CHAPTER 2
LITERATURE REVIEW

2.1 RESOURCE ALLOCATION PROBLEM

Resource allocation involves the distribution and utilization of available resources across the system. Because resource availability is usually scarce and expensive, it becomes important to find optimal or even ‘good’ solutions to such problems. Thus, resource allocation problems represent an important class of problems faced by mathematical programmers.

A conceptual framework for resource allocation problems based on literature review is detailed in Figure 2.1

![Figure 2.1 Conceptual Framework for Resource Allocation Problems](image)
2.2 REVIEW OF THE RA VARIANTS ADDRESSED IN CURRENT RESEARCH

Literature on the RA variants addressed in this study is presented in next few paragraphs.

2.2.1 Bi-Objective Generalized Assignment Problem

Literature pertains to bi-objective / multi-objective GAP is very limited. (Hajri Gabouj, S., 2003) Investigated a fuzzy genetic multi-objective optimization algorithm for a multilevel GAP, an application encountered in clothing industry. (Gengui Zhou et al., 2003) Explored a genetic algorithm approach for BGAP, an application of allocation of customers to warehouses. From the literature review, it was inferred that the BGAP was addressed less in the literature and also there would be lot of opportunity to explore several solution approaches to solve BGAP to find Pareto optimal solutions. It is also evident that none of the researchers proposed Simulated Annealing to solve BGAP.

A well known search heuristic that has been used to solve a variety of combinatorial optimization problem is SA (Kirkpatrick, et al., 1983; Golden, B. and Skiscim, 1986). SA is inspired from the physical annealing process emanating in statistical mechanics. It is a local search meta-heuristic, in the sense that it conducts local search while guiding the overall exploration process intelligently, offering the possibility of accepting, in a controlled manner, solutions that do not descend along the path of search. This feature allows SA to escape from a low quality local optimum.

More precisely, at each iteration of SA, a neighbour \( s' \in N(s) \) of the current solution \( s \) is generated stochastically and a decision is made concerning the replacement or not of \( s \) by \( s' \). If \( s' \) is a better solution than \( s \), i.e., \( B = c(s) - c(s') < 0 \) for a minimization problem or \( B = c(s) - c(s') > 0 \) for a maximization problem, the search moves from \( s \) to \( s' \); otherwise, the search
moves to \( s' \) with a probability of \( e^{-B/T} \). This probability depends on the
degree of the degradation (the smaller the value of \( B \), the greater the accepting
probability) and a control parameter \( T \) called temperature (higher temperatures
lead to higher accepting probabilities and vice versa); the evolution of the
temperature is governed by a cooling schedule specifying the steps for
progressive reduction of temperature. Introducing terms such as ‘cooling
schedule’ and ‘temperature’, it essentially searches for better solutions in a
discrete solution space with a provision to accommodate inferior solutions at
intermediate stages in order to avoid being trapped at local optima. Typically,
\( SA \) stops when a fixed number of non-improving iterations is realized with a
single temperature or when a pre-specified number of iterations is reached.

The \( SA \) method is known to be a compact and robust technique,
providing excellent solutions to single objective optimization problems with a
substantial reduction in computational cost. Later, this method has been
adapted for the multi-objective framework. Balram (2005) detailed the
literature pertain to the application of \( SA \) to multi-objective combinatorial
optimization problems. Given the proven success of \( SA \) to multi-objective
combinatorial optimization problems, It is believed that \( SA \) is suitable for
solving \( BGAP \).

2.2.2 Multi-Commodity Network Flow Problem

There are various works on the network optimization techniques.
The models were formulated for the various scenarios and worked out.
Significant work has been done for the various connotation of \( MCNF \). Here
are some works mentioned which is considered to be significant.

One of the earlier works on \( MCNF \) in an alternate derivation of the
dual condition (called the severance-value condition) proposed by by Onaga
and Kakusho (1971) is deemed to mention here.
Geoffrion and Graves (1974) formulated MCNF as a mixed integer linear program. They developed, implemented, and successfully applied a solution technique based on Benders Decomposition to a major food firm with 17 commodity classes, 14 plants, 45 possible distribution center sites, and 121 customer zones. Panagiotakopoulos (1976) presented a network model for the analysis of waste management systems. He formulated this MCNF problem as a linear program where each column in the constraint matrix corresponds to a chain in the network and used a column-generation scheme based on a shortest route algorithm to obtain the solution.

Minoux (1981) described an algorithm based on a generalisation of the max-flow min-cut theorem to solve the MCNF. He also introduced a generic model through MCNF to the Communication Networks (Minoux, 2001). Rees et al (1987) suggested that MCNF can serve as effective distribution planning tool wherein cost minimization is not always the sole objective of a firm involved in distributing commodity items through a network of outlets, retail centers etc. Typically many firms have objectives such as meeting preferred customer demand in order to establish good will or to reduce inventory levels at a particular store.

Leighton et al (1991) described the first polynomial-time combinatorial algorithms for approximately solving the multicommodity flow problem. Gabrel and Minoux (1997) focused in the development of relaxations for MCNF problems in order to derive lower bounds. They proposed an alternative re-laxation of the problem in terms of a large scale LP model, which can be solved by a generalized linear programming approach.

McBride (1998) used MCNF for solving extremely large logistics problems with more than 600,000 constraints and 7,000,000 variables in the food industry. Yan and Chen (2002) modeled the bus movements and passenger flow to find the optimal bus routes/schedules and passenger transportation plans. Mathematically, the model is formulated as a mixed
integer multiple commodity network flow problem which contains a fleet of 320 buses with 23,652 projected daily trips, between five cities. Gabrel et al (1999) described an exact solution procedure, based on the use of standard LP software, for MCNF with general discontinuous step-increasing cost functions. They proposed an improved implementation of the constraint generation principle to solve it. Gabrel et al (2003) presented and compared approximate solutions algorithms for discrete cost MCNF namely extensions of classical greedy heuristics, based on link-rerouting and flow rerouting heuristics and a new approximate solution algorithm, which basically consists of a heuristic implementation of the exact Benders-type cutting plane generation method.

Ozdaglar and Bertsekas (2003) proposed new integer-linear programming formulations for the Optical Networks which tend to have integer optimal solutions even when the integrality constraints are relaxed, thereby allowing the problem to be solved optimally by fast and highly efficient linear (not integer) programming methods.

