Literature Review

Review methodology

[35] Prescribed research methods to follow stages of question formulation, location of studies in literature, Evaluation out of these studies for the contribution with regard to narrowed down objective of a specific study, and ultimately, synthesis of the studies.

In this chapter, we zoom in and zoom out the research problem identified in chapter 1, from the point of view of literature search and analysis. We follow [35] and [36] proposed four-pronged survey of research problem: Context, Intervention, Mechanisms, and Outcome.

With a focus on our research problem, in this chapter, we begin with the context setting of reverse logistics and narrate how literature has addressed decision-making of reverse logistics problem characterized by multiple criteria and multiple alternatives. We further go on to how the problem is evaluated in the literature with regard to the alternatives using a multi-criteria decision-making method.

We further build on researchers’ presentation of one or more decision-makers (experts) opinion, based on different applications studied, to identify the relative importance of different alternatives, with a view to establish suited MCDM method and method to mathematically formulate, model and optimize the reverse logistics problem.

The literature has been searched through search engines like Scopus and Google Scholar through key words and strings relating to key entities associated with reverse logistics, like remanufacturing, recycle, reuse, recovery. Also strings like MCDM methods, techniques, mathematical formulation, etc. have been fed to search engines, institute libraries and research database repositories. The literature review has been done during year 2014 to 2016, and it largely ranges to relevant literature published between 2008 and 2015, for zeroing on to
analytical method for the multi-criteria decision making discourse, as a whole. We leave out present literature applied to other domains like medical and biology.


Context and pertinent literature

Recognition of logistics and supply chain as core to maintaining competitive edge dates back to 1980s, in literature. Still, industrial organizations have yet not been able to decompose key constructs of the supply chain in true essence. A lot of researchers have elaborated constructional definitions and conceptual frameworks of supply chain. It is well documented how supply chain management is considered a crucial business process improvement strategy, over a number of performance indicators.

While the forward or traditional logistics activity has received industrial organizations’ attention for streamlining and ensuring smooth flow of the products to the end customers through all years, in recent years, reverse logistic component of the supply chain has received a large chunk of researchers’ interest.

In this context, it is only fair to revisit the definition of reverse logistics: “Reverse logistics is the process of planning, implementing and controlling backward flows of raw materials, in process inventory, packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or point of proper disposal.” - European Working Group on Reverse Logistics, RevLog (1998) [37]

As per the RevLog’s definition, reverse logistics primarily targets to resurrect and retrieve economic and functional value of the product usage, and ultimately dispose-off the product or components that have reached end of life while safeguarding the environment.
This important consideration of value retrieval that distinguishes reverse logistics from conventional waste disposal management has been described as crucial in the literature. [10].

Table 2.1 below highlights some of the literature presented on broad domain of reverse logistics:

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Author</th>
<th>Key contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>[19]</td>
<td>discussed integrated forward/reverse logistics networks in their review on quantitative models for reverse logistics</td>
</tr>
<tr>
<td>2.</td>
<td>[38]</td>
<td>Surveyed that product manufacturers integrate their product returns’ management and reverse logistics network with their product distribution network</td>
</tr>
<tr>
<td>3.</td>
<td>[39] [40]</td>
<td>On premise of closed-loop supply chain, presented integrated logistics network that could typically have multi-layers and non-exclusive movements happening over multiple supply chains</td>
</tr>
<tr>
<td>4.</td>
<td>[41] [16]</td>
<td>Presented need of environmental focus and efforts to reduce or nullify the detrimental footprints of reverse logistics activities on the environment.</td>
</tr>
<tr>
<td>5.</td>
<td>[10]</td>
<td>Described green logistics as the term used to cover broader perspective of environment focus</td>
</tr>
<tr>
<td>6.</td>
<td>[42]</td>
<td>Described remanufacturing to be comprising of disassembly, replacement of components where necessary and assembly of a product to bring it back into as-good-as-new condition.</td>
</tr>
</tbody>
</table>

Reverse logistics constitutes more than one recovery options and product returns’ management methods associated with each. This variety of alternatives make reverse logistics network design more complicated as compared to forward logistics.

