Vehicle Routing and Shipment Consolidation in a 3PL DC: A Systematic Literature Review of the Solution Approaches

H.D.W. Weerakkody, A. Wijayanayake and D.H.H. Niwunhella
Department of Industrial Management,
University of Kelaniya,
Kelaniya, Sri Lanka.
weerakko_im15043@stu.kln.ac.lk, anni@kln.ac.lk, hirunin@kln.ac.lk

Abstract

Many of the manufacturing companies tend to outsource their logistic activities to third party logistics (3PL) providers due to numerous benefits they could obtain. Since 3PL providers provide their distribution services for multiple clients at the same time, managing these activities properly with an optimized cost is challenging for them. So, they are much interested in minimizing the distribution cost which will ultimately benefit the 3PL provider, and thereby the client as well. Shipment consolidation is one of the best and effective cost reduction strategies which could be followed by the 3PL firms, when distributing goods of multiple clients. Vehicle Routing Problem (VRP) which is a well-discussed problem in the literature can be applied here since it is beneficial for the 3PL providers to find the optimal routes to distribute the goods from the central 3PL Distribution Center (DC), while consolidating shipments of multiple clients. Therefore, this literature survey has been carried out to analyze the solution approaches, used in the literature related to VRP and shipment consolidation such that it would help in future research in developing a model to optimize the distribution in a 3PL DC by consolidating shipments of multiple clients. The results of the study have shown that most of the referred papers have used metaheuristic algorithms in solving their models and when the number of nodes are larger, it is suitable to use metaheuristic algorithms. Therefore, it can be concluded that a metaheuristic algorithm would be appropriate when developing a model to optimize the distribution in a 3PL DC by consolidating shipments of multiple clients.

Keywords
Consolidation, Third-party logistics, Vehicle Routing Problem, Metaheuristic algorithm

1. Introduction

Vehicle Routing Problem is one of the most discussed problems found in the literature in the field of Operations Research, where the objective is to find the optimal design of routes, in order to serve a set of geographically dispersed customers by a fleet of vehicles. It has gained a lot of attention among the researchers for the last few decades due to its complexity, and since it contains many variants and extensions by adding different constraints to the problem. Few of such variants are Capacitated Vehicle Routing Problem (CVRP) where the capacity of the vehicles is imposed as a constraint, Vehicle Routing Problem with Time Windows (VRPTW) where the customer must be served within a specific time interval. A lot of attention to research work has been paid for VRP and several techniques on exact methods and the heuristic and metaheuristic algorithms have been proposed and developed in solving the VRP. (Ibrahim et al., 2019). Third-party logistics providers (3PLs) are a team who are excelled in handling the logistics activities such as warehousing, distribution on behalf of the manufacturing companies. Most of these manufacturing companies tend to outsource their logistic activities to 3PL providers, due to the numerous benefits they could obtain namely, they could focus on their core business activities, cost burden could be alleviated. Since the distribution of goods of their multiple clients in a 3PL Distribution Centre (DC) is handled by the 3PL providers, they are much interested in minimizing the distribution cost which will ultimately benefit the 3PL provider and thereby the client as well.
Since 3PL service providers provide their distribution services for multiple clients at the same time, managing these activities properly with an optimized cost is challenging for them. Scheduling the vehicles and planning the routes is an important part of the process of reducing distribution costs. According to Hanbazazah, Abril, et al. (2019), one effective cost reduction strategy that has been used by 3PL companies is freight consolidation. By consolidating goods of multiple clients sent to the same region and distributing them together, 3PL providers could gain not only the benefit of cost reduction but also could reduce the impact on the environment since CO_2 emission will be less. Ghaffari-Nasab et al. (2015) states that the application of consolidation by 3PL companies is a new research area and deserves more attention.

