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Solving Urban Routing Problem in Supply Chain by Optimizing PSO Algorithm

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ABSTRACT

Addressing the effective distribution of service requests among vehicles in the supply chain stands out as a key hurdle in supply chain management, commonly referred to as vehicle routing with traffic balancing. The optimized vehicle routing, coupled with traffic balancing strategies, emerges as a pivotal factor contributing to heightened customer satisfaction, reduced delivery times, enhanced vehicle utilization, diminished service request demands, and an overall elevation in service quality within the supply chain. To address this, a proposed method involves real-time assessment of service requests and vehicle conditions, enabling balanced routing based on the current operational context. Given the NP-Hard complexity associated with the vehicle routing problem involving traffic balancing in the supply chain, leveraging optimization algorithms, such as PSO, proves to be a more efficient approach. This study introduces a PSO optimization algorithm tailored for the aforementioned challenge. By integrating real-time conditions of service requests and vehicles within the supply chain, the algorithm strategically selects optimal routes for each vehicle and service request. The PSO optimization algorithm undergoes simulation in Python software, undergoes evaluation, and is analyzed alongside comparable routing methods. The assessment outcomes reveal a reduction in distance traveled and total delivery time achieved through the application of the PSO optimization algorithm.

1. INTRODUCTION

The problem of vehicle routing is one of the most important current research problems, and today it has received a lot of attention due to its real applications in various problems. The supply chain includes a set of suppliers, manufacturers and distributors whose sole purpose is to meet the customer's needs. The issue of vehicle routing in the supply chain is one of the most important issues of supply chain management. This importance comes from the fact that the optimal allocation of vehicles to different routes will have a great impact on reducing financial and time overheads in the supply chain [1]. One of the challenges that is very important for the development of road transportation today and few studies have been done in this field is the routing problem (VRP) of the routes for the vehicles carrying goods to deliver the goods to the applicants. In the VRP problem, there are a set of vehicles that are required to meet the demands of the applicants, move from the sources of goods to them from different routes

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and return to the source of goods after serving all the customers from different routes [2]. In order to solve the problem of VRP along with the balance of traffic load in the supply chain, criteria such as the distance traveled, the speed of sending and the number of vehicles of each route should be balanced and finally the quality of service provision should be maximized. The VRP problem with traffic load balancing is NP-hard, and meta-heuristic methods are often used to solve it [3]. According to the mentioned materials, in this research, an optimal method based on the PSO algorithm will be presented to solve the VRP problem along with the traffic load balance for cargo carrying vehicles to deliver the goods to the applicants. According to the stated cases, the importance and necessity of conducting research is determined.

1.1. Thematic research literature

The urban routing problem in the supply chain is a critical issue that requires efficient optimization techniques to ensure smooth and cost-effective transportation of goods. One of the prominent methods for addressing this problem is the use of Particle Swarm Optimization (PSO) algorithms. This literature review aims to synthesize and integrate the findings from various studies that have focused on solving the urban routing problem in the supply chain by optimizing PSO algorithms.

Wang et al. (2019) proposed an approach where PSO algorithm was adopted for clustering in the supply chain. They utilized an Enhanced PSO (EC-PSO) for clustering and searched for energy centers using an improved PSO algorithm. This methodology was implemented for a heterogeneous wireless sensor network, demonstrating the potential of PSO algorithms in addressing complex routing problems. The study highlights the effectiveness of PSO algorithms in optimizing routing schemas and clustering strategies in the context of supply chain management [4].

Another study by Hannan et al. (2018) focused on the capacitated vehicle-routing problem in scheduled solid waste collection. The researchers employed a PSO algorithm for route optimization, emphasizing the applicability of PSO in addressing specific urban routing challenges. Their work contributes to the understanding of how PSO algorithms can be tailored to different urban logistics scenarios, including waste collection and management [5].

