Green Logistics Network Design: A Critical Review

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Abstract
This paper critically reviews research conducted from 1999-2013 on Green Logistics Network Design (GrLND). Basic features like decision variables, network structure, type of optimization techniques preferred, components of objective functions considered across various industries to improve their environmental performance has been identified. Finally, potential gaps for future studies are highlighted.

Keywords: Green Logistics Network Design, Literature Review

Introduction
Logistics network design decisions are considered to be strategic in nature and address the locations, numbers, and capacities of required facilities in a network as well as aggregate material flow between them. Most of the network design mathematical models have been constructed based on the facility location theory and applied extensively on the forward supply chain in the past decade (refer to Melo et al. 2009 for review on facility location model). With an increasing environmental concern, resource reduction, depletion of landfill capacity, strict government regulations and the global pressure on issues leading to climate change; many companies have started adopting the practice of using product recovery for various purposes. Consequently, the focus has shifted towards greening the supply chain through an environmentally friendly logistics network design. Henceforth, in the present review such network is referred to as *"Green Logistics Network Design (GrLND)"*.

The GrLND primarily consists of all the network design issues which benefits the environment, and consist of reverse logistics network as well as closed loop supply chain networks. The consolidation of literatures developed in GrLND issues is an important step towards the broader adoption and development of sustainability which concerns not only the economic aspect but also the ecology as well as the societal aspects. Majority of the network design models in GrLND are concerned with the single objective, hence present review attempts to explore the following with the same: (i) the recovery option predominantly studied in the past, (ii) application's of the study in the past (case vs non-case specific), (iii) understand the complexity of network structure studied in GrLND highlighting the optimization models used with performance measures along with its components.

The paper is organized as follows: section 2 describes the methodology used to collect and analyze the literature; Section 3 provides details of the basic issues that were identified and studied in the literature on strategic planning of GrLND. Concluding remarks are provided in section 4, along with an agenda for future research.

Review methodology

The search for the literature was confined to research papers published during the years 1999-2013 on Green Logistics Network Design issues with single objective function. The keyword search methodology was used to collate articles on the above issues published in the peer-reviewed journals available in online databases of Proquest, EBSCO, Emerald and ScienceDirect. Some of the keywords used to collect articles were Green networks, reverse logistics network, closed loop supply chain network, single objective network models, facility location decision etc. Also, published/unpublished conference papers and lectures have been excluded from the present review. With the scope of the study in mind we identified 120 articles that were published during the identified period dealing with the facility location and network design issues. As our study was concentrating in GrLND models hence further filtration on reverse logistics network and closed loop supply chain network was performed to finally get 36 articles for our study distributed over 16 Journals.

