Sustainable humanitarian operations: closed-loop supply chain

Daria Battini, Umberto Peretti,
Alessandro Persona and Fabio Sgarbossa*

Department of Management and Engineering,
University of Padova,
Stradella San Nicola, 3 36100 Vicenza, Italy
Email: daria.battini@unipd.it
Email: umberto.peretti@unipd.it
Email: alessandro.persona@unipd.it
Email: fabio.sgarbossa@unipd.it
*Corresponding author

Abstract: This paper explores the closed loop supply chain (CLSC) topic by providing a model and evaluating regular humanitarian logistics (R-HL) where the main objective of the operation moves from the reduction of population needs to a minimisation of the overall impact of the disaster and operations. The research focuses on the logistic facility management coupled with material distribution modalities in a situation where items are not just delivered using 'forward channels'. It considers others flows that usually have not been faced by the humanitarian literature, as 'reverse channels' on the management of operations waste. Constraints related to transportation resources in a complex environment, transportation vehicle capacities and delivery time restrictions are considered and different scenarios are analysed. The proposed model optimises resources allocation and prepositioning decisions on a number of test problems. The impact of each proposed practice is evaluated in order to understand its applicability in this particular context.

Keywords: humanitarian operations; closed-loop supply chain; CLSC; reverse model.

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Biographical notes: Daria Battini is an Associate Professor of Industrial Plants and Logistics at the University of Padua, Italy. She teaches industrial facilities design and industrial logistics. Her current research projects focus on logistics system design and management and include supply network modelling with particular attention to the healthcare supply network analysis and optimisation, ergonomics in material handling and in manufacturing, inventory management and material flow traceability, sustainability in freight transportation and humanitarian logistics. She is carrying out his research activities in national research programmes, local research programmes, European research programmes and private collaborations. Her researches appeared in several referred and ISI journals, international conference proceedings, trade magazines, industry reports and newspapers.

Umberto Peretti has received his PhD at Department of Management and Engineering (DTG) of the University of Padua. His field of specialisation is Logistics. He holds a Bachelor's in Industrial Engineering at the University of Parma and the Master's at University of Padova. He elaborates his Master's thesis at the University of Borås, Sweden. His main research interest is the comparison between industrial and humanitarian logistics, in order to underline some best practices will be transferred from a topic to the other one.

Alessandro Persona is a Full Professor of Industrial Plants and Logistics at the Department of Management and Engineering (DTG) at the University of Padua. He is the author of more than 120 publications, about the following topics: plants design, operations management, general services for plants, industrial logistics, maintenance. He is an editorial board member of the *International Journal of Operational Research* and referee of many important journals. He is the Director of the PhD School in 'Mechatronics and Mechanical Innovation of Product' which administrative seat is by the Department of Management and Engineering of the University of Padua. From 2005 to 2013, He has been the President of Mechanical Engineering Degree at the University of Padua.

Fabio Sgarbossa is an Assistant Professor of Industrial Plants and Logistics at University of Padua, working within the research group coordinated by Professor Persona, belonged to SSD ING-IND/17. The main activities of his research are about the design and management of industrial and service systems, study and management of production systems and maintenance, supply chain management, technological innovation in logistics, materials management and inventory control, operations management and logistics networks, humanitarian and healthcare supply chain management. He is the author and co-authors of more than 70 publications in important international journals and international research conferences.

1 Introduction

Tomasini and van Wassenhove (2004) define the humanitarian operations goal as "a successful humanitarian operation – that – mitigates the urgent needs of a population with a sustainable reduction of their vulnerability in the shortest amount of time and with the least amount of resources". For this reason, the most important humanitarian operations objective is to deliver the essential supplies and help to beneficiaries, people who need to be supported into the disaster area. In this context, literature underlines how logistic operations affect almost 80% of the humanitarian operations effort (van Wassenhove, 2006), becoming one of the most important factors. Transportation is a key element of delivery and in many NGOs, UN agencies and other humanitarian organisations, vehicle fleet management represents the second largest overhead cost after staff expenses (Disparte, 2007). In humanitarian operations, the typical 'commercial supply chain' challenges of allocating scarce resources in an efficient way (van Wassenhove and Pedraza Martinez, 2012) has to be contextualised in complex operations. Furthermore according to van Wassenhove (2006) these operators have to consider many different factors that can be invisible or/and ambiguous, that can have interactions, can increase and often are associated to new phenomena. Another important issue concerns the random and imprecise information about the scope, timing and resource requirements of the disaster prior to the event. According to Barbarosoğlu and Arda (2004), this affects the decision-making process and leads to the unpredictability and uncertainty due to the complex environment associated to the disaster. Furthermore, the humanitarian operations are also related to the qualitative factors such as social ones affected by the logistics operations.