Mousavi and Tavakkoli-Moghaddam (2013) introduced a hybrid simulated annealing algorithm for location and routing scheduling problems with cross-docking in the supply chain. Although not directly using PSO, their approach demonstrates the importance of exploring hybrid optimization techniques to tackle complex routing and scheduling problems in the supply chain. This study highlights the need for further research into the integration of PSO with other metaheuristic algorithms to enhance routing optimization [6].

Rafie-Majd et al. (2018) presented a model for solving the integrated inventory-location-routing problem in a multi-period and multi-perishable product supply chain with uncertainty. They utilized a Lagrangian relaxation algorithm, showcasing the diversity of optimization methods available for addressing supply chain routing challenges. This study emphasizes the importance of considering uncertainty and perishability in supply chain routing, suggesting opportunities for integrating PSO algorithms with robust optimization frameworks to handle such complexities [7].

Furthermore, Kechagiopoulos and Beligiannis (2014) proposed a PSO-based algorithm for solving the urban transit routing problem. Their work specifically targeted urban transit logistics, demonstrating the versatility of PSO algorithms in addressing diverse routing problems within the urban context. This study contributes to the understanding of how PSO can be tailored to meet the specific requirements of urban transit routing, opening up avenues for further research in this domain [8].

In conclusion, the literature on solving urban routing problems in the supply chain by optimizing PSO algorithms demonstrates the versatility and effectiveness of PSO in addressing diverse routing challenges. The findings from the reviewed studies underscore the need for further research to explore hybrid optimization techniques, integration of PSO with other algorithms, and addressing specific complexities such as uncertainty and perishability in supply chain routing. Future research directions could focus on developing adaptive PSO algorithms, considering dynamic urban environments, and enhancing the scalability of PSO for large-scale supply chain routing optimization. Overall, the literature provides valuable insights into the potential of PSO algorithms in revolutionizing urban routing in the supply chain.

2. RESEARCH METHODS

2.1. Investigating NP-Hard problems

The term NP-hard refers to problems that cannot be solved in polynomial time with respect to the size of the problem input [9]. The NP-hard community includes thousands of various problems with high complexities that have not yet been solved quickly and feasibly, and are unlikely to be discovered in the foreseeable future [10]. Moreover, it has not been proven that there is no fast solution for these kinds of problems [9]. However, it has been proven that if a fast solution is found for just one of these problems, it will lead to a fast solution for the rest of the problems. The chances of finding such an algorithm are minimal. If the execution time of the solution for these types of problems has a polynomial relationship with the size of the problem input, then this solution will be fast [11].

2.2. PSO Optimization Algorithm Concepts

Particle Swarm Optimization (PSO) is a powerful algorithm inspired by natural processes, particularly the collective behavior of birds and fish. It is a population-based stochastic search algorithm that aims to find optimal solutions in a given problem space. However, it can be prone to getting stuck in local optima, especially in high-dimensional spaces [12,13]. To address this, various modifications have been proposed, such as introducing a mutation mechanism and dynamic algorithm parameters [12], and a novel probability-based binary optimization algorithm [14]. Despite these challenges, PSO has been successfully applied in a wide range of fields, including aerospace design, manufacturing, and automobile [15].

Considerable progress has been made in the field of optimization algorithms, as indicated by various works. The initial paper outlines a distinctive method that signifies a significant advancement, outperforming established techniques such as BPSO, LDWPSO, and DNLPSO in specific aspects [16]. The second paper introduces an innovative strategy by integrating a learning automaton to tailor particle behavior within a Particle Swarm Optimization (PSO) model, showcasing the continual progression of optimization methodologies [17]. Lastly, the third paper underscores the ongoing evolution of PSO, revealing diverse variants that enhance its effectiveness and problem-solving capacities across a wide array of optimization challenges. Together, these sentences depict the persistent commitment to innovating and enhancing optimization techniques for superior performance [18].