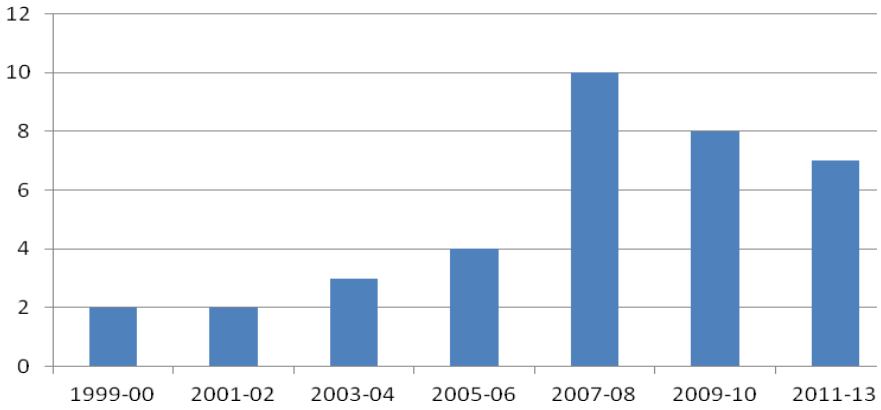


Figure 1: Progress of Literature of GrLND from 1999-2013

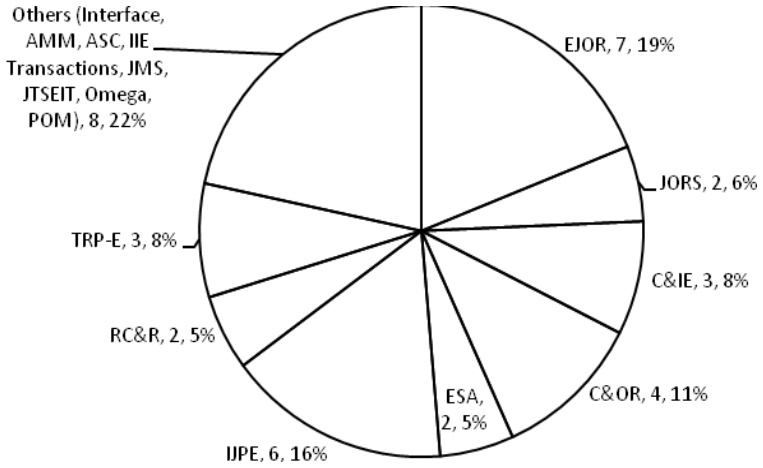


Figure 2: Journals Publishing Single Objective Literature of GrLND from 1999-2013
(Note: The details of abbreviation is provided in the reference section)

It is observed from Figure 1 that the research on GrLND issue has gained momentum on that past 5 years (with a special issues dedicated to reverse logistics in Computers & Operations Research Journal in 2007). Figure 2 highlights the degree of importance on publishing GrLND issues by a given journal through representation of the studies in the respective journals from 1999 onwards. It can be observed that European Journal of Operations Research (EJOR) and International Journal of Production Economics (IJPE) have published on GrLND. These two figures would motivate future researchers to work on GrLND issue and appropriately targeting the research journals for potential publications in the field. For a holistic review, a content analysis of the literature has been carried out across specific categories, in order to understand and gather interesting insights about the nature of research between the years 1999-2013.

Strategic Planning of GrLND

In this section we provide a blend of the existing literature in terms of important aspects and decisions that should be included in the GrLND models to assist in an improved decision making.

Recovery options in GrLND

Table 1: Recovery Option in GrLND

GrLN Activities	Recovery Option	Study performed
RECOVERY	Reuse	Shih (2001), Arasa and Asken (2008), Pishvaee et al. (2011)
REPROCESSING	Repair	Ko and Evans (2007), Chouinard et al. (2008), Yongsheng and Wang (2008), Min and Ko (2008), Sayed at al. (2010), Dat et al. (2012)
	Refurbish	Min et al. (2006), Chouinard et al. (2008), Rivera and Ertel (2009),
	Remanufacture	Jayaraman et al. (1999), Fleischmann (2001), Jayaraman et al. (2003), Salema et al. (2006), Listes (2007), Lu and Bostel (2007), Salema et al. (2007), Yongsheng and Wang (2008), Lee et al. (2009), Sayed at al. (2010), Salema et al. (2010), Paksoy et al. (2011), Sibel et al. (2012), Das and Chowdhury (2012)
	Cannibalization	
	Recycling	Louwers et al. (1999), Fleischmann (2001), Schultmann et al. (2003), Realff et al. (2004), Listes and Dekker (2005), Pati et al. (2006), Sayed at al. (2010), Kara and Onut (2010), Paksoy et al. (2011), Kannan et al. (2012), Sibel et al. (2012), Dat et al. (2012), Subramanian et al. (2013)
	Generic papers on reprocessing	Lieckens and Vandaele (2007), Lee and Dong (2008), Pishvaee et al. (2009), Lee and Dong (2009), Lee et al. (2010),
DISPOSAL	Incineration & Landfill	Shih (2001), Jayaraman et al. (2003), Listes and Dekker (2005), Arasa et al. (2008), Chouinard et al. (2008), Sayed at al. (2010), Kara and Onut (2010), Pishvaee et al. (2011), Paksoy et al. (2011), Kannan et al. (2012), Dat et al. (2012), Subramanian et al. (2013)

There are four main processes involved in reverse logistics. First there is collection, next there is the combined inspection / selection /sorting process, thirdly there is re-processing or direct recovery and finally there is redistribution. Collection refers to bringing the products from the customer to a point of recovery. At this point the products are inspected, i.e. their quality is assessed and a decision is made on the type of recovery. Direct recovery embraces re-use, re-sale and re-distribution. Reprocessing includes the following options: repair, refurbishing,

remanufacturing, retrieval (cannibalization), recycling and incineration or landfill. Finally, redistribution is the process of bringing the recovered goods to new users. The condition of returned products determines the nature of reprocessing to be performed on them.

