The Cybernaut's carbon footprint is almost two times smaller than a Traditional Shopper. In fact the main component of the Traditional shopper is the customer transportation, whereas Cybernaut's emissions are linked to a parcel carrier, who uses an optimized delivery process. The freight transportation has a bigger impact for the Cybernaut since the item is packaged individually, which increases packaging weight and volume, and the linehaul distance of online warehouse is bigger than a traditional one. The packaging is the main component of the Cybernaut's carbon footprint. As expected, the carbon footprint of maintaining a retailer website generates significantly less emissions than the energy related to a physical retail store. The other components do not have a notable influence on the carbon footprint of both behaviors. Fast delivery options for Cybernauts almost triple the impact of freight transportation, but do not increase the total carbon footprint enough to make it worse than Traditional Shoppers.

By comparing the Traditional Shopper Impulse and E-informed behaviors, their carbon footprints tend to be similar to a Cybernaut, as they both reduce the distance traveled during the search step.

One of the most interesting results is that a Modern Shopper has a carbon footprint within the range of the Traditional Shopper: by adding customer transportation during the search step erodes the benefit of the online behavior. Moreover, when adding fast delivery, Impatient Modern Shoppers will have a higher carbon footprint than Traditional Shoppers.

The Cybernaut - Quick Return behavior tends to have similar result as the Cybernaut. Hence, even if the return rate is higher for online shopping, the average carbon footprint for this behavior does not increase significantly by physically returning the item to the store. Also, a Cybernaut with product Pick-Up has a footprint slightly higher than the Traditional Shopper e-informed, as it implies a higher return rate due to an online search step, while the rest of the buying behavior generate emissions comparable to traditional retailing.

On average when comparing generic online and traditional behaviors, online shopping tends to be more efficient than traditional shopping. However, when taking into account the variability of multiple consumer behaviors, this is no longer the case. Figure 3 shows the wide range of results of each behavior due to the variability of the parameters; for example, consumer transportation distances tend to have wide fluctuation, especially in traditional shopping behaviors. Note that the three Traditional Shopper behaviors have the lowest carbon footprint in the experiments. On the other hand, the carbon footprint of Cybernaut behavior tends to have less fluctuation, as orders are fulfilled by a more controlled and efficient parcel delivery system.

Other scenarios were developed and simulated, providing additional insights:

Industry: The carbon footprint of the buying process of a toy and a t-shirt tends to be similar, even if clothing implies higher return rates. However, the buying process of a laptop generates a much higher environmental impact. This is mainly due to the retail store energy and the freight transportation.
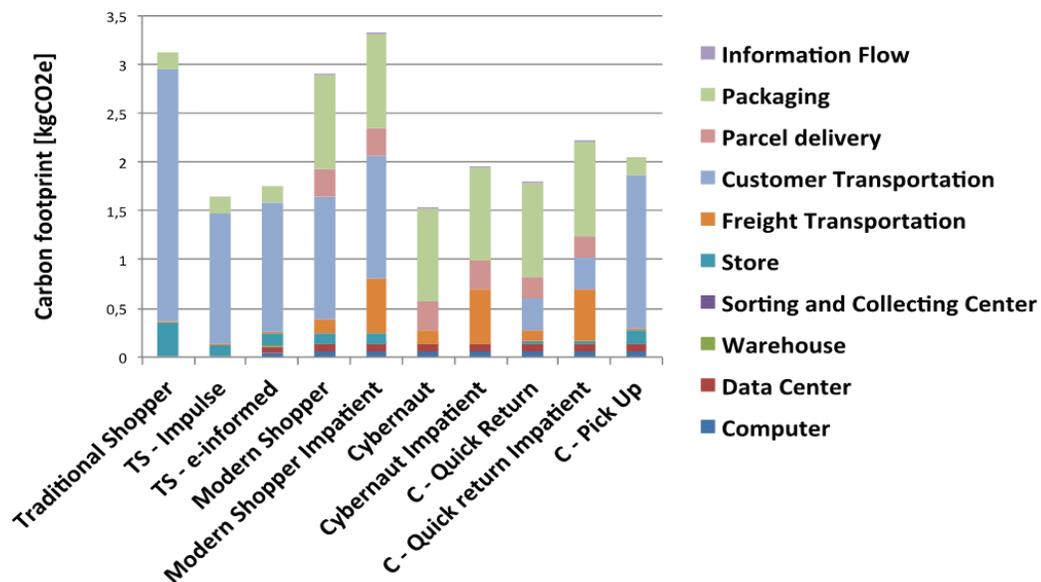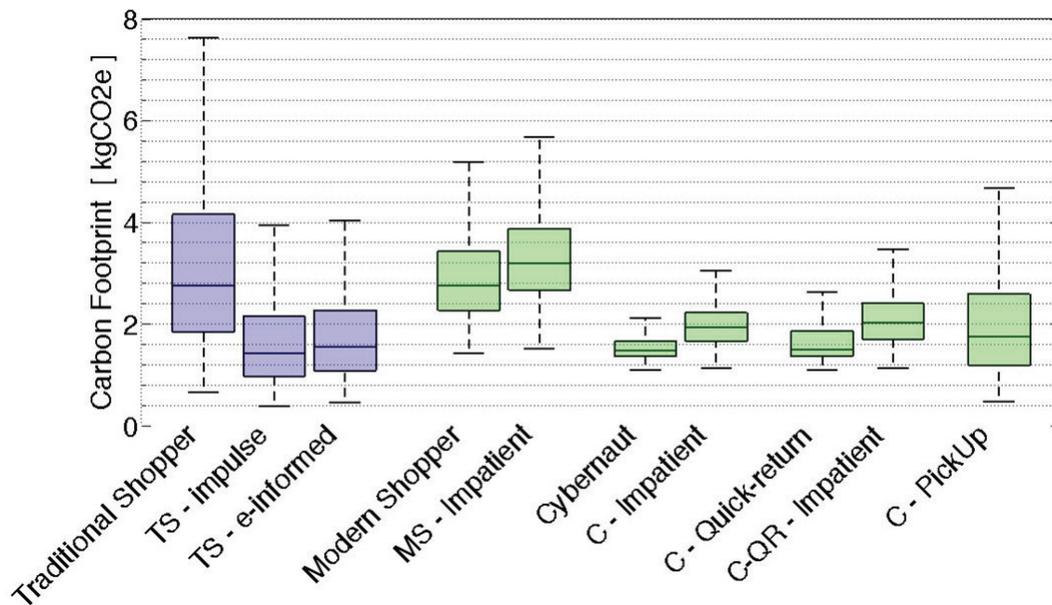

