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Application of Hybrid Genetic Algorithm for CLSC Network Design Problem in Fashion Footwear Industry—A Case Study Approach

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Abstract

This research paper deals with the implementation of suitable meta-heuristic for the closed loop supply chain network design problem of a fashion product industry. First, the paper presents a comprehensive literature review on the applications of reverse and closed loop supply chain network design problems in Fashion Footwear Industry. The research work employs the case study approach to implement the model and algorithm. Closed loop supply chain network design problem of a Fashion Footwear Industry in South India is studied and considered for the purpose. Then it deals with the application of mathematical model and a suitable hybrid genetic algorithm (HGA) developed for the CLSC network design problem of the Industry this research. The MINLP model and suitable HGA developed are implemented in the industrial case as per the reverse supply chain process conditions and model adopted in the respective closed loop supply chain and the results are presented.

Keywords

Case Study, Closed Loop Supply Chain, Fashion Products, Footwear, Hybrid Genetic Algorithms (HGA), Lifestyle Products, Meta-Heuristics, MINLP Model, Network Design

1. Introduction

The fashion, leather and lifestyle products industries have been witnessing positive growth across all price points and product categories in India. The domestic companies manufacturing and marketing fashion and lifestyle products like footwear, hand bags, and other fashion life style accessories have registered a positive busi-

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ness growth in the recent past due to drastic increase in the consumption of these products among the domestic customers. This shift may be due to the modern fashion conscious consumers with variety seeking behaviours prefer to buy these products for different formal, casual and special occasions like good wedding celebrations, festival seasons, office usage, and for short and long domestic and international travels. The growth is remarkable in higher-end products, including fashionable footwear, trendy hand bags, and other fashion accessories. Across the channels, several new ranges were launched in all brands and price points, in both open and closed footwear categories with a special thrust on business collections, semi-formal footwear, and high fashion categories.

As the demand and consumption of the short lived footwear and leather accessories are in the upward trend, returns of these products from the customers for repairing or at the end of life is also increasing and becoming a difficult task for the industries to manage these returns. Due to the increase in the price and decrease in the supply of virgin raw materials and components, enforcement of eco-friendly regulations by the government, the companies are facing difficulties in manufacturing and marketing 100% fresh and virgin products at a very competitive and affordable price brackets to the consumers. The industries have started using the raw materials from alternate sources like recyclable materials, reusable components and re-furbish able or reconditioned products to manufacture and supply the products both for primary and secondary markets. Therefore, the integration of the both forward and reverse supply chain systems is gaining importance in the fashion product industries also and the companies are looking into developing an efficient supply chain models to implement the integrated supply chain concepts.

In this context, the closed loop supply chain model and hybrid genetic algorithm developed are very much in need for the present situations prevailing in the fashion product industries. The researcher approached a couple of industries who have shown interests to implement the CLSC network design model and Hybrid Genetic Algorithm developed for solving their supply chain network design problems. The industry shown interest has been considered for the purpose and thus, this paper deals with an industrial case study for the validation of the HGA developed to suit the real life situations. The Case Study discusses and presents the implementation of the CLSC model and hybrid genetic algorithm to solve the supply chain network design problem of a footwear industry which manufactures and supplies footwear made out of leather and non-leather materials to the domestic consumers in India. The company is located at Chennai in the state of Tamil Nadu, India.

The organization of this research paper is given as follows. The second section presents the literature review in the identified area. The third section formulates the objectives of the research work from the identified research gaps. Fourth section presents the appropriate methodology for implementing the research work. Fifth section describes the industry case, its problem statement, implementation of the model and hybrid genetic algorithm developed and discusses the end results by giving the optimum solution with illustrated shipment pattern for the identified problem of the footwear industry case. The final section concludes the research with a summary of findings.

2. Literature Review on SCND Problems in Fashion and Footwear Industry

The researchers surveyed the research works on the supply chain network design models and algorithms for the past 15 years and reviewed the literature on forward, reverse and closed loop supply chains. The literatures reviewed are dealt on the applications of models and algorithms in the fashion and footwear industry cases and presented in this section.

2.1. Literature Review

Fleischmann *et al.* [1] presented the literature review of the case studies on the reverse supply chain network problems initially and then identified the methods and activities for executing the product recovery in the reverse supply chain networks. They recognized two parts in the product recovery process, viz. a convergent part which collects the products from the customers and a divergent part which dispose the recovered products after reprocessing. Barnes and Greenwood [2] presented their research on the application of supply chain system for the fast fashion demands. The researchers collected the data through in depth interview with the respondents from the fashion industry. They demonstrated the supply chain systems of fast fashion industry and presented the research agenda for future explorations. They also threw insights into the effect of the short lived fashion products on the supply chain and retail operation as the industry is entirely driven and influenced by the consumers. Staikos and Rahimifard [3] presented an initial investigation of the post-consumer waste management for the recovery and recycling process in the footwear industry. They reviewed the trends on the end of life product returns and their management options in the footwear industry. Then the researchers also developed an integrated strategy for re-use, recycling and energy recovery methods applicable to the industry while dealing the post-consumer wastes from end of life footwear.

Staikos and Rahimifard [4] presented a case study on the footwear industry dealing with end of life product management and recovery of footwear returns. The researchers proposed a product recovery process which includes recycle, repair/reuse, land-filling, and incineration operations in order to minimize the cost and end of life product wastage for an environmentally sustainable network model for footwear supply chain system. Staikos and Rahimifard [5] discussed the benefits of developing product recovery strategy and methods for an integrated footwear supply chain. They also developed an associated software tool to support decision making process for determining the most suitable method in which the end of life and post-consumer footwear wastes are treated to address the issues with respect to environmental, economic and socio-technical areas. The researchers suggested that the proposed methodology could provide adequate information for benchmarking the selection of the best practice for managing the end of life product returns for a selected range of different footwear types, in addition to supporting design and material selection processes. Li and Olorunniwo [6] presented the case study of three companies for exploring the reverse supply chain systems. The researchers dealt with the generic reverse logistics process flow, application of process technology and information technology that a firm needs in order to operate an effective RL system.