Table1 provides us an insight of the recovery options being researched in the period of our study on GrLND issues. It may be noted that a particular study may be a part of multiple recovery option, indication the article consider multiple reprocessing on the GrLND model (e.g. Jayaraman et al. 2003). It could be observed that most of the studies have been performed for remanufacturing and recycling reprocessing along with disposal (either landfill or incineration) options. No study could be found in the redistribution and resale option at the product recovery stage. Also no study was found for the cannibalization reprocessing option. Future studies in this field may significantly reduce the burden of disposal and improve the quality of products available to the market. For example, if a pharmaceutical drug is not being used by a given population because of less diseases infection in a particular year, we can design a GrLND model to retrieve the products pre-expiry for redistribution/resale in alternate market of need without compromising the quality of the drug. This would lead to sustainable operation as it benefits society, minimizes disposal and hence the cost to operations.

Network Structure and basic features of GrLND

Table 2: GrLND Decision in various articles collated from 1999-2013

GrLND Decisions	**Literatures covering the Decisions**	**% of Studies**
Flow Quantity & Facility Location	Jayaraman et al. (2003), Listes and Dekker (2005), Salema et al. (2007), Rivera and Ertel (2009), Salema et al. (2010), Schultmann et al. (2003), Jayaraman et al. (1999), Salema et al. (2006), Pishvaee et al. (2011), Subramanian et al. (2013), Lee et al. (2009), Louwers et al. (1999), Ko and Evans (2007), Listes (2007), Lu and Bostel (2007), Kara and Onut (2010), Dat et al. (2012), Chouinard et al. (2008), Min and Ko (2008), Lee et al. (2010), Das and Chowdhury (2012), Pishvaee et al. (2009), Yongsheng and Wang (2008), Min et al. (2006), Fleischmann (2001), Shih (2001), Kannan et al. (2012), Lee and Dong (2008), Lee and Dong (2009), Pati et al. (2006)	83.3
Flow Quantity	Paksoy et al. (2011)	2.8
Flow Quantity, Facility Location & Inventory at each period	Sibel et al. (2012), Sayed at al. (2010), Lieckens and Vandaele (2007), Realff et al. (2004)	11.1
Facility Location & Optimal Incentive Value	Arasa et al. (2008)	2.8

Supply chain network decisions are typically of strategic nature being capital intensive and the decisions lasts for a long period of time. The inclusion of reverse logistics or closed loop activities further add to the uncertainty associated with the network. Hence, proper understanding of the GrLND becomes much more important in the present context. Table 2 classifies the literature according to some typical network design decisions observed in the literatures identified in the study period. It could be observed that about 83% of the model developed was

with an objective to identify the facility locations and respective flow quantities between them (a typical decision of any facility allocation problem). In addition to this around 11% of the models also included the decision of identifying the inventory at each period in the optimal solution. The success of sustainability through GrLND is incomplete without taking the contextual factors (e.g. mode of reverse logistics, timing of collection, differential quality of returned products etc.) into account while developing a model. Hence, future researcher may also include the decision variables in the model which can take the factors into account.

Table 3: Green Logistics Network Structure featuring number of product; the nature of planning horizon (single/ multiple periods) and type of data (deterministic / stochastic)

		Deterministic Model	**Stochastic Model**
Single Product	**Single period**	Louwers et al. (1999), Fleischmann (2001), Shih (2001), Schultmann et al. (2003), Jayaraman et al. (2003), Min et al. (2006), Lieckens and Vandaele (2007), Lu and Bostel (2007), Yongsheng and Wang (2008), Lee and Dong (2008), Rivera and Ertel (2009), Pishvaee et al. (2011),Paksoy et al. (2011), Kannan et al. (2012)	Listes and Dekker (2005), Listes (2007), Arasa et al. (2008), Chouinard et al. (2008), Pishvaee et al. (2009), Kara and Onut (2010), Lee et al. (2010), Subramanian et al. (2013)
	Multiple Period		Sayed at al. (2010)
Multiple Product	**Single period**	Jayaraman et al. (1999), Salema et al. (2006), Pati et al. (2006), Lee et al. (2009), Salema et al. (2010), Dat et al. (2012), Das and Chowdhury (2012)	Salema et al. (2007), Lee and Dong (2009)
	Multiple Period	Realff et al. (2004), Min and Ko (2008), Sibel et al. (2012)	Ko and Evans (2007)

