Multi-Objective Integrated Green Lot Sizing and Vehicle Routing Model: A Framework

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Abstract

Economic concerns and laws regarding environmental awareness are the main reasons that have changed the dimensions of supply chain networks with environmentally friendly production and efficient transportation. Due to this, numerous studies have begun to focus on resolving environmental issues, particularly in the supply chain sector, where production and transportation are among the most significant contributors to emissions. This paper proposes a framework for developing a two-stage supply chain model with integrated optimization for solving the green inventory and transportation problems in the capacitated single supplier and multi-customer. This methodology integrates a lot-sizing model, vehicle routing model, and optimization procedure-based meta-heuristic for building a research methodological framework. This framework supports supply chain network analysis, modeling, and decision-making to improve economic and environmental performance.

Keywords: Lot sizing, Vehicle routing problem, Genetic Algorithm Optimization, Emission.

1. Introduction

Climate change and its effects on the earth and people are attracting significant attention, posing a threat to the human population's economic stability and quality of life. GHG emissions, which increase with industrialization owing to increased production and consumption, significantly impact climate change. Behind that is a business motive to increase income by meeting human needs. On the one hand, it can increase the burden of environmental degradation, which has fueled the need to integrate environmentally sound options into supply chain management research and practice. As a result, this is one strategy for assisting developed and developing countries to meet their obligations to carry out industrial activities for the next 150 years by setting more ambitious targets for decreasing environmental consequences, particularly GHG emissions.

In supply chain activities, production and transportation are the major contributors to GHG emissions (Absi et al., 2013; Elhedhli & Merrick, 2012; Kermeli & Weer, 2015; Sarkar et al., 2016). Both activities are associated with stock items (inventory), including processing material to create the stock and transferring between stock locations (Bonney & Jaber, 2011). Since these activities require energy/ resources to operate the engine, which emits emissions directly, it is vital to improve the ideal supply configuration that enables a business to maximize economic and environmental performance. As a result, many companies have started tracking their GHG emissions to assess how their operations affect the environment. The traditional production and distribution model strongly emphasizes reducing costs involved by operational limitations. Taking into account green supply chain objectives and restrictions will result in new issues and new combinatorial optimization models. As a result, eco-friendly supply chains must be designed effectively and efficiently to better the environment and the company's bottom line.

One of the ways to track GHG emissions in production and transportation is by considering the lot-sizing problem and Vehicle Routing Problem (VRP) with environmental parameters. Lot sizing refers to placing the required order/production quantity to meet future demands. When making this decision, it is essential to consider nonrenewable resources (coal, oil, natural gas, etc.) or activities that affect emissions. Due to the globalization of the supply chain, the distance between nodes in the distribution network has become an essential factor. Longer travel distances cause a rise in vehicle emissions on transportation routes, expanding GHG emissions. Based on both problems, thus, organizations that previously just considered operational costs must now reconsider their strategy to ensure the environmental sustainability of their operations. In parallel with this strategy, Green Supply Chain Management (GSCM) is introduced. GSCM's environmental considerations are included in all aspects of supply chain management, including product design, material sourcing and selection, production process, final product delivery to consumers, and product end-of-life management after its useful life (Srivastava, 2007).

As discussed previously, the necessity for companies to monitor their GHG emissions is becoming an increasingly attractive topic of study. This monitoring must align with production and distribution planning models that account for GHG emission limitations. The integration of environmental restrictions can be considered at several decision levels (strategic, tactical, and operational) depending on a company's goals (Absi et al., 2013). Designing supply chain networks or choosing a location for a factory or warehouse to have an impact on green restrictions and goals at the strategic level. GHG emissions can be considered while making decisions about production and distribution at the tactical level. GHG emission restrictions can be linked to decisions about production scheduling or VRP at the operational level. Therefore, this research proposes a methodological framework for integrating lot sizing inventory and VRP models to solve production and transportation problems while optimizing supply chain costs and GHG emissions. This model framework provides direction in developing decision models for lot sizing-based production at the tactical level and transportation under VRP at the operation level. Since two objectives must be achieved in an integrated model, this framework discusses addressing multi-objective optimization problems.