At the same time, as presented in the literature review, some researchers suggest the importance of improving operations performances trying to adapt the typical optimisation approaches for commercial supply chain to humanitarian context. As already proposed by the literature, closed-loop supply chain (CLSC) is considered one of the possible improvements not just to minimise the costs rather to increase operations sustainability and the opportunity to reuse items in other operations without buying or remanufacturing (Rajapakshe et al., 2013) more items than necessary. In literature this argument is considered as green supply chain (Olugu and Wong, 2011; Kim et al., 2014).

For these reasons, this research explores the possibility to apply CLSC practices into humanitarian operations by providing a model and studying the impact it can have in the regular humanitarian logistic (R-HL) operations where the main objective of the operation switches from the reduction of population needs to a minimisation of the overall disaster and operations impact. In particular, the research focuses on logistic facility management in the situation of using reverse logistics practices. Moreover, the model considers typical humanitarian RL features as items interested by the reverse flows (Peretti et al., 2014) or humanitarian distribution network.

1.1 Aim of the paper

This research objective is to explore the impact in terms of costs and performances of using CLSC practices into humanitarian context. This study has been suggested by the literature that is showing the growing importance of sustainability into humanitarian operations. For this reason, typical commercial CLSC practices, as recycling or reusing, are introduced in a linear programming model in order to optimise resources allocation and prepositioning decisions not only to minimise the overall costs, but also to show the possibility to minimise the overall environmental impact. The final results will show the importance of introducing reverse logistics practices for reuse or disposal; this is due to the cost associated to the fraction of uncollected demand.

2 Literature review

In the last decades, humanitarian operations have received increasing attention by the researchers and it is still increasing in terms of investigations (Caunhye et al., 2012; Kunz and Reiner, 2012; Dubey et al., 2014). Since logistics is considered one of the most important operations in terms of efforts ("Since disaster relief is about 80% logistics", van Wassenhove, 2006), many typical Commercial logistic aspects have been investigated both in what have been called R-HL and post-disaster humanitarian logistics (PD-HL). In particular transportation issues have been extensively studied (Caunhye et al., 2012), touching problems like last mile distribution (Balcik et al, 2008; Battini et al., 2014), resources allocation (Barbarogosğlu and Arda, 2004; Campbell and Jones, 2011) or fleet management (Pedraza-Martinez et al., 2011). In the well-structured humanitarian operations literature (Tatham, 2013), the ‘forward channels’ (Fleischmann et al., 1997) of the supply chain have received great attention, unlike ‘the reverse flows’.

For these reasons, in this research the authors want to analyse the possible implication of introducing a CLSC point of view into humanitarian operations. These practices have been already applied in the commercial context and well studied by its literature, but its application in humanitarian field has never dealt with it before. In fact, although Kovacs and Spens (2012) establish the inclusion of reverse flows “is yet to be researched in the humanitarian context” and although van Wassenhove (2006) considers the possibility of “Material flows, which represent physical product flows from suppliers to customers as well as reverse flows for product returns, servicing and recycling”, no real researches focused on this specific issue has been found in the literature (Caunhye et al., 2012; Kunz and Reiner, 2012; Tatham, 2013).

In the literature, only few investigations have proposed the application of the RL methods into the humanitarian logistics. In 2004, DeVore underlines that “often the reverse supply chain is overlooked, not planned for, and not used when deploying for aerospace expeditionary force rotations, contingencies, wars, sustainment operations, and humanitarian relief operations”. In 2013, Hall suggests some alternative views that could be included in humanitarian logistics. Among these alternatives, owned by the private sector, Hall comprises the ‘reverse logistics capacities’ and underlines the possibility to involve the CLSC (Guide and van Wassenhove, 2003; Dekker et al., 2004). At the same time, the academics focus on RL in order to achieve what has been called green humanitarian logistics (Christopher and Tatham, 2011). Especially concerning the environmental impact of the activities on the field where “non-degradable materials in the field have further environmental implications” and where there is practically the total absence of reverse logistics processes. In this way, an article presented by Humanitarian Research Group at INSEAD investigates the humanitarian response and in particular analyses the environmental impact of the humanitarian response in the post 2010 Haiti earthquake operations, with a focus on the impacts of some items (e.g., water bottles). Furthermore, Eng-Larsson and Vega (2011) study the trade-off in humanitarian field, achieving the green logistics without compromising the short-terms humanitarian objectives.