Crestanello and Tattara [7] analyzed the implementation and monitoring of supply chain activities in the traditional areas like clothing and footwear, with a focus towards decentralizing the production set up from Italian region of Veneto to the nearby country of Romania. They discussed how the networks in the two countries evolved through time with the help of many case studies and discussed the implications of three types of supply chain governance models applicable for different geographical territories having varied levels of developments and industrial establishments, for improving the development process and ensuring sustainability in those territories. Lee and Rahimifard [8] presented the novel model which deals with post-consumer shoe waste. They developed an air-based automated material recycling process which is economical for dealing the mixed end of life shoe returns. They showed through experimental studies with three different types of postconsumer footwear products that it is possible to reclaim four usable material streams such as leathers, textiles, foams and rubbers from the footwear end-of-life product returns. Ho and Choi [9] presented a Five-R analysis for sustainable fashion supply chain management in Hong Kong with case analysis. The researchers applied exploratory qualitative method to propose and apply the Five-R analysis in the real case which includes five critical processes, namely recycle, reuse, reduce, re-design and re-imagine. Nie *et al*. [10] proposed three types of models for closed loop supply chain system in which the manufacturers can use financial and physical supports to employ a third party logistic provider to collect the end of life or used fashion products for reprocessing like remanufacturing activities. They first examined two strategies for the collective recycling responsibility (CRR), namely the financial sharing (FS) and the physical sharing (PS) by using the model with no CRR as a benchmark. Then they conducted a detailed comparison among the three models in terms of the retail price, demand, return rate, and the profits received by the supply chain members.

Ciarniene and Vienazindiene [11] presented theoretical model illustrating supply chain management of modern fashion industry, which has fast-moving and trend-driven business involving three sectors of economy and four tiers of the supply chain. They observed that the fashion supply chain systems are characterized by three critical lead-times, which are time-to-market, time-to-serve and time-to-react, which stress the importance of agility in fashion supply networks. Aravendan and Panneerselvam [12] considered a multi-echelon closed loop network design problem with an objective to minimize the total cost of the network and increasing the quality of service. They developed a mixed integer non-linear programming model to solve the CLSCND problem. The researchers simulated the experiments and solve the model using the optimization software LINGO14. Guimaraes and Salomon [13] presented an Analytic Network Process (ANP) applied to the evaluation of performance indicators of reverse logistics in footwear industry by considering the environmental legislation, technology, costs and external relations, etc. They assessed the priorities of the indicators of reverse logistics in a small footwear industry in the Brazilian State of Ceara. The reverse logistics management model utilizes the ANP as a MCDM method suitable to allow qualitative and quantitative evaluations as well as to evaluate dependency relations in the interactions of elements and/or components of the model. Tokhmehchi, *et al*. [14] developed a hybrid approach to solve a model of closed loop supply chain, which includes plants, demand centers, collection centers and disposal centers. They proposed a mixed integer programming model for this problem to minimize the total cost. The researchers used four types of meta-heuristics, which are hybrid forms of genetic and firefly algorithms and analyzed the performance of the algorithms by generating adequate number of instances. The results show that hybrid algorithms provide better solution than that provided by other approaches for large size problems. Aravendan and Panneerselvam [15] presented four different hybrid genetic algorithms (HGAs) for network design problem in closed loop supply chain. The researchers compared the four HGAs using a complete factorial experiment with two factors, viz. problem size and algorithm and identified the best algorithm using Duncan's multiple range test. Then they compared the best HGA with their mathematical model in terms of total cost and found that the best hybrid genetic algorithm identified gives results on par with the mathematical model in statistical terms for small and medium size problems and also provides faster solution to large size problems. The model and algorithm developed can be applicable to a range of industries like Fashion & Clothing, Footwear & Leather, Consumer Electronics, Automobiles, Lifestyle and luxury products industries etc.

2.2. Research Gaps

In this section, the literature review of the design of the closed loop supply chain system and reverse supply chain system in the Fashion Footwear Industry is presented. It is found that the researchers applied models, heuristics, genetic algorithms and hybrid GAs, and other heuristics to solve the supply chain network design problems. The outcome of the review shows that the meta-heuristics particularly the genetic algorithm and its hybrids are applied by the researchers to deal with the supply chain network design problems. The concepts of closed loop and reverse supply chains for the fashion products sectors like fashion footwear industry are in practice only in few developed countries, where the environmental legislations are very stringent. Very less research work has been done in these areas, which is evident from the case study literature reviewed. So, it is the need of the hour for the footwear industries to focus and implement these systems in order to sustain in the business with the growing problems of shortage of raw materials like leathers, soles, non-leather trims etc. to fulfill the domestic consumption and also to comply with the environmental regulations and legislations.

3. Problem Statement and Research Objectives

The statement of the research problem of the footwear industry case considered and the research objectives to be implemented for solving the CLSCND problem of the industry case are described in this section.

3.1. Statement of the Problem

The closed loop supply chain network design model problem considered in this research is a multi-echelon and multi stage network design problem, which includes footwear manufacturers, footwear brand dealers, footwear brand retailers and first customers in the forward chain, and service/ repair centers, collector/dismantler/refurbisher (CDR), footwear remanufacturers, recyclers, disposal centers/land-fillers, footwear brand resellers and second customers in the reverse chain. The network deals with the two types of product returns, viz. product returns due to repair and product returns due to end-of-use or end-of-life in its reverse chain. The repair products are sent directly to the repair/service centre by the first customer for getting them repaired and the end-of-life (EOL) products are returned either directly or through the footwear brand retailer to the collector/dismantler/re-furbisher by the first customer for re-processing. The returned products thus collected in the CDR locations are sorted and then the parts are dismantled and segregated into recoverable and non-recoverable or waste items. The recoverable items are again segregated into refurbishable, remanufacturable and recyclable items, and they are shipped to the respective facilities or locations for recovery process. The non-recoverable or the waste items are shipped to the disposal centers/land-fillers and disposed through land filling or incineration. The recovered products through the process of refurbishing and remanufacturing are shipped to the second customers via footwear brand resellers. The items recovered through recycling process are shipped to the raw material suppliers market by the recycler. In this context, the main aim of the CLSCND model considered in this research is to minimize the total cost of the integrated closed loop supply chain system which includes the costs of forward and reverse supply chains there by increasing the total profit of the closed loop network.

3.2. Research Objectives

The research objectives of the closed loop supply chain network design problem identified for the footwear industry case considered in this research are furnished as follows.

1) To apply and compare the best GA based meta-heuristic with the mathematical model in terms of the total cost of the closed loop supply chain network to check its quality of solution with the optimal solution obtained by the mathematical model.
2) To propose and implement the application of the mathematical model at the first instance to obtain optimal solution in reasonable time for the closed loop network design problem of the Footwear Industry. If it is not possible to get the solution through the mathematical model for the case, then apply the best HGA to obtain very near optimal solution for the closed loop network design problem of the footwear industry case considered.