The outline of the paper is as follows. Section 2 provides literature reviews on lot sizing and VRP under consideration of GHG emissions. Moreover, the methodological framework for integrating lot sizing and VRP under GHG emission consideration is introduced in Section 3. The last section provides a conclusion and a discussion of certain aspects of this study.

2. Literature Review

Research on including GHG emission constraints in planning production and transportation models is expanding quickly. This section separates the two areas of the literature under consideration—lot sizing and VRP. This section concludes with a gap statement based on studies in both domains.

2.1 Lot sizing

One of the most significant and challenging issues in production planning is lot sizing. Production planning is a process that examines how to use production resources most effectively to achieve production goals over a predetermined time frame, known as the planning horizon (Goren et al., 2010). In production model research, Benjaafar et al. (2013) were the first to include GHG emission restrictions in lot sizing. The authors emphasize that operations management studies should consider this because operational decisions may impact GHG emissions. Absi et al. (2013) examined the multi-period lot sizing problem by considering deterministic demand, constant and variable inventory holding costs, and production and transportation costs. Their studies defined four alternative scenarios and described the emission function as a constraint: (1) periodic GHG emission constraint; (2) cumulative GHG emission constraint; (3) global GHG emission constraint; and (4) rolling carbon emission constraint.

Unlike Benjaafar et al. (2013), Bouchery et al. (2012) were the first to consider emission factors in the objective function of the Economic Order Quantity (EOQ) inventory model consisting of inventory holding as an objective function along with a cost function. Moreover, Absi et al. (2016) proceeded with their research by suggesting a single-item lot size problem with periodic carbon emission caps. In each selected mode period, fixed carbon emissions occur, such as activities linked with product packaging for the corresponding mode. Helmrich et al. (2015) investigated a generalization of the lot-sizing problem that incorporated emission capacity restrictions. In addition to the typical cost functions, emissions are associated with production, inventory, and production management. The model is NP-hard and requires several alternative solutions. They present an approach that can handle fixed-plus-linear cost structures and more general emission and concave cost functions, notably a Lagrangian heuristic, a pseudo-polynomial algorithm, and a polynomial time approximation scheme.

Cheng et al. (2016) examined the legislation governing carbon emissions on conventional Inventory Routing Problems (IRP), where carbon emissions are caused by fuel use. Integer mixed-nonlinear programming models were developed, and linearization methods were utilized. A hybrid genetic algorithm based on first allocation and second routing is proposed to find a near-optimal solution to this issue. Lamba et al. (2019) provided a mixed integer nonlinear program (MINLP) for co-supplier selection by finding the right lot sizes in a dynamic environment with multi-period, multi-product, and multi-supplier, to reduce overall supply chain costs and carbon-related emission costs. Phouratsamay & Cheng (2019) examined a single-item lot size problem with inventory restrictions under carbon emission constraints with two options for producing the item: regular or green. To avoid exceeding the carbon emission constraint at any given period, the issue might be resolved by formulating an optimal production quantity.

2.2 Vehicle routing problem

Vehicle routing problems are used in transportation planning, such as road network design, road maintenance, bus and train schedules, and traffic control. These problems are complex and difficult to solve. The solutions are often approximate and susceptible to human error. These are the implications of human behavior in transportation systems- how vehicles move from one place to another and the carbon emissions they generate.

In transportation planning, route planners use computerized mapping systems to design new roads or revise current ones. They can use vehicle routing algorithms to optimize vehicle travel routes and determine the best transport modes for various destinations. It entails utilizing a heuristics or metaheuristic method to design efficient ways for a fleet of vehicles—routes that save more time or money. Besides that, reducing the routes shows that GHG emissions can be lowered.

The prior research on vehicle routes and GHG emissions may generally be divided into homogeneous and heterogeneous vehicle types. Heterogeneous vehicles have several characteristics that must be accounted for in designing efficient vehicle transport routes. These include capacity, speed, and fuel consumption which determine the vehicle’s cruising. Otherwise, homogeneous assumes that the capacity and shape of the delivery vehicle are identical.

Based on research on the homogenous VRP problem, Figliozzi (2010) devised an approach for addressing the problem that aims to reduce GHG emissions and fuel usage.To account for not just mileage but also GHG emissions, fuel consumption, travel time, and operating costs, Bektaş & Laporte (2011) solved a pollution routing issue that decides the route and speed of vehicles. Then, to address the issue, Demir et al. (2012) developed an adaptable big environment search heuristic, while Fukasawa et al. (2016) took into account continuous velocity and offered a disjunctive convex programming model with certain sound inequalities.