Figure 2: Detailed carbon footprint of the buying process of a toy in an urban area

Figure 3: Carbon footprint of the buying process of a toy in an urban area with information variability

Urban Density: Customers living in a suburban area tend to have longer distances to travel, and online behaviors tend to have much lower carbon footprints compared to traditional behaviors.

Public transportation: The use of public transport (e.g. bus, metro) instead of personal car highly decreases the carbon footprint of traditional shoppers: they tend to be more efficient than online behaviors when public transportation is used during the search and purchase steps.

Smart shipping package: By optimizing the shipping package (removing primary packaging and reducing the amount of materials used), the carbon footprint of online behavior is highly improved. For instance, the Modern Shopper behavior has a similar carbon footprint to a Traditional Shopper with Impulse buying.

Closer Online warehouse: Online behaviors with delivery are slightly improved, but it does not significantly change the observed patterns.

Item bundling: When both traditional and online shoppers bundle items during the purchase step (e.g. multiple items in one store trip or multiple items in one box delivered from online purchases), it noticeably improves the absolute impact of all behaviors, by optimizing fuel consumption and the amount of material for packaging. However, it does not modify the relative patterns between behaviors.

7. Conclusion

This paper proposes an extended view of the buying process to include three major steps: search, purchase and return, to compare online vs. brick-and-mortar shopping. Seven archetype shopping behaviors are used including

Traditional Shoppers, Modern Shoppers, e-Informed Shoppers, Cybernauts and Impatient Cybernauts, resulting from the various combinations of online vs. brick-and-mortar choices for each of the buying process steps. These shopping behaviors provide a robust framework to evaluate the environmental impact of online shopping.

Although, online shopping tends to have a better environmental impact than traditional shopping, when taking into account the entire buying process, other shopping consumer behaviors that include online shopping steps are not always environmentally better.

The customer location (urban vs. suburban) and her choice of transportation (personal car vs. public transport) highly influence the carbon footprint of traditional shopping, as the customers' transportation is one of the main parameters of the carbon footprint. For a customer living in a suburban area, online shopping could be more appropriate, while this is less so for urban dwellers where traditional shopping could be more environmentally efficient.

Both brick-and-mortar and online retailers could inform their customer better of the environmental impact of their choices (e.g. item bundling, item pickup, fast delivery) to mitigate its impact.

Retailers could also improve the overall carbon footprint of their supply chain. Online retailers tend to have a more controlled environmental impact during the shipping process, and focusing on optimization of packaging and the return process would highly reduce its overall footprint. Brick-and-mortar retailers could focus on an efficient online search step, and leveraging their retail store locations to foster consumer pickup in dense urban areas.

As online shopping continues to increase, and retailers offer wider combinations of brick-and-mortar and online offerings, understanding how behaviors evolve across different geographies, will help develop tailored strategies to minimize the environmental impact of retail.

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