Generally, the steps of the PSO optimization algorithm are as follows:

Step 1) Start

Step 2) Create an initial group and evaluate this group

Step 3) Determine the best personal experience and the best collective experience

Step 4) Update acceleration and position

Step 5) If the stopping conditions are not met, go to step 2.

Step 6) End The most important advantages of the PSO algorithm, which led to the use of this algorithm as the proposed method in this study, are presented below:

1. The PSO optimization algorithm is a group-oriented algorithm, which makes it less likely to get trapped in a local minimum.
2. This optimization algorithm operates based on probabilistic rules, not deterministic rules. Therefore, the PSO optimization algorithm is a stochastic optimization algorithm that can explore uncertain and complex domains. This feature makes the PSO optimization algorithm more flexible and resilient compared to ordinary models.
3. The PSO optimization algorithm works with non-differential fitness functions. Since the PSO optimization algorithm uses the results (performance or fitness function) to guide the search in the problem domain.

4. The quality of solutions and the proposed path in the PSO algorithm does not depend on the initial group of particles. Starting from anywhere in the search space, the algorithm usually converges to the optimal solution.
5. The PSO optimization algorithm has a lot of flexibility to control the balance between local and global search in the problem domain. This property allows the PSO optimization algorithm to overcome premature convergence to a bad optimum and increase search capacity.

2.3. Conceptual view of the problem and the proposed method for vehicle routing in the supply chain

As mentioned, the supply chain consists of various processes and components that must be properly managed and planned, and one of the most important management issues in the supply chain is the balanced routing of vehicles. In this section, in order to conceptually understand the position and process of using the proposed PSO algorithm in solving the problem of vehicle routing with traffic balance in the supply chain, a conceptual view of the research is presented and explained in Figure 1.

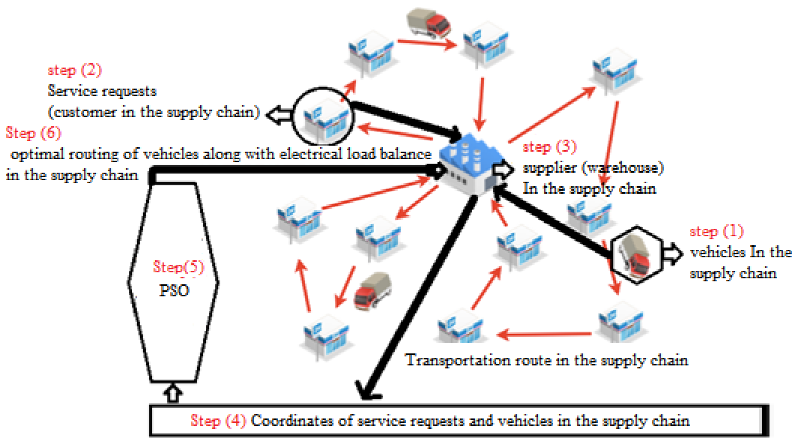


Fig. 1. Conceptual view of optimal vehicle routing along with traffic load balance research in the supply

chainAs shown in Figure 1, the conceptual view of optimal vehicle routing with traffic balance in the supply chain consists of six main stages, which are discussed in detail below.

Stage 1) In this stage, the current temporal and geographical coordinates of the vehicles in the supply chain are sent to the supplier (warehouse) in the chain.

Stage 2) In this stage, the temporal and geographical coordinates of service requests in the supply chain (customers) are sent to the supplier (warehouse) in the chain.

Stage 3) In this stage, the supplier (warehouse) in the supply chain sends the received coordinates to the routing and management unit of this chain.

Stage 4) In this stage, the routing and management unit in the supply chain receives the coordinates and sends them to the proposed PSO algorithm of the research.

Stage 5) In this stage, the proposed PSO algorithm optimizes the received coordinates based on its own parameters, which will be discussed below.

