Spektrum Industri
Vol. 24, No. 1, 2026, pp. 161-175
ISSN 1693-6590
https://journal3.uad.ac.id/index.php/spektrum/index

Soft Systems Methodology as a Conceptual Framework for Vehicle Routing Problem (Case Study of the Indonesian Fertilizer Industry)

Tombak Gapura Bhagya[a,b], Rahmi Maulidya[a*], Parwadi Moengin[a], Sally Cahyati[a]

[a]Doctoral Program in Industrial Engineering. Universitas Trisakti, West Jakarta, 11440, Indonesia
[b]Department of Industrial Engineering, Universitas Teknologi Bandung, Bandung, 40235, Indonesia
*Corresponding Author: rahmimaulidya@trisakti.ac.id

ARTICLE INFO

Article history
Received January 2, 2026
Revised February 20, 2026
Accepted April 2, 2026

Keywords
CATWOE;
Causal loop diagram;
Soft system methodology.
Vehicle routing problem.

ABSTRACT

Indonesia’s archipelagic geography and uneven infrastructure pose persistent challenges to the distribution of subsidized fertilizer, a strategic commodity critical to national food security. While Vehicle Routing Problem (VRP) models are widely applied to improve logistical efficiency, existing studies predominantly focus on algorithmic optimization and pay limited attention to policy constraints, stakeholder complexity, and service trade-offs in regulated distribution systems. This study addresses this limitation by developing a conceptual VRP framework grounded in Soft Systems Methodology (SSM), positioning fertilizer distribution as a policy-constrained socio-technical system. The research follows Check land’s seven-stage SSM process, moving from unstructured problem exploration to the identification of feasible and desirable changes. Supporting tools include VOSviewer for literature mapping, Rich Pictures for stakeholder representation, CATWOE for system definition, and Causal Loop Diagrams (CLD) to capture dynamic interdependencies. The analysis of a multi-echelon distribution network demonstrates that inefficiencies arise not merely from routing limitations but from structural misalignment among routing efficiency, service capacity, inventory control, and government subsidy ceilings. A key insight is the inherent trade-off between cost minimization and service responsiveness in subsidized logistics systems. The study contributes theoretically by reframing VRP within systems thinking, methodologically by integrating qualitative structuring with optimization design, and practically by offering a reusable framework for transparent and policy-responsive public logistics management.

1. Introduction

Indonesia is a vast archipelago, with natural resources spread from the western tip to the eastern tip. Indonesia’s topography is highly diverse, so each region may have its own unique strengths in producing natural resources. Even areas with natural resources are often quite remote from human populations, such as urban centers. Consequently, many companies that rely on natural resource-based raw materials establish factories close to production sites due to the high cost of transporting raw materials.

https://doi.org/10.12928/si.v24i1.584

Indonesia’s vast territory, separated by extensive waters, combined with factories located far from urban areas, necessitate effective supply chain management. A company’s ability to optimize supply chain management is a key factor in determining its success (Jaboob et al., 2024). Effective supply chain management improve cost efficiency and directly enhances service quality and customer satisfaction (Abdirad & Krishnan, 2022).

Industry 4.0 provides added value in improving supply chain management, as advances in information and communication technology enable greater access to real-time data and advanced analytics for better decision-making (Fatorachian & Kazemi, 2021). However, these technological advancements do not eliminate existing challenges. Supply chain management continues to face increasing complexity due to fluctuating market demand, supply uncertainty, sustainability issues, and geographically complex distribution channels.

Distribution remains a major issue in supply chain management in Indonesia. Distribution is a key element that plays a crucial role in ensuring products reach consumers efficiently and on time (Konstantakopoulos et al., 2022). The complexity of Indonesia’s distribution routes combine with growing consumer demand for fast delivery and high service levels, makes distribution a critical focal point in supply chain performance. The complexity of distribution routes in Indonesia makes it difficult for companies to guarantee delivery times. In addition, long and complicated routes lead to high transportation costs, which are ultimately transferred to consumers through higher product prices. These conditions are influenced by several factors, including the use of diverse transportation modes, the dispersion of product demand across regions, the length distribution channels, and limitation in transportation capacity (Lu et al., 2022; Sherif et al., 2021).

Problem solving related to route determination in supply chain management is commonly categorized under VRP. This VRP focuses on optimizing vehicle routes used to deliver goods from factories to distribution points or consumer centers with the objective of minimizing costs, travel time or distance (Mor & Speranza, 2022). In transportation contexts, VRP objectives may also include minimizing fuel consumption and environmental impact (Pak & Mun, 2024). In recent years, advances in information technology have enabled VRPs to be solved more efficiently, even with increasing problem complexity. Numerous VRP variants have been developed to address real-world constraints, including capacitated VRP, time window VRP, multi depot VRP, heterogeneous fleet VRP, and stochastic VRP (Kumari et al., 2023; Rostami et al., 2021; Sbai et al., 2022; Zhang et al., 2022). These models reflect the growing complexity of logistics systems and the need to incorporate multiple operational constraints.