Therefore, this study has been carried out with the objective of analyzing the solution approaches used in the literature related to VRP and shipment consolidation such that it would help in future research in developing a model to optimize the distribution in a 3PL DC by consolidating shipments of multiple clients. The approaches such as exact optimization, heuristic or metaheuristic algorithms used to obtain solutions in the literature have been discussed in this study. The findings of this study will help future research to consider suitable approaches when solving a model developed to optimize the distribution in a 3PL DC by consolidating shipments of multiple clients.

The rest of this paper is structured as follows. Section 2 provides the methodology used in the study followed by the results obtained from the literature survey in section 3, analysis of the solution approaches and discussion in section 4 and the paper concludes with the conclusion given in section 5.

2. Methodology

The systematic literature review was based on the content analysis to the shipment consolidation of multiple clients in a 3PL DC and the vehicle routing to optimize the distribution. Thus, the articles related to shipment consolidation and VRP have been selected from different academic databases like Science Direct, Research gate, Google Scholar. From the initial web search using the selected keywords in the study area, articles published very recently, after 2010 has been filtered. 39 articles were selected for the analysis from the final review. The flow diagram of the methodology could be summarized as in the Figure 1.

An analysis was then carried out based on the solution approaches used in the past literature which includes exact optimization, heuristic and metaheuristic algorithms. Computational time required for different algorithms and the number of nodes used for analysis in those studies were taken into consideration when doing this study. Further, some existing gaps in the literature related to this problem is highlighted in the study which will be elaborated later.

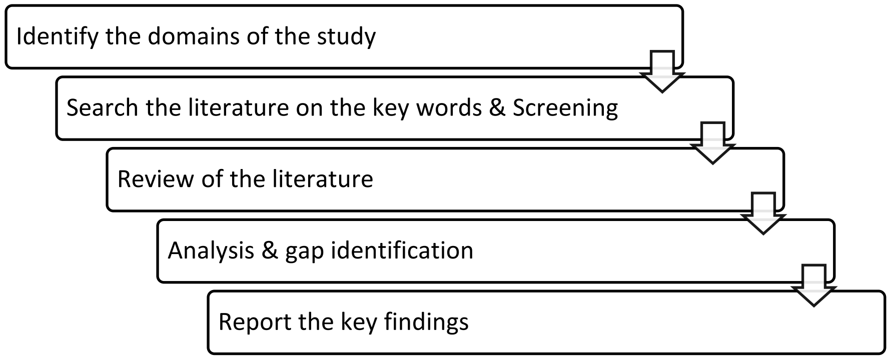

Figure 1. Flow diagram of the methodology

3. Results obtained from the Literature Review

3.1 Shipment Consolidation

A study was conducted on logistics network design problems to minimize the total logistics costs for the network while establishing consolidation hubs where the shipments are collected from several suppliers, consolidate them and direct them to the appropriate manufacturing plants. An integer linear optimization model has been formulated and the study further illustrates solving it using Lagrangian relaxation algorithm. (Cheong et al., 2007)
The study was conducted by (Birim, 2016) on VRP with Cross-Docking where the goods from several suppliers are consolidated in a cross-docking and distributed to customers considering their demands. In this problem, the authors have considered a heterogeneous fleet of vehicles. In Cross Docking goods from an inbound carrier are transferred to an outbound carrier where the goods are not stored in the warehouse. So, the inventory holding role is eliminated and at the same time products can be classified according to demand patterns and loaded to delivery vehicles. This has been conducted in two parts where the first goods are taken from the suppliers and delivered to the cross-dock where they are consolidated for the delivery. Second consolidated products are delivered to the customers based on the demands. The mathematical model formulated in the study has the objective to minimize the total transportation costs and the fixed costs of the vehicles. Since the authors have considered the two instances as picking up from suppliers and delivering to customers, the constraints have been developed on considering the vehicle capacities, successive move of vehicles and so on. A simulated annealing algorithm, which is a metaheuristic has been proposed to solve this problem and it had shown solutions that are reasonable in terms of computational time and best cost values. The study further suggests that split deliveries, multiple products, and time horizon may also be adapted to the model.
The study conducted by (Ma et al., 2016) on optimizing the container size and consolidating shipments which improve the carbon efficiency has suggested two models to minimize carbon emission. First, the authors have suggested a model for the Container Size Optimization (CSO) problem that minimizes the carbon emission by considering the selection of ideal sizes of containers for the shipment volume and determines the optimal number of containers that satisfies the shipment volume. As the second model, consolidation of shipments within a country (CSC) is proposed and thereby minimizes the overall carbon emission. It has been implemented using AIMMS and has been validated using a real-world dataset. Further research has been suggested by adding real-world considerations such as production schedules, trucking costs and constraints to be considered when consolidating shipments.
The study conducted by (Simoni et al., 2017) has considered locating urban consolidation centers (UCCs) where deliveries from logistic companies are dropped off, sorted, and consolidated into smaller vehicles. This leads to advantages such as more environmentally friendly vehicles than trucks could be used, decreased amount of traffic in the urban areas. The model has been formulated as a mixed integer linear program(MILP) where the decision variables used were, whether to use a facility or not, the number of certain vehicle types to be used, characterized by different capacities, speeds, costs and emissions and the routes to be taken to serve all customers. The model has been divided into two sub-models to solve the location and vehicle routing components separately where the first model ensures the best configuration of UCCs and the customers assigned to each UCC. The second model which has vehicle routing components has been treated to identify the best routes and vehicles to serve the customers from the facilities identified from the first model. Genetic Algorithm (GA) which is a metaheuristic technique has been adopted to solve the models.