Complexity of the GrLND also increases with variety of products (single/multiple) for which the GrLND is being planned. Network structure decisions last for a long period of time, hence, the decision makers should check the lifecycle of the product (rate of technological advancement), period of utility of the product (i.e. expiry dates) etc. These inputs would help in deciding whether the model developed should be developed as single period or multiple periods. Finally, the degree of uncertainty associated with product return's as well as quality of return's force the researchers/practitioners to develop deterministic/stochastic models. In Table 3, surveyed literatures have been classified according to these aspects. It can be seen that the most of the literatures developed over the years are single period problems in GrLND (86%) within which models on single products are 70% (approximately). Deterministic models have been extensively used to solve the problems (67%) with most of them being single period models. Hence, future research may concentrate on the multiple products and multiple period environments in both deterministic and stochastic environment.

Optimization model and its components for GrLND

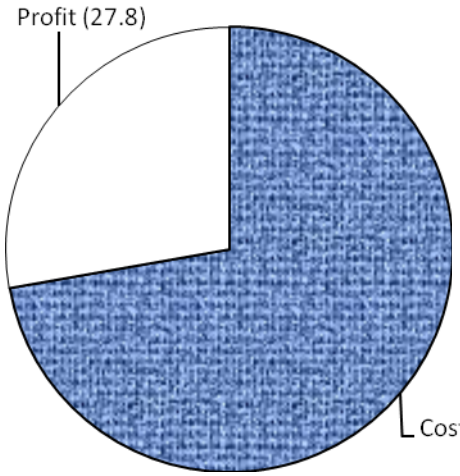
The sections attempts to understand the GrLND performance measures that have been used in the literature along with the methodologies to solve these problems. The performance measure have also been divided into various categories of costs/revenue to understand the common

parameters considered and those that should be considered in GrLND. Finally, applications of the GrLND models on various industries studied have been identified for academician's/practitioner's reference for future studies.

Table 4: Optimization models used for GrLND studied

Network Design Models Used	**Literatures**	**Total % of paper**
Network Optimization using MILP	Jayaraman et al. (1999), Shih (2001), Fleischmann (2001), Jayaraman et al. (2003), Schultmann et al. (2003), Realff et al. (2004), Salema et al. (2006), Pati et al. (2006), Lu and Bostel (2007), Salema et al. (2007), Yongsheng and Wang (2008), Pishvaee et al. (2009), Rivera and Ertel (2009), Lee et al. (2009), Lee et al. (2010), Salema et al. (2010), Pishvaee et al. (2011), Kannan et al. (2012), Sibel et al. (2012), Dat et al. (2012), Das and Chowdhury (2012)	58.3
Network Optimization using MINLP	Min et al. (2006), Lieckens and Vandaele (2007), Ko and Evans (2007), Arasa et al. (2008), Min and Ko (2008)	13.9
Network Optimization Using other techniques	Louwers et al. (1999), Listes and Dekker (2005), Listes (2007), Chouinard et al. (2008), Lee and Dong (2008), Lee and Dong (2009), Sayed at al. (2010), Kara and Onut (2010), Paksoy et al. (2011), Subramanian et al. (2013)	27.8

Realff et al. (2004), Listes and Dekker (2005), Lieckens and Vandaele (2007), Listes (2007), Arasa et al. (2008), Sayed at al. (2010), Kara and Onut (2010), Lee et al. (2010), Sibel et al. (2012), Das and Chowdhury (2012)



Louwers et al. (1999), Jayaraman et al. (1999), Shih (2001), Fleischmann (2001), Jayaraman et al. (2003), Schultmann et al. (2003), Min et al. (2006), Salema et al. (2006), Pati et al. (2006), Ko and Evans (2007), Lu and Bostel (2007), Salema et al. (2007), Chouinard et al. (2008), Yongsheng and Wang (2008), Lee and Dong (2008), Min and Ko (2008), Pishvaee et al. (2009), Rivera and Ertel (2009), Lee and Dong (2009), Lee et al. (2009), Salema et al. (2010), Pishvaee et al. (2011), Paksoy et al. (2011), Kannan et al. (2012), Dat et al. (2012), Subramanian et al. (2013)

Figure 3: GrLND Performance measure of the model (i.e. Objective function)

As in the case with forward supply chain and other facility location models it could be seen that from Table 4 that majority of the studies (58%) used Mixed Integer Linear Programming (MILP) model, mainly because of their attempt to have identify facility location and flow quantity decision (refer Table 2). Figure 3 indicates that most of the optimization models formulated in the literature mainly focus on cost minimization (approximately 72%) as

their GrLND performance measure. This observation is surprising as majority of the business are assumed to be profit oriented. The increased uncertainty associated with GrLND structure compared to the forward supply chain generally motivates the entrepreneur not to participate in any activity in reverse logistics or closed loop supply chain voluntarily. Hence, future models should ideally be developed for GrLND with "Profit" as the objective function considering various cost as well as the revenue (both sales revenue as well as positive opportunity costs) to have a positive impact on the practitioner (although mathematically both may lead to exactly same decisions).