Belotti (2005) investigated three problems, arising in the field of Telecommunication, of networks design with survivability constraints, and solved them through different approaches on a number of real-world network topologies with up to 40 nodes. Teng et al (2007) discussed MCNF with random demand using the equilibrium theory and method of variational inequality. They also analysed the behavior of the various decision-makers as well as the effect of their interaction in different level. Agarwal and Ergun (2008) studied a collaborative multicommodity flow game where individual players own capacity on the edges of the network and share the capacity to deliver commodities. They presented membership mechanisms, by adopting a rationality based approach using notions from game theory and inverse optimization, to allocate benefits among the players in such a game. Calitz (2008) applied MCNF for waste collection vehicles to ensure quality efficient service at minimum cost by reducing the total distance travelled by the
collection vehicles within each day. Fayazbakhsh and Razzazi (2008) claim that MCNF might be an appropriate tool to help the decision makers that result in the minimisation of the whole supply chain cost.

Li et al (2009) extended their classical capacitated plant location problem by introducing a multi-commodity flow problem in the distribution issue. They proposed a Lagrangean-based method, including a Lagrangean relaxation, a Lagrangean heuristic and a subgradient optimization, to provide lower and upper bounds of the model. They also employed a Tabu search to further improve upper bounds provided by the Lagrangean procedure. Ghatee and Hashemi (2009) utilised fuzzy shortest paths and $K$ - shortest paths to generate preferred paths to solve the MCNF. Frangioni and Gandroni (2009) studied 0–1 reformulations of the multi-commodity capacitated network design problem, which is usually modeled with general integer variables to represent design decisions on the number of facilities to install on each arc of the network. They compared two cutting-plane algorithms to compute the same lower bound on the optimal value of the problem: one based on the generation of residual capacity inequalities within the model with general integer variables, and the other based on the addition of extended linking inequalities to the 0–1 reformulation. To further improve the computational results of the latter approach, they developed a column-and-row generation approach. Gamst et al (2010) solved Multi-commodity $k$-splittable flow problem through branch-and-price.

Moreover survey papers on multi-commodity network flow problem by Assad (1978), Kennington (1978), Crainic et al (2001) and Minoux (2001) illustrate the wide and variety of application of the problem for a longer period. Nevertheless the gap in the literature is evident that the application of the meta-heuristics for the MCNF is few. And also the literature clearly explains the implication of MCNF for the optimization in the patient distribution system.
Liu and Zhang (2008) developed the optimal decision of channel selection for the manufacturer by using a three-stage dynamic game model. Yadav et al (2009) presented a robust optimisation technique viz. Endosymbiotic Evolutionary Algorithm (EEA) for a multi-stage, multi-period logistics system. Min et al. (2009) proposed an Analytic Hierarchy Process (AHP)-based Decision Support System (DSS) to help multinational firms tackle the problem of determining the optimal transportation route to inland destinations in land-locked countries. Xanthopoulos and lakovou (2010) described the optimal configuration of efficient reverse logistics networks and an application of the optimization model is demonstrated, while obtained managerial insights are discussed. Min and Guo (2010) proposed an equilibrium model combines game theory with GA to promote a compromise between the conflicting interests of the carrier and the shipper, while optimally balancing the shipper's desire to contain cost against the carrier's desire to increase profit. Paksoy et al (2011) developed a novel linear programming model for the production/distribution network of an edible vegetable oils manufacturer. Mathirajan et al (2011) proposed a two-stage integrated solution framework. In the first stage, they presented a mathematical model to solve the facility location and production distribution policy for the company by minimizing the cost comprising production costs at factory, fixed and labour cost of new warehouses and shipment cost from factories to warehouses and warehouses to distributors. In the second stage, they presented a breakeven analysis to compare the new proposed network with the existing network based on the distribution cost. RamKumar and Sivakumar (2011) developed the combinatorial optimisation problem of routing freight on a capacitated hub-and-spoke network known as the Capacitated Hub Routing Problem (CHR%P) and a Mixed Integer Programming (MIP) model is also proposed for the problem. Azadeh et al (2011) presented a simulation model for analyzing performance of inventory policy in multi-product mode in two-echelon supply
chain including four retailers and one capacitated supplier. Pradhananga et al (2011) summarizes an optimization model for transportation of the hazardous material (Hazmat) and they used GA to solve the model. Sujatha (2011) reviewed the role of intelligent agents for managing seamless information flow in a supply chain. Seifi (2011) proposed a heuristic approach to solve a real Periodic Vehicle Routing Problem (PVRP) that aims at extending the market share with the minimum transportation cost. The objective is to determine the scheduling and routing policies of the vehicles to minimize the fleet size and to maximize the selling benefits.

From the state of art literature, it is evident that the MCNF problem is critical and development of mathematical model to solve MCNF adds value to the literature of logistics and operations research field.

Multi-commodity flow problems arise whenever commodities, vehicles are to be shipped or transmitted simultaneously from certain origins to certain destinations along arcs of an underlying network. These problems find applications in the study of urban traffic, railway systems, logistics, communication systems, and many other areas. The multi-commodity network-flow model concerns routing of a number of commodities through a capacitated network at minimal cost. MCNF problems have received considerable attention from the research community. Lagrangian techniques have been commonly used to solve the capacitated MCNF problem with piecewise linear concave costs. Consequently there exists a vast body of literature on manufacturing and transportation logistics pertaining to this problem. Researchers have therefore developed specialized adaptations of linear programming algorithms which exploit the special structure and the sparsity inherent in multi-commodity network flow problems. Three "classical" approaches to multi-commodity flow problems are price-directive decomposition, resource-directive decomposition, and partitioning.
Golden (1975) developed an algorithm for handling nonlinear minimum-cost multi-commodity flow problems and applies it to a specific large-scale network of imports and exports and they also discussed about Negative cycles.

Kimemia and Gershwin (1976) approached network flow optimization for the problem of choosing an optimal mix of operating strategies in a flexible manufacturing system. They outlined Mathematical methods which exploit the structure of the problem to generate manufacturing strategies.

Balakrishnan and Graves (1989) and Amiri and Pirkul (1997) approach the Multi-commodity Network Flow Problem with Piecewise Linear Concave Cost (MNFP) using Lagrangian relaxation techniques. The former strictly tackle the uncapacitated problem, although the formulation presented could be used to include capacitated cases, whereas the latter explicitly consider arc capacities. The algorithms developed in both papers are tested on similarly structured, randomly generated 3 instances, where capacities are never tight.