A study was conducted on Freight Consolidation by (Hanbazazah, Abril, et al., 2019) which considered divisible shipments, delivery time windows, and piecewise transportation costs. The study has been conducted as an in-transit freight consolidation problem in a two-echelon transportation network, where products are transshipped by a 3PL company from multiple suppliers to a single customer via consolidation facilities. The study initially presents a binary mixed-integer linear programming model that incorporates piecewise transportation cost structure, delivery time windows and FCL consolidation for the time constraint, divisible shipments freight consolidation problem. The model proposed in the study has the objective to minimize the total cost of shipments from multiple suppliers to a single customer via multiple gateways and it has incorporated three types of constraints; piece-wise cost structure, flow balance and supply-demand parity. The authors have identified that, though the model could be used to solve small to medium size problems, real-life large size problems need increasing computational time requirements. So, the authors have suggested an exact solution algorithm referred to as the 3PD algorithm which composes 3 phases as container load relaxation, temporal decomposition, and valid cut generation. The proposed algorithm has been proved to solve realistic problems using a case study and a sensitivity analysis on several parameters such as time windows, LCL costs, demand structures has been conducted. The study elaborates that the proposed 3PD algorithm is more effective with shorter delivery time windows and lower LCL costs.
A study conducted by (Hanbazazah, Castro, et al., 2019) on in-transit freight consolidation with the indivisible shipment (FCIS) which is a problem faced by 3PL providers, has proposed a mixed-integer linear programming model. Indivisible shipments mean the shipments cannot be split into multiple lots and assigned to separate routes. Since it is solvable only for small-sized problems using commercial solvers, a heuristic has been developed which decomposes the problem into multiple small subproblems. The paper concludes with the effectiveness of the proposed model solved with a large-scale problem.

3.2 Vehicle Routing Problem (VRP)

Vehicle Routing Problem is a well-discussed problem in the field of Operations Research which is an extension of the travelling salesman problem. It can be described as finding the optimal design of routes to serve a set of geographically dispersed customers by a fleet of vehicles. There are many variants of VRP out of which two of them will be discussed in this paper; VRPTW and Multiple products and Compartment-related VRP. Since the consolidation of shipments of multiple clients is the major problem discussed in this paper thus it is concerned with multiple products, Multiple product and Compartment related VRP is considered here with the VRPTW, since it is essential to satisfy the demands of multiple clients in a given time. This study has been carried out to identify how the models have been formulated and solved in the literature and the approaches used in them.