The problem of greening the humanitarian operations has been underlined by Kovacs and Spens (2012) and Srivastava (2007). Kovacs and Spens (2012), in particular in the 11th chapter (‘A study of the barriers to greening the relief supply chain’ by Sarkis et al., 2011), present the importance of an environmental point of view in the evolution of the humanitarian response in order to fit “a variety of pressures faced by the organisation including regulatory, competitive, and community/public pressures” even if there are some barriers that have to be passed. According to Kovacs and Spens (2012), these barriers do not allow the application of some new practices and procedures into humanitarian context, but the authors underline the importance of future studies “to overcome the barriers and hopefully aid in greening the relief supply chains”. On the other hand, Srivastava (2008) considers and presents the possibility reverse flows in order to achieve the greening supply chain goal. From the commercial supply chain literature, in particular according to Guide and van Wassenhove (2003, p.3), the CLSCs in commercial SC “include traditional forward supply-chain activities and the additional activities of the reverse supply chain”, where the forward activities are typical industrial process while, according to Dowlatshahi (2000) the *reverse channels* are the “process in which a manufacturer systematically accepts previously shipped products or parts from the point for consumption for possible recycling, remanufacturing, or disposal". This process has to be incorporated in a RL system where the "supply chain has been redesigned to manage the flow of products or parts destined for remanufacturing, recycling or disposal and to use resource effectively". The RL has been widely discussed in the literature (Fleischmann et al., 1997; Mahapatar et al., 2013) and usually it faces three main areas of interest: the distribution planning, inventory control and production planning. The RL distribution (Bloemhof-Ruwaard et al., 1999) is focused on channels, location and routing problems. Inventory, instead, considers the possibility of returned modules or spare parts in order to be reinstalled in new products (Teunter et al., 2000; Dobos, 2003). At the end, the RL in production is focused on the opportunity to reuse the returned product 'as is' or after minor repairs (Srivastava, 2007, 2008). The literature presents different possibilities that can belong to different reutilisations of the products, the return flows. A good exhaustive example of the forms of return flows is summarised by Farahani et al. (2011), where once the products return they are selected and after different solutions they are available. The main activities after the selection can include two main possibilities: the redistribution and the waste management. The waste management is considered when "a firm has decided that it is no longer of value to reuse, upgrade, or recover materials from a specific product, the product then becomes waste" (Hazen et al., 2012) and the activities that are associated to this are disposal and incineration. On the other hand, for the redistribution, the options for the process include different levels of re-elaborating, from a low level of re-elaboration (reuse 'as is') to a recycling level, where the operation is not focused on retaining the functionality of used products or parts (Bloemhof-Ruwaard et al., 1999). The literature (Ferrer, 1997; Bloemhof-Ruwaard et al., 1999) divided the discarded products into three graduations: product recovery, parts recovery and material recovery. The first considers products or packages that could be directly reused or that need just a quick inspection or cleaning, the second graduation (remanufacturing) contemplates the products that can be disassembled and which components can be reused for new products but the identity of the products is preserved, the third and last degree (recycling) is focused on the reutilisation of the disassemble products parts without maintaining the functionality of the former product. This classification of the post-selection activities is similarly proposed by Hazen et al. (2012) with the addiction of waste management.

In general in the commercial supply chain, all the products that have a strategic cost, products that can increase the overall quality or the customer service, products that can have environmental consequences or that are interested by legislative concerns can be considered as interesting by reverse flow practices. The products usually involved in RL can be various; according to Stock (2001) the items that come back and require reverse logistics processing may include product returns, product recalls, end-of-lease equipment, old/obsolete items being replaced, packaging materials and myriad other items.