In the context of heterogeneous vehicle routes with GHG emissions, Kwon et al. (2013) showed that it is possible to reduce carbon emissions without sacrificing the total cost. It can be done by taking into account the heterogeneous vehicle routes that minimize the sum of vehicle operating costs and trade emission costs/benefits. Additionally, the issue of homogeneous route pollution was expanded upon by Koc et al. (2014) to include heterogeneous vehicles. Kopfer et al. (2014) proposed a strategy that concentrates on reducing GHG emissions emitted by transportation. They incorporated the option of selecting vehicles of various sizes for route fulfillment into Dantzig's traditional vehicle routing model to account for the observation that vehicles with varying maximal capacity values have variable payload-dependent fuel consumption attributes.

Moreover, Kim et al. (2019) solved the issue of determining a heterogeneous vehicle routing that satisfies the interaction between service, client demand, and vehicle capacity was taken into account. The objective is to reduce the total cost of operating a vehicle and the costs and benefits of trading carbon emissions. Trading costs are incurred to purchase carbon emission rights if total emissions exceed the maximum in a given period. At the same time, trading benefits can be obtained by selling ownership in a given period and vice versa.

2.3 Gap opportunities

Based on previous studies in sections 2.1 and 2.2, both lot sizing and VRP problems are modeled independently using mixed integer linear programming. As this logistic problem, most research is focused on optimizing the objective function, including economic and environmental. Although this stream research of both lot sizing and VRP model is growing interestingly and independently, they need to be combined due to their importance in efficiently dealing with the synchronization flow of material or product from production to distribution. However, both problems may be complex and difficult to solve if combined. It becomes a new challenge to model these two problems and their solution approach. Therefore, this study proposes a methodological framework for developing both lot sizing and VRP problems. This framework involves the decision variables and parameters of lot sizing and VRP modeled in two objective functions: costs and environmental. This framework can be a helpful guide to improve both functions, especially for environmental objectives, GHG emissions become essential to be handled due to their impact to the atmosphere and global warming.

3. Proposed a Methodological Framework

Before developing the methodological framework of integrated lot sizing and VRP models, both models should be first described independently.

3.1 Green Lot sizing model

The main features of the lot sizing model have been classified by Goren et al. (2010), as shown in Figure 1.

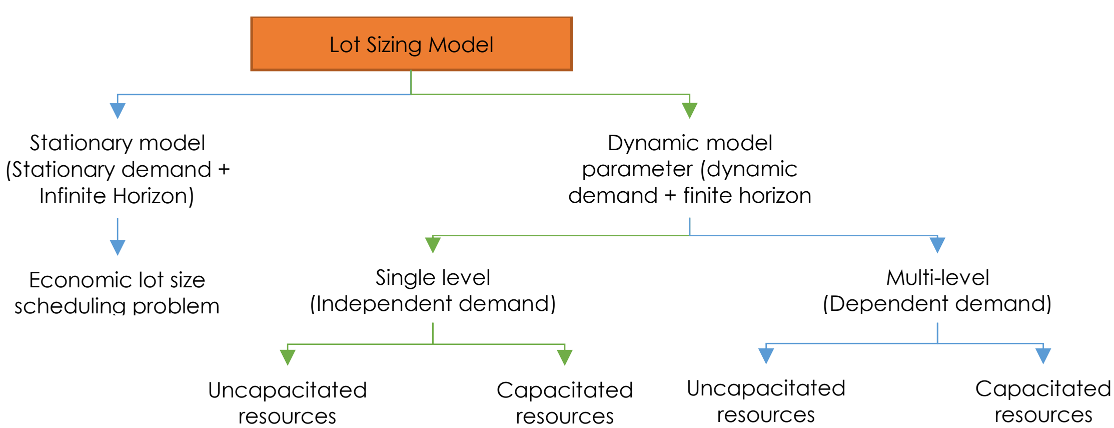

Figure 1. Features of lot sizing model (Source: Goren et al., 2010)

Most scholars on lot size acknowledge Economic Order Quantity (EOQ) as the fundamental idea of the inventory model for production planning. Nevertheless, it is known that the assumptions of the EOQ model do not reflect or cannot be applied to the actual situation. Thus, the lot sizing model is evolved to overcome inventory problems, mainly due to the problem of variable demand.

