

ABSTRAK

Distribusi cold chain berperan penting dalam menjaga kualitas pangan mudah rusak. Namun, banyak UMKM di Indonesia masih menghadapi ketidakstabilan suhu, tingginya spoilage, konsumsi energi, dan emisi karbon akibat rute distribusi yang belum optimal. Selain itu, penelitian Green Vehicle Routing Problem (GVRP) pada cold chain umumnya belum mengintegrasikan energi pendingin berbasis temperatur, degradasi kualitas produk, dan emisi karbon dalam satu model. Oleh karena itu, penelitian ini bertujuan mengembangkan model GVRP time-dependent berbasis temperatur untuk meningkatkan efisiensi distribusi sekaligus menjaga kualitas produk dan mengurangi dampak lingkungan.

Penelitian ini mengembangkan cold chain dari Wicaksono melalui tiga studi kasus distribusi nyata di Yogyakarta serta merancang VRP Optimizer berbasis Google Workspace untuk mendukung operasional UMKM cold chain. Studi melibatkan tiga perusahaan distribusi yang menangani produk chilled, frozen, dan deep frozen dengan total 204 pelanggan dan 10 kendaraan. Model yang dikembangkan mengintegrasikan enam komponen biaya, yaitu biaya tetap, transportasi, energi pendingin, penalti keterlambatan, kerusakan produk, dan pajak karbon. Permasalahan optimasi diselesaikan menggunakan Genetic Algorithm (GA) untuk menentukan rute distribusi yang optimal.

Hasil optimasi menunjukkan penurunan total biaya distribusi sebesar 51,2%, 16,8%, dan 18,1% pada masing-masing kasus. Emisi CO₂ berkurang hingga 53,7%, sedangkan konsumsi energi pendingin turun hingga 75,9%. Kualitas produk juga meningkat dengan kenaikan indeks kualitas rata-rata dari 0,9691 menjadi 0,9904. Analisis sensitivitas menunjukkan bahwa pengiriman pada pagi hari lebih efektif dibandingkan siang hari dalam menekan biaya distribusi. Hasil ini membuktikan bahwa integrasi GVRP time-dependent berbasis temperatur dengan Genetic Algorithm mampu meningkatkan efisiensi biaya, mengurangi emisi karbon, dan menjaga kualitas produk cold chain.

Kata kunci: *Green Vehicle Routing Problem, cold chain, Genetic Algorithm, energi pendingin, sistem pendukung keputusan.*

ABSTRACT

Cold chain distribution plays a vital role in maintaining the quality of perishable food products. However, many SMEs in Indonesia still face temperature instability, high spoilage rates, excessive energy consumption, and carbon emissions due to inefficient distribution routes. Furthermore, existing Green Vehicle Routing Problem (GVRP) studies in cold chain logistics generally do not integrate temperature-based refrigeration energy, product quality degradation, and carbon emissions into a single optimization framework. Therefore, this study aims to develop a temperature-based time-dependent GVRP model to improve distribution efficiency while preserving product quality and reducing environmental impacts.

This study extends the cold chain model proposed by Wicaksono through three real-world distribution case studies in Yogyakarta and develops a Google Workspace-based VRP Optimizer to support SME cold chain operations. The study involves three distribution companies handling chilled, frozen, and deep-frozen products, covering 204 customers and 10 vehicles. The proposed model integrates six cost components, namely fixed costs, transportation costs, refrigeration energy costs, late-delivery penalties, product deterioration costs, and carbon tax costs. The optimization problem is solved using a Genetic Algorithm (GA) to determine optimal distribution routes.

The optimization results demonstrate reductions in total distribution costs of 51.2%, 16.8%, and 18.1% across the three case studies. CO₂ emissions were reduced by up to 53.7%, while refrigeration energy consumption decreased by up to 75.9%. Product quality also improved, with the average quality index increasing from 0.9691 to 0.9904. Sensitivity analysis indicates that morning deliveries are more effective than midday deliveries in reducing distribution costs. These findings confirm that integrating a temperature-based time-dependent GVRP with a Genetic Algorithm can significantly enhance cost efficiency, reduce carbon emissions, and maintain product quality in multi-commodity cold chain distribution.

Keywords: *Green Vehicle Routing Problem, cold chain, Genetic Algorithm, refrigeration energy, decision support system.*