Researchers have looked to explore use of mathematical modeling to quantify and improve forward flow of logistics. Materials management, aggregate planning for resource management and scheduling of production process are the most influenced decisions with respect to logistics. Inventory management and production planning has been of particular interest of researchers, as they are the ones that influence logistics decision making. On reverse logistics front, however, owing to the complication in inventory control and production planning per se,
these models worked on premise of forward logistics doesn’t provide adequate decision making support. This has necessitated development of comprehensive solution modeling that is exclusive for variety of reverse logistics networks.

Further, since the crux of theory is value retrieval in reverse logistics, it stays clear of traditional waste management activities.

Following Table describes how literature has addressed three key issues of reverse logistics decisions: Quality of returned products, Remanufacturing for product recovery, and closed loop supply chain.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Author</th>
<th>Contribution</th>
</tr>
</thead>
</table>
| 1. | [43] | • Described scheduling and inventory control decisions relate to quality aspect of returns  
• Quality grading systems for reuse, repair and minor rework, remanufacturing for restoring the functional condition, recycling for material retrieval, and, ultimately, disposal. |
| 2. | [44] | Inspection for product returns for determination of recovery route |
| 3. | [45] | Finds that up to 40% of part price is reimbursed by Caterpillar to dealers which return parts and engines depending on their conditions |
| 4. | [46] | Summarized advantages of RM as  
a. labour, material and energy cost savings,  
b. reduced production lead-times,  
c. balanced production lines,  
d. new market opportunities, and  
e. Positive environmentally concerned corporate image. |
| 5. | [47] | Included landfill reduction, pollution reduction, and creation of new jobs and skills for product recovery |
| 6. | [48] | Described how federal taxation and abiding-laws helped in encouraging users and manufacturing organizations delay/reduce disposal of the product through reuse and remanufacturing. |
| 7. | [49] | discussed four characteristics that renders remanufacturing as a complex avenue for product recovery, namely,  
• Timing and volume of product returns,  
• Estimation of recovery percentage,  
• Syncing original manufacturing demand with that of remanufacturing demands and  
• Incorporating reverse logistics while estimating aggregate remanufacturing demand. |
| 8. | [50] | discussed “technology evolution, take-back ratio, and inventory holding costs as critical factors in the manufacturing/remanufacturing system. The primary goal of remanufacturing should be a product whose quality meets customers’ expectations and exceeds that of competitors’ products. |
8. [51] Categorized economic advantages and process improvement as key factors influencing remanufacturing decisions

9. [52] Have considered “economies of scale, transaction costs, coordination of needs, and tacit knowledge as the major factors affecting remanufacturing profitability

10. [53] Have studied the scenario where the manufacturer sells new and remanufactured product, wherein they have considered effects of remanufacturing unit costs, direct channel cost and customers’ preferences in a multi-agent supply chain.

11. [54] Identified three reasons for remanufacturing failures: 1) high set-up cost of establishing reverse logistics networks, 2) high cost of quality assurance, and 3) the fact that product was not designed for remanufacturing.

12. [55] Studied remanufacturing of modular products with substitution of low quality modules by high quality modules and found that when the customer demand rate and return rate were equal, the cost would be minimized. Also, substitution became more desirable as the quantity of low quality and high quality returns got closer.

13. [56] Have noted Germany-based automotive industry statistics

14. [57] Lack of significant technical, environmental and quality data to convince customers to undertake remanufacturing”.

**Closed Loop Supply chain**

15. [58] Described three options for product collection by the manufacturer

16. [59] have prescribed an algorithm for designing a reverse supply chain with five criteria for scheduling of recyclable products, namely: 1) material recovery revenue, 2) incoming product revenue, based on quantity and frequency of incoming products, 3) inventory space, 4) customer demand, based on material or recovered products that had high demand, and 5) material recovery revenue and inventory space which were a combination of 1) and 3).

17. [34] Developed a model to determine the most economical collecting centers and suggested that the distance of collection center from the customer, return processing time and costs, and return flow rates were key decision making parameters.

In later chapters, the present work demonstrates an optimization model for the mathematical formulation, by inputting real life values in terms of location and product transaction volumes and associated costs.