An important issue is due by the barriers that can make difficult the application of CLSC practices in commercial SC as there are some others, as presented above, that can make it even more difficult in humanitarian SC. As proposed by Rogers and Tibben-Lembke (2001), these barriers are: the importance of RL relative to other issues, company policies, lack of systems, competitive issues, management inattention, personnel resources, financial resources and legal issues.

As suggested by the commercial literature review, one of the areas that can influence the CLSC regards the distribution planning and the costs that can arise with the reverse flows. In this study, the topic considered is the facility location and the minimisation of costs in the situation where reverse flows are applied. In humanitarian literature, many researches explore the prepositioning of facility to better perform during humanitarian crisis (just few examples are Drezner et al., 2006; Balcik and Beamon, 2008; Doerner et al., 2009; Dõyen et al., 2011) but no one introduces, the presence of the reverse flows. Taking into account all of the features that are raised up in the literature review and barriers, this study wants to explore a facility location in the situation of CLSC model and its application in humanitarian operations context, considering some features usually present in the field.

3 Model

The model is a CLSC linear programming model that considers humanitarian features and proposes the presence of reverse flows in order to understand when it is possible to implement reverse flows and whether these applications can lead to improvements in terms of supply chain cost and their applicability in humanitarian field. In particular, this model studies the opportunity to collect the products once they have been used by the population.

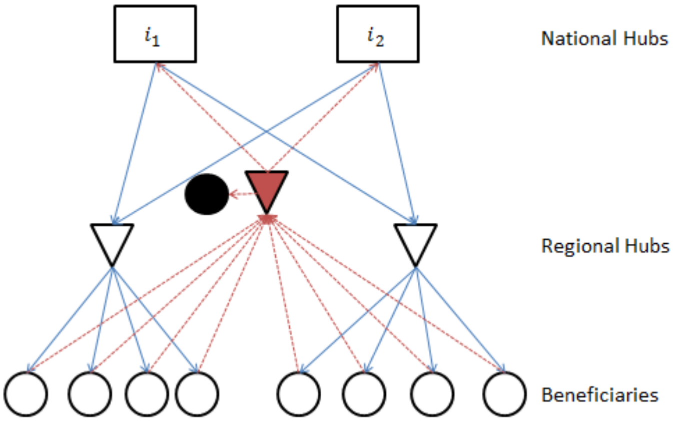
The main reverse flow after the selection activities, as it is suggested by the literature, includes two main possibilities: the redistribution and the waste management (Battini et al., 2015). In the first case the items return to the national hub while in the second case they go to the disposal. The product considered are the ones suggested by (Peretti et al., 2014):

1. items that have not been used
2. items that have been used
3. packaging.

In the model, these products are indicated by $E = \{1, 2, 3\}$. These products have different minimum disposal fraction (γ_e) because they have different features and different possibilities of being reused. Constraints related to transportation resources in a complex environment, transportation vehicle capacities and delivery time restrictions are here considered. The proposed model optimises resources allocation and prepositioning decisions on a number of test problems.

The layout of the distribution network is shown in the figure below. Different percentages of reverse flows are analysed by the model to show how the costs can vary in function of reverse fraction of collection.

Figure 1 Distribution network (see online version for colours)



Index set

I	Set of potential national hubs i location.
J	Set of potential regional hubs j location.
D	Set of disposal options d location.
L	Set of disassembly options l location.
E	Set of demand types e: $E = \{1, 2, 3\}$.
N	Set of all demand locations n.
K	Set of beneficiary locations in disposer and reuse market k.

The model

$$FO = \min\left(\sum SC + \sum RC + \sum DC + \sum Pns + \sum PnR + \sum FI + \sum FJ + \sum FDs + \sum FD\right)$$

SC	Supply cost.
RC	Reverse cost.
DC	Disposal cost.
PnS	Penalty cost for not supplying.
PnR	Penalty cost for not collecting (reversing). This considers the saving it is possible to achieve with reuse etc.
FI	Fixed cost to open a national hub.
FJ	Fixed cost to open a regional hub.
FDs	Fixed cost to open a disassembly point.

FD Fixed cost to open a disposal point.

Variables

X^{f}_{ijke} Fraction of product e demand of beneficiary *k* to be served from national hub *i* and regional hub *j*.

