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OPTIMISING WEEE FLOWS: A CASE STUDY OF A REVERSE SUPPLY CHAIN FOR MIXED SMALL ELECTRICAL WASTE

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INTRODUCTION

Waste Electrical and Electronic Equipment (WEEE), is the one of the fastest growing waste streams in Europe with 12 million tonnes expected to be generated by 2020 (European Commission, 2018). In terms of unit numbers, small WEEE represents the largest fractions of WEEE arisings and the reuse/recycling return rates for small WEEE items (e.g. household appliances, mobile phones, computers, toys) are much lower than large WEEE (e.g. white goods and televisions). WEEE contains hazardous materials so diverting these away from landfill is environmentally beneficial, and there are also economic benefits associated with recovering and reusing components. As a result there has been growing interest in the Reverse Supply Chains (RSCs) of electronic goods and what value can be extracted from these unwanted items. Whilst there are many examples of electronic reverse supply chains in the literature, these typically focus on one specific product type. This paper presents an empirical case study of a RSC for the recovery of a mixed electrical product stream. The authors design a bespoke three tier collaborative RSC for the collection, transport and treatment of mixed household WEEE. The RSC is unique in that it is a collaboration between an electronics ReManufacturer (RM), and a Collecting Firm (CF) whose primary business is the national distribution of news publications.

The live pilot implementation of the collaborative RSC allowed the researchers a rare opportunity to collect primary data into the potential value recovery of the mixed WEEE stream. From a practical perspective, the study is an example of how firms can collaborate to harness surplus logistics capacity to support environmental activities and potentially lead to business diversification opportunities. For academics, this paper would be a useful addition as unique, empirical case study.

LITERATURE

Reverse supply chains

Guide Jr and Van Wassenhove (2002) define reverse supply chains as a series of activities required to retrieve a product from a customer for disposal or value recovery. Reverse supply chains are comprised of five fundamental activities (Guide Jr., Teunter, and Van Wassenhove 2003) which are shown in Figure 1; an overview of a RSC for returned products and the various value recovery pathways. Fleischmann et al. (2001) noted that recovery networks form a link between two markets; 1) the "disposer market" where used products are detached from their former users, and 2) the "reuse market" where there is demand for recovered products. Both markets may converge, creating a closed-loop goods flows where recovered components and remanufactured products are reintegrated into the original forward supply chain in Figure 1, or diverge to form an "open loop" in the case of recovered "Scrap" which is passed on to the Recyclates market to be used in another supply chain. The scope of our study will not be on the entire reverse supply chain but from Product Acquisition where customer returns a product to the Returns Evaluation stage.

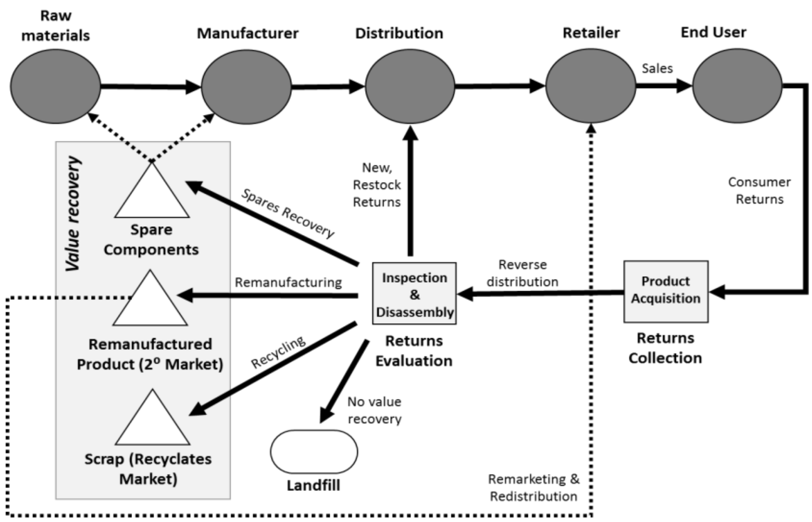

Figure 1: Schematic of a reverse supply chain for product returns. Adapted from Blackburn et al. (2004) and Guide and Van Wassenhove (2003)