In the next section, we analyze literature based on multi-criteria decision making for reverse logistics network design.
Classification and analysis of literature on multi-criteria decision making for reverse logistics

Multi-criteria decision-making (MCDM) methods have been applied to various reverse logistics problems extensively by researchers. In order to develop a reliable knowledge base through accumulating knowledge from previous studies, we conduct a systematic review of the applications of different MCDM methods to different reverse logistics problems. We found about 80 relevant papers published in scientist journals, which are application of different MCDM methods to different reverse logistics problems.

We classify the literature based on two dimensions: problem context and methodology. The results show that recycling and AHP are the most researched problem and methodology respectively.

In the context of reverse logistics there are different decision-makers such as governmental bodies, buying companies and suppliers that are responsible for several decisions. One approach to formulate complex decisions is multi-criteria decision-making where a (or a group of) decision-maker(s) should evaluate a number of alternatives with respect to a set of decision criteria in order to select the (or a number of) best alternative(s). The methods which are used for this kind of decision-making problems called multi-criteria decision-making (MCDM) methods.

MCDM methods have been widely applied to many different areas, and we tabulate literature present in a summarized form in Table 2.3.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Author</th>
<th>Contextual contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>[60]</td>
<td>sustainable energy planning, review of more than 90 published papers to analyze the applicability of various MCDM methods</td>
</tr>
<tr>
<td></td>
<td>[61]</td>
<td>supplier evaluation and selection</td>
</tr>
<tr>
<td></td>
<td>[62]</td>
<td>financial decision-making</td>
</tr>
<tr>
<td></td>
<td>[63]</td>
<td>natural resource management</td>
</tr>
<tr>
<td></td>
<td>[64]</td>
<td>in construction</td>
</tr>
<tr>
<td></td>
<td>[65]</td>
<td>Supplier focused MCDM application: New supplier performance evaluation, in which a case study of integrated circuit (IC) packaging companies supplier performance was studied</td>
</tr>
<tr>
<td></td>
<td>[66]</td>
<td>Implementation of a supplier evaluation model using Analytical Hierarchical Process</td>
</tr>
</tbody>
</table>
a methodology of Supplier Quality Performance Assessment (SQPA) for industrial computer industry that introduces modified Importance-Performance Analysis (IPA) on supplier quality

on a framework and a suitable method for selecting the best logistics supplier

on a decision framework where analytic network process (ANP) integrated QFD and zero-one goal programming (ZOGP) models are used in order to determine the design requirements which are more effective in achieving a sustainable supply chain (SSC)

Quality Management Domain

On improvement of service quality among domestic airlines in Taiwan

On process conditions for the transfer molding of electronic packages

On a new AHP method for the expert evaluation of quality of learning scenarios

Production Management domain

Have presented work on prioritizing sustainable electricity production technologies using multi-criteria decision making method

multi-person selection of the best wind turbine based on the multi-criteria integrated additive-multiplicative utility function

dynamic schedule execution in an agent based holonic manufacturing system

aspired intelligent global manufacturing & logistics systems

Identification and modeling the links between machine tool alternatives and manufacturing strategy.

The next section describes work present in literature for the multi-Criteria decision making, confined to applications in reverse logistics.

**Methodology-based classification of multi-criteria decision making in literature base**

As documented by [65], [79], “Multi-criteria decision methods cover a wide range of quite distinct approaches”. [80] have suggested that more formalized decision making tools are being researched about owing to grown complexity of the networks. The last decades have intensified the interest in the application of formalized decision-analytical tools, due to the increased data availability to solve complexity of problems as well as the higher availability of data [80]. We find The available methods can be categorized into three schools [81] [82] [83] have discussed three approaches to solve the multi-criteria problems:

- Weight assignment and Value measurement models: A numerical score for each alternative is constructed. Furthermore, a weight w is assigned to each criterion, which represents the importance of the criterion (e.g., Weighted Sum Model, Analytic Hierarchy Process).

- Goal, aspiration and reference level models: These methods measure how good
alternatives reach determined goals or aspirations (e.g., TOPSIS).

- Outranking models: These methods compare the alternatives pairwise for each criterion, finding the strength of preferring one over the other (e.g., ELECTRE, PROMETHEE).