However, most existing VRP studies primarily emphasize algorithmic optimization and computational performance. Limited attention has been given to integrating VRP with systemic and conceptual modelling approaches that capture the institutional, organizational, and multi-stakeholder characteristics of complex logistics systems. As a result, there remains a research gap in developing VRP frameworks that align routing optimization with real-world logistics environments, particularly in geographically fragmented countries such as Indonesia.

In Indonesia, VRP development must consider several contextual factors, such as the use of multiple transportation modes, limited fleet availability, and real-time demand uncertainty. The complexity of distribution channels increases operational costs for companies, while uncertainty in delivery times contributes to price volatility. These conditions are regularly observed in Indonesia, particularly for essential commodities such as fertilizer (Ricome et al., 2024), sugar (Anokić et al., 2021), fuel (Xu & Lyu, 2021), and seafood (Firmansyah et al., 2022).

To address these challenges, Soft Systems Methodology (SSM) emerges as a relevant approach. SSM enables researchers to understand and structure complex, unstructured problems by developing conceptual models that reflect multiple stakeholder perspectives (Gilbert & Pratt-Adams, 2022). Within the context of a VRP-based distribution systems, SSM can be used as a preliminary framework to identify key actors, constraints, and interactions before formal optimization modelling is conducted (Reynolds & Holwell, 2010).

SSM offers advantages in mapping diverse stakeholder perspectives and aligning their objectives and needs (Stowell, 2024). In distribution systems, SSM can support better decision-making, improve supply chain efficiency, and minimize inefficiencies arising from misaligned policies and operational practices (Nurhasanah et al., 2020). Systems based approaches such as SSM have been successfully applied across sectors including health, education, and transportation (Wilson & Van Haperen, 2015). However, applications of SSM in transportation route design, particularly in combination with VRP, remain relatively limited in in the existing literature.

This research is expected to form the basis for developing a VRP model grounded in a systemic understanding of Indonesia's distribution context. The complexity of distribution channels leads to additional costs for companies, while uncertainty in delivery times causes frequent price fluctuations. A critical case can be observed in the Indonesian fertilizer industry, where subsidized fertilizer often becomes unavailable during peak planting seasons (Ricome et al., 2024). This shortage forces farmers to purchase fertilizer at higher market prices, increasing production costs and ultimately raising rice prices at harvest time (Fahmid et al., 2022). Therefore, this study emphasizes the importance of a developing a conceptual framework that systematically guides VRP model development. SSM is proposed as a suitable reference framework, as it enables complex distribution problems to be decomposed into manageable components for structured analysis (Reynolds & Holwell, 2010).

2. Method

The VRP is used to determine and optimize transportation routes. The primary objective of the VRP is generally to minimize logistics costs (Sluijk et al., 2023). This model is relevant for further development, considering that Indonesia, as an archipelagic country, still has suboptimal transportation routes (Puspitasari & Kurniawan, 2021).

However, due considerable complexity of VRP in real-world distribution systems involving multiple stakeholders and contextual constraints, a problem-structuring approach is required prior to optimization modelling. Peter Checkland's Soft Systems Methodology is used to help analyze and understand the various perspectives involved in a system. SSM is used in accordance with the reference from (Reynolds & Holwell, 2010) following the seven stages framework proposed by Checkland, that is:

1) Stage 1: The Problem Situation is Perceived as Problematic
   Identifying unstructured problems; this stage refers to the understanding to explore the problem without any preconceptions or particular structure, with the aim of identifying the key elements and dynamics involved in the problem (Rodriguez-Ulloa & Paucar-Caceres, 2005).
2) Stage 2: The Problem Situation is Expressed
   Revealing the problem situation; at this stage, data and information are collected to describe the relationships and process in the system (Rodriguez-Ulloa & Paucar-Caceres, 2005). Rich pictures are employed to visually represent actors, processes and conflicts within the distribution system.
3) Stage 3: Root Definition of Relevant Systems (CATWOE Analysis)
   Defining the system relevant to the problem; this stage formulates a root definition of the relevant system, which includes the perspectives of various stakeholders. CATWOE analysis (Customer, Actors, Transformations process, Worldview, Owners and Environmental constraints) is used to help understand the complexity of the system from various perspectives, so that there is assurance that all important aspects are considered in the system (Zarezadeh, 2024).
4) Stage 4: Conceptual Model
   Creating a conceptual model; based on the relevant system definition and the CATWOE analysis, a conceptual model of the system is created. This allows the model to illustrate the activities required to achieve the system`s objectives according to the identified perspectives. This is usually complemented by creating a causal loop diagram (CLD) in Zarezadeh, (2024) which captures feedback relationships within the distribution system.