Reverse supply chains for electronic goods

The literature contains many examples of reverse supply chains for electronic products. These studies tend to focus on large WEEE such as fridges, TVs and office printers (Krikke, Bloemhof-Ruwaard, and Van Wassenhove 2003; Fleischmann et al. 2001) or one specific small WEEE type such as printer cartridges and mobile phones (Dat et al. 2012). Studies by Wakolbinger et al. (2014), Toyasaki, Boyacı, and Verter (2011), focus on general WEEE but in the context of strategic network design problems and do not address the problem of heterogeneity of the waste stream. Therefore, a focus on mixed small household WEEE (such as mobile phones, games consoles, kettles, toasters, lamps, etc.), would be of interest to the research community – particularly in highlighting the challenges that firms may face in dealing with the heterogeneity of the products.

Value recovery in WEEE reverse supply chain

In reverse supply chains, the value of returned products can be recovered via a number of different recovery processes depending on product quality and extent of disassembly required. According to Thierry et al. (1995), there are six typical value recovery processes: (1) direct reuse, (2) repair, (3) refurbishing, (4) remanufacturing, (5) cannibalization, and (6) recycling. For returned electrical products, the preferred value recovery option would be reuse. This is supported by the EU WEEE Directive 2012/19/EU which aims to maximise the reuse of EOL products. Despite the potential benefits of reuse, these activities for WEEE remains limited especially in the case of household products (Bovea et al. 2016). Reuse and recycling for large WEEE items (e.g. white goods and televisions) have a high recovery rate, but capture rates for small WEEE are much lower due to supply uncertainty and the fact that they are ideally sized for disposal in household refuse bins so their value are lost in landfill (Noble 2013; Cole, Cooper, and Gnanapragasam 2016).

Greater value can be obtained if products underwent higher value recovery processing. For example, a study by WRAP (2011) shows that reuse of waste electrical appliances is preferable to recycling and that the resale values of small WEEE has the greatest economic potential on a £/tonne basis. In Ferrer (1997), the authors exemplify the financial benefits of remanufacturing computers for the OEM by extending their useful lives beyond the typical 2-3 years life-cycle. They were able to demonstrate a net financial benefit of £153 per machine if End of Life computers were upgraded with 6 months equivalent of technological development. These studies highlight the potential financial benefits of reuse and remanufacturing activities but assume returned products are in a suitable condition for these higher value recovery activities. However, a trial conducted by WRAP (2009) revealed that the collection of WEEE using bulk waste skips (similar to those found in public Household Waste Recycling Centres) led to many items that were deposited in working order to become damaged and contaminated – effectively preventing their potential for higher value reuse. Therefore, to increase the potential of a WEEE item for reuse activities, the product must be returned in the best possible condition so needs to be appropriately handled and stored during the product acquisition stage. An efficient collection system for reuse application should also provide convenient access to local collections sites for end-users to dispose of their items responsibly (Khetriwal, Kraeuchi, and Widmer, 2009). Given the challenges of collection and value recovery, and the lack of empirical studies that focus on mixed small household WEEE, a study into alternative reverse supply chains for this product group would be of interest.

PROBLEM/CHALLENGE

The literature has not revealed any studies on the capture of mixed small household WEEE for value recovery activity. Therefore, more research on mixed WEEE product streams, particularly those that generates empirical data would be a useful contribution to the research community. Secondly, operational insights into collaborative RSCs and examples of how surplus logistics capacity from one supply chain could be harnessed to complement the activities of other SCs would also be useful contributions to the academic environ. Based on gaps identified in the extant literature, the authors have derived the following research questions:

R1: What is the value recovery profile of heterogeneous small WEEE?

R2: Is the proposed collaborative RSC for heterogeneous small WEEE financial viable?

The Case Study

The case study is a bespoke three tier RSC for the collection, transport and treatment of mixed household WEEE for the purpose of value recovery. The RSC comprises of an independent electrical ReManufacturing firm (RM) and a third party Collecting firm (CF) and CF's first tier customers (newsvendors). CF's primary business is the national daily distribution of newspapers and collection of unsold publications. CF's logistics infrastructure is extensive because their product are time critical (newspaper have a shelf life of one day or less), and they must serve all their customers 364 days a year. Failure to do so would mean lost sales for CF's their newsvendor customers. As part of their incumbent operational process, CF simultaneously pick up any unsold newspaper from the previous day (t-1) as part of the outbound delivery process for new newspaper. CF's incumbent forward and reverse supply chain for their newspaper distribution and collection service is shown in Figure 2.