**AHP/ANP**

[84] Proposed multi-criteria decision making method Analytic hierarchy process (AHP), which compares the criteria to determine the preference amongst them. In AHP, multiple criteria present in the decision making is expressed as a hierarchy of levels of decisions/objectives. These levels could be principal criteria, followed by sub-criteria(s), and alternatives amongst the sub-criteria. AHP methodology pairs the alternatives by including weight assigned to each alternative in relation to its paired alternative, resulting in a matrix of comparison.

Literature dating back to as early as 1979 present application of various multi-criteria decision making methods that operates on weight-assignments to the alternatives, namely, the principal eigenvector technique [84], the weighted least square method (WLSM) [85], the logarithmic least square method (LLSM) or geometric mean method (GMM) [86], goal programming method (GPM) [87] [88]. Assigned weights to the alternatives are synthesized to return the alternative with highest weight, and therefore, preference.

[89] Had also proposed another methodology that addresses the non-hierarchical processes, and relate to feedback issues amongst the defined criteria, name Analytical Network Process (ANP).

To model randomness (fuzziness) in weight assignments and preference comparisons of alternatives, versions of different fuzzy AHP and ANP models are described in literature. As compared to normal AHP/ANP, the fuzzy variants employ qualitative (linguistic) yardsticks and fuzzy numbers to compare the criteria/alternatives. Fuzzy AHP [90], [91] [92] [93] and fuzzy ANP [94] have been described in literature, along with other methods.

This category, by far, has the most number of applications in this field. From the total literature studied [36] on multi-criteria decision making, an overwhelming 40% have adopted the AHP (including fuzzy AHP), and around 8% used ANP.
ELECTRE

Ror (1968) had proposed two indices: Concordance and discordance, “to find a kernel solution” for multi-criteria decision making using method ELECTRE (ELimination and Choice Expressing REality), that compares goodness of alternatives against each other. Also, the method relates and ranks alternatives by two indices, to determine the preference. Before this, a model named ELECTRE I was proposed to develop the kernel set that is used to compare the alternatives.

The model was further developed and improved later. [95] Proposed ELECTRE II that improved the decision making of the multiple criteria. Fuzziness quotient was added to further improve out rankings in ELECTRE III. [96] Presented ELECTRE IV that simplified earlier versions.

ELECTRE III extends the crisp outranking relations to fuzzy outranking relations, and ELECTRE IV [96] is an attempt to simplify ELECTRE III. [97], later, described different versions of the methods and improvements at each revisions.

However, in literature base thereafter, only two papers that addressed recycling decisions, and three addressing electronic waste management were found. This reflects relatively low adoption of this technique for solving multi-criteria problems.

PROMETHEE

[98] [99] referred to multi-criteria decision making method that had features of two methods discussed in earlier sub-sections, named PROMETHEE. For purpose of understanding the method integrities, we have referred to relatively recent work by [100]. In this method, multi-criteria and their pairwise comparisons are synthesized into a uni-criteria preference, and thereafter, criteria are compared by a degree of preference. Outranking of the alternatives is determined by the net difference in entering and leaving flows.

Going by the frequency of appearance in literature base, PROMETHEE has considerable presence, after AHP being distant largest. Most documented multi-criteria with applications that used PROMETHEE originate from waste management background. Of course, we exclude other hybrid methods (discussed in separate sub-section later) here.
TOPSIS/VIKOR

[101] introduced TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method, which was later improved by [102] and [103].

[103] Described that TOPSIS worked on premise of establishment of preference based on alternative’s closeness to the ideal solution. Fuzziness of relative performance of alternatives is addressed by another add-on: Fuzzy TOPSIS. As described by [103], “The performance rating used in TOPSIS which shows the performance of each alternative with respect to different criteria usually involves uncertainty, which has called for fuzzy TOPSIS”. [104] and [105] present applications of fuzzy TOPSIS methods.