3.3 Multiple products and compartment related VRP

The study conducted by (El fallahi et al., 2008), has considered the VRP with multi-compartments. In their study, the authors have considered the problem where customers can order several products, and the vehicles contain several compartments, but one compartment is dedicated to one product. A memetic algorithm and a tabu search algorithm have been proposed in the study. A study has been conducted by (Hasani-Goodarzi & Tavakkoli-Moghaddam, 2012) on split VRP with capacity constraints for multi-product cross-docks. In VRP with split deliveries, customers can receive goods in multiple shipments, so the customer can be served more than one vehicle. A mathematical model has been proposed to optimize the total operational and transportation cost. GAMS software has been used to obtain solutions for this problem in small-sized instances.
Asawarungsaengkul et al. (2013) has conducted a study on Multi size compartment VRP with a split pattern where the distribution of multiple types of fluid products to customers has been considered. The authors have mainly focused on splitting the order quantities and loading each split demand to the compartments with different capacities and then determine the optimal routes. The paper has proposed three mathematical models and solution procedures of an optimization approach using CPLEX, 2-opt algorithm, and clustering technique. The study conducted by (Zhang & Chen, 2014) on VRP in the frozen food distribution has proposed a model to optimize the total cost including transportation, refrigeration, penalty, and cargo damage cost. A heuristic-based genetic algorithm has been proposed to solve the model. The paper concludes that the proposed GA method can provide sound solutions in a reasonable time span.
A study has been conducted by Kabcome & Mouktonglang (2015) on VRP for multiple product types, compartments, and trips with soft time windows. A soft time window is a special case of time windows where the time windows can be violated if a penalty is being paid. The mathematical model proposed in the study has been developed in 3 cases as

in the first case VRP for multiple product types, compartments, and trips and not considering time windows. In the second case time window is considered while in the final case, a soft time window is considered. The model proposed in this study contains lots of constraints since the study deals with several aspects of VRP. A set of data obtained from literature was used to validate the model while AIMMS software has been used to obtain the solution.
The study conducted by (Chowmali & Sukto, 2020) on a multi-compartment VRP with a heterogeneous fleet of the vehicle has proposed a model to minimize total driving distance using a minimum number of vehicles. A heuristic algorithm has been proposed in the paper which had shown effective results in solving the model. A study conducted on Fuel Replenishment Problem by Wang et al. (2020) has considered the multi-compartment VRP with multiple trips to determine the routing of vehicles and the allocation of multiple products to vehicle compartments. The proposed MILP model in the study has been solved using CPLEX and an Adaptive Large Neighborhood Search (ALNS) heuristic algorithm which had given optimal solutions much faster than the exact MILP model using CPLEX.

3.4 Vehicle Routing Problem with Time Windows (VRPTW)

Vehicle Routing Problem with Time Windows (VRPTW) is an extension of the general VRP where it is required to satisfy the customer order in a given specific time window. A study has been conducted by (Nazif & Lee, 2010) on applying a genetic algorithm to VRPTW. The genetic algorithm proposed has been tested and compared with other heuristics proposed previously which had shown better results in terms of quality of the solutions given.
The study (Agra et al., 2013) has considered a robust optimization of vehicle routing problems with time windows where the travel times are stochastic. For example, in maritime transportation, there are frequent delays which should be taken into consideration. The authors have proposed two new formulations for the problem which were being solved using a branch-and-cut algorithm and column-and-row generation algorithm. The paper concludes that the results of the two formulations are similar while it was significantly faster than previously proposed formulations. Bae & Moon (2016) has conducted a study on multi-depot VRPTW. The authors have considered the problem of scheduling installation vehicles for electronics through synchronization with delivery service vehicles from multiple depots. A heuristic algorithm and a genetic algorithm have been developed to obtain the solutions for the developed mathematical model in the study. The paper concludes with the results demonstrating that the algorithms proposed can efficiently be used to solve problems with large instances.
In the study conducted by Afshar-Nadjafi & Afshar-Nadjafi (2017) on time-dependent multi-depot VRP, a hard time window constraint for the customers has been considered. The problem also considers a heterogeneous fleet of vehicles. A mixed integer programming model has been formulated and a heuristic method has been proposed to solve it. The performance of the proposed algorithm has been compared with the results obtained from Lingo which had shown that the algorithm is efficient to give a satisfying solution.
Overview of the literature review is given in Figure 2.