Whilst CF have optimised the vehicle usage of their outbound delivery journeys, there is on average, 50% surplus capacity in their inbound journey. As such, a RSC for WEEE was designed to exploit 1) the surplus capacity that is inherent in CF's inbound journeys and; 2) CF's close relationship with their newsvendor customers who are typically located in community setting - close to end users of WEEE. These two factors were identified in the literature as being appropriate design features of a RSC for WEEE. Aras, Boyaci, and Verter (2010) noted that closer proximity to end users would maximise consumer participation in returning WEEE for value recovery, whilst Fleischmann et al. (2001), observed that few reverse networks are set up "from scratch" but typically intertwined with pre-existing forward logistics structures. As illustrated in Figure 2, a bespoke reverse logistics mechanism for WEEE items has been incorporated into CF's incumbent forward and backwards logistics operations for daily newspaper deliveries. The end user handover their unwanted WEEE, the newsvendor carefully handle and place the WEEE item in a sturdy plastic container which provides protection to the item. The WEEE item(s) remain in the container during CF's collection and transport to RM in order to minimise damage and increase its potential for higher value recovery in line with WRAP (2011).

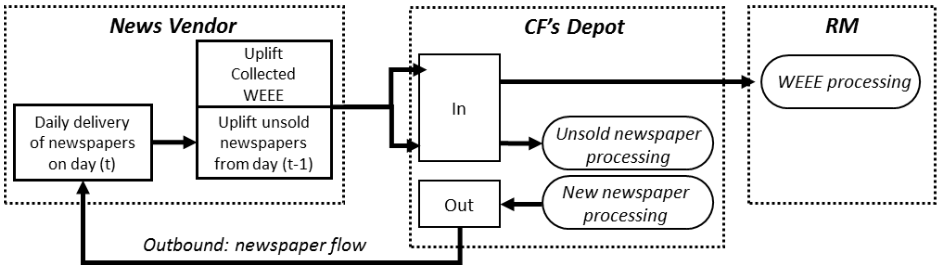

Figure 2: Schematic of the WEEE reverse supply chain integrated into CF's newspaper supply chain

THE RESEARCH WORK

Rubio, Chamorro, and Miranda (2008) state that research on "management of the recovery and distribution of end-of-life products" typically involve both quantitative and qualitative techniques, mathematical models and case study as main methodologies. Therefore, this study adopts a mixed method approach; A case study is appropriate because the authors are evaluating a phenomenon that is taking place in a real world setting (Yin 2012). The bespoke RSC was implemented by CF and RM for 12 weeks in November 2017 to January 2018. The live pilot was carried out in two urban areas in the west of Scotland and involved 12 newsvendors. During that time, WEEE end users could drop off their unwanted small WEEE items at one of the 12 collecting newsvendors. CF carried out the reverse logistics operation and RM triaged and carried out appropriate value recovery activities on the received WEEE. The live pilot allowed the collection of the following data; 1) Quantity and type of WEEE by category; 2) Quantity assigned for remanufacture, reuse and recycling, and; 3) Value recovered from remanufacture, reuse and recycling.

Following the conclusion of the 12 week pilot, the data was analysed to evaluate the following; 1) Type of WEEE received; 2) Proportion of WEEE assigned to each value recovery stream, and; 3) Value that could be derived from the received WEEE. In addition, the direct and incremental costs associated with the operation of the reverse logistics and value recovery activities of the RSC were analysed. A cost model was constructed to assess the financial viability of the RSC.

RESULTS/ANALYSIS

Over the 12 week period, a total of 692kg of WEEE was received by RM for value recovery activities. This equates to each newsvendor collecting on average, 4.8kg of WEEE per week. Based on the 10 categories in the EU WEEE Directive 2012/19/EU, the profile of the WEEE items received is shown in the first column of Table 1. The largest WEEE product category was IT and telecommunication equipment at 35%, followed by consumer equipment which comprises items such as hi-fi stereos, DVD players, games consoles, etc. Uncategorised WEEE denotes items where no descriptor was available in the dataset.