5) Stage 5: Comparison Between Conceptual Model and Reality
Comparing the conceptual model with reality; the conceptual model is compared with the actual situation to identify any differences and gaps. This process helps in understanding areas that require change or improvement (Zarezadeh, 2024).
6) Stage 6: Identification of Feasibel and Desirable Changes
Identifying feasible and desirable changes; from the previous comparison, changes that are culturally feasible and systemically desirable are identified to improve the system. Consideration of cultural, political, and social aspects is very important in this stage (Reynolds & Holwell, 2010).
7) Stage 7: Action to Improve the Problem Situation
Taking action to improve the problem situation; this is the final stage of SSM by implementing the changes that have been identified with the aim of improving and enhancing the problem situation according to the analysis and models that have been developed (Reynolds & Holwell, 2010).

Briefly, the use of the seven stages in SSM can be seen in Fig. 1.

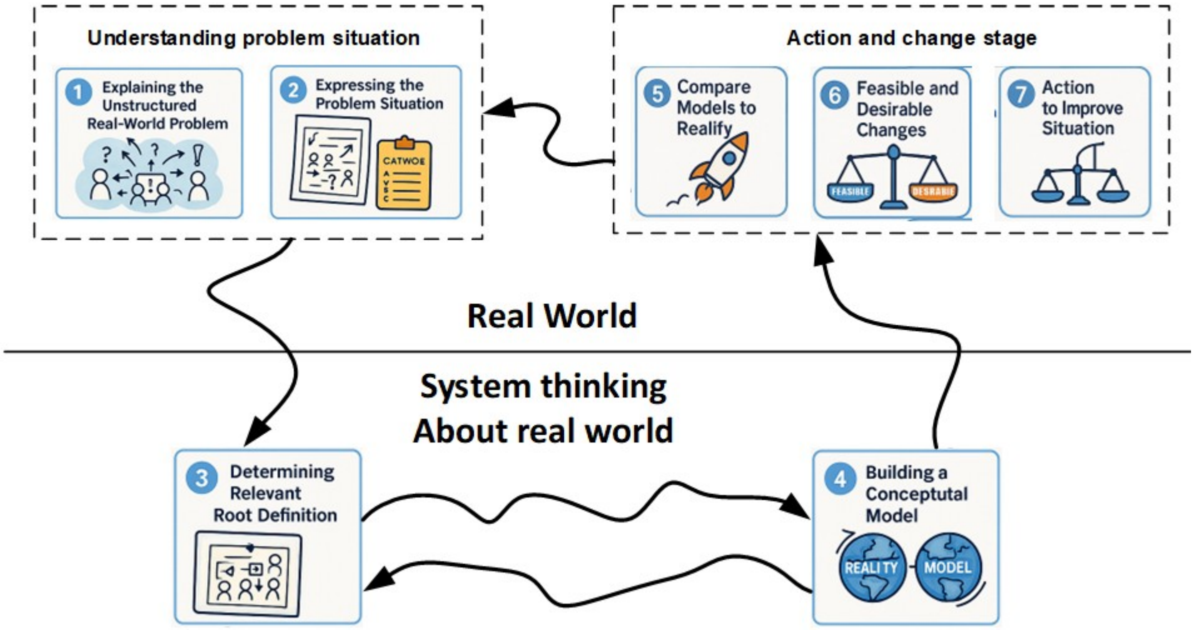

Fig. 1. Stages of soft systems methodology

3. Results

In accordance with the SSM stages used in the previous section, the results of this study will be presented in seven stages.

3.1. Stage 1: The Problem Situation is Perceived as Problematic

The problem identified in the VRP domain is the inefficiency of vehicle delivery routes, which causes high operational costs, delivery delays, and suboptimal resource utilization. To avoid subjective interpretation in defining the problem situation, a structured bibliometric analysis was conducted to objectively explore dominant research themes and emerging directions within VRP studies. A review analysis was carried out on 1.000 articles obtained from science direct. The keywords used to retrieve the articles were “vehicle routing problem”. The following inclusion were applied to ensure consistency and reproducibility: publication year between 2019 and 2025, research article, peer-reviewed journal publication, subject areas related to transportation, logistics, supply chain and operation research.