X^{r}_{klie} Fraction of product *e* returns from beneficiary *k* via disassembly point *l* to national hub *i*.

X^{r}_{klde} Fraction of product e returns from beneficiary *k* via disassembly point *l* to disposal point *d*.

Uke Fraction of unsatisfied demand of beneficiary *k* [=0].

Wke Fraction of uncollected demand of beneficiary *k*.

Yi Indicator opening national hub *i*.

Yj Indicator opening regional hub *j*.

Yl Indicator opening disassembly point *l*.

Yd Indicator opening disposal point *d*.

Costs

C^{f}_{ijke} Unit variable cost of satisfy product *e* demand of beneficiary *k* to from national hub *i* and regional hub *j*.

C^{r}_{klie} Unit variable cost of product *e* returns from beneficiary *k* via disassembly point *l* to national hub *i*.

C^{r}_{klde} Unit variable cost of disposing product *e* returns from beneficiary *k* via disassembly point *l* to disposal point *d*.

P^{s}_{ke} Unit penalty cost for not serving product *e* demand of beneficiary *k*.

P^{c}_{ke} Unit penalty cost for not collecting product *e* returns from beneficiary *k*.

Fi Fixed cost for opening national hub *i*.

Fj Fixed cost for opening regional hub *j*.

Fl Fixed cost for opening disassembly point *l*.

Fd Fixed cost for opening disposal point *d*.

Parameters

dke Product *e* demand from beneficiary *k* in reuse market.

rke Product *e* returns from beneficiary *k* in disposer market.

γe Minimum disposal fraction per *e* product (different categories of product lead to different percentage of disposal).

$$FO = \min \begin{pmatrix} \sum X_{ijke}^{f} C_{ijke}^{f} d_{ke} + \sum X_{klie}^{r} C_{klie}^{r} r_{ke} + \sum X_{klde}^{r} C_{klde}^{r} \\ + \sum U_{ke} P_{ke}^{s} d_{ke} + \sum W_{ke} P_{ke}^{c} r + \sum_{i} Y_i F_i \\ + \sum_{j} Y_j F_j + \sum_{l} Y_l F_l + \sum_{d} Y_d F_d \end{pmatrix}$$

Subject to

$$\sum_{i} \sum_{j} X_{ijke}^{f} = 1 - U_{ke}$$

The fraction of the supplied product is equal to the satisfied demand for the product *e* at the customer *k*

$$\sum_{l} \left(\sum_{i} X_{klie}^{r} + \sum_{d} X_{klde}^{r} \right) = 1 - W_{ke}$$

The fraction of the returned products is equal to the satisfied collection for the product *e* at the customer *k*

$$\gamma_e \left(\sum_{i} X_{klie}^{r} + \sum_{d} X_{klde}^{r} \right) \leq \sum_{d} X_{klde}^{r}$$

The disposing products are at least a γ fraction of all the returned products.

$$\sum_{k} \sum_{l} r_{ke} X_{klie}^{r} \leq \sum_{j} \sum_{k} d_{ke} X_{ijke}^{f}$$

The total amount of shipped products is mayor than the returned items flow

$$\sum_{k} \sum_{e} \sum_{j} X_{ijke}^{f} \leq Y_i$$

$$\sum_{k} \sum_{e} \sum_{i} X_{ijke}^{f} \leq Y_j$$

$$\sum_{k} \sum_{e} \left(\sum_{i} X_{klie}^{r} + \sum_{d} X_{klde}^{r} \right) \leq Y_l$$

The total amount of shipped products managed is less than the plant capacities.