4. Research Methodology

The methodology adopted for this research work is a combination of modeling, algorithmic and case study based research methods. The mathematical model and the meta-heuristic *i.e.* the hybrid genetic algorithm developed by Aravendan and Panneerselvam [12] [15] are applied in this research work. The case study research method is applied by involving a company from fashion product industries like Footwear industry in South India. All the three methods applied are briefly given hereunder.

1) Modeling Research—Implementation of Mathematical Modeling:

The model developed for solving the closed loop supply chain network design problem by Aravendan and Panneerselvam [12] is the generic model which can be applicable for a range of industry sectors like fashion & clothing, footwear, leather goods, automobiles, consumer electronics and other life style products etc. The model class is mixed integer linear programming (MINLP) and based on the branch and bound technique concepts presented by Panneerselvam [16]. There, all the model parameters and variables are assumed hypothetically and the problem has been solved using LINGO 14. This model approach is adopted for solving the CLSCND problem of the industry case identified. The model is customized for the footwear industry and the real data collected for parameters and variables from the industry are applied for solving the model in LINGO 15.

2) Algorithmic Research—Implementation of Hybrid Genetic Algorithm

In the research works presented by Aravendan and Panneerselvam [15], the mathematical implemented could not provide the optimum solution for the generic CLSCND problems of larger size even after implementing the model in LINGO 14 for several hours. So, the researchers have developed the variants of meta-heuristics, i.e four hybrid genetic algorithms, viz. HGA1, HGA2, HGA3 and HGA4 by varying the GA parameters like chromosome selection methods, chromosome cross over methods and chromosome replacement methods. The basic concepts and principles of Genetic Algorithm (GA) are referred from Panneerselvam [17]. All the four HGAs are coded in C# and implemented in VB.NET and Microsoft SQL server platforms. From the results obtained, the HGA4 has emerged as the best hybrid genetic algorithm providing the best optimum solution for the generic CLSCND problem as presented by Aravendan and Panneerselvam [15].This best hybrid genetic algorithm is adapted and customized for solving the specific CLSCND problem of the fashion footwear industry considered in this research work.

3) Case Study Research-Implementation of Fashion Footwear Industry Case

The industry case study presented in this research work is for the specific fashion product industry dealing with fashion footwear in South India. The model proposed has an objective to minimize the total cost of the integrated supply chain and also to reduce the wastage due to end of life goods returns from the customers. A descriptive and secondary research was applied to study and understand the company's business profile and performance, its supply chain management strategies, frame work and implementation processes. The input data required for implementing the MINLP model and the best hybrid genetic algorithm (HGA4) proposed by Aravendan and Panneerselvam [12] [15] for this research were collected through personal interviews and surveys over phone among the top and middle level management teams of the company. The input data collected were applied in the CLSCND model and hybrid genetic algorithm to conduct the experiments for the industrial case considered. The solutions obtained from the mathematical model using LINGO 15 and by implementing the HGA4 in C# under VB.NET platform are compared and the results are summarized under the case study.

Due to the confidentiality agreement is being enforced between the company and researchers, the researchers have not disclosed the basic identities of the company and used a dummy company name for the industrial case study discussed in this section. All the data collected with respect to the company are used purely for academic and research purpose and not used for any commercial purpose.

5. The Case Study: Footwear Industry

India is ranked as the second largest footwear producer after China in the world with an annual production of 2200 million pairs. The country has a huge domestic retail market in which about 1950 million pairs are sold to fulfil the demands of the domestic consumers. The export of footwear is accounted for 45% share in India's total leather and leather products export. The Footwear product mix consists of gents' model for 55%, ladies model for 35% and children model for 10%.

The Footwear Industry is an ever growing and diversified manufacturing sector which applies a wide range of materials to make footwear ranging from different types and styles of footwear for all genders and age groups to more specialized footwear for special consumers like athletes, sports persons, kids, differently abled and old age people. Leather, Non-Leather materials like synthetic leathers, coated fabrics, rubber and textile materials are the basic materials most commonly used in footwear manufacture. These footwear materials are unique in their physical appearance, qualities, characteristics and performance, and require different treatments for using them to make virgin footwear for primary markets and reusable footwear secondary markets at the end of their life. The design, selection and application of footwear materials for the different types of footwear and the fabrication method significantly influence the life of the footwear and the scope for treating and managing the end of life product returns.

In the recent years, consumers demand a large variety of footwear for different occasions owing to their enhanced lifestyle and increased buying capacity. The market is very dynamic and the consumer preferences are very rapidly changing due to fashion awareness and trend adaptations among the consumers. Responsiveness to this consumer demands leads to the production of footwear with shorter product development cycle and shorter life cycle leading to a higher level of End-of-Life product returns and post-consumer waste. The amount of waste generated from the EOL product returns or the post-consumer footwear across the world is estimated to reach millions of tons per year, where a major share of it is disposed as wastes through incineration and landfills. The footwear industry's response to this increasing problem of EOL product returns and the post-consumer shoe wastes has been very poor or negligible which leads to major environmental pollution affecting the healthy and sustainable lifestyle of the society. It is the need of the hour for the footwear industries in India to rise to the situations and implement appropriate cost effective supply chain systems to tackle the growing environmental concerns by minimizing the wastage and total cost involved in the supply chain system. This could be achieved by managing the EOL product returns and post-consumer wastes efficiently through an integrated forward and reverse supply chains in a closed loop distribution network design in the footwear industry.

In this context, the researcher has approached a footwear industry in the state of Tamil Nadu, which has shown its concern over the problems due to post-consumer wastes and has shown interest to implement the closed loop supply chain network design model and suitable hybrid meta heuristic developed in this research work to manage the EOL product return issues in the Footwear Industry. Accordingly, the investigations and research works are carried out and the implementation process for the proposed footwear industry model is presented in the following sections.

5.1. Company Overview—"XYZ Shoes Pvt. Ltd."

The company, "XYZ Shoes Pvt. Ltd." was established in late seventies in the state of Tamil Nadu and since then exporting formal, semi-formal and casual footwear to USA, UK and other European countries. The company's product basket includes Ankle Boots, Formal Shoes based on Derby, Oxford, Monk and Brogue, Semi-Formal shoes based on Casual Slip-on and Moccasin styles. The company manufactures and exports mostly leather footwear with a combination of soling materials like Leather, Leather inserted PVCs, Poly-Urethane (PU), and Thermo Plastic Rubber (TPR), etc. The company markets footwear for both Gents and Ladies customers. As the domestic consumption of leather and non-leather footwear has been drastically increasing, the company has entered into the domestic market in the year 2010 by establishing a domestic brand in order to cater to the middle, upper middle and high class customers in India. The company has set up three manufacturing plants at the industrial estates in and around Chennai. The product basket for the domestic market includes formal, semi-formal and casual shoes and sandals made out of leather and combination materials. The company supplying variety of short lived fashion footwear in the semi-formal, casual and daily wear segments as these categories hold a major share of consumption by the domestic customers. The products are distributed to the end customers through the brand dealers, multi brand retailers and also through the company owned brand stores and franchisee stores.