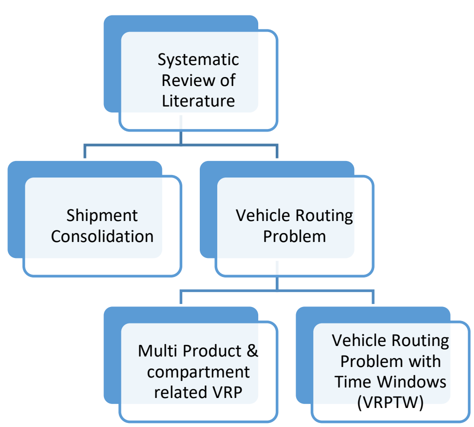

Figure 2. Overview of the literature review

Table 1 summarizes the articles reviewed in the study with the solution approaches used. The articles are categorized as shipment consolidation, multi-product and compartment related VRP and VRPTW.

Table 1. Summary of articles reviewed with the solution approaches

Category	Solution Approach	Articles
Shipment Consolidation	Exact	(Ma et al., 2016) (Dondo et al., 2011) (Perboli et al., 2010)
	Heuristic	(Cheong et al., 2007) (Hanbazazah, Abril, et al., 2019) (Hanbazazah, Castro, et al., 2019) (Crainic et al., 2011) (Perboli et al., 2011)(Mesa-Arango & Ukkusuri, 2013)
	Metaheuristic	(Perboli et al., 2011) (Simoni et al., 2017) (Kargari Esfand Abad et al., 2018) (David et al., 2017)
	Other	(Van der Heide et al., 2018) (Turkensteen & Hasle, 2017)
Multi-product & compartment related VRP	Exact	(Hasani-Goodarzi & Tavakkoli-Moghaddam, 2012) (Kabcome & Mouktonglang, 2015)
	Heuristic	(Asawarungsaengkul et al., 2013) (Zhang & Chen, 2014) (Wang et al., 2020) (Chowmali & Sukto, 2020)
	Metaheuristic	(El fallahi et al., 2008)
VRPTW	Exact	(Agra et al., 2013) (Qureshi et al., 2010) (Oesterle & Bauernhansl, 2016)
	Heuristic	(Afshar-Nadjafi & Afshar-Nadjafi, 2017) (Hu et al., 2013) (Guerriero et al., 2014)
	Metaheuristic	(Bae & Moon, 2016) (Nazif & Lee, 2010) (Balseiro et al., 2011) (Liu & Lee, 2011) (Buhrkal et al., 2012) (Sivaram Kumar et al., 2014) (Dhahri et al., 2014) (Yan & Zhang, 2015) (Pace et al., 2015) (Dhahri et al., 2016) (Alvarez & Munari, 2017)

4. Results Analysis and Discussion

The study was conducted on VRPTW, VRP with multiple products and compartments and Shipment consolidation where 39 papers were used from the final screening for the analysis. The solution approaches used in these articles can be mainly divided into three types, exact methods, heuristic approaches, and metaheuristic approaches. Table 2 shows the solution methods with the number of articles in the referred papers while Figure 3 shows it using the percentages. It is noted that most of the papers have used metaheuristics-based algorithms and approaches to solve the models related to multiple products and compartment related VRP, VRPTW and consolidated shipments. Some of the metaheuristics used, were Genetic algorithms, tabu search, simulated annealing. Since VRP related problems are NP-hard problems (nondeterministic polynomial hard problem), it is evident that metaheuristics approaches are suitable to obtain solutions within a reasonable time which may not give the optimized results.
Furthermore, the analysis shows that, most of the articles which had used exact optimization has considered a dataset with a lesser number of nodes such as 15 nodes. Most of the studies with heurstic approaches have used datasets with around 50 nodes, while metaheuristic studies have used datasets with large number of nodes which is more than 100 in many cases. When the number of nodes or customers increases, the complexity of the problem indeed increases. Therefore, it can be noted that, most of the studies with datasets which has large number of nodes have used metaheuristics to solve the problem.