Based on Figure 1, the first category specifies the stationary lot sizing problem, precisely the Economic Lot Sizing Problem (ELSP). ELSP is related to planning the production of several goods in a single machine to reduce the typical long-term holding and setup costs under known demand and production rates. The second category is the dynamic lot sizing problem, which addresses dynamic demand within a finite planning horizon. The green line in Figure 1 defines the most usage model, which is a single level with a finite production capacity and one product over a certain period T, the dynamic lot size problem can be expressed as follows (Goren et al., 2010; Wagner & Whitin, 1958):

$$\text{Min} \sum_{i=1}^{T} S_i Y_i + C_i X_i + h_i I_i \quad (1)$$

s.t. $X_i + I_{i+1} - I_i = D_i$ $\quad (\forall \in T)$ $\quad$ (2)

$X_i \leq U_i Y_i$ $\quad (\forall \in T)$ $\quad$ (3)

$Y_i \in (0,1)$ $\quad (\forall \in T)$ $\quad$ (4)

$X_i, I_i \geq 0$ $\quad (\forall \in T)$ $\quad$ (5)

Eq. (1) represents a single-level lot sizing model with uncapacitated resources, where S_i is setup costs in period i, C_i is production costs per unit product in period i, h_i is holding costs for period i, Y_i is a binary variable that represents a product produced (1) and (0) otherwise in period i. Meanwhile, X_i is the production quantity variable that needs to produce in period i under consideration of U_i is the upper limit of production in period i. I_i is the level of inventory in period i which can obtained by considering demand D_i for each period i. The objective of Eq. (1) is to minimize all costs of setup, production, and inventory by optimizing the value of Y_i and X_i for each period i. In addition, the multi-level lot sizing problem is based on a single level where the items have a parent-component relationship. The result of one level serves as the input for another level.

The primary objective, costs, is the critical issue that needs to be minimized based on the lot sizing problem in Eq. (1). Moreover, GHG emissions, for example, need to be considered in the function for another objective. Generally, production quantity $X_i$and Binary Y_i variables that must be produced are related to the emission function. This is because every product that is produced causes GHG emissions. Emission occurs, for instance, during machine setup, electricity use, and combustion during the machining process. The relation of those variables to the emission function can be expressed as:

$$Min \sum_{i=1}^{T} \sum_{f=1}^{F} E_{if} \, (Y_i + X_i) \quad (6)$$

E_{if} represents the overall GHG emissions (CO_2) in period i and for each emission source f. In this instance, any emission source may be released during the production due to combustion, the use of electricity, or any other activities used for producing the amount of X_i and setup the machine (Y_i). Eq. (6) is just a simple Equation. In reality, the amount of X_i can be related to the production time of a unit product. For instance, the total production time can be obtained by multiplying X_i and the production time of a unit product (P_t). Following that, total production activity data can be derived and GHG emission due to production process can be precisely estimated. Therefore, E_{if} can be expressed as follows:

$$\sum_{i=1}^{T}\sum_{f=1}^{F}\sum_{g=1}^{G} E_{if} = A_{i,f}W_{f,g}\left(G_{CO_2} + G_{Ch_4} + G_{N_2O}\right) \quad (7)$$

The activity data obtained from the extension of X_i depending on the source of emission f is known as $A_{i,f}$=$X_i P_t$, where P_t is a production time of a unit product. $W_{f,g}$ is emission factor due to emission source f for each emission type, $g = \{G_{CO_2}, G_{Ch_4}, G_{N_2O}\}$. To convert each emission type g into CO_2, then it needs to multiply by the global warming potential $G_{CO_2} = 1$, $G_{Ch_4} = 27$, $G_{N_2O} = 273$. Therefore, we can obtain E_{if} with measurement unit in Kg or Ton CO_2e.