5.2. CLSC Network Design Model

The company has envisaged implementing an integrated closed loop supply chain system to minimize the total cost of the supply chain and to manage the growing end-of-life products due to the major consumption of short lived products. Therefore, the supply chain network model developed in this research work is customized and tailored to the requirement of the footwear industry considered in this case study. The illustration of the model as shown in Figure 1 along with its description is presented in this section.

5.3. Model Description

The proposed model is the formulation for the closed loop network design problem which integrates both forward and reverse logistics in the supply chain. The closed loop network presented in this research is a single product, single period (*i.e.* considered annually) and multi-echelon supply chain, which channelizes footwear manufacturers, footwear brand dealers, footwear brand retailers and first customers in the forward chain and channelizes repair/service centers, collectors/dismantlers/re-furbishers, remanufacturers, recyclers, land fillers, footwear brand resellers and second customers in the reverse chain. In the Figure 1, the "forward flow" implies the shipment of fresh products in the forward chain; the "product returns" implies the footwear returned from first customers for repair and after end of life or use; the "reverse process" implies the different recovery process carried out after screening the EOL footwear in CDR locations and the "reverse flow" implies the shipment of footwear to second customers after the reverse process.

5.4. Model Conditions and Limitations

The conditions and limitations of the proposed model are considered as follows.

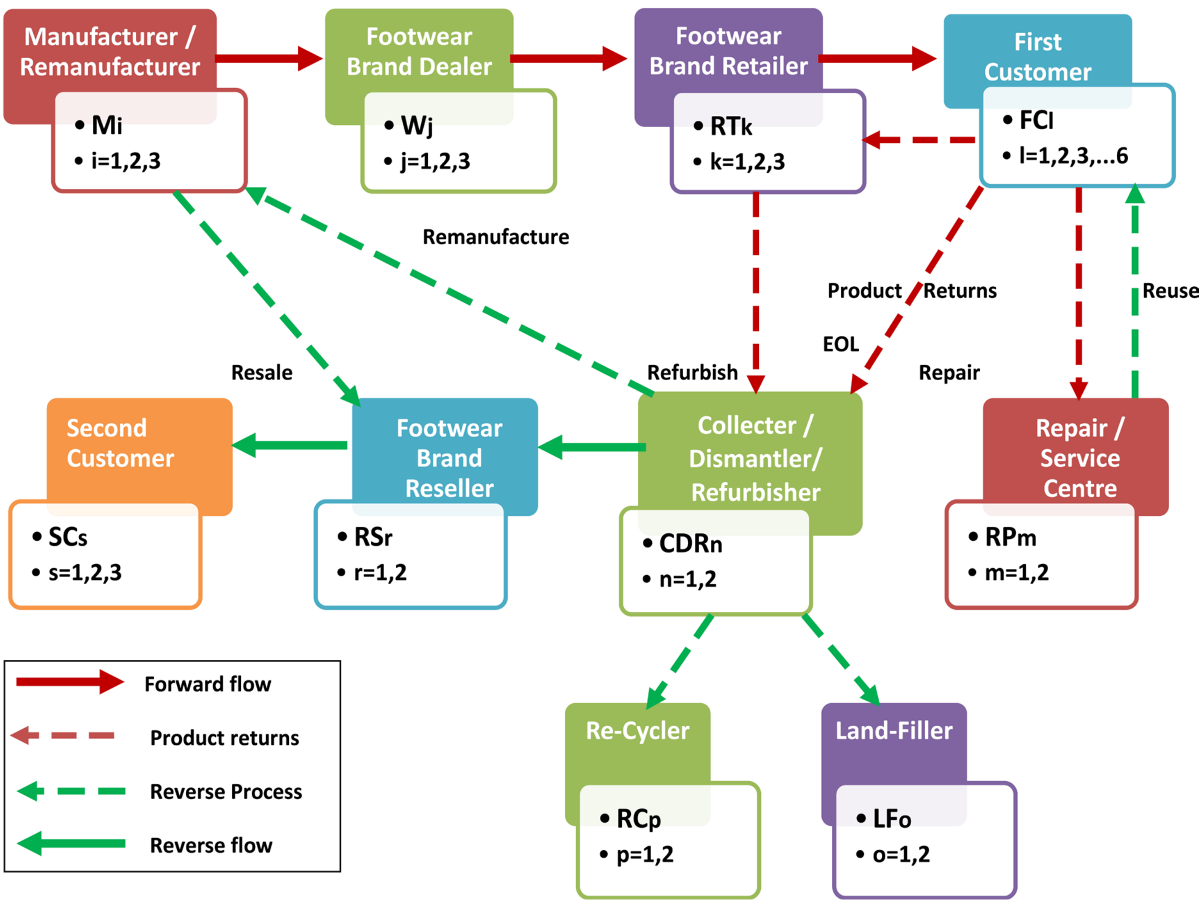

Figure 1. Proposed CLSCND model for the footwear industry case study.

1) The model is for a single product and single period network design.
2) The locations of the first customers and second customers are known and are with certain demands.
3) There is no shipment happening between the nodes in the same stage and the quantities of products returned are certain.
4) 50% the total quantity of footwear supplied are returned as EOL products and accounted for reverse process.
5) 30% of the total quantity of footwear supplied are returned as repair products by the customers and returned back to the customer after repairing for reuse.
6) 20% of the total quantity of the footwear supplied is not returned by the customers.
7) 40% of the EOL products are returned via footwear brand retailers and remaining 60% of the EOL products are returned directly, to the Collectors/Dismantlers/Re-furbishers (CDR).
8) Out of the total returned EOL products, 20% are re-furbishable items, 40% are re-manufacturable items, 25% are recyclable items and 15% are non-recoverable and disposed by land-fillers.
9) The quality of the remanufactured, refurbished and repaired products is different from that of the new products.
10) The locations of footwear manufacturers, footwear brand dealers, footwear brand retailers, collectors/dismantlers/re-furbishers, repair/service centers, recyclers, land fillers and footwear brand resellers and their capacities are known.
11) The costs parameters considered (viz., opening costs, operating costs, un-utilized capacity costs and transportation costs) are known for all the facilities and nodes.
12) The measure of quantity of products transported per trip is defined in the form of number of units per trip.