Chan et al (2001) show that the linear programming relaxation of the formulation used is very strong for uncapacitated instances; moreover, the relaxation is proven to be tight for certain simple network structures. They also derive structural properties of the linear programming relaxation and use them to develop an effective linear programming based algorithm. Efficient heuristic algorithms have been developed for the uncapacitated case (Balakrishnan et al 1989). The higher complexity of the capacitated problem is demonstrated in a stream of recent work in this area; see Crainic et al (2001), which describes the different approaches to solving this problem – Lagrangian relaxation, cutting plane methods and heuristics - and discusses how combining these methods may lead to effective solution schemes.
Yan and Chen (2002) developed a model that will help Taiwan inter-city bus carriers in timetable setting and bus routing/scheduling. The model employs multiple time–space networks that can formulate bus movements and passenger flows and manage the interrelationships between passenger trip demands and bus trip supplies to produce the best timetables and bus routes/schedules. They formulated this problem as a mixed integer multiple commodity network flow problem and they developed an algorithm, based on Lagrangian relaxation, a sub-gradient method, the network simplex method, a Lagrangian heuristic and a flow decomposition algorithm.

A very specific network structure with general piecewise linear costs is considered in Croxton et al (2003) to model the selection of different transportation modes and shipment routes in merge-in-transit operations. In this case, a set of capacitated warehouses coordinates the flow of goods from a number of suppliers to multiple retailers with the objective of reducing costs through consolidation. They use a simplex-based cutting plane approach, for their arc based formulation, generating cuts with disaggregation techniques to solve the problem.

Holmberg and Yuan (2003) extended the basic multi-commodity network-flow model to include such side constraints on paths. The extended problem is NP-hard with the constrained shortest-path problem as a special case. They used a column-generation approach to solve this model, in which the solution is built up successively by path generation. The side constraints are efficiently handled in the path-generation sub problem.

Babonneau et al (2004) proposed to solve the linear multi-commodity flow problem using a partial Lagrangian relaxation. The relaxation is restricted to the set of arcs that are likely to be saturated at the optimum. This set is itself approximated by an active set strategy. The partial Lagrangian dual is solved with Proximal-ACCPM, a variant of the analytic center cutting plane method. The new approach makes it possible to solve huge problems
when few arcs are saturated at the optimum, as it appears to be the case in many practical problems.

Vaidyanathan (2007) studied railroad optimization problems, the crew scheduling problem, in the context of North American railroads. The crew scheduling problem is to assign crew to scheduled trains over a time horizon at minimal cost while honoring several operational and contractual requirements. They developed a network-flow based crew-optimization model that has applications in all levels of decision making in crew scheduling: tactical, planning, and strategy and further they formulate the crew assignment problem as an integer-programming problem on this network, which allows this problem to be solved to optimality. They also develop several highly efficient algorithms using problem decomposition and relaxation techniques.

Haouari et al (2009) investigate network flow-based heuristic approaches for a Given schedule of flights to be flown, the aircraft fleeting and routing problem consists of determining a minimum-cost route assignment for each aircraft so as to cover each flight by exactly one aircraft while satisfying maintenance requirements and other activity constraints.

Saxena et al (2010) addressed the issue of designing multipath routing algorithms. They consider the problem of establishing a specified throughput from multiple sources to destination pairs in the network, given bounds on the buffer sizes available at the network intermediate nodes and a bound on the maximum delay that the paths are allowed to have. They formulate the problem using a linear programming model.

Li X.-Y. et al (2010) discussed the single-path multi-commodity network flow problem, in which the flow of each commodity can only use one path linking its origin and destination in the network. They studied two versions of this problem based on two different objectives and proposed an ant colony optimization (ACO) based metaheuristic to deal with this problem.
Considering different problem properties, they devise two versions of ACO Meta-heuristics to solve these problems.

Paksoy et al (2011) developed a novel linear programming model for the production/distribution network of an edible vegetable oils manufacturer. They solved their proposed model and analysed results for various scenarios in order to identify some managerial insights.

Mathirajan et al (2011) proposed a two-stage integrated solution framework. In the first stage, they presented a mathematical model to solve the facility location and production distribution policy for the company by minimizing the cost comprising production costs at factory, fixed and labour cost of new warehouses and shipment cost from factories to warehouses and warehouses to distributors. In the second stage, they presented a breakeven analysis to compare the new proposed network with the existing network based on the distribution cost.

RamKumar and Sivakumar (2011) introduced the combinatorial optimization problem of routing freight on a capacitated hub-and-spoke network known as the Capacitated Hub Routing Problem. The hubs are limited in capacity for channeling flows between the nodes served by the system. A Mixed Integer Programming and a simple but effective heuristic models are proposed for the problem.

2.2.3 Multiple Measures Resource Allocation Problem

Towill (1991) and Towill et al (1992) use simulation techniques to evaluate the effects of various supply chain strategies on demand amplification. In supply chain, members choose immediate suppliers based on the given data and rules set (Piramuthu, 2005). Managing a supply chain involves the flow of both tangible and intangible resources including materials, information, and capital across the entire supply chain (Wu and Olson, 2008). The strategies investigated are as follows:
● Eliminating the distribution echelon of the supply chain, by including the distribution function in the manufacturing echelon.
● Integrating the flow of information throughout the chain.
● Implementing a Just-In-Time (JIT) inventory policy to reduce time delays.
● Improving the movement of intermediate products and materials by modifying the order quantity procedures.
● Modifying the parameters of the existing order quantity procedures.

The objective of the simulation model is to determine which strategies are the most effective in smoothing the variations in the demand pattern. The just-in-time strategy and the echelon removal strategy were observed to be the most effective in smoothing demand variations. Wikner et al (1991) examine five supply chain improvement strategies and then implement these strategies on a three-stage reference supply chain model. The five strategies are:

● Fine-tuning the existing decision rules.
● Reducing time delays at and within each stage of the supply chain.
● Eliminating the distribution stage from the supply chain.
● Improving the decision rules at each stage of the supply chain.
● Integrating the flow of information, and separating demands into “real” orders, which are true market demands, and “cover” orders, which are orders that bolster safety stocks.