3.2 Green VRP model

Additionally, when planning distribution or transportation, researchers should consider parameters that describe the actual logistic problem or VRP, as illustrated in Figure 2. Most researchers consider five significant parameters while analyzing VRP: the number of depots or customers, the number of vehicles, time windows, capacity consideration, distance, and travel time (Erdoğan, 2017). VRP, which tries to reduce the cost of transportation by vehicle fleet operating out of a base called a depot, is one of the most often addressed optimization challenges in logistics. To achieve this, VRP is crucial for planning the shortest and fastest routes to produce minimal costs and emissions by considering all constraints in Figure 2. Transportation costs can be minimized under consideration of partial or full constraints in Figure 2 are satisfied.

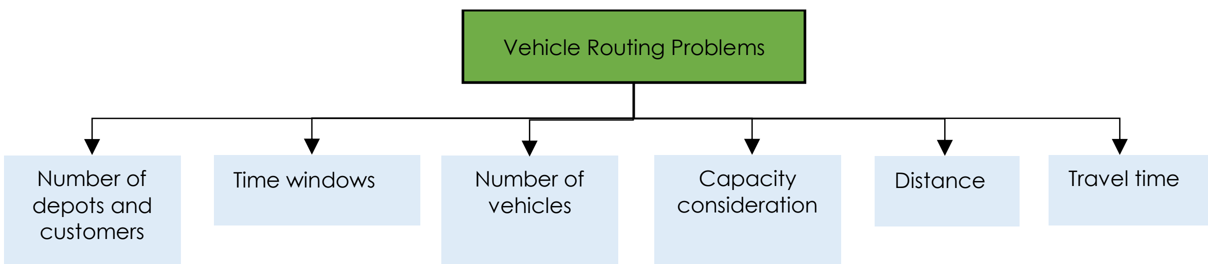

Figure 2. Features of vehicle routing problem (Source: Erdoğan, 2017)

The following formulation of the example of the VRP equation, which was obtained from Guo et al. (2022):

$$\text{Min} \sum_{k=1}^{K}\sum_{r=1}^{R}\sum_{j=1}^{J} V^C a_{i,j} N_{r,j,k} \quad (8)$$

$$\text{Min} \sum_{k=1}^{K}\sum_{j=1}^{R} N_{r,j,k} = 1 \qquad \forall_R \in N_c \quad (9)$$

$$\text{Min} \sum_{k=1}^{K}\sum_{r=1}^{R} N_{r,j,k} = 1 \qquad \forall_j \in N_c \quad (10)$$

$$\sum_{i=1}^{N_c} N_{0,j,k} = \sum_{i=1}^{N_c} N_{j,0,k} = 1 \qquad \forall_k \in K \quad (11)$$

$$q_r \le Q_{r,k} \le Q \qquad \forall_r \in N_c,\ k \in K \quad (12)$$

$$Q_{r,k} - Q_{j,k} + QN_{r,j,k} \le Q - q_j \qquad \forall_r,\ j \in N_c,\ k \in K \quad (13)$$

$$\sum_{k=1}^{K}\sum_{r=1}^{R}\sum_{j=1}^{J} m_{i,j} N_{r,j,k} \le M \quad (14)$$

$$N_{r,j,k} \in \{0,1\}, \forall_r, j \in N_c, r = j, k \in K \tag{15}$$

Eq. (8) aims to minimize transportation costs by determining the best routes. All notations and constraints from Equations (8) to (14) can be read with minor modifications (change in the notations and no multiple products) in Guo et al. (2022). In addition, if GHG emissions are included in Eq. (8), transportation based on GHG emission functions should be involved. There are a few emission functions for which the vehicle's speed controls GHG emissions from vehicles (Cai et al., 2021). Thus, the first problem is establishing a correlation between speed, fuel consumption, and emissions.

Moreover, Wang et al. (2019) and Liu et al. (2014) also used a transportation emission function based on the relationship between vehicle type, driving speed, vehicle weight, load, and distance. All these factors become activity data used to estimate GHG emissions. If such activity data is connected into to the formula in (8), then Eq. (7) can be used by modifying the notation $A_{i,f}$ according to the problem. Therefore, this important emission function should be included in VRP to represent the green logistic.