Table 5: Components of Objective function in the GrLND models

	Network			Objective		Components of objective function												
Manuscript	RSC	CLSC	Recovery option	cost min	Profit max	Fixed cost	PR cost	Env. Cost	TPT cost	IC cost	Brand cost	SRT/PEN cost	Coll. Cost	Sorting cost	PUR/MAT cost	Disposal cost	Revenue from returned product	Quality Cost
Louwers et al. (1999)	Y		Recycle	Y			Y		Y	Y					Y	Y		
Jayaraman et al. (1999)	Y		Remanufacture	Y		Y	Y		Y	Y								
Shih (2001)	Y		Reuse & Disposal	Y		Y	Y		Y							Y	Y	
Fleischmann (2001)		Y	Remanufacture / Recycle	Y		Y	Y		Y	Y		Y				Y		
Jayaraman et al. (2003)	Y		Remanufacture / Disposal	Y		Y			Y									
Schultmann et al. (2003)	Y		Recycle	Y		Y	Y		Y					Y				
Realff et al. (2004)	Y		Recycle		Y	Y	Y		Y	Y			Y				Y	
Listes and Dekker (2005)	Y		Recycle / Disposal		Y	Y	Y		Y								Y	
Min et al. (2006)	Y		Reburbish	Y		Y	Y		Y	Y								
Salema et al. (2006)		Y	Remanufacture	Y		Y			Y			Y						
Pati et al. (2006)		Y	Recycle	Y		Y	Y	Y	Y	Y		Y	Y	Y		Y		Y
Lieckens and Vandaele (2007)	Y		Reprocess		Y	Y	Y					Y				Y	Y	
Ko and Evans (2007)		Y	Repair	Y		Y			Y									
Listes (2007)		Y	Remanufacture		Y	Y	Y		Y			Y		Y		Y	Y	
Lu and Bostel (2007)		Y	Remanufacture	Y		Y	Y		Y							Y		
Salema et al. (2007)		Y	Remanufacture	Y		Y	Y		Y									
Arasa et al. (2008)	Y		Reuse / Disposal		Y								Y				Y	
Chouinard et al. (2008)		Y	Repair/ refurbish / Disposal	Y		Y	Y		Y	Y					Y			
Yongsheng and Wang (2008)	Y		Repair/ Remanufacture	Y		Y	Y		Y	Y		Y	Y					
Lee and Dong (2008)		Y	Reprocessing	Y		Y	Y		Y				Y					
Min and Ko (2008)	Y		Repair	Y		Y	Y		Y									
Pishvaee et al. (2009)		Y	Recover	Y		Y	Y		Y			Y						
Rivera and Ertel (2009)	Y		Refurbish	Y		Y			Y									
Lee and Dong (2009)		Y	Reprocess	Y		Y	Y		Y									
Lee et al. (2009)	Y		Remanufacture	Y		Y	Y											
Sayed at al. (2010)		Y	Repair/Remanufacture/Recycle / Disposal		Y	Y	Y		Y	Y		Y	Y	Y	Y	Y	Y	
Kara and Onut (2010)	Y		Recycle/Disposal		Y	Y	Y	Y	Y				Y	Y			Y	
Lee et al. (2010)		Y	Reprocessing		Y	Y	Y		Y									
Salema et al. (2010)		Y	Remanufacuring	Y		Y	Y		Y			Y				Y		
Pishvaee et al. (2011)		Y	Reuse / Disposal	Y		Y			Y									
Paksoy et al. (2011)		Y	Recycle/Remanufacture/Disposal	Y				Y	Y					Y			Y	
Kannan et al. (2012)	Y		Recycle/ Disposal	Y		Y		Y	Y				Y			Y		
Sibel et al. (2012)	Y		Remanufacture/ Recycle		Y	Y	Y		Y	Y					Y		Y	
Dat et al. (2012)	Y		Repair/Recycle/ Disposal	Y		Y	Y		Y				Y			Y	Y	
Das and Chowdhury (2012)		Y	Remanufacture		Y	Y	Y		Y				Y		Y		Y	
Subramanian et al. (2013)		Y	Recycle/ Disposal	Y		Y	Y		Y						Y			
			% of manuscript	72.2	27.8	91.7	77.8	11.1	91.7	27.8	0.0	25.0	27.8	16.7	16.7	30.6	33.3	2.8