Makipaa (2008) explores on cooperative inter-organizational relationships levels of cooperation. Biswas et al (2002) in his study evaluated the various algorithms and tools deployed for supply chain modeling and problem solving. These are based on stochastic models, mathematical programming models, heuristic techniques, and simulation.
Min and Zhou (2002) argued that most supply chain simulation models have been developed on the basis of discrete-event simulation. Since supply chain systems are neither completely discrete nor continuous, the need for constructing a model with aspects of both discrete-event and continuous simulation is provoked, resulting in a combined discrete–continuous simulation. In this paper, architecture of combined modeling for supply chain simulation is proposed, which includes the equation of continuous portion in the supply chain and how these equations can be used in the supply chain simulation models. The simple example of a supply chain model dealing with the strategic level of the supply chain presented in this paper shows the possibility and the prospect of this approach.

Wadhwa et al (2008) has given three stages inventory coordination mechanisms between chain members and solves a cost minimization model for each. This show that some of the coordination mechanisms can result in a significantly lower total cost than matching production and delivery along the chain.

Nilsson (1999) presents a dynamic simulation model for analysis of various delivery alternatives while designing straw fuel delivery system.

Smith et al (2002) uses a Decision Support System for a retail supply chain planning for private – Laval Merchandise with multiple vendors. While offering a number of benefits, this approach also poses a different set of supply chain challenges than manufacture-brand – based retailing, in that the retail firm must take a more active role in organizing and coordinating the planning and materials management activates in a supply base that is often dispersed and heterogeneous.

Sabri et al (2000) developed an integrated multi-objective SC for use in simultaneous strategic and operational SC planning. The authors adopted multi-objective decision analysis to allow use of a performance measurement system. This measurement system provides more comprehensive
measurement of supply chain system performance than do traditional, single-measure approaches. Moreover, this model incorporates production, delivery and demand uncertainty and provides a multi-objective performance vector for the entire SC network.

Han and Damrongwongsiri (2005) constructed a mathematical model to describe the stochastic multiple-period two-echelon inventory with the many-to-many demand-supplier network problem. GA was applied to derive optimal solutions through a two-stage optimization process. The model simultaneously constitutes the inventory control and transportation parameters as well as price Uncertainty factors.

Wang et al (2004) related product characteristics to supply chain strategy and adopt supply chain operations reference (SCOR) model level I performance metrics as the decision criteria. They developed an integrated analytic hierarchy process (AHP) and preemptive goal programming (PGP) based multi-criteria decision-making methodology to take into account both qualitative and quantitative factors in supplier selection. While the AHP process matches product characteristics with supplier characteristics to qualitatively determine supply chain strategy, PGP mathematically determines the optimal order quantity from the chosen suppliers. Since PGP uses AHP ratings as input, the variations of pair wise comparisons in AHP will influence the final order quantity.

2.2.4 Mixed Capacitated Arc Routing Problem

The research on lower bounding procedures, solution and modeling approaches of MCARP performed in the last decade is surveyed by Wohlk (2008). Many real-world applications, such as household refuse collection, winter gritting, postal distribution, meter reading, street swiping, can be modeled as MCARP.
The surveys on arc routing include Assad and Golden (1995); Eiselt et al (1995) and Dror (2000). More recent publications on arc routing real world applications include postal delivering (Ir nich, 2008), a real situation arising on an industrial company (Moreira et al 2007) and garbage collection, which is a main concern of municipalities (Amp onsah and Salhi, 2004). Bautista et al (2008), Pia and Filippi (2006), Ghiani et al (2005), Maniezzo (2004), Mourao and Almeida (2000) and Mourao and Amado (2005) are some of the references of MCARP.

Many MCARP applications differ on the features of the system collection design, namely the number of depots and its location (Amaya et al 2007; Del pia and Filippi, 2006; Ghiani et al 2001; Mourao and Almeida, 2000).

An approach to solve MCARP is by means of well known transformations into equivalent node routing problems (Pearn et al 1987; Baldacci and Maniezzo, 2006; Longo et al 2006; Bautista et al 2008). The main idea is to use available and well tested methods for node routing problems. However, these transformations lead, in general, to networks that are substantially larger than the originals and many authors prefer to develop models on the original graph.

The first formulation for the MCARP was proposed by Golden and Wong (1981) and includes an exponential number of constraints. It is also stated that the exponential sized set of subtour-breaking constraints may be replaced by a more compact set, based on flow variables. The lower bound provided from the LP relaxation of this formulation is known to be equal to zero. Eglese and Letchford (2000) and Golden and Wong (1981) did not use the compact model to get lower bounds for the MCARP. Instead, a different lower bound method is developed and its bound was shown to be equal to the bound obtained from the optimal value of a relaxation where capacity and connectivity constraints are omitted.
Ismail and Yunos (2010) proposed a new solution approach known as Reactive Tabu Search (RTS) heuristic method to solve the MCARP. The RTS solution algorithm adopts a dynamic tabu list rather than static tabu list as in the classical Tabu Search (TS). The newly developed algorithm had generated a good solution for solving solid waste collection problems for the city of Johor Bahru, Malaysia.

Lacomme et al (2006) proposed a multi-objective genetic algorithm for this more realistic MCARP. Inspired by the second version of the Non-dominated sorted genetic algorithm framework, the procedure is improved by using good constructive heuristics to seed the initial population and by including a local search procedure. The new framework and its different flavour are appraised on three sets of classical MCARP instances comprising 81 files. Yet designed for a bi-objective problem, the best versions are competitive with state-of-the-art Meta-heuristics for the single objective MCARP, both in terms of solution quality and computational efficiency. Indeed, they retrieve a majority of proven optima and improve two best-known solutions.

Lacomme et al (2005) described several versions encountered in practice and suggest a simple classification, enabling the definition of a very general MCARP. For instance, the demand for each arc treatment may depend on the period or on the date of the previous visit. The proposed solution method is a memetic algorithm based on a sophisticated crossover, able to simultaneously change tactical decisions, such as the treatment days of each arc, and operational decisions, such as the trips performed for each day.