VIKOR

[106] Came up with another tool for multi-criteria decision making. The method was similar to TOPSIS in a way that it also worked on premise of choosing preferred alternative based on closeness to ideal solution. The name VIKOR originated from Serbian word ViSeKriterijumska Optimizacija I Kompromisno Resenje, which is translated into English as Multicriteria Optimization and Compromise Solution, and pronounced as VIKOR. [107] Conducted a comparative study of TOPSIS and VIKOR with two examples. He described that “In VIKOR linear normalization and in TOPSIS vector normalization is used to eliminate the units of criterion functions. The VIKOR method of compromise ranking determines a compromise solution, providing a maximum “group utility” for the majority and a minimum of an individual regret for the opponent”.

Of late, the literature base finds that researchers use a combination of (fuzzy) AHP and (fuzzy) TOPSIS to solve multi-criteria problems, with preference for AHP for weight-assignments to criteria, whilst, TOPSIS for criteria rankings.

Literature classified by nature of reverse logistics activity

In this section, we segregate and tabulate different multi-criteria decision making methods as available in the literature, for different reverse logistics activity classification as recycle, reuse/remanufacture, Disassembly, waste management, and other uncommon reverse logistics activities.
Recycling

[108] Defined recycling as “the process of systematically collecting, sorting, decontaminating and returning of waste materials to commerce as commodities for use or exchange”. Going by a high percentage of papers relating to recycling, we can infer that it is the most researched reverse logistics activity. Most of the available work pertain to identifying sector-specific and product-specific technology for recycling, and the time frame thereof.

In recent years, [109], have presented work to examine the nutrient-recycling dilemma by analyzing the preferences of a group of residents in the city of Zurich for various management scenarios for recycling of anthropogenic nutrients from wastewater. They have used AHP for choosing the best management alternative. [110] [111] [112] [113] [114] have presented many studies focusing on determination of best strategy for recycle within the last decade or so. They presented their work on the premise of EU legislation restricting the use of hazardous substances in electrical and electronic equipment, named WEEE directive.

Remanufacturing and Reuse

As [115] describes, “Remanufacturing is the transformation of used units, consisting of components and parts, into units which satisfy exactly the same quality and other standards as new units”. In another work, [116] describe that “Reuse is the process of collecting used materials, products, or components from the field, and distributing or selling them as used”. No additional processing is done on the used products, materials or components.

In the recent years, [117] [118] have sought to determine best remanufacturing technology. [54] Have presented a remanufacturing decision-making framework (RDMF) and validated it for the automotive industry. They targeted the six parameters for remanufacturing: strategic product planning, design for remanufacturing, plant location, production systems, physical distribution, and cooperation among remanufacturing stakeholders.

[119] in their work based in China, introduces some basic concepts on automotive component remanufacturing in China and analyses its roles, and goes on to obtain main key technology factors influencing automotive component remanufacturing industry development in China. [120] have described Supply chain-based barriers for truck-engine remanufacturing in China.

Many researchers have investigated the influence of factors and/or barriers affecting remanufacturing processes. Other areas touched upon by researchers are: Assessment of re-
manufacturability or re-usability, and proper material selection for the purpose of remanufacturability or re-usability.

**Disassembly and Design**

Though not considered a direct and logical constituent of a typical reverse logistics activity, disassembly and design play a role in other key reverse logistics activity domains. In fact, many researchers [121] [122] [123] [124] [125] [126] have used multi-criteria decision making methods to determine best design of the product to maximize and ease their recyclability, remanufacturability or re-usability..

[127] have presented a Kano model, fuzzy-AHP, and M-TOPSIS-based technique, to successfully find the optimal order of component removal using AND/OR precedence relation. [128] presents a new multi-criteria decision making (MCDM) model and uncertainty analysis method for the environmentally conscious materials selection problem.

**Waste management**

[129] describe waste management activities as “all the activities including collection, transport, handling, treatment, material and energy recovery and disposal of waste”. Waste management is a very broad topic. In this paper we include the following topics: management of wastewater, WEEE, Construction & Demolition, industrial waste, hazardous, hospital, and used oil, and do not include management of ‘municipal solid waste’ and ‘nuclear/radioactive waste’.

[130] described multi-criteria decision analysis to tackle waste management problems. [131] presented application of multi-criteria decision analysis for solving municipal solid waste management problems with more focus on the studies that have considered multiple stakeholders and offers solutions for such problems. They infer that AHP is the most common approach in consideration of multiple stakeholders.