Note: The abbreviation used in table 4 has the following meaning: PR (Processing), Env. (Environment), TPT (Transportation), IC (Inventory carrying), SRT/PEN (Shortage/Penalty), RSC (Reverse Supply Chain), CLSC (Closed Loop Supply Chain)

In addition to these, Table 5 clearly indicates that most of the model available in GrLND considered mainly the three cost components i.e. fixed cost (92%), processing cost (78%) and

transportation cost (92%). Around 30% of the models also considered one or combinations of inventory carrying cost/ disposal cost/penalty cost/ collection cost or revenue generated due to green practices through sale of reprocessed goods. Limited number of studies only considered the environmental cost (11%), cost of quality (2.8%), impact on brand (an opportunity cost no literature consider this). These are some of the important components an organization cannot forgo while claiming to have a sustainable operation by claiming to have green practices in the logistics network design through recovery options.

Table 6: Application of GrLND in various industries (case study) or general (using Numerical)

Industry Specific/ General studies	**Literatures**
Electrical and Electronics Items (Washing M/c, office equipment, copier, Electronic electrical Appliances, computers)	Lee and Dong (2008), Salema et al. (2006), Fleischmann (2001), Shih (2001), Salema et al. (2007), Sibel et al. (2012), Subramanian et al. (2013),
Paper Recycling	Fleischmann (2001), Pati et al. (2006), Kara and Onut (2010)
Plastic recycling	Kannan et al. (2012)
Sand recycling	Listes and Dekker (2005)
Carper recycling	Louwers et al. (1999), Realff et al. (2004)
Battery recycling	Schultmann et al. (2003)
End of Life Vehicles	Rivera and Ertel (2009)
Glass Recycling	Salema et al. (2010)
Non Industry (using numerical)	Jayaraman et al. (1999), Jayaraman et al. (2003), Lieckens and Vandaele (2007), Ko and Evans (2007), Listes (2007), Lu and Bostel (2007), Arasa et al. (2008), Chouinard et al. (2008), Yongsheng and Wang (2008), Min and Ko (2008), Pishvaee et al. (2009), Lee and Dong (2009), Lee et al. (2009), Sayed at al. (2010), Lee et al. (2010), Pishvaee et al. (2011), Paksoy et al. (2011), Das and Chowdhury (2012)

Finally, we Table 6 categories the papers based on models developed for given industry (explicitly addressing the application through a case study) or non-industry specific with the help of numerical taken hypothetical data/ multiple scenario's. It could be seen that most of the paper using cases are basically from either electrical or electronic industry where the legislations on product take back are very stringent in developed countries. There are few papers on recycling industry like paper, plastic, carpet, glass. Future research on pharmaceutical drugs redistribution (an important sector of the economy) should be conducted as it has a specific time period prior to expiry of the medicines (i.e. declared as not fit for consumption).

Conclusion

In this paper we have reviewed the most recent literatures (1999-2013) on Green Logistics Network Design (GrLND) and discussed the quantum of studies conducted on various recovery options to identify the areas which are unexplored like resale/ redistribution option. Moreover, we also identified decision variables used in modeling along with the elements of the network structure in a three frame of reference i.e. number of products, single/multi period and deterministic/stochastic models. The role of optimization models, performance measures of the

models, and components of the performance measures used was also analyzed. Finally, the applications of these models conducted on various industries were identified. It could be seen from various tables presented in the review that GrLND is at its nascent stage and many new researches in several directions can be carried. One such area is multi-period, multi-product deterministic as well as stochastic model with profit objective function especially in the case of time sensitive product returns like pharmaceutical drugs for resale/redistribution thus maintaining the original quality of the product. The objective function components of the GrLND could also consider the impact of quality, brand image (in terms of opportunity cost) and costs associated with environmental impacts of considering recovery, reprocessing as well as proper disposal as an option.

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