

Applying Kruskal's Algorithm in Supply Chain Management for Cost-Effective Network Optimization

Pooja Pandya^{1*}, Gunja Dave², Nirali³

Abstract

Transportation route optimization and cost reduction are major difficulties in today's dynamic and complicated supply chain systems. To produce economical and effective network designs, this study investigates the use of Kruskal's algorithm for supply chain network optimization. The algorithm guarantees that all supply chain nodes, including delivery hubs, warehouses, and distribution centers, relate to the lowest possible total transportation cost by building the minimum spanning tree (MST). The study shows how Kruskal's algorithm systematically chooses the most economical routes, resulting in notable cost savings and improved operational effectiveness. This study demonstrates the algorithm's ease of use, scalability, and adaptability through real-world examples and comparative analysis, making it a useful tool for supply chain management. The results highlight how crucial it is to gather precise data and consider other elements like delivery schedules and capacity limitations in order to guarantee thorough optimization. All things considered, this study highlights Kruskal's algorithm as a crucial tool for developing effective, economical supply chain networks.

Keywords: Kruskal's algorithm, supply chain optimization, minimum spanning tree (MST), transportation cost reduction, cost-effective supply chain, graph theory in supply chain, supply chain network optimization, algorithmic optimization, supply chain management, transportation routes

INTRODUCTION

In the ever-changing world of supply chain management, companies looking to stay efficient and competitive must prioritize cost reduction and transportation route optimization. The complexity of contemporary supply chains frequently defies traditional approaches, calling for the use of sophisticated algorithms and strategies. The use of Kruskal's algorithm, a proven technique in graph theory, to supply chain network optimization is investigated in this study. Businesses can create cost-effective network architectures that guarantee good connectivity between crucial nodes like distribution centers, warehouses, and delivery hubs by utilizing this algorithm. The study explores the real-world application

of Kruskal's algorithm, demonstrating how effective it is at lowering transportation costs and improving overall operational effectiveness. This study emphasizes through comparative analysis and real-world examples.

LITERATURE REVIEW

Recent research has focused on leveraging Kruskal's algorithm to optimize supply chain networks, aiming to minimize transportation costs while maintaining efficient connectivity between nodes. This review highlights key studies and findings in this area.

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This systematic review explores the use of machine learning (ML) methods in supply chain management (SCM), focusing on their role in improving demand prediction, inventory control, and logistics efficiency. The authors categorize various ML models and compare their effectiveness in different SCM scenarios. They emphasize the potential of ML to address the complexities and dynamic nature of modern supply chains, which is highly relevant for integrating Kruskal's algorithm for cost-effective network optimization [1].

This review provides an overview of different modeling and algorithmic approaches used in SCM, including metaheuristics and decomposition methods. The paper discusses how these algorithms address strategic, operational, and tactical issues within supply chains. It highlights the importance of models that can handle large datasets and complex interactions, which aligns with the application of Kruskal's algorithm to minimize transportation costs and optimize network design [2].

This comprehensive review covers the use of machine learning in SCM over a decade, focusing on how ML methods are applied to various SCM tasks. The authors identify current applications and research gaps, emphasizing the role of ML in managing complex supply chains. This study underscores the relevance of integrating algorithms like Kruskal's for optimizing supply chain networks and reducing costs [3].

Packowski's book provides an in-depth look at global supply chain management strategies, planning, and implementation practices. It discusses various optimization techniques and models used to streamline supply chain operations. The book emphasizes the importance of efficient network design and cost management, which directly relates to the application of Kruskal's algorithm for optimizing supply chain networks [4].

This article examines the concept of VUCA (volatility, uncertainty, complexity, and ambiguity) and its impact on supply chain management, emphasizing the need for supply chains to adjust to volatile, uncertain, complex, and ambiguous conditions. The discussion on adaptive strategies and robust network design is relevant to understanding the benefits of using Kruskal's algorithm in creating resilient and cost-effective supply chain networks [5].

Akpan and Iwok's study explores the use of the minimum spanning tree (MST) approach to solve transportation problems in supply chain networks. The authors demonstrate how Kruskal's algorithm can be applied to determine the MST, thereby minimizing the total transportation cost. The paper provides practical examples and computational methods, supporting the effectiveness of Kruskal's Algorithm in optimizing supply chains [6].

This research paper presents an application of Kruskal's Algorithm for transportation plan optimization in supply chain management. Basel and colleagues describe the process of implementing Kruskal's algorithm to identify the MST in a network of transportation routes. The study shows significant cost savings and improved efficiency, illustrating the practical benefits of using this algorithm in real-world supply chain scenarios [7].