Gouveia et al (2010) presented a compact flow based model for the MCARP. Due to its large number of variables and constraints, they have created an aggregated version of the original model. Although this model is no longer valid, they show that it provides the same linear programming bound than the original model. Different sets of valid inequalities are also derived.
Corbera et al (2003) summarizes theoretical insights, modeling approaches, and heuristic and exact algorithms for routing and location. A different model for the undirected CARP was proposed by Belenguer and Benavent (1998). In 2003, the same authors Belenguer and Benavent (2003) suggested a different formulation for the same problem that has only a single variable for each edge of the underlying graph, but it contains 3/21 an exponential number of constraints. This formulation is shown to be non valid, similarly to what happens with one of the models presented in this paper.

Later on, Belenguer et al (2006) developed a study on lower bounds for the MCARP based on the model defined in Belenguer and Benavent (2003). This non-valid model for the MCARP is similar to models presented for other mixed arc routing problems, as the mixed Chinese postman problem (Nobert and Picard, 1996) and the mixed general routing problem (Corberan et al 2003). The authors use this model and several valid inequalities in a cutting plane fashion to get lower bounds for the MCARP that outperformed the previous best known bounds.

Two well known ideas are used to design this formulation for the problem: i) the concept of flows to guarantee the connectivity of the solutions of Gavish and Graves (1978) and Gavish and Graves (1982) and ii) the concept of indexing the variables by vehicle to guarantee a matching between trips and vehicles see, for instance, (Magnanti, 1981). The model will be used within an ILP package to solve medium sized problems and to produce lower bounds on larger instances. Lower bounds are also obtained from the corresponding linear programming relaxation.

MCARP proposed by Golden and Wong (1981) includes several aspects: i) it formulates the mixed case while their model is developed for the undirected MCARP; ii) the flow variables have a different interpretation (here they are related with the demands to be served and in their paper flows are associated with the number of edges to serve); iii) additional constraints are
included to ensure that trips start at the depot and iv) extra valid inequalities are considered to strengthen the linear programming relaxation.

A straightforward extended formulation of Golden and Wong (1981) to the mixed MCARP was tested on small instances by Lacomme et al (2003). Due to the vehicle indexing, the number of variables and constraints in our model is huge.

Comparing with the Belenguer and Benavent (2003) formulation, the main difference between our aggregated model and their model lies on the network type (mixed versus undirected) and on the size of the models since our model is compact and theirs has an exponential number of constraints. That is, in our model capacity and connectivity constraints are enforced by using the additional flow variables and the constraints linking the two sets of variables. In Belenguer and Benavent (2003), the authors do not use the extra set of variables but use, in turn, exponential sized sets of constraints to force connectivity.

### 2.2.5 Employee Routing Problem

Employee Routing Problem (ERP) can be defined as the facility of an Enterprise or organisation transportation from their living location to their Working locations or ERP can be defined as the provision of public transportation from their residences to and from their organizations. It consists of finding out of a series of bus routes that ensure that the service is provided equitably to all employees. The solution to this problem is the creation of an efficient schedule for a fleet of buses where each bus picks up employee from various bus stops and delivers them to their designated organizations while satisfying various constraints such as the maximum capacity of a bus, the maximum riding time of an employee in a bus, and the time window of an organization. This includes finding out of a series of Routes that ensure that the service is provided equally to all employees. The current literature deals
primarily with single-objective problems and the models with multiple objectives typically employ a weighted function to combine the objectives into a single one. The employee routing problem falls into a larger class of problem that is called the vehicle routing problem (VRP). VRP focuses on the efficient use of a fleet of vehicles (e.g., trucks, buses and cars) that must make a number of stops to pick up and/or deliver passengers or products. A survey of the literature may be found in Fisher, Desrosiers, Federgruen, Laporte and Bodin. Because VRP is a well-known hard problem, it is futile to search for an algorithm that gives the optimal solution in every instance. Therefore most of the research in this area concentrates on the development of heuristic algorithms.

Newton and Thomas (1969) developed a practical method for generating school bus routes and schedules on a digital computer. Routing is accomplished by a two-step procedure. First, the shortest route a bus of infinite capacity traverses in order to visit all of the stops is determined. This route, the solution of the traveling-salesman problem associated with the set of bus stops, is obtained by an efficient heuristic procedure which yields near-optimal solutions to problems of a realistic size. This single route is then partitioned to provide individual bus routes and schedules which satisfy bus capacity, bus loading policy, and passenger riding time constraints. Bennett and Gazis (1972) described a procedure for the designing of school bus routes by computer. The procedure is an extension of the clark and wright algorithm for scheduling delivery vehicles.

Newton and Thomas (1974) describes and evaluates a practical computer based method for translating data concerning the location of each school in a multi-school system to be serviced by a bus fleet, the location of each student to be transported to each school, the time period during which students assigned to each school are to be transported, and the available bus facilities into a set of bus routes which specify school-to-school sequencing of
each bus and the stop-to-stop route to be followed in traveling to every school. Each route is designed so that bus capacity and student riding time constraints are satisfied while attempting to minimize both total bus travel time and the number of routes required to service all the stops associated with the school. The mathematical models developed were programmed in FORTRAN IV for use on a CDC 6400 computer and were applied to four schools in a Western New York school district.

Russell and Igo (1979) examined a routing design problem in which the objective is to assign customer demand points to days of the week in order to solve the resulting node routing problems over the entire week most effectively. The emphasis is on obtaining approximate solutions for this type of combinatorial problem. They developed and tested several heuristics on a large scale refuse collection problem.

Bowerman et al (1995) presented a multi-objective mathematical formulation for the Urban School Bus Routing Problem. They developed a heuristic algorithm and it was tested with data from a sample school board location in Wellington County in Ontario, Canada. This report reviews traffic modeling and bus-routing optimization for urban cities by means of a entropy-based formulation of their vehicular movements within the domain under examination. The perceived level of disorder caused by the numerous vehicle-student-trips in the domain under examination is subsequently used for the formulation of a policy and a bus-routing scheme in order to minimize the entropy in the system.

Corberan et al (2002) addressed the problem of routing school buses in a rural area with a node routing model with multiple objectives that arise from conflicting viewpoints. From the point of view of cost, it is desirable to minimise the number of buses used to transport students from their homes to school and back. From the point of view of service, it is desirable to minimise the time that a given student spends en route. They
developed a solution procedure that considers each objective separately and search for a set of efficient solutions instead of a single optimum and their solution procedure is based on constructing, Improving and then combining solutions within the framework of the evolutionary approach known as scatter search. Experimental testing with real data is used to assess the merit of their proposed procedure.

