Environmental sustainability in B2C e-commerce: the impact of multiitem shopping

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Purpose: B2C e-commerce is growing worldwide, and a major concern regards its environmental sustainability. Some studies compared the environmental impact of the online and offline purchasing processes, considering the shopping made at one store at a time (e.g. a book bought in a physical store or on internet). This work aims instead to investigate the environmental impact of multi-item shopping.
Methodology: The environmental impact of the purchasing processes is evaluated in terms of CO2e emissions. The model, based on an activity-based approach, allows to assess the environmental impact of the online and offline shopping in the main industries (fashion, consumer electronics, books, grocery) considering (i) one purchase at a time and (ii) multiple purchases in different stores, either online or offline.
Findings: If comparing the same purchase made in the online and offline channels, for a specific industry, the e-commerce case generates lower emissions – even if the results depends on many variables, e.g. customer density, mean of transport. Results overturn when, in the same offline shopping trip, the customer buys in more than one store.
Originality: The main contribution is the multi-item approach while evaluating the environmental sustainability of the purchasing processes, which is not tackled by literature in this regard. This allows to make significant considerations on sustainability from a logistics perspective.

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1 Introduction

B2C e-commerce is growing worldwide, and an increasing concern regards its environmental sustainability. Several studies compare the online and offline purchasing processes from an environmental perspective. They usually consider the environmental impact of one purchased product or order, being equal the number of items bought online and offline.

Anyway, reality may display very different situations. On the one hand, the order composition may be different between the traditional and the e-commerce purchasing processes (Carrillo et al., 2014). As an example, the value of the online grocery shopping is on average higher than the traditional grocery shopping in store (B2C e-commerce Obsevatory, Politecnico di Milano, 2019). On the other hand, a customer buying in the offline channel may purchase, in the same shopping tour, more items related to different product categories. This is, as an example, the case of a customer driving to a mall and buying some fashion clothes from a shop and the groceries from the supermarket. If the same customer ordered the same products online (i.e. all the groceries and the fashion clothes), there will presumably two different shipments (i.e. from the grocery store and from the retailer of fashion products). In this regard, the comparison of the emissions related to the two purchasing processes - online vs offline - must consider, on the one hand, only one customer tour and, on the other hand, two deliveries.

Being this the premise, the present work aims to evaluate the environmental sustainability of B2C e-commerce by considering multi-item shopping. In particular, the environmental impact of online and offline purchasing processes is assessed in the main industries (i.e. fashion, consumer elec-

tronics, books, grocery) considering (i) one purchase at a time and (ii) multiple purchases in different stores. More precisely, environmental impact is measured in terms of CO2e (i.e. CO2 equivalent) emissions. An assessment model following an activity-based approach is presented. Since precise data are necessary to feed the algorithms of the model and thus data from companies need to be collected, the Italian context is considered by the present study.

The reminder of the paper is organized as follows. The next section provides the literature review, with a focus on environmental impact of B2C e-commerce from a logistics perspective. Then, the objective and the methodology adopted within the study are described. The next section reports the environmental assessment model. Results are shown and, in the final section, conclusions are drawn, and research limitations are identified.

2 Literature review

The environmental assessment in the field of B2C e-commerce purchasing process is typically carried out for reaching two purposes. On the one hand, provide companies and logistics service providers with information useful to take the sustainability perspective in their decisions, in particular identifying the main areas to act on in order to reduce emissions (e.g. Van Loon et al., 2015; Mangiaracina et al., 2016). On the other hand, give governments insights about how to improve urban areas through measures which could affect city logistics (e.g. privileged access to delivery vans, free city tax for green vehicles) or about developing policies and regulations for the long-term development of the industry (e.g. Yi et al., 2017). Moreover, the studies almost always make a comparison of the environmental impact of the online and offline purchasing processes, in all their different variants, and the identification of the variables most affecting them. Transportation activities are the ones, in general, most affecting the results (e.g. Brown and Guiffrida, 2014; McLeod et al., 2006; Wiese et al., 2012). Anyway, results depend on many other context factors, above all the type of industry considered. In this regard, when dealing with FMCG, warehousing related emissions get significant as well. Literature displays different methodologies attempting to assess the environmental impact of online and offline purchasing processes. In particular, studies propose environmental assessments considering different functional units (see 2.1) and system boundaries (see 2.2), for general or specific industries (see 2.3)

2.1 Functional unit

The functional unit is intended as the object for which the environmental impact is assessed (Van Loon et al., 2014). Literature displays two main approaches. First, the single item is considered (e.g. Williams and Tagami, 2002; Sivaraman et al., 2007). Second, the whole order is accounted (Weber et al., 2010; Mangiaracina et al., 2016).