Table 2. No. of articles referred

Solution Approaches	No. of Articles in the referred literature
Exact	8
Heuristic	13
Metaheuristic	16
Other	2
Total	39

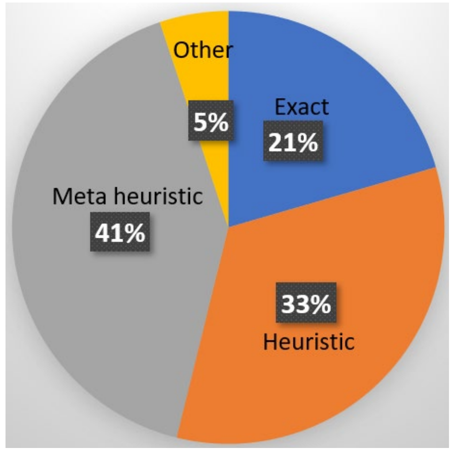

Figure 3. Solution methods used in referred literature

Table 3 shows some of the algorithms used in the referred papers with their relevant problem. It is visible that most of the papers have used Genetic algorithm based algorithms to solve the related problem.

Table 3. Algorithms used with the relevant article and problem

Solution Algorithm	Article	Problem Discussed
Tabu Search	(El fallahi et al., 2008)	Multi-compartment VRP
	(Liu & Lee, 2011)	Inventory routing problem with time windows (IRPTW)
	(Jia et al., 2013)	VRP
	(Gmira et al., 2021)	Time-dependent VRP
Memetic Algorithm	(El fallahi et al., 2008)	Multi-compartment VRP
Simulated Annealing	(Pace et al., 2015)	Heterogeneous Fleet CVRPTW and Three-Dimensional Loading Constraints (3L-HFCVRPTW)
	(Birim, 2016)	VRP with Cross Docking
Genetic Algorithm	(Zhang & Chen, 2014)	VRP in frozen food distribution
	(Nazif & Lee, 2010)	VRPTW with limits on capacity and travel time
	(Bae & Moon, 2016)	Multi-depot VRPTW (MDVRPTW)
	(Sivaram Kumar et al., 2014)	Multi-objective VRPTW
	(Yan & Zhang, 2015)	Multi-objective VRP with soft time-window
	(Simoni et al., 2017)	Multi-depot VRP with heterogeneous vehicle fleet problem (MDHFVRP)
	(Kargari Esfand Abad et al., 2018)	Pickup and delivery pollution-routing problem with integration & consolidation shipments
Lagrangian relaxation	(Cheong et al., 2007)	Logistics Network Design with Supplier Consolidation Hubs and Multiple Shipment Options
Adaptive large neighborhood search (ALNS)	(Wang et al., 2020)	multicompartment, multi-trip, split delivery VRP
	(Buhrkal et al., 2012)	Waste Collection VRP with Time Window (WCVRPTW)
Variable neighborhood search	(Dhahri et al., 2014)	VRPTW
	(Dhahri et al., 2016)	VRPTW with preventive maintenance constraints (VRPTW-PM)
Ant colony	(Balseiro et al., 2011)	Time-Dependent VRP with Time Windows (TDVRPTW)

Table 4 given below shows those algorithms with the number of papers. Figure 4 shows the same in the graphical form. It is visible that most of the papers have used genetic algorithm in this process, which is a metaheuristic suitable for generating high-quality solutions for optimization and search problems.