Stage 6) In this stage, the optimized vehicle routing with traffic balance in the supply chain is sent by the proposed PSO algorithm to the supplier (warehouse) in the chain for implementation and operation. After properly understanding the conceptual position and process of optimal vehicle routing with traffic balance in the supply chain, it is necessary to design and simulate the proposed PSO algorithm in Python, which will be discussed in the next section.

2.4. Design and simulation of the proposed vehicle routing method in the supply chain

In the proposed PSO vehicle routing method in the supply chain, each member in this swarm is identified by its acceleration and location axis in the exploration space (the coordinate axis of the vehicles and service requests received in the supply chain). The flowchart of the proposed PSO vehicle routing method in the supply chain is presented and discussed in Figure 2.

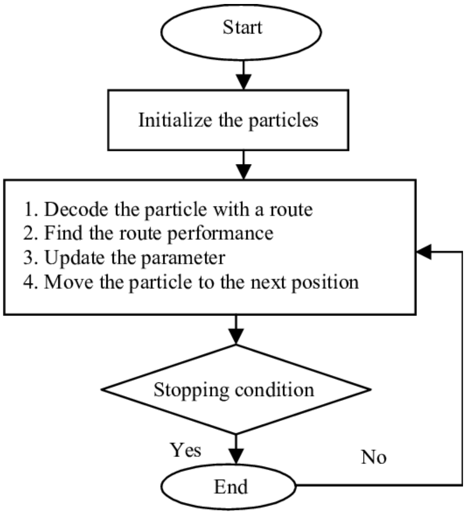


Fig. 2. Flowchart of the proposed PSO routing method of vehicles in the supply chain

At each iteration of the optimization process in the proposed method of this research, the new position of each particle is determined based on its acceleration and location axis in the exploration space. As shown in Figure 3, during the optimization process iteration, the new position of each particle is updated (moved towards the optimal vehicle routing with traffic balance in the supply chain) based on its current acceleration axis, its own best personal experience, and the best experience of the whole swarm or cluster.

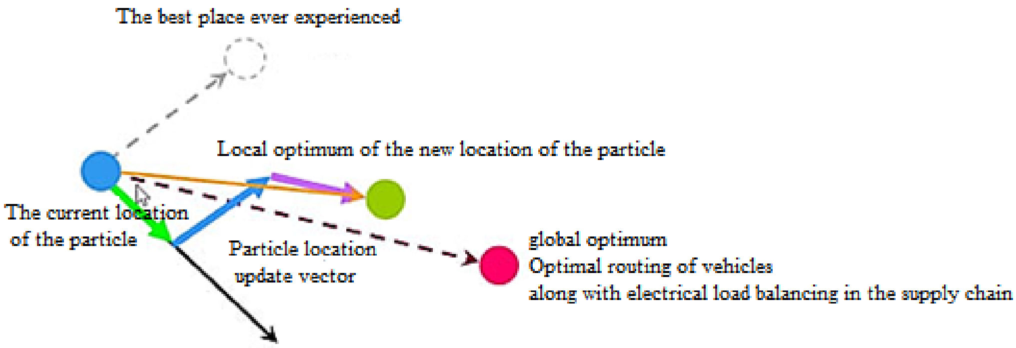


Fig. 3. How to update the location and acceleration of each particle in the PSO routing method of research vehicles

As shown in Figure 3, the update of the position and acceleration of each particle in the proposed PSO vehicle routing method in the supply chain is composed of three general operations, which include the current acceleration of particles, the amount of acceleration change for each particle, and the best personal experience of particles and the best experience of the swarm. Therefore, the best particle in the swarm (optimal vehicle routing with traffic balance in the supply chain) remains fixed in its position, and other particles move towards it. In fact, the movement of swarm particles in the proposed PSO vehicle routing method in the supply chain is a process in which the search space gradually shrinks and local exploration around the best particle (optimal vehicle routing with traffic balance in the supply chain) takes place.