WEEE value recovery profile

Each WEEE item was evaluated and assigned to a value recovery stream. The value recovery activity applied to each WEEE category is summarised in Table 1. Recycle (stripped) denotes items which were manually dismantled to recover higher value materials/components, whilst the Recycle (shredded) process involved feeding the items through a shredder for reclamation as mixed recyclate material.

Overall, the majority of WEEE (58%) were assigned to the lower value Recycle (shredded) stream, with only 4% not generating any financial value. None of the WEEE items were suitable for the highest value recovery method, Remanufacturing. However, 6% was appropriate for Reuse value recovery; predominately comprising Toys, leisure and sports equipment and IT and telecommunications equipment. Consumer equipment and Display screens tended to be allocated to higher value recovery streams, with 73% and 100% assigned to Recycle (stripped) respectively.

Table 1: Value recovery profile of the WEEE received

	Input tonnage kg (%)	**Reuse**	**Recycle (stripped)**	**Recycle (shredded)**	**No value (Non WEEE)**
IT & telecommunications equipment	239 (35)	15%	46%	39%	0%
Consumer equipment	95 (14)	3%	73%	24%	0%
Small household appliance	93 (14)	2%	4%	94%	0%
Display screens	39 (6)	0%	100%	0%	0%
Lighting equipment	25 (4)	0%	0%	72%	28%
Non WEEE	18 (2)	0%	0%	0%	100%
Toys, leisure and sports equipment	6 (<1)	18%	4%	78%	0%
Monitoring & control instrument	1 (<1)	0%	0%	100%	0%
Uncategorised WEEE	178 (26)	0%	0%	100%	0%
Total tonnage (kg)	**692**				
Overall percentage		**6%**	**32%**	**58%**	**4%**

Weekly cost model for the RSC

Analysis of the weekly cost model of the RSC revealed that based on the current number of collecting newsvendors, the value recovery profile of the WEEE and captured tonnage, the RSC is not profitable. The overall weekly loss of £30 is shown in the Sankey chart in Figure 3. The chart summarises the incremental reverse logistics cost of £35 accrued by CF for providing one WEEE pick up per week for each of the 12 retailers, whilst £55 is RM's direct cost of processing the WEEE. In total £60 in value is recovered from WEEE, but this is insufficient to cover the £90 total reverse logistics and processing cost. In terms of per tonne "treatment" cost (collection and processing), this would equate to £1,552/tonne of WEEE of which; Collection = £603/tonne and Processing = £948/tonne. Meanwhile, value recovery would equate to £1,034/tonne.

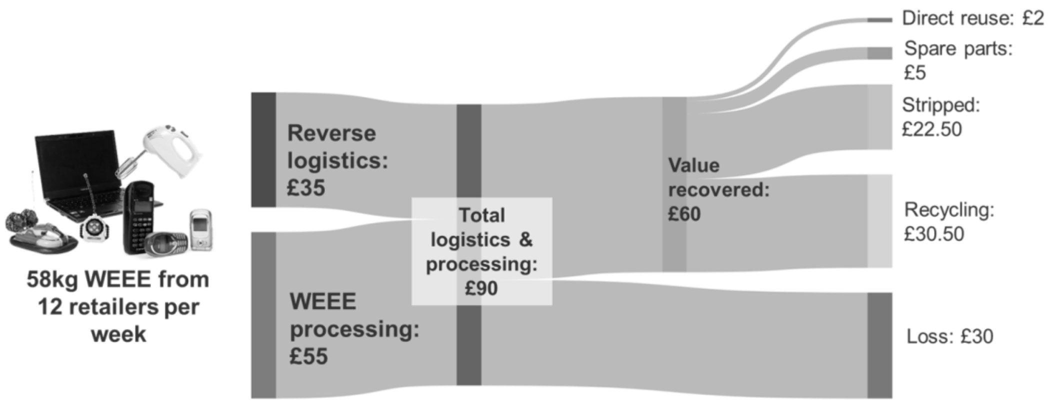

Figure 3: Sankey chart of the direct costs of the reverse supply chain

DISCUSSION

The profile of the WEEE items collected during the pilot is in line with WRAP (2009) and WRAP (2011) studies that found that the three biggest categories of mixed household WEEE were small household appliances, IT and telecommunication equipment and consumer equipment. At present, our results contained a 26% "uncategorised WEEE", so the percentage composition of the other categories are likely to be higher.