Table 4. Summary of solution algorithms used in the literature

Solution Algorithm	**# of Articles in Referred literature**	**Percentage**
Tabu	4	20%
Memetic	1	5%
Simulated Annealing	2	10%
Genetic Algorithm	7	35%
Lagrangian relaxation	1	5%
adaptive large neighborhood search (ALNS)	2	10%
variable neighborhood search	2	10%
Ant colony	1	5%

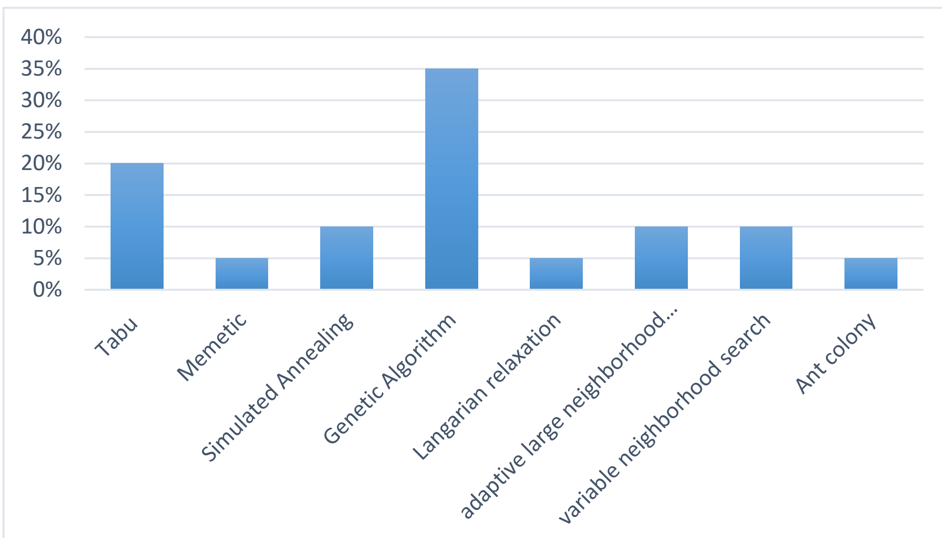

Figure 4. Some algorithms used in referred literature

Computational time required to solve a problem using an algorithm is one of the best ways to assess the performance of the algorithm. Computational time depends on the number of the nodes or customers used in the dataset where it increases exponentially when the number of customers increases.(Bae & Moon, 2016).
It is a challenge to compare the time taken by different algorithms in different studies since it usually depends on many factors. Number of nodes used for the data analysis one such factor which is also different in many studies. Some of the studies have not mentioned the computational time taken in their studies. In such case, it is very hard to compare the time taken for algorithms in different studies.

From the study, it was identified that, the suitable approach to be followed would depend on the number of nodes or customers in the dataset. Based on the referred literature, it was noted that, exact optimization would be better if the number of nodes are lesser which is usually 15. When the number of nodes are around 50, heuristic approach is better while metaheuristic algorithms are preferred when the number of nodes are more than 100. This is due to the complexity of the problem increases when the number of nodes increases. Figure 5 summarizes the above situation and the average computational time taken for three different metaheuristic algorithms are shown when the number of customers are 100. From the below figure, future researchers can get an understanding on the solution approach to be followed depending on the number of customers in the study.