Earlier, [132] discussed framework for soil suitability evaluation for sewage effluent renovation.

**General**
Published literature addressing multi-criteria decision making and reverse logistics problems also feature some other categories of reverse logistics activities. They generally relate to more than one problem in reverse logistics.


[28] [136] have discussed about comprehensive performance measurement and causal-effect decision making model for reverse logistics enterprise. RL performance measurement is the topic of two papers. [137] have discussed selection of third-party logistics providers. [138] have described a robust hybrid multi-criteria decision making methodology for contractor evaluation and selection in third-party reverse logistics. [139] discuss outsourcing reverse logistics of high-tech manufacturing firms by using a systematic decision-making approach for TFT-LCD sector in Taiwan. Also, [27] presented a holistic approach for selecting a third-party reverse logistics provider in the presence of vagueness.

Literature presents most number of papers in this general categorization, because it can consider many domains in reverse logistics problem analysis. For a generic reverse logistics problem, it is always prudent to validate the problem solutions by hybrid methodology like AHP/TOPSIS and combine it with mathematical formulations.

**Other/Hybrid methodologies**

Over and above the discussed multi-criteria decision making methods, literature presents few other methods. As early as in 1974, [140] proposed a pairwise comparison method, named DEMATEL (Decision Making Trial and Evaluation Laboratory).

SAW (simple additive weighting) is another such method that uses a simple equation that is a multiproduct of the criteria weights by the alternative utilities with respect to the criteria method. This method was initially applied by [141].

[142] presented decision making technique called MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique), that qualitatively compares different criteria with
respect to their attractiveness. He discussed construction of cardinal value function using MACBETH.

More recently, [143] described best vendor selection for conducting the recycled material based on a hybrid decision making model, combining DANP with VIKOR. They solve the recycled materials vendor selection problems of multiple dimensions and criteria that are interdependent, instead of the independent assumption of an analytic hierarchy process.

[133] analyzed the drivers of end-of-life tire management using interpretive structural modeling (ISM). They proposed a framework to analyze the motivating factors of End-of-Life tire management, and validated with the assistance of a multi-criteria decision-making (MCDM) approach, in the Indian scenario. [144] presented an integrated qualitative and quantitative approach to the development of a balanced scorecard for a real life case of organic food Sector Company in India.

Table 2.4 below summarizes presented literature for different multi-criteria decision making techniques for different reverse logistics activities.

**TABLE 4**

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Recycling</th>
<th>Remanufacturing/ Reuse</th>
<th>Disassembly/ Design</th>
<th>Waste Manage.</th>
<th>General</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(fuzzy) AHP</strong></td>
<td>[111], [145], [109], [110], [128], [146], [102], [147], [148]</td>
<td>RM: [119], [54],[149], [118], [124]</td>
<td>[125], [124], [123], [122]</td>
<td>[151], [130], [152], [153]</td>
<td>[47], [154], [28], [155], [27], [86], [156]</td>
</tr>
<tr>
<td><strong>ANP</strong></td>
<td>[157]</td>
<td></td>
<td>[121]</td>
<td>[158]</td>
<td>[139], [159], [160]</td>
</tr>
<tr>
<td><strong>ELECTRE</strong></td>
<td>[161], [114]</td>
<td></td>
<td></td>
<td></td>
<td>([162], [114])</td>
</tr>
</tbody>
</table>

Tabulated classification indicates clear majority of use for AHP/Fuzzy AHP by the researchers, and that spans for all categories of reverse logistics activity.

Figure 2.1 displays number of publications during the year 2008 and 2014 on multi-criteria decision making for reverse logistics.

Table 2.5 displays numbers and percentage of applications of different multi-criteria
Summary of the multi-criteria decision making methods

Analytical Hierarchy Process (AHP): Developed by Saaty, AHP is one of the most used technique for complex decision-making problems. Designed to reflect the way people actually think, AHP continues to be the most highly regarded and accepted decision-making method. AHP can efficiently deal with tangible (i.e., objective) as well as non-tangible (i.e., subjective) attributes, especially where the subjective judgments of different individuals constitute an
important part of the decision process. [163] has discussed AHP decision making in Manufacturing Environment Using Graph Theory and Fuzzy Multi Attribute Decision Making Methods.