Li and Fu (2002) describe a case study of the school bus routing problem. It is formulated as a multi-objective combinatorial optimization problem. It also aims at balancing the loads and travel times between buses. They proposed a heuristic algorithm for its solution. The algorithm has been programmed and run efficiently on a PC. Numerical results are reported using test data from a kindergarten in Hong Kong.

The school bus routing problem (Schittekat et al 2006), is similar to the standard vehicle routing problem, but has several interesting additional features. They develop an integer programming formulation for this problem, as well as a problem instance generator. They then show how the problem can be solved using a commercial integer programming solver and discuss some of their results on small instances.

Bektas and El mastas (2007) described an exact solution approach for solving a real-life school bus routing problem (SBRP) for transporting the students of an elementary school throughout central Ankara, Turkey. The problem is modelled as a capacitated and distance constrained open vehicle routing problem and an associated integer linear program is presented. The integer program borrows some well-known inequalities from the vehicle routing problem, which are also shown to be valid for the SBRP under consideration.

Junhyuk Park and Kim (2010) aims to provide a comprehensive review of the SBRP, the various assumptions, constraints, and solution
methods used in the literature on SBRP are summarized. They also presented

A list of issues requiring further research.

Christodoulou (2010) presented a method by which traffic flow
estimation between known origins and destinations can be evaluated based on
a modified entropy model, and by which bus-routing optimization can be
performed. The traffic flow analysis is performed by use of an entropy-based
formulation of the vehicular movements of students within the domain under
examination, while the perceived level of disorder caused by the numerous
vehicle-student-trips in the domain under examination is subsequently used
for the formulation of a policy and a bus-routing scheme in order to minimize
the original entropy in the system. The entropy metric used in the scheduling
optimization is related to the probability of student-trips by origin and
destination, and an application of the method is illustrated via a case study of
an urban university initiating bus service for its students.

Souza and Siqueira (2010) discussed similar to the Vehicle
Routing Problem (VRP), however a heuristic algorithm is proposed to
determine the set of the Bus Stops. They proposed to construct digital maps
containing the roads where the vehicles will be able to travel, since there are
no digital maps of these regions. The real distances between the points are
calculated and the heuristics Location Based Heuristic with some additional
features was used to propose the new routes. The algorithm was named by
Adapted Location Based Heuristic .The School Transportation Problem was
implemented in the State of Parana for 399 cities.

Ledesma and Gonzalez (2012) introduced a generalization of the
vehicle routing problem called the multi-vehicle traveling purchaser problem,
modeling a family of routing problems combining stop selection and bus route
generation. It discusses a Mixed Integer Programming formulation extending
previous studies on the classical single vehicle traveling purchaser problem.
The proposed model is based on a single commodity flow formulation
combining continuous variables with binary variables by means of coupling constraints. Additional valid inequalities are proposed with the purpose of strengthening its Linear Programming relaxation. These valid inequalities are obtained by projecting out the flow variables. They develop a branch-and-cut algorithm that makes use of the proposed model and valid inequalities. This cutting plane algorithm is implemented and tested on a large family of symmetric and asymmetric instances derived from randomly generated problems, showing the usefulness of the proposed valid inequalities.

2.2.6 Vehicle Routing Problem With Backhauls With Time Windows

The Vehicle Routing Problem with Backhauls (VRPB), also known as the linehaul-backhaul problem, is an extension of the VRP involving both delivery and pickup points. Linehaul (delivery) points are sites that are to receive a quantity of goods from the single Distribution Centre (DC). Backhaul (pickup) points are sites that send a quantity of goods back to the DC. The critical assumption is that all deliveries must be made on each route before any pickups can be made. This arises from the fact that the vehicles are rear-loaded, and rearrangement of the loads on the trucks at the delivery points is not deemed economical or feasible. The quantities to be delivered and picked up are fixed and known in advance. The vehicle fleet is assumed to be homogeneous, each having a capacity of some weight or volume. Hence, a feasible solution to the problem consists of a set of routes where all deliveries for each route are completed before any pickups are made and the vehicle capacity is not violated by either the line haul or backhaul points assigned to the route. The objective is to find such a set of routes that minimizes the total distance traveled.

(Kearney, 1984) estimates annual distribution costs in the United States in 1983 at $650 billion, approximately 21% of the GNP. In addition, Kearney reports that logistics costs account for 22.5% of the controllable costs
in manufacturing. *VRPB's* significance can also be attributed to the continuing effort to reduce distribution costs by taking advantage of the unused capacity of an empty vehicle traveling back to the *DC*. The Interstate Commerce Commission News (1980) estimated the potential fuel savings of using backhauling to be 42 million gallons a year nationally. Kearney includes a summary of programs implemented by companies in the period from 1978-1983 for improving productivity in logistics. The number one program, utilized by 83% of the survey respondents, was coordination of inbound with outbound freight to provide private fleet backhauls.

In addition, government deregulation of interstate commerce restrictions in the Motor Carrier Act of 1980 has made it possible for backhauling to become a profitable venture for any company with a large fleet of vehicles. Commodities can now be backhauled not only for the owning company, but also for other companies who are willing to pay for the backhauls as though for common carriage. One company in Michigan increased its backhauling revenues from $697,000 to almost $2 million in just two distribution centers (Orr, 1989). Other companies which are utilizing backhauling to generate revenues include Frito-Lay, K Mart, and Friendly Ice Cream (Chancellor, 1988). Backhauling is truly emerging as an untapped resource for improved productivity in industry.