2.5. Indicators of research vehicle routing method in the supply chain

Table 1. Values of research method indicators for vehicle routing in the supply chain by PSO

Variables used	status/quantity
Optimization variables of research routing method	3
Variable W	1
Variable lb	0
variable ub	100
Coefficient C1	2
Coefficient C2	2
Acceleration update function	More particle acceleration due to the best private and global particle experience
Location update function	Relocating particles to the best private and global experience of each particle
The number of optimization iterations	100
The amount of primary particles	100
Valuation function	$\sum_{i=1}^{100} \lvert \boldsymbol{Veh_i(P_{1.2.3}) - Rrq_i(P_{1.2.3})} \rvert$

As shown in Figure 4, the proposed PSO algorithm in this research for solving the vehicle routing problem with traffic balance in the supply chain evaluates the particles (vehicle routing with traffic balance in the supply chain) in 100 iterations. At the end of the optimization iterations, the proposed PSO algorithm will provide the optimal vehicle routing for balanced distribution of service requests on vehicles in the supply chain.

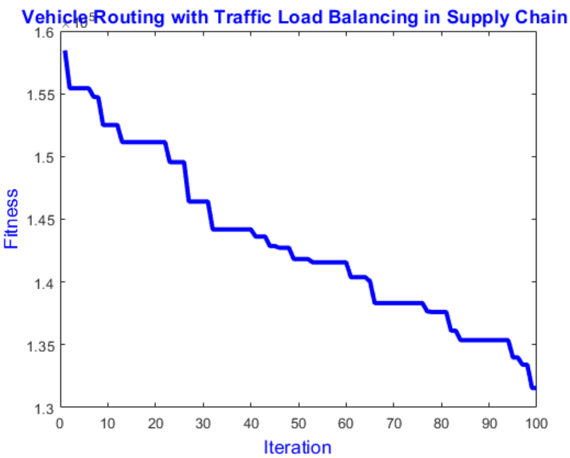


Fig. 4. The optimization process of the PSO algorithm proposed by the research

2.6. The evaluation data of research vehicle routing method in the supply chain

The data used to evaluate and analyze the proposed vehicle routing method along with the traffic load balance in the supply chain are significant compared to the methods compared in the research in Table 2.

Table 2. Evaluation data of the proposed vehicle routing method along with traffic load balancing in the supply chain

Feature	**Values**
Number of vehicles in the supply chain	200-300
The number of supply chain service requests	200-300
The number of vehicle coordinates in the supply chain	3
The number of coordinates of supply chain service requests	3
Coordinates of service requests	Congestion (congestion) of the service request route Geographic longitude coordinates of the location of the request to receive the service Geographic latitude coordinates of the location of the service request

Coordinates of vehicles in the supply chain	The degree of crowding (congestion) of the vehicle path Geographic longitude coordinates of vehicle location Geographic latitude coordinates of the location of the vehicle
The range of coordinates of vehicles in the supply chain	[1-100]
The range of coordinate values of service requests	[1-100]
Results evaluation criteria	The total time of sending goods by vehicles in the supply chain The distance traveled by the goods in the supply chain
Scope of evaluation and review	Shiraz urban area

After the proposed vehicle routing method is implemented along with traffic load balancing in the supply chain, in the next section and using the significant data in Table 2, the compared methods are analyzed and evaluated by the criteria of shipping time and distance traveled by the goods. will be placed.

2.7. The results of the evaluation of the research vehicle routing method in the supply chain

In this section, the results of the research evaluation criteria, i.e. the shipping time and the distance traveled by the goods in the proposed PSO routing method for vehicles in the supply chain and similar methods, have been presented and analyzed. The main purpose of conducting this research is to reduce the distance traveled by goods and also to reduce the total time of sending goods (increasing speed) in the supply chain; Therefore, at the beginning of this section, the results obtained for the distance traveled by goods in the number of service requests 200 and 300 for balanced routing on vehicles in the supply chain have been investigated.