AHP is capable to represent many levels necessary to define the decision model that characterize the situation, by decomposing the decision-making problem into a system of hierarchies of objectives, attributes (or criteria), and alternatives.

Principal merits of the AHP lies in the flexibility it offers, and in its capability to comprehend inconsistencies. Also, since it adopts the geometric mean of alternative pairs, it leads to effective group decision making.

Demerit of AHP is substantial length of calculations for synthesis of pair-wise comparisons. Also, the point-scale sometimes lead to confusion in exactly determining weight of preference.

In the next section, we survey the literature presented for quantitative models used to solve reverse logistics network design problem.

**Quantitative Models for reverse logistics network**

Available literature presents many mathematical models that were used to solve reverse logistics network design problem. Operations research has been the most dominant optimization tool most researchers have opted for. [164], in their work on literature review on reverse logistics networks, infer that models presented after year 2000 till 2013 (in order of preference and use-frequency) include Mixed Integer Linear Programming (MILP) model, Mixed Integer Non-Linear Programming (MINLP) model, Mixed Integer Goal Programming (MIGP) model.

[165], in Proceedings of IEEE international engineering management conference presented a multi-objective and multi-period MILP model for reverse logistic network design for modularized products which determines the number of existing forward flow facilities to be used and the number of dedicated facilities to be setup for handling return flows. A mixed integer goal programming (MIGP) model was established to determine the facility location, route and flow of different varieties of recyclable wastepaper in the multi-item, multi-echelon and multi-facility environment.

[33] Presented an analysis to formulate a mixed integer goal programming (MIGP) model to
assist in proper management of the paper recycling logistics system. They studied the inter-
relationship between multiple objectives (with changing priorities) of a recycled paper
distribution network. They considered cost reduction, product quality improvement and
environmental benefits through increased wastepaper recovery as the objectives for their study.

[166] presented a structured reverse logistic network to collect end-of-life appliances. They
presented a simulation model of a reverse logistics network.

[167] have addressed the problem of determining the number and location of centralized return
centers. They proposed a nonlinear mixed-integer programming model and a genetic algorithm
to solve the reverse logistics return processing problem for on-line sales.

[168] presented a nonlinear integer program to solve the multi-echelon, multi commodity
closed loop network design problem involving product returns. [169] presented an
optimization-based model to deal with integrated logistics operational problems of green-
supply chain management (G-SCM). They formulated a linear multi-objective programming
model to optimize the operations of both integrated logistics and corresponding used-product
reverse logistics in a green-supply chain.

[20] presented comprehensive analysis of logistics networks in a product recovery environment
in their work aimed at characterization of logistics networks for product recovery.

Table 2.6 below classify different quantitative operations research models presented in
literature, indicating a clear preference for Mixed Integer Linear Programming (MILP)
modelling, amongst other models, for reverse logistics network design.

An important issue in reverse logistics network design is integrating forward and reverse flow
management, in terms of logistics management (for sharing transportation and warehouse, for
instance). A disaggregated logistics solution raises the product recovery cost substantially
higher.

<table>
<thead>
<tr>
<th>Quantitative modelling method</th>
<th>Author</th>
</tr>
</thead>
</table>

**TABLE** Error! No text of specified style in document.

**6 Quantitative models in reverse logistics network**
A closed-loop supply chain (CLSC) consists of both forward supply chain and reverse supply chain. Correspondingly, an integrated supply chain generally spans to multiple organizations/agencies operating for different supply chain operations.

[181] developed a hybrid model to establish a closed-loop supply chain model for spent batteries. They described a hybrid approach that combines an optimization model for planning a reverse-supply network and a flow-sheeting process model that enables a simulation tailored to potential recycling options for spent batteries in the steelmaking industry. They deduce that almost complete recycling of spent batteries can be achieved by transforming current structure into a modified recovery network.