Solution methodologies for the classical *VRP* include both exact and heuristic techniques. A comprehensive literature review can be found in (Bodin et al 1983) and many other studies in the area of vehicle routing have been reported in the years since. (Casco et al 1988) provide an extensive review of the recent literature on vehicle routing. This section will describe how some of the methods for VRP could be adapted to VRPB, and report on current *VRPB* research. (Kannan et al 2008) approached the problem with another meta-heuristics known as the Nelder and Mead methodology to save the computational time with a little iteration and obtain better results with the
help of a program in C++. (Mahamani et al 2008) objective of this work is to develop the best ordering policy with a low total inventory cost to ensure a better service efficiency level across a single-echelon supply chain. (Saen and Wang 2010) developed a theoretical approach to examine the value of information sharing for the manufacturer and the e-retailer first, and then further check to see how information sharing is moderated by the e-retailer’s market share and the product’s e-market-base demand. (John Wang et al 2008) discussed between the cow-calf producers and the meat packing companies, to determine the degree to which information technologies are currently being utilized and the degree to which these new technologies have driven improvements within the beef industry’s supply chain. (Jing Hou et al 2009) the authors focus on examining the coordination mechanisms for a two-stage supply chain comprising one supplier and one retailer. (Dhanalakshmi et al 2009) discussed with the results of other optimization techniques of complete enumeration, LINDO, and CPLE. (Liya Wang and Vittal Prabhu 2009) This research proposes Augmented Simultaneous Perturbation Stochastic Approximation (ASPSA) algorithm in which ASPSA is augmented to include research, ordinal optimization, non-uniform gain, and line search. (Charu Chandra and Janis Grabis 2009) discussed the use of goal modeling to formally represent the supply chain design problem, defines transformations to obtain the multi-objective optimization model on the basis of the goal model and uses business intelligence methods to represent modeling results (KatiBrauer and harlotte Backholer 2009) emphasized the value of generating transparency over transportation processes in supply networks and supports the concept of establishing a continuous planning procedure. (Reza Farzipoor Saen 2010) proposed a methodology to select the most efficient third-party reverse logistics (3PL) provider in the conditions that both weight restrictions and nondiscretionary factors are present. (John Wang et al 2009) developed a solution procedure which computes optimal policy effectively. (Iwan Vanany
et al 2009) proposed various types of risks, the unit of analysis, the industry sectors, and the risk management process or strategies. (Kattan and Khudairi 2010) results have shown that regardless of demand distribution pattern and customer order rate, the outcomes of the model are consistent and provide promising RFID technology adoption to improve inventory control of the entire supply chain system. (Kenneth Saban and John Mawhinney 2010) proposed a holistic approach to supply chain management (SCM), clarifies the forces that facilitate human collaboration, and identifies the steps management can take to create a more collaborative network. The standard VRP can be thought of as a special case of VRPB, with the number of backhaul points equal to one (the distribution center). Since VRP is NP-complete (Lenstra & Rinooy Kan, 1981), the VRP with backhauls is also NP-complete. The development of heuristic approaches is therefore a reasonable approach for practical applications. An exact procedure based on set covering is developed by (Yano et al 1987) for a special case of the VRPB. Relaxing the special route conditions or increasing the number of backhaul points would make this exact procedure computationally intractable. (Gelinas, 1991) also developed an exact procedure for the VRPB with time windows.

The literature described here proposes ways to solve the backhaul routing problem based on some well-known methods for the classical VRP. The solution methodologies are categorized according to a scheme suggested by (Bodin et al 1983). (Jordan and Burns 1984) examined the impact of backhauling on terminal locations and developed a method for determining which truckloads should be backhauled. (Jordan, 1987) extended this work to inFcludef systems with more than two terminals. (Gillet and Miller1974) discussed the sweep approach can easily be extended to the VRPB by truncating the clusters when either line haul or backhaul capacity is exceeded. (Clarke and Wright 1964). Developed a constructive approach whereby a configuration of points is changed to an alternative configuration which yields
a 'savings' in terms of a particular objective. (Deif and Bodin 1984) have proposed an extension of this algorithm for \textit{VRPB}. (Golden et al 1985) and (Casco et al 1988) report on an insertion procedure for \textit{VRPB} where any \textit{VRP} algorithm is used to initially sequence the delivery customers. (Lin and Kernighan 1973) developed the best known method of the r-opt algorithm. (Min et al 1992), (Fisher and Jaikumar 1978 and 1981), (Jarvis et al 1981) and (Cullen et al 1981) and (Cullen 1984) developed a methodology for solving the \textit{VRPB} when multiple depots are involved, denoted by \textit{MDVRPB}. (Desrosiers and Solomon 1992) presented a set partitioning algorithm for \textit{VRP} with time windows (\textit{VRPTW}) which can be used to find optimal solutions to the problem. (Gelinas, 1991) has extended this work for \textit{VRPB}. (Goetschalckx and Jacobs – Blecha, 1989) developed an integer programming formulation for the \textit{VRPB} problem by extending the (Fisher et al 1981) formulation to include pickup points. (Goetschalckx et al 1989) showed that for Euclidean distances the \textit{VRPB} routes will never be more expensive than executing separate delivery and pickup routes. (Goetschalckx et al 1989) also derived a worst case bound equal to 3 for the a simple heuristic for the \textit{VRPB} by extending the results of (Haimovich and Rinnooy Kan 1985) for the classical \textit{VRP}, whose bound equals 2.

From the literature survey, it is evident that \textit{VRPB} is very important and present-day problem, impacting costs and productivity in many distribution systems. Like many other routing problems, the \textit{VRPB} is a complex problem and heuristic algorithms are required to obtain solutions in a reasonable amount of time for realistic problem sizes. This project is focused on developing the mathematical model for static \textit{VRPB} with different constraints and developing a \textit{DSS} for dynamic \textit{VRPB} for Sangam dairy of Guntur District.

Efficient distribution of goods is a main issue in most supply chains. The transportation process between members of the chain can be
modeled as a Vehicle Routing Problem with Backhauls and Time Windows (VRPBTW). For example, the distribution of mineral water from a producer to a retailer (linehauls) may be coupled with the distribution of empty recyclable bottles from the retailer to the producer (backhauls). Both linehauls and backhauls may be constrained by possible service times at the producer and the retailers.

More formally, the VRPBTW involves the design of a set of pickup and delivery routes, originating and terminating at a depot, which services a set of customers. Each customer must be supplied exactly once by one vehicle route during her service time interval. The total demand of any route must not exceed the vehicle capacity. The total length of any route must not exceed a pre-specified bound. Additionally, it is required that, on each route, all linehauls have to be performed before all backhauls. The intuition for that is, that rearranging goods en route is costly and inefficient. The objective is to minimize the fleet size, and given a fleet size, to minimize operating costs. This problem is a generalization of the VRP, which is known to be NP-hard, such that exact methods like Branch and Bound work only for relatively small problems in reasonable time.

Applications of the VRPBTW arise in public and private sectors that manufacture goods requiring delivery to be made to customers and raw materials to be picked up from distributors, such as retail distribution, airline scheduling, railway fleet routing and scheduling. The efficient routing of vehicles for both linehaul and backhaul customers can save the public and private sectors millions of dollars per year.