5.5. Solving the CLSC Network Design problem of Footwear Industry Case

The closed loop supply chain model proposed for the footwear industry is a single period, single product and multi-echelon closed loop supply chain network design model. It has four echelons, viz. three manufacturers, three wholesalers, three retailers, six first customers in the forward chain and five echelons in the reverse chain, viz. two repair centres, two collectors/dismantlers/re-furbishers (hybrid), two recyclers, two land-fillers, three remanufacturers (hybrid), two resellers and three second customers in the reverse chain as shown in **Table 1**. The data collected on various model parameters pertaining to the nodes/channel players at the different echelons in the CLSC model is given in **Table 2**. The maximum count of the facilities and nodes at the different echelons with the entire forward and reverse flows between the pair of facilities and nodes are illustrated in **Figure 2**.

The distances between different pairs of facilities/nodes and that of between different pairs of facilities and customers (first customers, second customers) are given in **Appendix 1**.

First, the mathematical model presented by Aravendan and Panneerselvam [12] has been formulated for the footwear industry case using the data shown in **Table 1**, **Table 2** and **Appendix 1**. The model belongs to MINLP class and was developed using the branch and bound technique concepts given in Panneerselvam [17]. When it is solved using LINGO 15 software, it is found that the model did not give solution even after several hours of execution. The LINGO 15 software was run on MS Windows 7 Professional platform in a 64-bit operating system of Hewlett-Packard Lap Top Computer with a processor: Intel(R) Core(TM) i5-2430 CPU@2.40 GHz 2.40 GHz. with 4.00 GB installed memory (RAM) capacity.

Since, the mathematical model did not provide the optimum solution, next, the case study is solved using HGA4, which is presented by Aravendanand Panneerselvam [15] using the data given in **Table 1**, **Table 2** and **Appendix 1**. The steps involved in the configuration of the best hybrid genetic algorithm (HGA4) are presented below along with its process flow chart as given **Figure 3**.

Table 1. Facilities and nodes in the CLSC network design model of footwear industry case study.

Facilities/Nodes	No.	Facilities/Nodes	No.
Manufacturers/Remanufacturers (Hybrid centres)	3	Collectors/Dismantlers/Re-furbishers (Hybrid centres)	2
Footwear Brand Dealers	3	Footwear Brand Resellers	2
Footwear Brand Retailers	3	Recycler (3 PL)	2
First customers	6	Land-filler (3 PL)	2
Repair/Service centres (3 PL)	2	Second customers	3

Table 2. Numerical data for model parameters and variables in footwear industry case study.

Parameters/Variables	Value
Unit price of virgin/first products $UP_{1,}$ 100%	Rs.3000
Unit price of second products UP_2, 50% of UP_1	Rs.1500
Total Demand of first customer D1, 100%,	100,000 pairs
Total Demand of second customer D2, 30% of D1	30,000 pairs
Max return ratio of total EOL product returns to CDR $FCDF_{EOLR}$, 50% of D1	50,000 pairs
Max return ratio of EOL returns to CDR via Retailer, 40% of $EOLF_{RT}$	20,000 pairs
Max return ratio of EOL returns directly to CDR 60% of $EOLF_{CDR}$	30,000 pairs
Max return ratio of repair products $FCDF_{RR}$, 30% of D1	30,000 pairs
Land filling fraction CDRF1, 15% of EOL_{CDR}	7500 pairs
Recycling fraction CDRF2, 25% of $EOLF_{CDR}$	12,500 pairs
Re-Furbishing fraction (to Reseller) fraction CDRF3, 20% of $EOLF_{CDR}$	10,000 pairs
Remanufacturing fraction CDRF4, 40% of $EOLF_{CDR}$	20,000 pairs
Capacity of Manufacturer-1	35,000 pairs
Capacity of Manufacturer-2	35,000 pairs
Capacity of Manufacturer-3	40,000 pairs
Capacity of Footwear Brand Dealer-1	35,000 pairs
Capacity of Footwear Brand Dealer-2	33,000 pairs
Capacity of Footwear Brand Dealer-3	32,000 pairs
Capacity of Footwear Brand Retailer-1	35,000 pairs
Capacity of Footwear Brand Retailer-2	33,000 pairs
Capacity of Footwear Brand Retailer-3	32,000 pairs
Repair/Service Centre capacity	30,000 pairs
Collector/Dismantler/Re-Furbisher capacity (CDR)	50,000 pairs
Capacity of Re-Furbishers	10,000 pairs
Capacity of Re-Manufacturer -1	6000 pairs
Capacity of Re-Manufacturer -2	7000 pairs
Capacity of Re-Manufacturer-3	7000 pairs
Capacity of Footwear Brand Reseller-1	15,000 pairs
Capacity of Footwear Brand Reseller-2	15,000 pairs
Capacity of Recycler-1	6250 pairs
Capacity of Recycler-2	6250 pairs
Capacity of Land-Filler-1	3750 pairs
Capacity of Land-Filler-2	3750 pairs
Opening costs/pair for Manufacturer 1	Rs.1000
Opening costs/pair for Manufacturer 2	Rs.1200
Opening costs/pair for Manufacturer 3	Rs.1500
Opening costs/pair for Footwear Brand Dealer 1	Rs.500
Opening costs/pair for Footwear Brand Dealer 2	Rs.400
Opening costs/pair for Footwear Brand Dealer3	Rs.300
Opening costs/pair for Footwear Brand Retailer 1	Rs.200
Opening costs/pair for Footwear Brand Retailer 2	Rs.220
Opening costs/pair for Footwear Brand Retailer 3	Rs.200
Opening costs/pair for Repair/Service Centre 1	Rs.100