3.3 Framework of Integrated Lot Sizing and VRP models

Previous sections have discussed lot sizing and VRP models independently. Integrating green lot size and VRP models becomes a challenging supply chain problem. Integrated green lot sizing and VRP models might be referred to simply as IGLSVRP. Therefore, this paper provides a foundation for the reader to understand how to incorporate it, as shown in Figure 3.

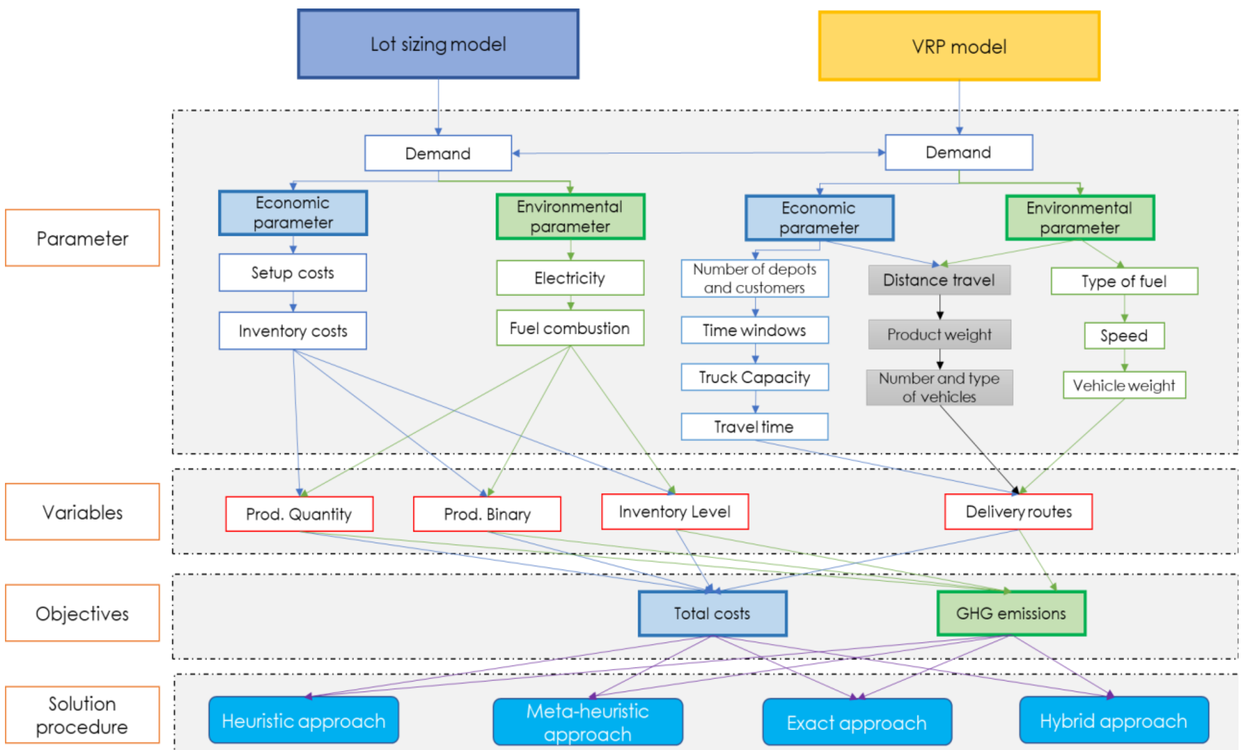

Figure 3. Integrated framework of green lot sizing and VRP model.

Figure 3 shows four elements in developing IGLSVRP: parameters, variables, objectives, and solution procedures. Sections 3.1 and 3.2 explored parameters and variables for the lot-sizing and VRP models, which we used to describe the production and distribution issues in the supply chain. It should be noted that the IGLSVRP can be developed if the parameter demands for the two models are combined. In this scenario, the demand or quantity ordered q_r for each customer is collected in D_i for the lot sizing model throughout a single period i. Based on this integration, the order of all customers will be processed in the lot sizing model; then, it will be delivered through the VRP model.

Additionally, a function is designed to describe the costs and GHG emission problem by combining parameters and variables in Figure 3. The objective of such a function is to minimize costs and GHG emissions through all operations in the supply chain by optimizing production quantity, production binary, inventory level, and delivery routes.