Van Loon et al. (2015) investigate the environmental impact (quantified in terms of CO2e) of one item - belonging to a larger shopping basket - fulfilled through different channels. A particular allocation of emissions regards the last mile delivery, where emissions are usually allocated based on the number of deliveries (Edwards et al., 2010), regardless of the type of item shipped. The constrain in the last mile delivery tour is indeed typically the time, and not the weight of the products (Siikavirta et al., 2002). Similarly, Weber et al. (2010) defined the functional unit as a unit of one album of music and Williams and Tagami (2002) use the single item, the book. Sivaraman et al. (2007) set a quite particular functional unit, i.e. renting three DVDs at one time (going to the DVD rental shop or ordering online). In this precise case, the choice of the authors is because at the manufacturing facility, DVDs are packed in three. The order as functional unit was also considered by Mangiaracina et al. (2016), whose study assessed the impact of an order made of, on average, 1.3 fashion products.

2.2 System boundaries

Williams and Tagami (2002), which propose one of the first studies in the field, considered mostly transportation and packaging related emissions. In particular, they estimated the energy generated in the following stages:

(i) the consumer travel to and from the bookstore in the traditional offline model, (ii) the transport of books by shipping and courier services, (iii) production of packaging and (iv) sales point consumption, either at the bookstore or in the consumer's home in the case of e-commerce purchase. This study, even if it considers the energy consumption in the stores, does not include neither warehousing nor fulfilment activities. Sivaraman et al. (2007), which focused on the DVD rental, included not only warehousing activities, but the whole manufacturing (DVD in the specific case) process. In the e-commerce case, it is considered that placing a DVD order require the usage of a computer, lights, and air conditioning/space heating. Emissions related to computer energy consumption are quite commonly considered (e.g. Mangiaracina et al., 2016). Not only the energy spent to make the purchase is accounted, but also computer manufacturing is allocated based on a burden factor, which is usually the ratio between the number of hours the computer is used to place the order and the overall number of hours a computer is used throughout its lifetime (Sivaraman et al., 2007; Van Loon et al, 2014). The energy for computer disposal is also determined and allocated using the burden factor. Weber et al. (2010) study instead the environmental impact of different music delivery methods: emissions are assessed from recording though distribution to a final consumer. The boundaries considered by this study are: (i) warehouse energy usage, (ii) electricity use at home computer to place e-commerce order, (iii) transport from the wholesale warehouse to the retail store, distribution centre, or retail warehouse, (iv) last-mile transport from local distribution centre to customer home or from retail store to customer home, (v) data centre electricity usage to run e-commerce and online music sites, (vi) bulk versus individual

cardboard packaging, (vii) energy usage in traditional retail store and (viii) internet network electricity usage for download. In Weber et al. (2010) only differential emissions among purchasing processes are accounted. The approach by Weber et al. (2010) was similarly suggested by Edwards et al. (2010), who stated that the environmental effects of fulfilling a consumer item are compared from the point of deviation to the point of consumption. With the e-commerce growth along years, fulfilment methods become a key significant issue to be tackled. This topic was investigated in particular by Van Loon et al. (2015), who propose an LCA model to compare the environmental impact of different fulfilment methods for Fast Moving Consumer Goods. This study investigates the most common B2C e-commerce models (e.g. pure players, merchants fulfilling orders from a large e-fulfillment center, merchants fulfilling orders from stores, or "drop-ship") and the offline channel. The point of divergence is usually the factory's outbound operation (Potter et al., 2011): all the emissions related to the activities of moving and storing products from the factory to the customer are therefore considered by the study. Emissions instead generated from the production and usage of the item, as well as the primary packaging, are excluded since they do not depend on the channel through which the item was bought.