Continued

Opening costs/pair for Repair/Service Centre 2	Rs.100
Opening costs/pair for Collector/Dismantler/Re-furbisher 1	Rs.200
Opening costs/pair for Collector/Dismantler/Re-furbisher 2	Rs.180
Opening costs/pair for Remanufacturer 1	Rs.400
Opening costs/pair for Remanufacturer 2	Rs.450
Opening costs/pair for Remanufacturer 3	Rs.500
Opening costs/pair for Recyclers	Rs.90
Opening costs/pair for Footwear Brand Resellers	Rs.100
Opening costs/pair for Land-Fillers	Rs.50
Operating costs/ pair for Manufacturer 1,	Rs.100
Operating costs/pair for Manufacturer 2	Rs.130
Operating costs/pair for Manufacturer 3	Rs.150
Operating costs/pair for Footwear Brand Dealer1	Rs.120
Operating costs/pair for Footwear Brand Dealer2	Rs.130
Operating costs/pair for Footwear Brand Dealer3	Rs.120
Operating costs/pair for Footwear Brand Retailer 1	Rs.50
Operating costs/pair for Footwear Brand Retailer 2	Rs.50
Operating costs/pair for Footwear Brand Retailer 3	Rs.50
Operating costs/pair for Repair/Service Centre 1	Rs.50
Operating costs/pair for Repair/Service Centre 2	Rs.50
Operating costs/pair for Collector/Dismantler/Re-Furbisher 1	Rs.70
Operating costs/pair for Collector/Dismantler/Re-Furbisher 2	Rs.80
Operating costs/pair for Remanufacturer 1	Rs.80
Operating costs/pair for Remanufacturer 2	Rs.90
Operating costs/pair for Remanufacturer 3	Rs.100
Operating costs/pair for Recyclers	Rs.20
Operating costs/pair for Land fillers	Rs.10
Operating costs/pair for Footwear Brand Resellers	Rs.30
Transportation cost per kilometre/pair	Rs.1.00
un-utilized capacity costs for Manufacturer 1/ pair	Rs.220
un-utilized capacity costs for Manufacturer 2/ pair	Rs.230
un-utilized capacity costs for Manufacturer 3/ pair	Rs.250
un-utilized capacity costs for Re-Manufacturer 1/ pair	Rs.120
un-utilized capacity costs for Re-Manufacturer 2/ pair	Rs.130
un-utilized capacity costs for Re-Manufacturer 3/ pair	Rs.150

Steps of Hybrid Genetic Algorithms

The various steps implemented sequentially to develop the best hybrid genetic algorithm (HGA4) are furnished as follows.

***Step* 1**: Input the following;

Number of stages = 11 (Footwear Manufacturers, Footwear Brand Dealers, Footwear Brand Retailers, First Customers, Repair Centers, Collector/Dismantler/Re-furbisher, Recycler, Land filler, Footwear Remanufacturers, Footwear Brand Resellers and Second Customers).

Maximum number of units/nodes in each stage from first to last stage (*i.e.* 3, 3, 3, 6, 2, 2, 2, 2, 3, 2 and 3, respectively) as genes of the chromosome.

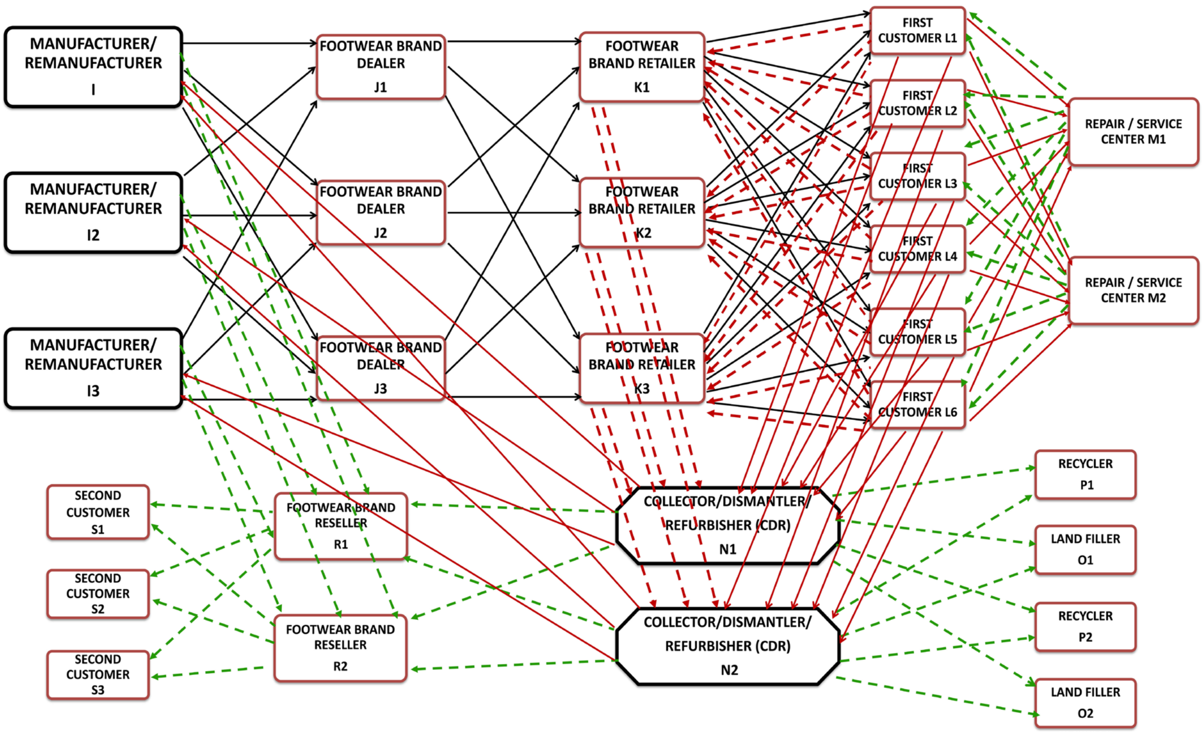

Figure 2. Shipment flows in CLSCND model for the footwear industry case study.

Maximum number of successive populations to be generated (N) = 50.

Maximum number of Chromosomes in each population—population size (L) = 100.

The Generation Count, GC = 1.

***Step* 2**: Apply the binary encoding method for the chromosomes to decide on the status (open or close) of the genes (units) in the Chromosomes.

***Step* 3**: Generate a random initial population of L chromosomes (suitable solutions for the problem). Let it be a larger population, L = 100.

***Step* 4**: Evaluate the Fitness function f(x) of each chromosome in the initial population L. The fitness function is as used in the mathematical model proposed in this research work, which is as given below.

Fitness Function Value (FFV) = OPC + OPRC + UCC + TC, where OPC = Opening Cost, OPRC = Operation Cost, UCC = Un-utilized Capacity Cost and TC = Transportation cost. (The Transshipment Algorithm, which is a combination of VAM method and U-V method, is incorporated to evaluate the transshipment cost of the fitness function).

***Step* 5**: Sort the population L by the objective function (fitness function) value in the ascending order, because it is a minimization problem.

***Step* 6**: Apply Elite Count (say top 2) and Rank selection. Select a given percentage (say 30%) from the top of the larger population L leaving the elite count, to form a sub-population S.

***Step* 7**: Randomly pickup any two unselected parent chromosomes from the sub-population S. Let them be the parents x and y.