2.8. Checking the routing of 200 service requests and 200 vehicles in the supply chain

Fig. 5. Location coordinates 200 request to receive service in Shiraz urban area

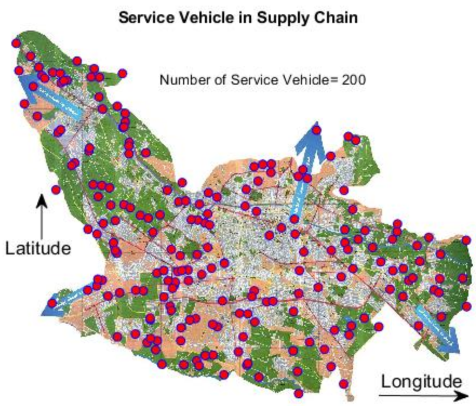


Fig. 6. Location coordinates 200 request to receive service in Shiraz urban area

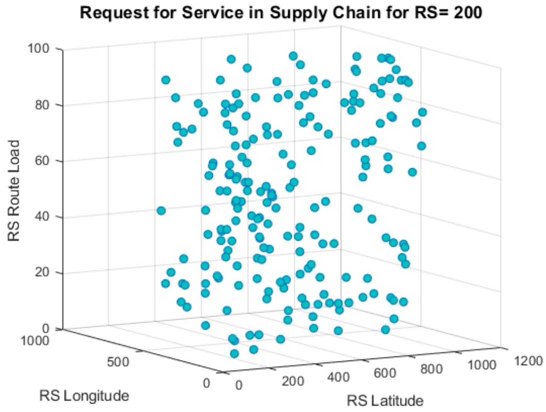


Fig. 7. Coordinates 200 request to receive a simulated service for routing on vehicles in the supply chain

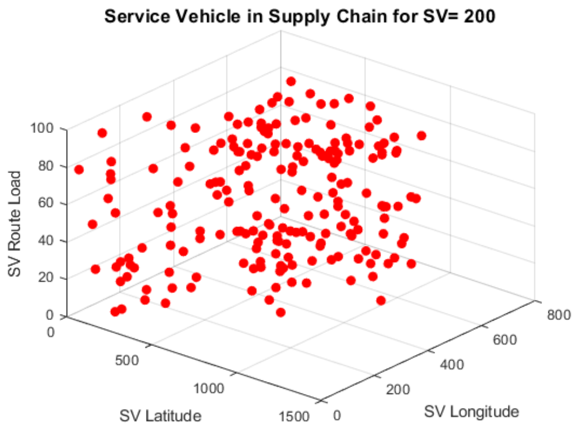


Fig. 8. Coordinates of 200 vehicles in the simulated supply chain to implement service requests

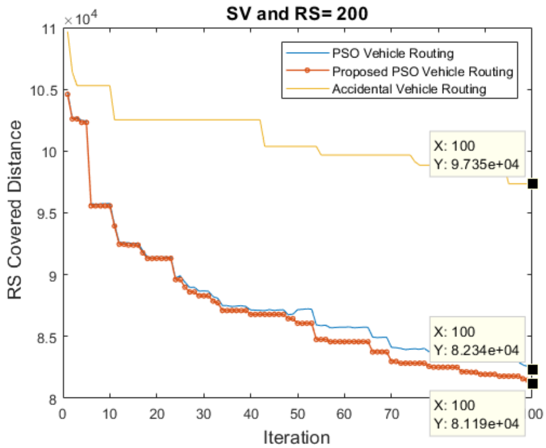


Fig. 9. Distance traveled by goods for 200 service requests and 200 vehicles in the supply chain

Fig. 10. Total shipping time for 200 service requests and 200 vehicles in the supply chain