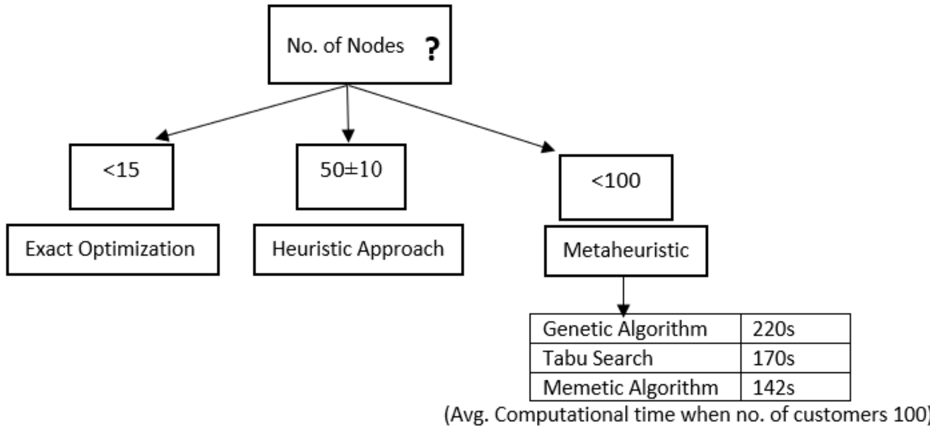

Figure 5. Approach to be followed based on no. of nodes

5. Conclusion

The consolidation of shipments of multiple clients when distributing their goods is one of the effective cost reduction strategies that could be followed in a 3PL DC. This literature survey has been carried out with the objective of analyzing the solution approaches used in the past literature which could be incorporated when optimizing the distribution in a 3PL DC by consolidating shipments of multiple clients. Since this is concerned with the VRP and shipment consolidation, the analysis was conducted on the papers related to VRPTW, multiple products and compartment-related VRP and shipment consolidation. The analysis has shown that most of the papers have used metaheuristics and heuristics-based algorithms when solving the models related to the above problems. This is because, VRP related problems are NP-hard in nature, therefore metaheuristic algorithms are more sutaible since solutions can be obtained in a reasonable computational time. It was also noted that, Genetic algorithm has been used in many of the papers. Furthermore, it was identified that most of the studies with datasets which has large number of nodes have used metaheuristic algorithms. The paper suggests that exact optimization is suitable when the number of nodes is less than 15 while heuristic approaches are suitable when the number of nodes are around 50. When the number of nodes are more than 100 which forms a complex problem, metaheuristic algorithms such as genetic, tabu search or memetic algorithms are better approaches to be used. The paper concludes that a metaheuristic algorithm would be appropriate when developing a model to optimize the distribution in a 3PL DC by consolidating shipments of multiple clients. However, some challenges were existed when conducting the analysis such as difficulty to compare the computational time required by different algorithms in the literature. Furthermore, this study identifies that still there is room for improvement or gaps to address. It is well noted in reality when consolidating shipments where the product categories are not compatible or though the product categories are compatible and homogeneous yet the competitive brands are not allowed to distribute together, the 3PL service providers has their own difficulties in managing their disributions when such restrictions are imposed. Most of the times the vehicles were not upto the full truck load to meet such restrictions. Therefore, these important aspects are yet to address for future research.

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6423(14)72340-5

Biographies

H.D.W. Weerakkody is a final year undergraduate reading for B. Sc. (Honours) in Management and Information Technology in the Department of Industrial Management, University of Kelaniya, Sri Lanka.

Annista Wijayanayake received her Doctor of Engineering and Master of Engineering in Industrial Engineering and Management, specializing in Financial Engineering from Tokyo Institute of Technology Japan, respectively in 2001 and 1998. Currently she is serving as a Senior Lecturer at the Department of Industrial Management, University of Kelaniya- Sri Lanka. She had served as a honorary Research Fellow at Royal Melbourne Institute of Technology (RMIT) Australia in 2004 and as a lecturer, at the Faculty of Economics and Business and Faculty of Information Technology Monash University-Australia from 20017-2019. Also, she had served as an Academic Advisor for B.Sc. in Management and Information Technology degree programme, University of Kelaniya from 2003-2008. She won many international awards for her research and teachings. She received the academic excellence award for her Master's degree by research by Tokyo Foundation- Japan for Inbound Students. She also received the 2019 teaching excellence award from the Department of Econometrics and Business Statistics - Monash University for her teachings. Her research has been featured in prestigious journals such as Mathematical Programming, International Journal of Theoretical and Applied Finance, Journal of Global Optimization and in many International Conference Proceedings.

D. H. H. Niwunhella is a Lecturer in the Department of Industrial Management, University of Kelaniya, Sri Lanka. She received the B.Sc. (Honours) in Management and Information Technology from the University of Kelaniya, Sri Lanka, specialized in Business Systems Engineering and was awarded as the best graduating student in 2018.