***Step* 8**: Perform the crossover of the parents x and y to form their two new offspring x_1 and y_1 (Uniform crossover method is applied to form hybrid genetic algorithm, HGA4).

***Step* 9**: Perform the mutation of each of the offspring x_1 and y_1 for a mutation probability P_m (say $P_m = 0.06$).

***Step* 10**: Evaluate the fitness function value of each of the offspring x_1 and y_1. (The Transshipment Algorithm, which is a combination of VAM and U-V algorithms, is incorporated in the fitness function to evaluate the transshipment cost of the fitness function).

***Step* 11**: Replace the parent chromosomes x and y along with their fitness function values in the larger population L with offspring x_1 and y1 along with their fitness function values, respectively. (Here, weak parent replacement method is applied to form hybrid genetic algorithm, HGA4).

***Step* 12**: Repeat Step 7 to Step 11 until all the chromosomes in the sub-population S are selected to create offspring.

***Step* 13**: Increase the Generation Count (GC) by 1, *i.e.* GC = GC + 1.

***Step* 14**: If GC ≤ N, then go to Step 5, else go to Step 15.

***Step* 15**: Identify the chromosome in the larger population L, which has the best fitness function value and print the corresponding results.

***Step* 16**: Stop.

On implementation, the best hybrid genetic algorithm(HGA4) is found to be very efficient in providing the solution in terms of processing time and it provided the optimized solution value of 0.6970369E+08 in just few seconds. The optimized flows of the solution thus obtained for the design of the closed loop supply chain network is illustrated in **Figure 4**. The configuration of the HGA4 applied for this industry case study is given in Appendix II.

5.6. Summary of Results

In this section, the integrated foreword supply chain and reverse supply chains in the closed loop supply chain

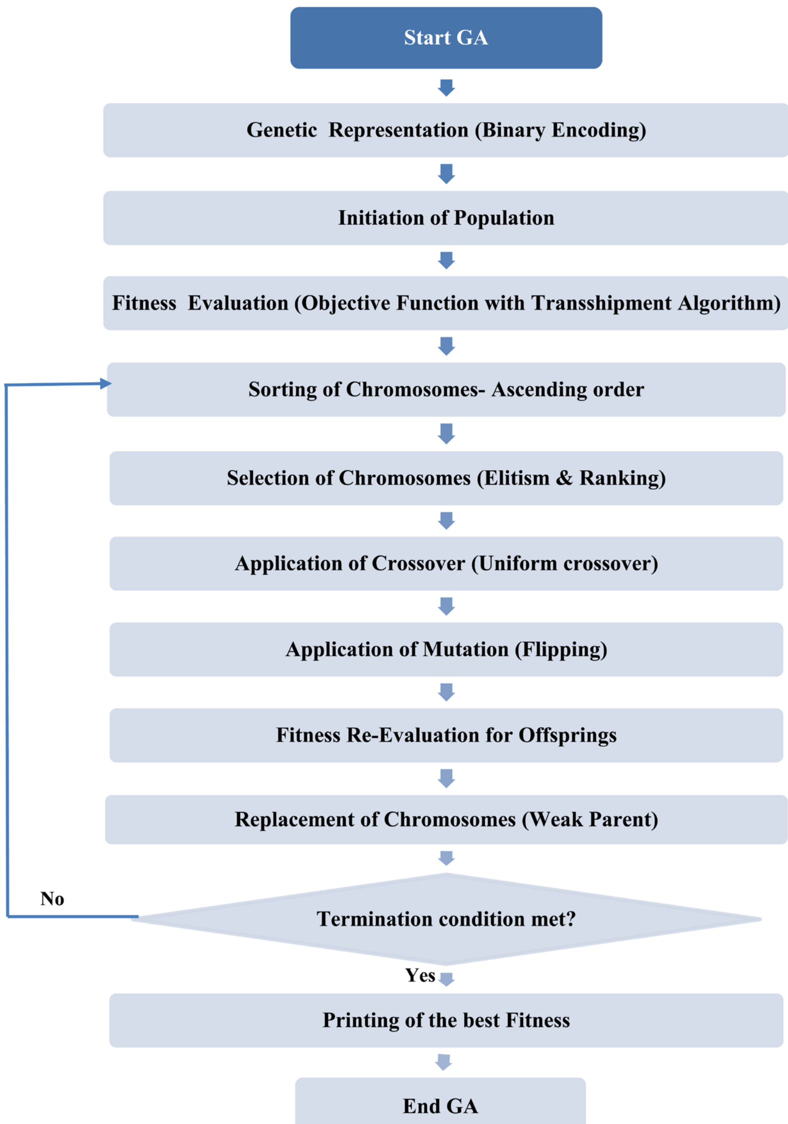

Figure 3. Process flowchart of the best hybrid genetic algorithms (HGA4).