2.9. Checking the routing of 300 service requests and 300 vehicles in the supply chain

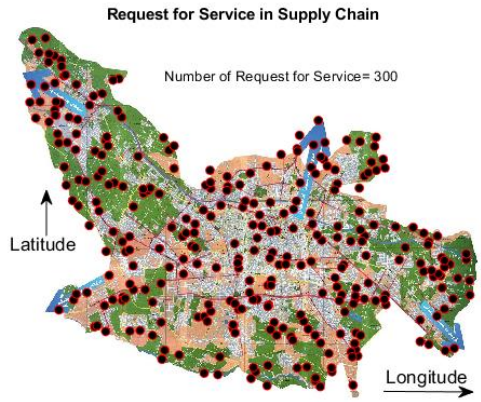


Fig. 11. Location coordinates 300 request to receive service in Shiraz urban area

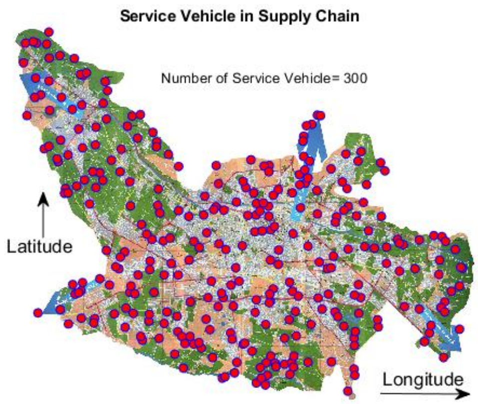


Fig. 12 Location coordinates of 300 service vehicles in Shiraz urban area

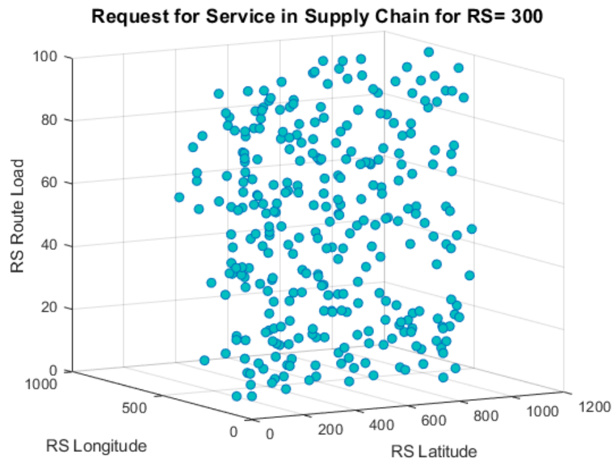


Fig. 13. Coordinates 300 request to receive a simulated service for routing on vehicles in the supply chain

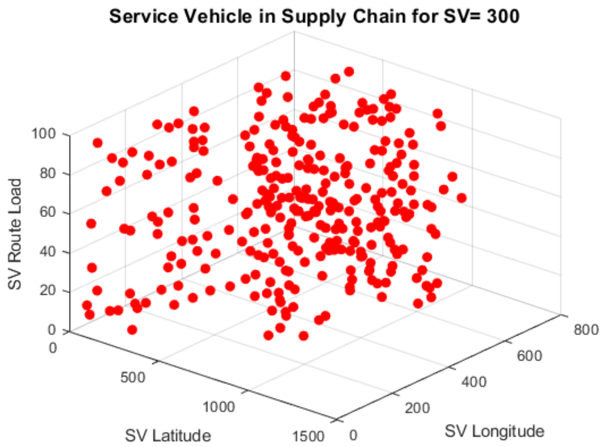


Fig. 14. Coordinates of 300 vehicles in the simulated supply chain to execute service requests