2.3 Industries

The industry sectors typically tackled are the apparel, consumer electronics and books, since they are the ones were e-commerce has experienced the highest penetration rate (Zhang and Zhang, 2013; Potter et al., 2010). The most recent studies are instead also focusing on grocery (e.g. Heard et

al., 2019; Gee et al., 2019; Fikar, 2018). It is interesting to notice the differences among those supply chains in terms of activities performed during the fulfilment process, as well as variables affecting the carbon footprint. For instance, product temperature and product perishability are influencing exclusively the food supply chain, where emissions related to product disposal are more relevant and the picking process becomes critical also in environmental terms (Gružauskas et al., 2019). High return rate, instead, are typical of the apparel and the consumer electronics market, increasing considerably the CO2 emissions related to transportation.

Anyway, most of the studies does not specify the industry of analysis, thus their conclusions can be generalized to all of the above-mentioned industries. As an example, papers concerning the last-mile delivery problem - several of which including routing optimization - range from different industries and are common for all B2C e-commerce fulfilment processes (e.g. Guo et al., 2019; Pan et al., 2015).

3 Objectives and methodology

The environmental impact of multi-item shopping - intended as the purchase of products belonging to different categories - resulted under investigated in literature. Studies proposing environmental assessment compare the online and offline purchasing processes typically considering (i) one product only, or (ii) one order made of a certain number of products of the same industry, and so bought from the same retailer, either online or offline. Relying on this consideration, the aim of the present work is to propose an environmental assessment allowing to compare different types of purchasing processes - reflecting thus different purchasing behaviors. In order to reach this goal, an environmental assessment model is employed. The model architecture is adapted from the one proposed by Mangiaracina et al. (2016), whose main peculiarity is the possibility to breakdown the total emissions - in terms of kgCO2 - in each phase of the purchasing process, i.e. pre-sale and sale, replenishment, order picking and assembly, delivery and post-sale. More specifically, this modular approach (see ¶4 for further details) allows to combine phases of purchases from different industries into a new multi-item purchasing process. As an example, starting from the environmental impact of the purchase of a piece of clothes and a book as two separate purchases, the impact deriving from the joint purchase of both the items can be derived. This particularly affects the environmental assessment of the offline process. Regarding instead the e-commerce case, it depends on many factors, e.g. if the two items are purchased by two different retailers or, in case the retailer is the same, whether there are separate shipments. According to this premise, the originality of the present

work is mainly in the context it aims to investigate, while relying on an established assessment model. The industries considered are among the most tackled in literature, i.e. fashion, consumer electronics, books and grocery.

4 Environmental assessment model

The model grounds on the definition of the reference purchasing processes for both e-commerce and traditional channel. Each of the two processes is divided in macro-phases (i.e. pre-sale and sale, replenishment, order picking and assembly, delivery, post-sale), which are then divided into activities (Mangiaracina et al., 2016). The environmental impact is calculated at the activity level. Processes are in particular affected by the structure of the distribution network (Van Loon et al., 2015). The present study considers two types of distribution networks according to the industry. (i) Fashion, book and consumer electronics industries rely on a distribution network made of a warehouse which replenishes points of sales and where online orders are fulfilled. (ii) The grocery retailer is instead assumed to have points of sales for the shopping in the traditional channel, a dedicated warehouse for fulfilling online orders and a central warehouse which replenishes both the points of sale and the dedicated warehouse. Figure 1 and 2 represent the distribution network of reference respectively for the first cluster of industries (i.e. fashion, book and consumer electronics) and for the grocery one. Illustrations also displays the five macro-phases of the online and offline purchasing processes, which are later described in 4.2 and 4.3.

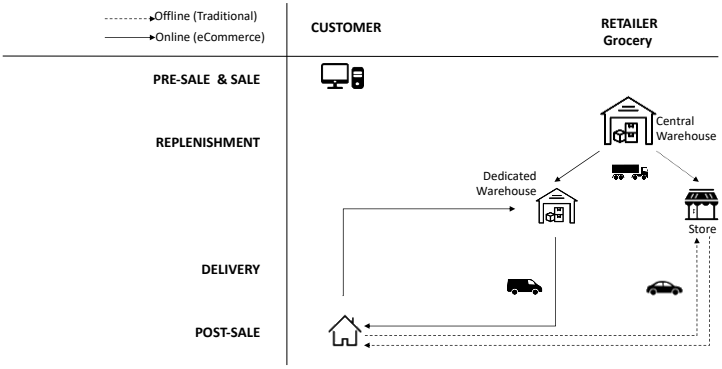

Figure 1: Fashion, consumer electronics and books industries: reference distribution network