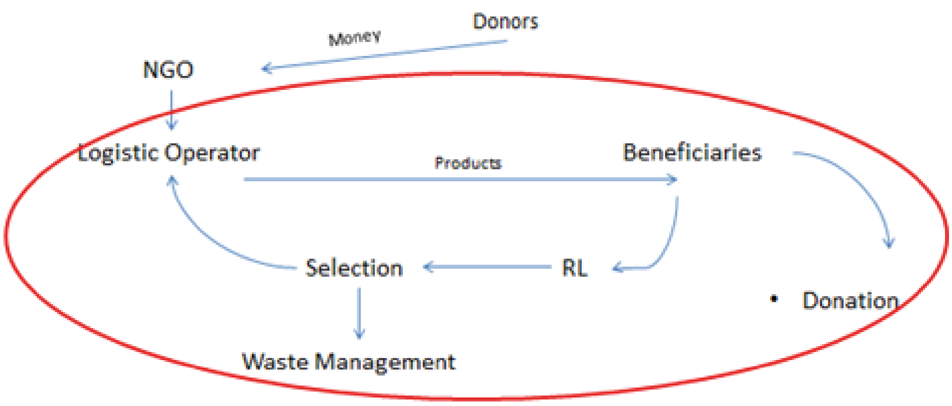
$$Y_j, Y_l, Y_d \vee \{0, 1\}$$

$$0 \leq X_{ijke}^{f}, X_{klie}^{r}, X_{klde}^{r}, U_{ke}, W_{ke} \leq 1$$

4 Model discussion

The proposed model, a linear programming model, is innovative because it has never been used in literature. Usually the humanitarian literature usually applies forward channels to study typical humanitarian issues, as distribution or prepositioning. With this model the authors want to introduce a typical industrial supply chain approach to humanitarian context. In particular, in the model, the possibility to consider reverse flows with typical humanitarian features considered is introduced in order to better preposition the plants, while the phase of the disaster in which the logistics model is applied is the regular humanitarian operations phase. The best choice is function of the cost of managing different quantities of reverse products. Indeed from a reverse flow of zero products, the authors have studied the complete collection of the products.

Figure 2 Typical humanitarian flows (see online version for colours)



As introduced in Figure 2, a humanitarian supply chain is typically financed by the donors, public and private ones, that allow the NGO's to set up the distributions, the specific countries programmes or others activities. Concerning the distribution, the activities are usually outsourced to logistic operators. These operators follow the NGO's directives and distribute the items to the beneficiaries. Nowadays, once the items are supplied, the organisations do not consider their possible return, only some radio equipment or vehicles are subjected to return in order to be reused in others humanitarian programmes. The here introduced model applies this possibility to all the items and to the packaging in reverse flows in order to be reused or disposed.

Furthermore, the model considers other humanitarian operations features. According to the literature (Peretti et al., 2014), there could be mainly three types of items that could be involved. In particular, it is important to distinguish between:

a items that have not been used

b items that have been used

c packaging.

Each of these categories has a potential residual value, and could have the opportunities in the reverse flows. These different products have been considered in the model

(E = 1, 2, 3) with different features and different γ_e = minimum disposal fraction per product. The different features have been translated in the model with some different items characteristics:

- penalty cost for not collecting
- disposal cost
- transportation cost
- disposal and disassembly operations costs.

Moreover the humanitarian literature widely presents the importance of delivering items in the area hit by the disaster and underlines the primary importance to satisfy beneficiaries' needs before thinking about the others features of the supply chain.

5 Results

In the proposed model, the importance of the forward is underlined, indeed the study of the reverse flows starts only when the forward flows are completely satisfied. In some situations, the forward distribution can have lower impact in terms of supply chain management; in this case it is possible to change the model giving penalty costs to unsatisfied demand. This situation is presented in the mathematical section of the model where the fraction of unsatisfied beneficiaries demand U_{ke} is fixed as 0. The model shows whether or not it is economic to consider the reverse flows, if the costs are the translation of sustainability, and where the disassembly point has to be put in the case of reverse.

The application of the model has been carried out considering the features presented above, in particular the different items and the primary importance of forward flows, in a context of CLSC in humanitarian field. The results are about the optimisation of the reverse logistics. It has been assumed that the disposal capacity is infinite while the reverse available capacity is the variable. In the figure above the results have been found passing from 100% to 0% of reverse available capacity per item.

Figure 3 % of collected and disposal items in function of the reverse available capacity (see online version for colours)

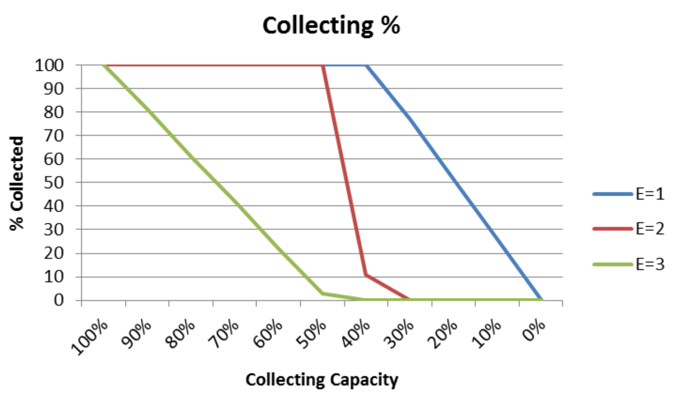


Figure 3 % of collected and disposal items in function of the reverse available capacity (continued) (see online version for colours)