[169] described a linear multi-objective programming model to optimizes the operations of both integrated logistics and corresponding used-product reverse logistics in a given green-supply chain. They deduce that the chain-based aggregate net profits can be improved by 21.1%, compared to the existing operational performance in the particular case they studied.

[179] presented a generic stochastic model for the design of networks comprising both supply and return channels in a closed loop system. They presented a decomposition approach based on the branch-and-cut procedure known as the integer L-shaped method.

[185] proposed a multi-echelon closed loop supply chain network design with forward and reverse logistics components. They develop a mixed integer non-linear programming model for this problem with different costs so that the sum of the total cost is minimized subject to different constraints pertaining to capacities of the entities of the system, demands of first customers and second customers.

[186] have presented logistics network design for end-of-lease computer products recovery by developing a deterministic programming model for systematically managing forward and reverse logistics flows. They describe a two-stage heuristic approach to decompose the integrated design of the distribution networks into a location–allocation problem and a revised network flow problem.

[188] presented a case study at a company providing repair services on behalf of a computer manufacturer in the Asia-Pacific region. They examined the manufacturing company's redesign of its repair network. [170] presented a work on optimum usage of secondary lead recovered from the spent lead-acid batteries for producing new battery. They proposed heuristics based genetic algorithm (GA) as a solution methodology to solve mixed integer linear programming model (MILP).

Generalized models have also been developed by many researchers. [177] proposed design of a reverse distribution network that considered repairing and remanufacturing options simultaneously. They used mixed integer formulation which is solved using standard Branch and bound method. [171] propose a generalized model that considers capacity limits, multi-product management and uncertainty on product demands and returns, and solve it using standard branch and bound technique.

As established earlier, ascertainment of returning products’ quality and quantity for product recovery is particularly complex and difficult in reverse networks, essentially owing to uncertainty factor. Some researchers have addressed this issue under stochastic environment. [189] presented a stochastic programming based approach wherein uncertainties are accounted for in a deterministic location model. They applied stochastic models to a representative real case study based in the Netherlands on recycling sand.

In the same breath, researchers have proposed risk modelling as well. [175] developed a multi-period multi-echelon forward–reverse logistics network design under risk model. They formulated a stochastic mixed integer linear programming (SMILP) decision making form as a multi-stage stochastic program.

[186] demonstrated a heuristic approach to logistics network design for end-to-lease computer products recovery. Later, [190] proposed a two-stage stochastic programming model that is further developed such that a deterministic model for multi-period reverse logistics network
design can be extended to account for the uncertainties. They proposed a solution approach integrating a sampling method with a heuristic algorithm, along with a numerical experiment.

Another important area that has emerged for research attention is Third Party Logistics (TPL). TPLs are preferred by industrial organizations for the principle reasons of expertise and economy of scales they bring to the table. [191] proposed developing logistics competencies through third party logistics relationships. Recently, [192] summarized research on quantitative models for forward supply chains.


[176], in their work on dynamic design of a reverse logistics network from the perspective of third-party logistics service providers, proposed a mixed-integer programming model and a genetic algorithm that can solve the reverse logistics problem involving the location and allocation of repair facilities for TPLs.

**Summary**

The literature studied gave an insight into the categories of logistics and supply chain problems, and threw light on the varieties of spheres researched by the researchers in the broad domain of supply chain, with a reverse logistics focus. We focused on literature pertaining to different aspects of reverse logistics with a view to build comprehensive returns’ management framework.

Although AHP is a decision-making methodology in itself, its ability to get ratio-scale measurements and combine them across multiple criteria has led to AHP applications in conjunction with other decisions support tool and methodologies. In this chapter we analysed AHP, FAHP, ANP, TOPSIS, VIKOR, WSM, PROMETHEE and ELECTRE for MCDM in reverse logistics. We consider the results, ability of having detailed sensitivity analysis, ability of using graphical design model, ability of the team decision support, ability of considering variable weights for alternatives, accuracy in determining the results and velocity in the use of decision making methods as defining parameters, and AHP emerges among the study methods as the optimal and most- preferred choice for decision making in reverse logistics framework management.
The next chapter describes AHP model building for MCDM framework for reverse logistics, along with the validation of framework through quantified industries’ responses.