The IGLSVRP is thought to fall under operations research rather than operations management, despite its operational focus. It is inherently difficult to solve an IGLSVRP because of the complexity of the underlying solution algorithms and real-world implementation issues. Based on Figure 3, we can suggest that IGLSVRP might be solved by considering the solution procedures, including the heuristic, meta-heuristic, exact, and hybrid approaches. Therefore, IGLSVRP is very interesting to solve due to its model representing the practical problem in the supply chain.

4. Conclusion

Economic and environmental challenges in the supply chain are always a major concern for practitioners and researchers, particularly regarding production and distribution problems. Typically, researchers employ lot sizing models for production problems in which they attempt to optimize production quantities to reduce production and inventory costs. In the meantime, VRP is frequently linked to transportation issues to identify the best delivery routes and minimize transportation costs. On the other hand, the emission function has been incorporated into the lot sizing and VRP models in response to the escalating environmental challenges, particularly the recent rise in GHG emissions due to production and transportation operations. This study aims to develop a framework incorporating lot sizing and VRP models to resolve production and transportation issues. Thus, the goal of decreasing production, inventory, and transportation costs can be achieved. This framework includes potential parameters, variables, objective functions, and solution procedures that can be used to develop an integration model between lot sizing and VRP to generate optimal decisions. Lastly, this paper gives scholars and practitioners recommendations for using this framework to develop models to address supply chain issues.

References

Absi, N., Dauzère-pérès, S., Kedad-sidhoum, S., Penz, B., & Rapine, C. (2013). Lot sizing with carbon emission constraints. *European Journal of Operational Research*, *227*(1), 55–61. https://doi.org/10.1016/j.ejor.2012.11.044

Absi, N., Dauzère-Pérès, S., Kedad-Sidhoum, S., Penz, B., & Rapine, C. (2016). The single-item green lot-sizing problem with fixed carbon emissions. *European Journal of Operational Research*, *248*(3), 849–855. https://doi.org/10.1016/j.ejor.2015.07.052

Bektaş, T., & Laporte, G. (2011). The Pollution-Routing Problem. *Transportation Research Part B: Methodological*, *45*(8), 1232–1250. https://doi.org/10.1016/j.trb.2011.02.004

Benjaafar, S., Li, Y., & Daskin, M. (2013). Carbon Footprint and the Management of Supply Chains: Insights From Simple Models. *IEEE Transactions on Automation Science and Engineering*, *10*(1), 99–116. https://doi.org/10.1109/TASE.2012.2203304

Bonney, M., & Jaber, M. Y. (2011). Environmentally responsible inventory models: Non-classical models for a non-classical era. *International Journal of Production Economics*, *133*(1), 43–53. https://doi.org/10.1016/j.ijpe.2009.10.033

Bouchery, Y., Ghaffari, A., Jemai, Z., & Dallery, Y. (2012). Including sustainability criteria into inventory models. *European Journal of Operational Research*, *222*(2), 229–240. https://doi.org/10.1016/j.ejor.2012.05.004

Cai, L., Lv, W., Xiao, L., & Xu, Z. (2021). Total carbon emissions minimization in connected and automated vehicle routing problem with speed variables. *Expert Systems with Applications*, *165*(May 2020), 113910. https://doi.org/10.1016/j.eswa.2020.113910

Cheng, C., Qi, M., & Wang, X. (2016). Multi-period inventory routing problem under carbon emission regulations. *International Journal of Production Economics*, *182*, 263–275. https://doi.org/10.1016/j.ijpe.2016.09.001

Demir, E., Bektaş, T., & Laporte, G. (2012). An adaptive large neighborhood search heuristic for the Pollution-Routing Problem. *European Journal of Operational Research*, *223*(2), 346–359. https://doi.org/10.1016/j.ejor.2012.06.044

Elhedhli, S., & Merrick, R. (2012). Green supply chain network design to reduce carbon emissions. *Transportation Research Part D: Transport and Environment*, *17*(5), 370–379. https://doi.org/10.1016/j.trd.2012.02.002

Erdoğan, G. (2017). An open source Spreadsheet Solver for Vehicle Routing Problems. *Computers and Operations Research*, *84*, 62–72. https://doi.org/10.1016/j.cor.2017.02.022