Aljanabi and colleagues propose a modified version of Kruskal's algorithm to address transportation problems more effectively. The paper discusses the limitations of the traditional Kruskal's algorithm and introduces modifications to enhance its performance. The results indicate that the modified algorithm achieves better optimization in complex supply chain networks, providing a more efficient solution for cost-effective transportation [8].

This recent research explores how reinforcement learning algorithms can be used to enhance the efficiency of supply chains. Zhou and colleagues explore how reinforcement learning can be integrated with Kruskal's algorithm to enhance decision-making and improve network optimization. The research

demonstrates that combining these advanced techniques can lead to more resilient and cost-effective supply chain networks [9].

OBJECTIVES / AIMS

- Demonstrate how Kruskal's algorithm can be employed to minimize transportation and distribution costs within a supply chain network.
- Evaluate the effectiveness of Kruskal's algorithm in enhancing overall supply chain efficiency and resilience.
- Provide a comprehensive analysis of the practical applications and benefits of using Kruskal's algorithm in real-world supply chain scenarios.

RESEARCH METHOD / METHODOLOGY

Minimize transportation costs in the supply chain network while ensuring that all nodes (e.g., delivery hub, regional distribution, warehouse) are connected efficiently. Identify all the participants in the supply chain. Define the connections between these entities, including the transportation costs associated with each connection.

1. *Collect Initial Data:* Gather the initial transportation costs between all nodes in your supply chain network. This will form the basis of your weighted graph. Collect data on transportation costs, distances, and any other relevant metrics for each route. Verify the accuracy of the data to ensure reliable optimization results.
2. *Represent the Supply Chain Network as a Graph:* Each node symbolizes a component within the supply chain, such as a delivery hub, regional distribution center, or warehouse). Each edge represents the transportation route between two nodes, with the edge weight representing the transportation cost.
3. *Create an Edge List:* List all the edges with their respective weights (transportation costs).
4. *Sort the Edges:* Sort all the edges in non-decreasing order of their weights.
5. *Initialize Minimum Spanning Tree (MST):* Start with an empty set to store the edges of the MST.
6. *Apply Kruskal's Algorithm:* Go through the sorted list of edges and include the smallest edge in the MST, provided it doesn't create a cycle (use the Union-Find data structure to check for cycles). Continue this process until the MST contains exactly $V-1$ edges, where V is the number of vertices (nodes) in the graph.
7. *Calculate the Total Cost of MST:* Calculate the total weight of all the edges that are part of the MST. This sum represents the optimized total transportation cost. Compare the optimized cost with the initial cost to determine the savings achieved.
8. *Network Optimization:* Implement the optimized network in supply chain operations for the optimized network. Adjust routes and operations based on the MST.
9. *Validation and Adjustment:* Ensure the optimized network meets real-world constraints and performs as expected. Validate the optimized network by comparing its performance to the initial network.
10. *Implementation:* Deploy the optimized network in day-to-day supply chain operations. Roll out the optimized network across all relevant areas of the supply chain. Monitor the network's performance and make continuous improvements.

Example Calculation

Let us use the hypothetical data from one of the previous examples: An e-commerce company needs to optimize its distribution network to connect warehouses to regional distribution centers and then to local delivery hubs as shown in Tables 1 and 2.

Applying Kruskal's Algorithm

1. *Add edge:* RDC 1 - Delivery Hub A (Cost: \$600)
2. *Add edge:* RDC 2 - Delivery Hub A (Cost: \$700)
3. *Add edge:* RDC 1 - Delivery Hub B (Cost: \$800)
4. *Add edge:* Warehouse 1 - RDC 1 (Cost: \$1200)

Table 1. Initial data.

Node Pair	Initial Cost (USD)
Warehouse 1 - RDC 1	1200
Warehouse 1 - RDC 2	1400
Warehouse 2 - RDC 1	1300
Warehouse 2 - RDC 2	1500
RDC 1 - Delivery Hub A	600
RDC 1 - Delivery Hub B	800
RDC 2 - Delivery Hub A	700
RDC 2 - Delivery Hub B	900

RDC, regional distribution center.

Table 2. Sorted edge list.

Node Pair	Initial Cost (USD)
RDC 1 - Delivery Hub A	600
RDC 2 - Delivery Hub A	700
RDC 1 - Delivery Hub B	800
RDC 2 - Delivery Hub B	900
Warehouse 1 - RDC 1	1200
Warehouse 2 - RDC 1	1300
Warehouse 1 - RDC 2	1400
Warehouse 2 - RDC 2	1500

RDC, regional distribution center.

Optimized Total Cost (MST)

Sum of the costs of edges in MST = \$600 + \$700 + \$800 + \$1200 = \$3300

By applying Kruskal's algorithm, you can efficiently calculate the optimized total transportation cost for your supply chain network. This approach ensures that you achieve the most cost-effective network design, minimizing overall expenses and improving operational efficiency [10].