In terms of answering R1, this study has been able to ascertain a value recovery profile for heterogeneous small household WEEE (Table 1). A limitation of the study is that it only covered two geographical area so there are implications in terms of their generalisability of the results. Another limitation is that 24% of our WEEE fell within the uncategorised WEEE category due to RM's incomplete data collection. Nevertheless, the results provided a higher level of detail of the value recovery pathways associated with each WEEE category. No previous studies have been found which provide such detailed insights into the value recovery streams for different categories of the mixed small household WEEE products. These findings themselves are a valuable contribution to the both the academic and practitioner communities – particularly, waste managers.

The cost modelling of the RSC revealed that the processing cost were greater than the reverse logistics cost and this is associated with the labour intensive nature of RM's evaluation activities. Upon receipt of the WEEE, RM must inspect and/or disassemble products to assess component quality and/or cleaning operations. Disassembly is time-consuming and labour-intensive (Kim, Lee, and Xirouchakis 2007) which impacts on operational costs. To directly address R2, based on the weekly cost model presented in our study and in its current operating model, the collaboration between RM and CF for the recovery and treatment of mixed small household WEEE is financially unfeasible because it is operating at a loss. This result supports previous industry studies by the European Commission (2014) and WRAP (2009) which both demonstrate no net revenue is generated for mixed household WEEE. Despite the unprofitability, the case study processing cost is significantly cheaper, with only a net treatment cost of £518 compared to WRAP (2009)'s £1,787 per tonne, as shown in Table 2. The WRAP (2009) cost is actually even higher because it does not include any transport/logistics costs. The WRAP (2009) study also focussed on the recovery of raw materials for recycling only whilst in the case study, RM considered the products for remanufacture and reuse streams so was able to achieve 10 times higher value recovery per tonne. The results of this study demonstrates that significantly more value could be obtained from mixed small WEEE streams if Reuse processing is considered and would contribute to reducing the treatment/revenue cost deficit.

Table 2 Comparison of WEEE treatment and revenue costs

	WRAP (2009)	Case study
Per tonne treatment cost, £	1,921 (excl. logistics)	1,552
Per tonne value/revenue cost, £	134	1,034
Net treatment cost, £	**1,787**	**518**

Although a few years have passed since the WRAP study was conducted, our results indicates that from a business perspective, revenue recovery from the small household WEEE stream is still not yet feasible. Although our RSC isn't financially viable, a sensitivity analysis indicated that based on the current value recovery profile, increasing the tonnage collected by the 12 collecting newsvendors from 4.8kg to 28kg per week (approximating to 17,800kg per year), the RSC could achieve break even. However, there are likely to be newsvendor storage constraints associated with collecting 28kg of WEEE per week. Previous studies (Atasu, Toktay, and Van Wassenhove 2013; Wojanowski, Verter, and Boyaci 2007), examine optimal solutions for the return of used goods to OEMs found that financial input will be required to stimulate and increase the flow of product returns, e.g. incentivising retailers to promote bring back schemes or consumer deposit-refund schemes. Although such incentives will improve returned WEEE product flow, the inclusion of a financial incentive will negatively impact the cost model of the collaborative RSC and change the breakeven point due to the additional cost of the financial incentive.

CONCLUSION

The findings of our study demonstrates that potentially much greater value could be obtained from small mixed household WEEE than previous studies suggested. However, the RSC cost model revealed that the current operating model, the system is not profitable. However, net treatment costs of small mixed WEEE appears to have decreased when compared to a previous WRAP (2009) WEEE recycling study.

Our study provided a greater level of detail into the value recovery profile (remanufacture, reuse, recycling) for small mixed household WEEE that has not been found in the literature. Another contribution is that this a unique study that examines a mixed electronic product stream; whilst the live pilot live implementation of the RSC provided an opportunity to collect empirical data on a heterogeneous WEEE product stream - examples of which are lacking in the academic environ. One limitation of this study is that it did not quantify the environmental benefits or impacts. As such, the development of a model that will capture both financial and environmental costs benefits would be a natural evolution of this research. Finally, with mixed small household WEEE becoming an increasing environmental and societal problem, the authors call for more research in the recovery of this waste product stream be conducted.

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