Figliozzi, M. (2010). Vehicle routing problem for emissions minimization. *Transportation Research Record*, *2197*, 1–7. https://doi.org/10.3141/2197-01

Fukasawa, R., He, Q., & Song, Y. (2016). A disjunctive convex programming approach to the pollution-routing problem. *Transportation Research Part B: Methodological*, *94*, 61–79. https://doi.org/10.1016/j.trb.2016.09.006

Goren, H. G., Tunali, S., & Jans, R. (2010). A review of applications of genetic algorithms in lot sizing. *Journal of Intelligent Manufacturing*, *21*(4), 575–590. https://doi.org/10.1007/s10845-008-0205-2

Guo, N., Qian, B., Na, J., Hu, R., & Mao, J. L. (2022). A three-dimensional ant colony optimization algorithm for multi-compartment vehicle routing problem considering carbon emissions. *Applied Soft Computing*, *127*, 109326. https://doi.org/10.1016/j.asoc.2022.109326

Helmrich, M. J. R., Jans, R., Van Den Heuvel, W., & Wagelmans, A. P. M. (2015). The economic lot-sizing problem with an emission capacity constraint. *European Journal of Operational Research*, *241*(1), 50–62. https://doi.org/10.1016/j.ejor.2014.06.030

Kermeli, K., & Weer, P. (2015). Energy efficiency improvement and GHG abatement in the global production of primary aluminium. *Energy Efficiency*, *8*(4), 629–666. https://doi.org/10.1007/s12053-014-9301-7

Kim, H. W., Joo, G. H., & Lee, D. H. (2019). Multi-period heterogeneous vehicle routing considering carbon emission trading. *International Journal of Sustainable Transportation*, *13*(5), 340–349. https://doi.org/10.1080/15568318.2018.1471555

Kopfer, H. W., Schönberger, J., & Kopfer, H. (2014). Reducing greenhouse gas emissions of a heterogeneous vehicle fleet. *Flexible Services and Manufacturing Journal*, *26*(1–2), 221–248. https://doi.org/10.1007/s10696-013-9180-9

Kwon, Y. J., Choi, Y. J., & Lee, D. H. (2013). Heterogeneous fixed fleet vehicle routing considering carbon emission. *Transportation Research Part D: Transport and Environment*, *23*, 81–89. https://doi.org/10.1016/j.trd.2013.04.001

Lamba, K., Singh, S. P., & Mishra, N. (2019). Integrated decisions for supplier selection and lot-sizing considering different carbon emission regulations in Big Data environment. *Computers and Industrial Engineering*, *128*, 1052–1062. https://doi.org/10.1016/j.cie.2018.04.028

Liu, W. Y., Lin, C. C., Chiu, C. R., Tsao, Y. S., & Wang, Q. (2014). Minimizing the carbon footprint for the time-dependent heterogeneous-fleet vehicle routing problem with alternative paths. *Sustainability (Switzerland)*, *6*(7), 4658–4684. https://doi.org/10.3390/su6074658

Phouratsamay, S. L., & Cheng, T. C. E. (2019). The single-item lot-sizing problem with two production modes, inventory bounds, and periodic carbon emissions capacity. *Operations Research Letters*, *47*(5), 339–343. https://doi.org/10.1016/j.orl.2019.06.003

Sarkar, B., Ganguly, B., Sarkar, M., & Pareek, S. (2016). Effect of variable transportation and carbon emission in a three-echelon supply chain model. *Transportation Research Part E: Logistics and Transportation Review*, *91*, 112–128. https://doi.org/10.1016/j.tre.2016.03.018

Srivastava, S. K. (2007). Green supply-chain management: A state-of-the-art literature review. *International Journal of Management Reviews*, *9*(1), 53–80. https://doi.org/10.1111/j.1468-2370.2007.00202.x

Wagner, H. M., & Whitin, T. M. (1958). Dynamic Version of the Economic Lot Size Model. *Management Science*, *5*(1), 89–96. https://doi.org/10.1287/mnsc.5.1.89

Wang, J., Yao, S., Sheng, J., & Yang, H. (2019). Minimizing total carbon emissions in an integrated machine scheduling and vehicle routing problem. *Journal of Cleaner Production*, *229*, 1004–1017. https://doi.org/10.1016/j.jclepro.2019.04.344