A comprehensive review of the VRP can be found in Bodin et al (1983) and Ball et al (1995). Useful techniques for the general VRP are outlined in Golden and Assad (1988) and Aarts and Lenstra (1997). Reeves (1993) covers modern techniques such as simulated annealing, tabu search, and genetic algorithms. Various heuristic methods may be found in the
literature for both the VRPTW (Potvin et al 1996b; Potvin and Bengio 1996; Russell 1995; Chiang and Russell 1997) and the VRPB (Casco et al 1988; Deif and Bodin, 1984; Golden et al 1985; Goetschalckx and Jacobs-Blecha 1989; Jacobs-Blecha and Goetschalckx 1993; Toth and Vigo 1996).

The exact algorithm, heuristics, and meta-heuristics for solving the VRPBTW are reviewed. Gelinas et al (1995) proposed an exact algorithm, based on a column generation technique for solving a set partitioning formulation of the VRPBTW. This algorithm found optimal solutions to different problems, with up to 100 customers, derived from those found in Solomon’s (1983) VRPTW test set.

A parallel insertion heuristic, Push-Forward Insertion Heuristic (PFIH), for the VRPBTW is proposed in Kontoravdis and Bard (1995). This heuristic uses an efficient method for inserting customers into the routes, and was applied to problems with up to 100 customers and 3 vehicles. Thangiah et al. (1996) propose a heuristic based on the insertion procedure of Kontoravdis and Bard (1995) to obtain initial solutions to the VRPBTW. Then, the initial solutions are improved through the application of -interchanges and 2-opt* exchanges, which previously developed for the VRPTW only. This two-phase heuristic was used to solve problems of size 25, 50 and 100 (Gelinas et al., 1995), for which the optimal solution is known in most cases. In addition, the heuristic was tested on 24 newly created problems of size 250 and 500.

Potvin et al. (1996) present a Genetic Algorithm (GA) which is combined with a greedy route construction heuristic. The greedy heuristic inserts the customers one by one into the routes, using a fixed ordering of customers. The genetic algorithm is used to find good orderings for the insertion heuristic. In Duhamel and Potvin (1997), a Tabu Search (TS) meta-heuristic is proposed to solve the VRPBTW. The TS includes a greedy insertion heuristic from Kontoravdis and Bard (1995) for constructing an initial feasible
solution, and a tabu search procedure based on three different neighborhood search heuristics: extended 2-opt, Or-opt and Swap.

Shen (1999) proposed a two-stage meta-heuristic, RNETS, based on a route neighborhood structure to solve the VRPBTW. In the first stage, a nested parallel method is used to construct initial feasible routes from the lower bound direction. Then, those routes are improved by local search in the stage II. Table 2.1 summarizes the previous works. Most researchers adopt the insertion-based heuristics to construct feasible routes firstly. Several methods execute the local search heuristics to improve the initial solution. Meta-heuristics, such as Tabu Search (TS) and Genetic Algorithm (GA), present good performance on solving the VRPBTW. On the other hand, the testing instances almost are modified from the Solomon’s VRPTW benchmark instances.

**Table 2.1 The Existing Solution Methods for VRPBTW**

<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Methods</th>
<th>Size of Instances</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>Kontoravdis and Bard</td>
<td>Parallel Insertion (PFIH)</td>
<td>25,50,100</td>
</tr>
<tr>
<td>1995</td>
<td>Gelinas et al</td>
<td>Column Generation</td>
<td>25,50,100</td>
</tr>
<tr>
<td>1996</td>
<td>Thangiah et al</td>
<td>Parallel Insertion Local Search</td>
<td>25,50,100,250,500</td>
</tr>
<tr>
<td>1996</td>
<td>Potvin et al</td>
<td>Greedy Insertion Genetic Algorithm</td>
<td>25,50,100</td>
</tr>
<tr>
<td>1997</td>
<td>Duhamel and Potvin</td>
<td>Greedy Insertion Local Search Tabu Search</td>
<td>25,50,100</td>
</tr>
<tr>
<td>1999</td>
<td>Shen</td>
<td>Route Neighborhood Local Search</td>
<td>100</td>
</tr>
</tbody>
</table>
2.3 OBSERVATIONS AND RESEARCH GAP

A careful analysis of literature on the RA variants, methodologies and applications published hitherto reveals the following: It is evident that there is a need to address a variety of complex variants of the classical RA variants pertaining to several domains such as resource allocation variant in bi-objective capacitated supply chain network, resource allocation variant in bi-objective bound driven capacitated supply chain network, resource allocation variant in multiple measures driven capacitated multi echelon supply chain network, resource allocation variant in integrated decision and upper bound driven capacitated multi echelon supply chain network, resource allocation variant in integrated decision and time driven capacitated multi echelon supply chain network and resource allocation variant in integrated decision, bound and time driven capacitated multi echelon supply chain network.

From the state of art of literature, it is evident that the below constrains pertain to RA in the stated are not considered in the research.

- Realistic constraint to maximize or minimize or compromise the two objectives, subject to the varying (equal and unequal) capacity constraints of destination source to produce non-dominated solutions in RA variant is less considered in the research
- Allocation with the consideration of two objectives and lower and upper bound as the service limit in the serving nodes with varying capacity less addressed in the research
- Multiple measure allocation based on a cost and time performance analysis with the different configurations to support the selection of suitable polices and parameters of the operations network is less addressed in the research
• Optimal allocation and routing to minimize the total allocation and routing costs for the set of vehicles with upper bound on the vehicle resource and restriction is less addressed in the research

• Optimal allocation and routing of vehicles to pick-up the customers with capacity constraint in the vehicle and within the stipulated time windows is less addressed in the research

• Optimal allocation and routing for the vehicles with the objective of minimizing the total distance by considering the constraints on time windows and bound on resource by covering delivery service during the linehaul and the collection / pick-up service during the backhaul is less addressed in the research

The objective of this research to address all these new variants and to propose suitable comparative solution methodologies leveraging heuristics of meta-heuristics or combination approaches.

2.4 SUMMARY

This chapter presents a survey of literature on the selected and complex RA variants of supply chain network. It also highlights a report on variants, methodologies and applications that call for further investigations. The gaps identified literature provided the motivation for the issues addressed in this thesis.