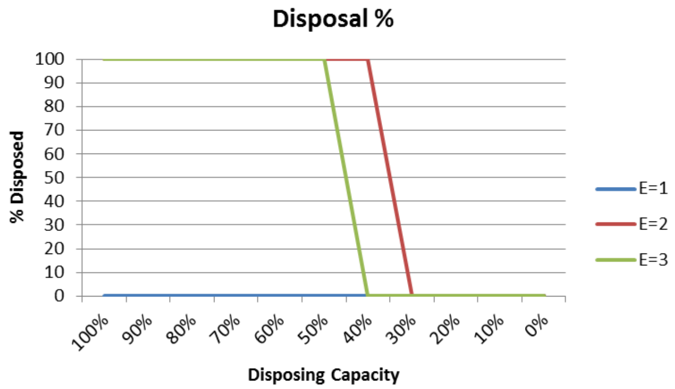
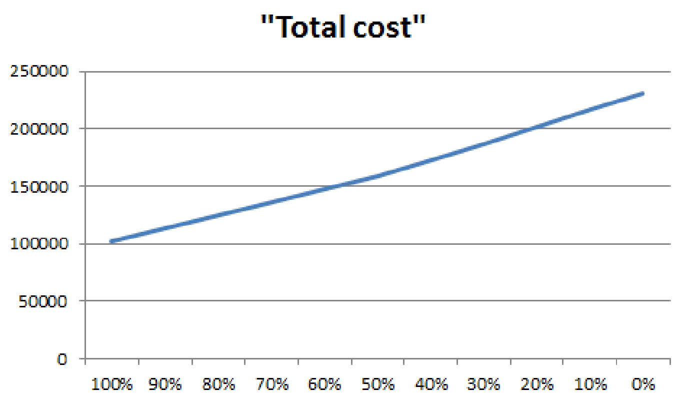


Figure 3 shows that different items with different penalty costs, for not collecting and with different cost for not disposing, have different priority of return to national hub to be reused. In particular items $E = 1$, the ones that have not been used, are pushed to return to the national hub and never disposed. This situation translates the great opportunity to reuse them. This product is the first one that is collected. On the other hand, packaging ($E = 3$) is the first product that is left in the area, however with a cost. In the case where the organisations have high disposal capacity, all the products will be collected to minimise the total costs.

Figure 4 Total cost for not reversing (see online version for colours)



In figure 4 the total cost that can grow up in the case of not reversing is presented. This cost is due to the un-sustainability of the operations and can be minimised considering CLSC and not just a forward one. In the case of high reverse capacity (collecting and disposal) there will be the minimisation of the costs.

6 Conclusions

In this research, our objective was to develop a prepositioning model that could consider reverse flows to support long terms humanitarian operations. This objective has been achieved proposing a CLSC model that has never been proposed before for humanitarian operations. This model is applied in a situation where humanitarian operators are not only focalised on supply items. Organisations are giving more and more importance to the sustainability of the humanitarian operations, in terms of environmental impact and from an economical point of view. In humanitarian operations, social costs usually have to be considered to reduce population needs. These costs are usually applied to forward logistics researches into post disaster operations. With this study, the authors have presented the importance of considering the whole operation, including reverse logistics into. In fact, in dismantling operations, when the urgency of response is lower, the reverse channels start to have an important role. The study shows the results in terms of costs these practices can have. This cost is having a more sustainable operation. This is the first research that presents a mathematical model to show and to study the application of reverse practices in humanitarian operations. The implications are huge, because only when the humanitarian organisations will consider the total impact of these operations, there will be an improvement in terms of sustainability. The limitation concerns the numerical example that is presented rather than real case applications.

Further researches will focus on real case applications, carried out with the support and the supervision of many well-known organisations that are starting to consider green supply chain point of view in humanitarian field (Peretti et al., 2014).

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