RESULTS / FINDINGS

By representing the supply chain network as a weighted graph and applying Kruskal's algorithm, we can identify the most cost-effective connections between nodes, ensuring efficient transportation routes and minimizing overall costs. Imagine a simple diagram to visualize the optimized supply chain network as shown in Table 3. From the above initial data, we made a graph visualization for initial cost with label as shown in Figure 1.

Data Output

Here generate MST after applying Kruskal's algorithm and the total cost optimized for supply chain to its distribution network to connect warehouses to regional distribution centers and then to local delivery hubs. The number of edges is $[V - 1]$ and we can say that number of vertices are $[E+1]$ as shown in Figure 2.

Utilizing Kruskal's algorithm allows for the precise determination of the least expensive transportation routes within your supply chain. This method guarantees the development of the most economical network structure, ultimately reducing costs and enhancing operational effectiveness.

As a result, the total cost in MST = \$600 + \$700 + \$800 + \$1200 = \$3300.

Table 3. Distribution node.

Nodes	Label
Religion distribution 1 (RD1)	A
Delivery hub A (DHA)	B
Religion distribution 2 (RD2)	C
Delivery hub B (DHB)	D
Warehouse 1	E
Warehouse 2	F

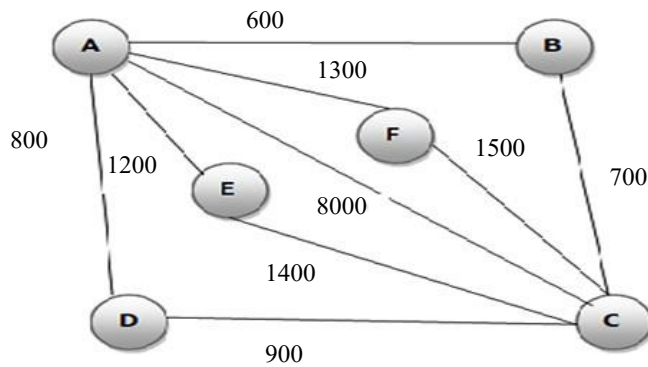


Figure 1. Initial.

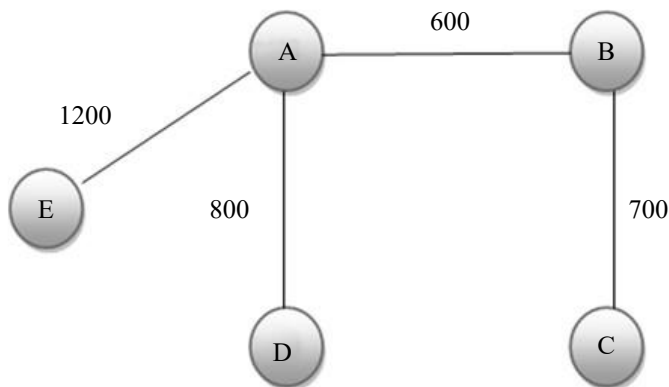


Figure 2. Sorted edge list output.

DISCUSSION / ANALYSIS

Kruskal's algorithm helps streamline supply chain networks by reducing transportation expenses. It systematically selects the least expensive connections to form a MST, ensuring all nodes (e.g., delivery hubs, warehouses, distribution centers) are connected efficiently. This approach reduces total transportation expenses, enhancing operational efficiency.

The algorithm's scalability makes it suitable for both local and global supply chains. By applying Kruskal's algorithm, businesses can significantly cut costs, allowing for resource reallocation to other critical areas. Real-world applications have shown its practicality in optimizing routes, inventory distribution, and logistics planning. Compared to other algorithms, Kruskal's is often preferred for its simplicity and effectiveness, especially in sparse graphs.

However, it is essential to supplement the algorithm with additional techniques to address delivery times and capacity constraints. Accurate data gathering is essential for obtaining the best outcomes. In general, Kruskal's algorithm is an effective method for building affordable and efficient supply chain networks.

CONCLUSION

In conclusion, Kruskal's algorithm is a highly effective tool for optimizing supply chain networks by minimizing transportation costs. It ensures efficient connectivity by forming a MST that links all nodes with the least total cost. This strategy is especially advantageous for supply chains at both local and global levels, leading to notable cost reductions and enhanced operational effectiveness. The algorithm's simplicity and scalability make it a preferred choice, especially for sparse graphs. However, accurate data collection and consideration of additional factors such as delivery times and capacity constraints are crucial for achieving the best results. Kruskal's algorithm is an essential tool for building cost-efficient and effective supply chain networks.

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