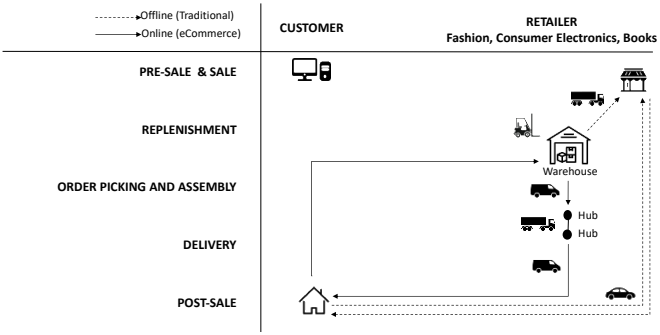

Figure 2: Grocery industry: reference distribution network

4.1 Model structure

The environmental assessment model is made of five parts.
First, input data regarding the customer (e.g. return rate, average distance travelled to reach the store), the order (e,g, product category, number of items, number of order lines), the packaging (e.g. typology, dimension), the characteristics of the warehouse and the store (e.g. dimension, energy performance). Second, activity data regarding the duration of the activities (i.e. online, warehouses, transit point, store and transport). Third, data on consumptions of resources and the related conversion factors. Fourth, model algorithms, which collects all the mathematical formulas connecting the previous sections to the output. In the end, the output data, which is the environmental impact generated (i.e. kgCO2e) by a purchase - online and offline - either considering one purchase at a time and multiple purchases in different stores. The overall result can be broken down by macro-phase and by activity type.

4.2 E-commerce purchasing process

The e-commerce process is made of five phases. For sake of simplicity, the following description is based considering an order from a single retailer. The description of the phases is based on Mangiaracina et al. (2016).
Pre-sale and sale: information about the products are gathered by the customer, who then purchases the item and pays (online).
Order picking and assembly: the retailer receives the order and picks the required items (i) in the dedicated area of the warehouse for the first cluster of industries (fashion, consumer electronics and books); and (ii) in the dedicated warehouse for the grocery sector.

Stock replenishment: in the first cluster of industries, the picking area is replenished with goods from the storage area within the warehouse. In the grocery sector, the dedicated warehouse is replenished by goods from the central warehouse.
Delivery: after the picking and assembly of the order in the retailer's warehouse, it is sent to the customer. The order can be shipped directly to the customer in the case of grocery, or it pass through some transit points (typically two) before reaching the destination.
Post-sale: goods are sent back to the retailer's warehouse. Returns are negligible for the grocery orders.
The environmental impact is computed by summing up the emissions generated in each activity of the macro-phase.

4.3 Traditional purchasing process

Similar to the online process, the offline one is divided into macro-phases and activities. The main difference is that the order picking and assembly phase is included in the "pre-sale and sale" since it is done by the customer in the store.
Pre-sale and sale: the customer goes to the store, where products are collected and then paid.
Replenishment: goods are picked in the retailer's central warehouse and transported to the store.
Delivery: it is the distance travelled by the customer to come back home after the purchase,
Post-sale: the customer comes back to the store and asks for the change. He travels then back home with the changed product.

4.4 Multi-item purchasing process

4.2 and 4.3 were aimed at explaining the process in the case of a single product category purchase. It doesn't mean that only one product is bought, but that the online order is made of a certain number of products from the same category - e.g. grocery, fashion - as well as the traditional shopping is made in one store only - e.g. supermarket, fashion store. Reality displays also other situations, and different purchasing behaviors. Indeed, it happens that a customer buys in more than one store during his traditional shopping tour. In this case, the customer is supposed to reach a mall, or a city center - where there are typically many shops - and makes purchases in different stores. If considering the online shopping, the most common case is that customer buys from different specialized retailers. In this regards, different shipments are performed. The macro phases of the online and offline purchasing processes just presented are detailed below.

When the customer places online orders from different retailers, the number of shipments is equal to the number of orders (the case of more than one shipment for an order is out of the scope of the present study). The total environmental impact is given by the sum of emissions of the different online orders.