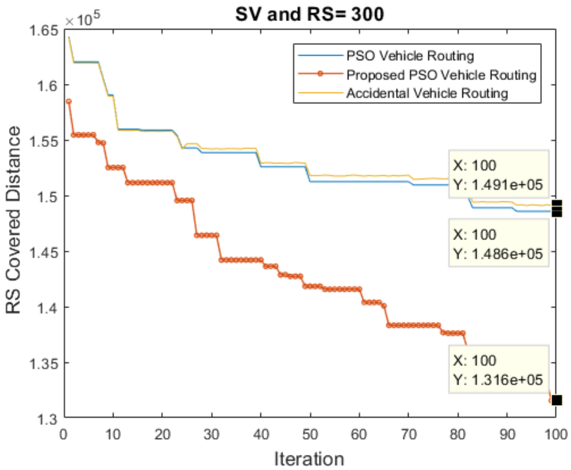


Fig. 15. Distance traveled by goods for 300 service requests and 300 vehicles in the supply chain

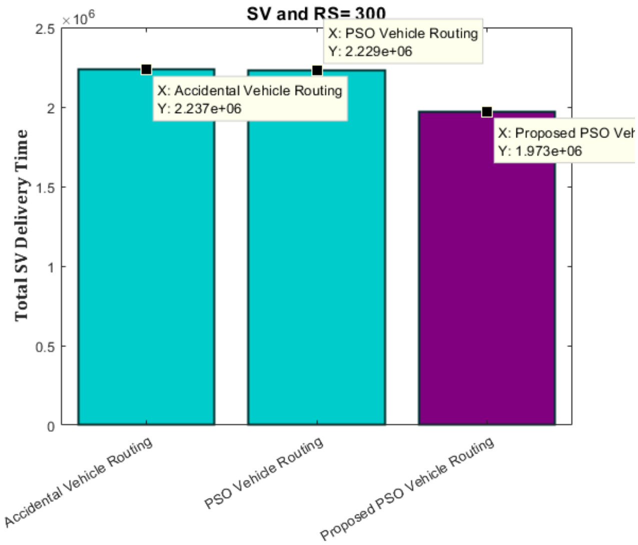
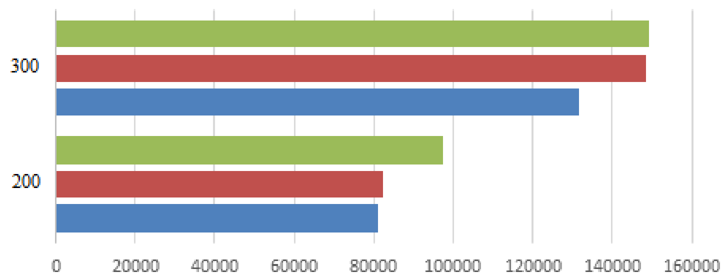


Fig. 16. Total shipping time for 300 service requests and 300 vehicles in the supply chain

3. RESULTS AND DISCUSSION

As mentioned, the main criteria for evaluating the proposed method in vehicle routing with traffic balance in the supply chain using the PSO algorithm are the distance traveled and the total delivery time. The main goal of this research is to reduce the distance traveled by goods and subsequently, to reduce the total delivery time (increase velocity) in the supply chain. Thus, first, the results obtained for the distance traveled by goods for 200 and 300 service requests in balanced vehicle routing in the supply chain were investigated. After executing and extracting these criteria in the proposed algorithm and the compared methods in this chapter, it has been proven that the vehicle routing with traffic balance in the supply chain using the proposed method will reduce both the distance traveled and the total delivery time in the supply chain. These results are shown in Table 3.

Table 3. The distance traveled by the goods in the proposed PSO method and other investigated methods



	200	300
Sudden method	97350	149100
Compared particle mass method	82340	148600
Research method	81190	131600

■ Sudden method ■ Compared particle mass method ■ Research method

4. SUGGESTIONS

- Searching and investigating other evaluation parameters of vehicle routing methods with traffic balance in the supply chain, such as service quality, efficiency, etc. for the proposed method in this research.

- Increasing the number of vehicles in the supply chain and service requests in the supply chain, researching and analyzing the evaluation results.
- Analyzing the use of optimal combined optimization methods for vehicle routing with traffic balance in the supply chain.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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