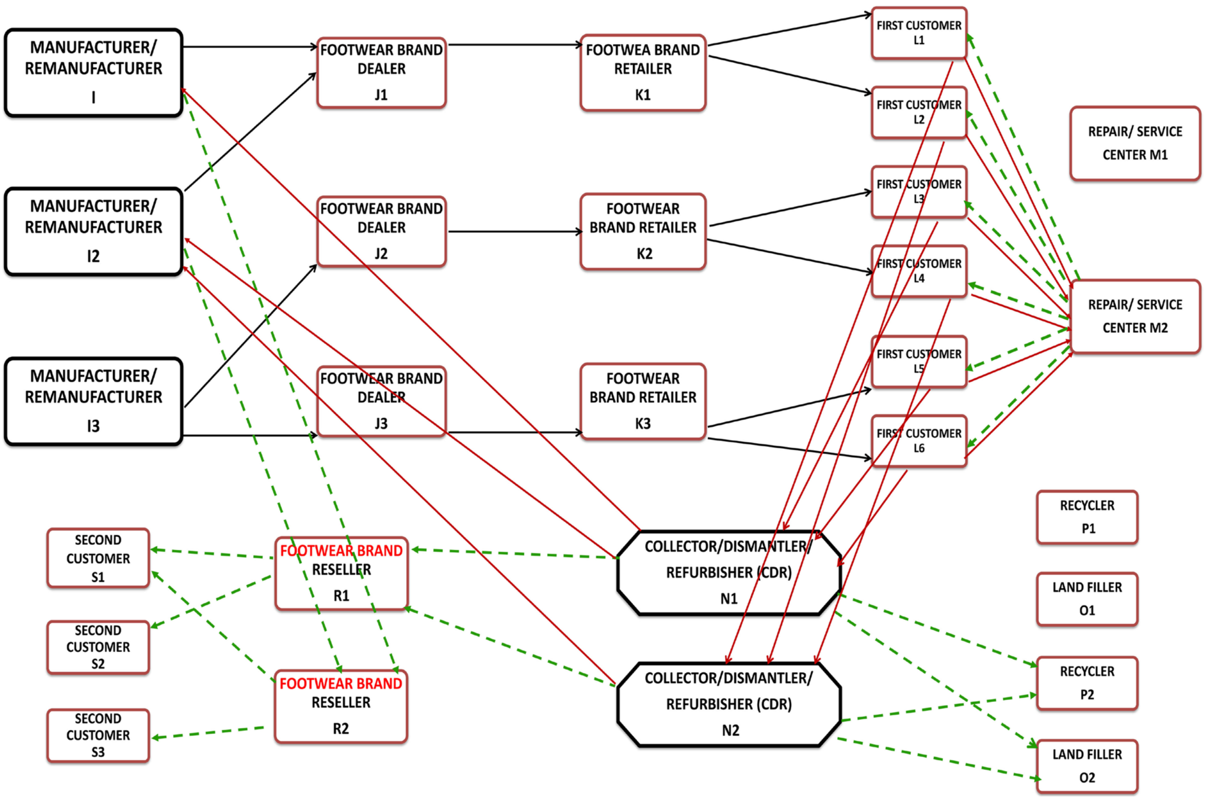

Figure 4. Optimized shipment flows in CLSCND model for the footwear industry case study.

network design of the Footwear Industry case is considered with the objective of minimizing the total costs of the entire supply chain distribution network. The MINLP model has been developed for the footwear industry case study and an attempt has been made to solve it using LINGO15 software. But it was observed that even after several hours of execution, this model did not give the final solution. Hence, the CLSC network design problem of footwear industry case was solved using HGA4 and the optimized solution with the corresponding optimized shipment pattern for the supply chain network design problem has been obtained and presented.

6. Conclusion

In this research work, the closed loop network design problem of fashion product industry case study *i.e.* case of a Footwear Industry is considered. In the implementation of the methods to solve the CLSC network design problem of the industry case study, first the mixed integer programming model has been applied to check whether the optimum solution could be obtained in reasonable time using LINGO 15. It was found that even after several hours of execution, the Lingo 15 software did not give the final solution for the closed loop supply chain network design problem. So, in the next stage, the case study problem has been solved using the best hybrid genetic algorithm (HGA4) developed for this purpose which provided the solution in just few seconds. The results obtained proved that, since the mathematical model could not provide the optimal solution in a reasonable period of time, the solution obtained by the implementation of the best hybrid genetic algorithm *i.e.* HGA4 has been assumed to be an optimal solution in terms of minimizing the total cost of the closed loop supply chain network problem of the fashion footwear industry.

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Appendix 1: Tables of Distance between Different Pairs of Facilities/Nodes and Customers in Kilometers, Used in Mathematical Model and HGA of Footwear Industry Case Study

Table A1. Distance between manufacturers (I) and footwear brand dealers (J) D1.

	Footwear Brand Dealer J1	Footwear Brand Dealer J2	Footwear Brand Dealer J3
Manufacturer I1	7	16	25
Manufacturer I2	12	2	16
Manufacturer I3	37	29	13

Table A2. Distance between footwear brand dealers (J) and footwear brand retailers (K) D2.

	Footwear Brand Retailer K1	Footwear Brand Retailer K2	Footwear Brand Retailer K3
Footwear Brand Dealer J1	9	15	21
Footwear Brand Dealer J2	4	7	13
Footwear Brand Dealer J3	21	22	6

Table A3. Distance between footwear brand retailers (K) and first customers FC (L) D3.

	FC L1	FC L2	FC L3	FC L4	FC L5	FC L6
Footwear Brand Retailer K1	5	5	10	8	15	25
Footwear Brand Retailer K2	13	6	7	5	14	22
Footwear Brand Retailer K3	16	18	12	21	3	8

Table A4. Distance between first customers FC (L) and repair centers (M) D4 = D5.

	FC L1	FC L2	FC L3	FC L4	FC L5	FC L6
Repair Center M1	5	4	13	6	17	27
Repair Center M2	6	7	8	10	10	20

Table A5. Distance between first customers FC (L) and collectors /dismantlers/re-furbishers CDR (N)D6.

	FC L1	FC L2	FC L3	FC L4	FC L5	FC L6
CDR N1	6	5	11	9	16	25
CDR N2	6	7	8	10	10	20

Table A6. Distance between first customers FC (L) and footwear brand retailers (K) D7.

	FC L1	FC L2	FC L3	FC L4	FC L5	FC L6
Footwear Brand Retailer K1	5	5	10	8	15	25
Footwear Brand Retailer K2	13	6	7	5	14	22
Footwear Brand Retailer K3	16	18	12	21	3	8

Table A7. Distance between footwear brand retailers (K) and collectors/dismantlers/re-furbishers CDR (N) D8.

	Footwear Brand Retailer K1	Footwear Brand Retailer K2	Footwear Brand Retailer K3
CDR N1	2	9	17
CDR N2	7	6	12

Table A8. Distance between collectors/dismantlers/re-furbishers CDR (N) and land fillers (O) D9.

	Land Filler O1	Land Filler O2
CDR N1	16	12
CDR N2	19	11

Table A9. Distance between collectors/dismantlers/re-furbishers CDR (N) and recycler (P) D10.

	Recycler P1	Recycler P2
CDR N1	13	12
CDR N2	18	11

Table A10. Distance between collectors/dismantlers/re-furbishers CDR (N) and footwear brand footwear brand resellers (R) D11.

	Footwear Brand Reseller R1	Footwear Brand Reseller R2
CDR N1	6	4
CDR N2	6	3

Table A11. Distance between collectors/dismantlers/re-furbishers CDR (N) and remanufacturers (I) D12.

	Remanufacturer I1	Remanufacturer I2	Remanufacturer I3
CDR N1	14	6	33
CDR N2	16	2	28

Table A12. Distance between remanufacturers (I) and footwear brand resellers (R) D13.

	Footwear Brand Reseller R1	Footwear Brand Reseller R2
Remanufacturer I1	11	16
Remanufacturer I2	7	3
Remanufacturer I3	37	29

Table A13. Distance between footwear brand resellers(R) and second customers SC (S) D14.

	SC S1	SC S2	SC S3
Footwear Brand Reseller R1	7	8	13
Footwear Brand Reseller R2	11	12	10