In the pre-sale phase of the offline shopping, the customer reaches the mall, the city center or, more in general, the shops. He is supposed to use the car. The customer performs the purchase in the first store, then he walks to next store, make the purchases and so on till the last visited shop. As explained in 4.3, the order picking and assembly phase is included in the sale activities. After visiting the last store, the customer is supposed to drive back home. The replenishment activity is the same explained in 4.3: what

changes in the multi-item purchase is that related emissions are accounted for each product category considered.

5 Results

First of all, the environmental assessment model was applied to the single industries - comparing the online and offline purchases made of a product category only. In this regard, Table 1 displays the environmental impact, in terms of kgCO2e/order in the four main industries, i.e. fashion, consumer electronics, book and grocery, in both the traditional and e-commerce purchasing processes, as well as the repartition of the emissions among the five phases. Table 2 shows instead the repartition of emissions by type of activity. Input data typical of the sectors were partially retrieved from Mangiaracina et al. (2016), Mangiaracina et al. (2019a) and Mangiaracina et al. (2019b), respectively for the fashion, consumer electronics and grocery industries. Activity and purchase profile information are primary data from players of each sector. All data regarding consumptions of vehicles and buildings were respectively retrieved from DEFRA (2018) and CENED (2020) reports.

Overall the online purchasing process generates lower emissions than the traditional offline shopping (i.e. 3.93 vs 4.6 kgCO2e in fashion, 3.03 vs 4.31 kgCO2e in consumer electronics, 3.12 vs 4.41 kgCO2e in books, 7.34 vs 8.66 kgCO2e in grocery). Emissions are quite similar - both in value (i.e kgCO2e) and in the repartition among the type of activity - in the fashion, consumer electronics and book industries. Emissions in the grocery sector are instead almost doubled if compared to the just mentioned cluster of industries (i.e. 3.82 kgCO2e as average of emissions for fashion, consumer electronics and books online orders vs 7.34 kgCO2e of e-grocery). Indeed, the order composition and the distribution network of reference differ. On the hand, while the order of the first cluster of industries is made of about 1.2-1.4 pieces,

the grocery order counts 65 items. On the other hand, the presence of the dedicated warehouse involves not only additional buildings-related emissions, but also transportation-related ones due to its replenishment. In the traditional shopping, the pre-sale and sale activity accounts up to about the 50% of the overall emissions. This phase indeed considers the travel to the store - which is responsible for about half of the pre-sale and sale emissions - and all the energy consumptions in the store. The replenishment phase is the second source of emissions in the fashion, consumer electronics and book industries (about 30% of total online emissions), but the first one in the grocery (50% of total online emissions). As mentioned, replenishment in the grocery case implies not only transportation activities, but buildings emissions of the whole dedicated warehouse. In this regard, while in the first cluster of industries transportation activities cause about half of the overall emissions, in the grocery sectors they cause about the 30%.

Table 1: Environmental impact single product category purchase - emissions repartition by phase

	Fashion		**Consumer electronics**		**Book**		**Grocery**	
	Traditional	E-commerce	Traditional	E-commerce	Traditional	E-commerce	Traditional	E-commerce
Pre-sale and Sale	45,10%	0,64%	48,06%	0,72%	47,04%	0,57%	43,93%	0,66%
Replenishment	29,45%	0,02%	25,83%	0,02%	27,90%	0,01%	50,76%	46,06%
Order picking and assembly	-	37,87%	-	41,00%	-	43,00%	-	25,43%
Delivery	23,08%	47,22%	24,60%	56,74%	24,07%	55,44%	5,31%	27,52%
Post-sale	2,37%	14,25%	1,51%	1,53%	0,99%	0,97%	0,00%	0,33%
Environmental impact [kgCO2e/order]	**4,60**	**3,93**	**4,31**	**3,03**	**4,41**	**3,12**	**8,66**	**7,34**

Table 2: Environmental impact single product category purchase - emissions repartition by type of activity

	Traditional	E-commerce	Traditional	E-commerce	Traditional	E-commerce	Traditional	E-commerce
Transportation	52,43%	47,50%	52,62%	45,31%	50,44%	41,90%	30,42%	42,00%
Warehouse/handling	24,06%	51,51%	22,38%	53,66%	25,10%	57,25%	27,08%	57,07%
Other (Purchasing, Communication, Management)	23,51%	0,99%	25,00%	1,03%	24,46%	0,85%	42,51%	0,93%
Environmental impact [kgCO2e/order]	**4,60**	**3,93**	**4,31**	**3,03**	**4,41**	**3,12**	**8,66**	**7,34**

Table 3: Environmental impact multi-item shopping

Fashion	Consumer Electronics	Book	Grocery	Purchasing Process	Emissions [kgCO2e]
X	X			Traditional	6,79
				E-commerce	6,96
X		X		Traditional	6,88
				E-commerce	7,05
	X	X		Traditional	6,60
				E-commerce	6,15
	X		X	Traditional	11,45
				E-commerce	10,38
X			X	Traditional	11,74
				E-commerce	11,27
X	X	X		Traditional	9,07
				E-commerce	10,08
	X	X	X	Traditional	13,74
				E-commerce	13,50
X	X		X	Traditional	13,93
				E-commerce	14,30
X	X	X	X	Traditional	16,21
				E-commerce	17,42

Second, the perspective of the multi-item shopping was applied. With the aim of representing different purchasing situations, scenarios displayed in table 3 were investigated. In particular, purchases made in two, three and

four shops are considered, as well as different combinations of product categories. When two orders are considered, overall emissions are very similar (e.g. 6.79 and 6.96 kgCO2e for fashion and consumer electronics; 6.88 and 7.05 kgCO2e in fashion and book). Anyway, based on the input data employed, the traditional process gets slightly more environmentally sustainable when fashion and consumer electronics, or fashion and books, are bought in the same shopping process. The peculiarity of the fashion industry is indeed the higher return rate of online purchases (about 30%) if compared to the other industries (less than 5%). When three different purchases are instead considered, and among the analyzed scenarios, the traditional shopping remains slightly less environmentally sustainable when the grocery shopping is done, and no fashion products are bought (13.74 kgCO2e in traditional shopping vs 13.50 kgCO2e in e-commerce). When instead all the four product categories are supposed to be bought in a shopping tour, e-commerce displays the highest environmental impact (17.42 kgCO2e in the e-commerce vs 16.21 in traditional shopping). All these considerations are valid when the online orders for the different products are made in different websites, and so from different retailers. In this regard, each online order corresponds to a shipment.

6 Discussion and conclusions

The present work is aimed at investigating the environmental impact of purchasing processes which have not been so far tackled by literature. In this regard, studies proposing environmental assessment usually compare the online and offline purchasing processes typically considering (i) one product only, or (ii) one order made of a certain number of products of the same industry, and so bought from the same retailer, either online or offline. The aim of the present work was instead to propose an environmental assessment allowing to compare different types of purchasing processes - reflecting thus different purchasing behaviors. In order to reach this goal, an environmental assessment model was employed. First, it was applied to the single industries - comparing the online and offline purchases made of a product category only. Second, different shopping situations were created (see table 3) and the related environmental impacts were assessed.

If comparing the same purchase made in the online and offline channels, for a specific industry, the e-commerce case is generally more environmentally sustainable – even if the results depends on many variables, e.g. customer density, mean of transport. Transportation related activities resulted to be the main source of emissions in the fashion, consumer electronics and book industries, accounting for about the 50% of the overall impact. In the grocery industry, transportation and warehousing related emissions have the same weight in terms of impact, and its mainly due to the peculiar distribution network of reference, which employed a dedicated warehouse for fulfilling online orders. Results overturn when, in the same offline shopping trip, the customer buys in more than one store. Emissions are almost the same when two product categories are bought. When three different orders

are instead placed, the presence of product categories characterized by high return rates make the e-commerce process less environmentally sustainable. In the case of four different orders, e-commerce definitely displays the highest emissions.

The main contribution of the present work does not lie in the development of a new assessment model, but in the in the investigation of the multi-item approach while evaluating the environmental sustainability of the purchasing processes. Even if some real shopping situations are investigated, further scenarios should be assessed by future works. In particular, results are applicable when the online orders for the different products are made in different websites, and so from different retailers. In this regard, each online order corresponds to a shipment. As an example, the case of buying online from general merchandise retailers is not studied by the present work and it represents an interesting and real situation to be explored.

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