The articles were sorted by relevance in ScienceDirect, and the first 1.000 most relevant articles meeting the criteria were selected. A manual screening of titles and abstracts was conducted to remove duplicate and unrelated records. This procedure enhances methodological transparency and allows the bibliometric dataset to be replicated. VOSviewer has been widely used as a tool for mapping scientific publications to assess research trends (Pratiwi et al., 2024; Sihombing et al., 2025). VOSviewer was used to map 1.000 selected articles based on keyword co-occurrence analysis. Overall, 2.579 keywords were identified from the dataset. To improve analytical clarity, a minimum occurrence threshold was applied, and only 100 most frequently occurring keywords were retained for network visualization. Within the SSM framework, VOSviewer is not used solely for bibliometric description, but as a problem-structuring instrument in Stage 1 and Stage 2. The mapping results provide an evidence-based foundation for identifying dominant paradigms and underexplored aspects in VRP research, which subsequently inform the root definition in Stage 3.

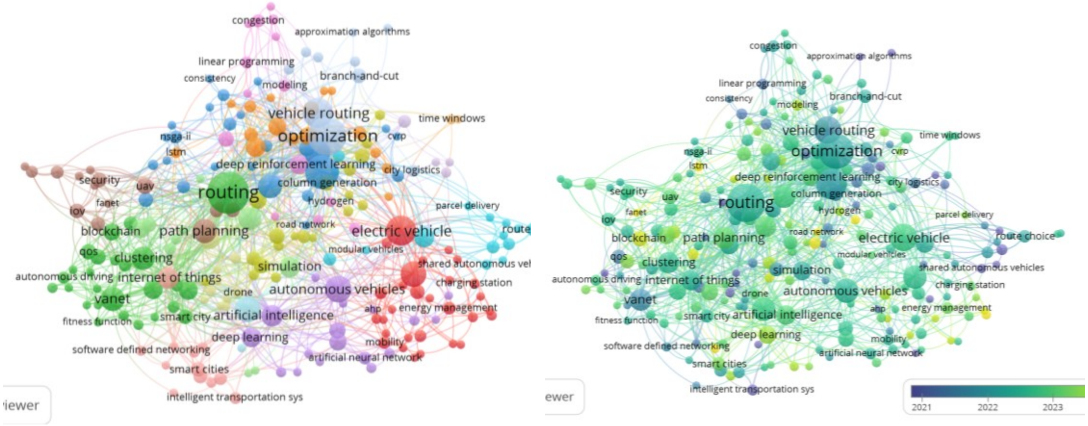

Fig. 2. Vosviewer from VRP

Based on Fig. 2, several clusters related to VRP can be identified. The red cluster indicates research focused on mathematically complex VRP modelling that incorporates dynamic elements and uncertainty. The blue cluster indicates environmentally oriented VRP research, including electric vehicle and sustainability issues, combined with advanced optimization techniques. The yellow cluster represent more classical VRP problems, such as capacitated VRP and time window constraints, which remain relevant in current applications. The purple cluster reflects methodological development, particularly metaheuristic and hybrid algorithm approaches addressing computational performance and classical time constraints.

The mapping results indicate that contemporary VRP research is predominantly centered on algorithmic refinement, sustainability integration, and computational efficiency improvements. However, relatively limited attention is directed toward systemic problem structuring, multi-stakeholder perspectives, and institutional or regulatory influences in real-world distribution systems. This finding supports the research gap identified earlier, namely that VRP research remains largely algorithm-centric, while contextual and systemic dimensions are underrepresented. The bibliometric findings derived from VOSviewer serve as an empirical input for defining the relevant system in Stage 3 of SSM. By identifying dominant and underdeveloped research themes, the study ensures that the conceptual model does not merely replicate prevailing algorithmic approaches, but instead incorporates systemic elements that are currently underexplored in VRP literature. Thus, the VOSviewer analysis functions as a structured diagnostic tool within the SSM process rather than as an independent bibliometric exercise.

3.2. Stage 2: The Problem Situation is Expressed

Tools such as rich pictures are used to express the complexity of relationships among stakeholders (problem owners, problem users, problem customers, and problem solvers), distribution flows, regulatory structures, and operational constraints (Seki et al., 2021). The data prepared include geographic locations of sources and destinations, vehicle capacity, delivery schedules, customer demand, road conditions, and institutional regulations governing fertilizer distribution. The problem situation is based on the case study of the fertilizer industry in Indonesia. The distribution process of subsidized fertilizer consists of several echelons: the first echelon, distribution from the fertilizer factory to the warehouse 2, the second echelon, distribution from warehouse 2 to warehouse 3a (Province), the third echelon, distribution from warehouse 3a (Province) to warehouse 3b (district/city), and the fourth echelon, distribution from warehouse 3b (district/city) to cooperative/farmers. The government provides fertilizer subsidized up to warehouse 3b. Therefore, this study focused on the VRP model up to the third echelon (warehouse 3b), since this is the boundary of government-controlled logistics responsibility. Fig. 3 present the rich picture illustrating the overall VRP situation in the fertilizer distribution system in Indonesia.

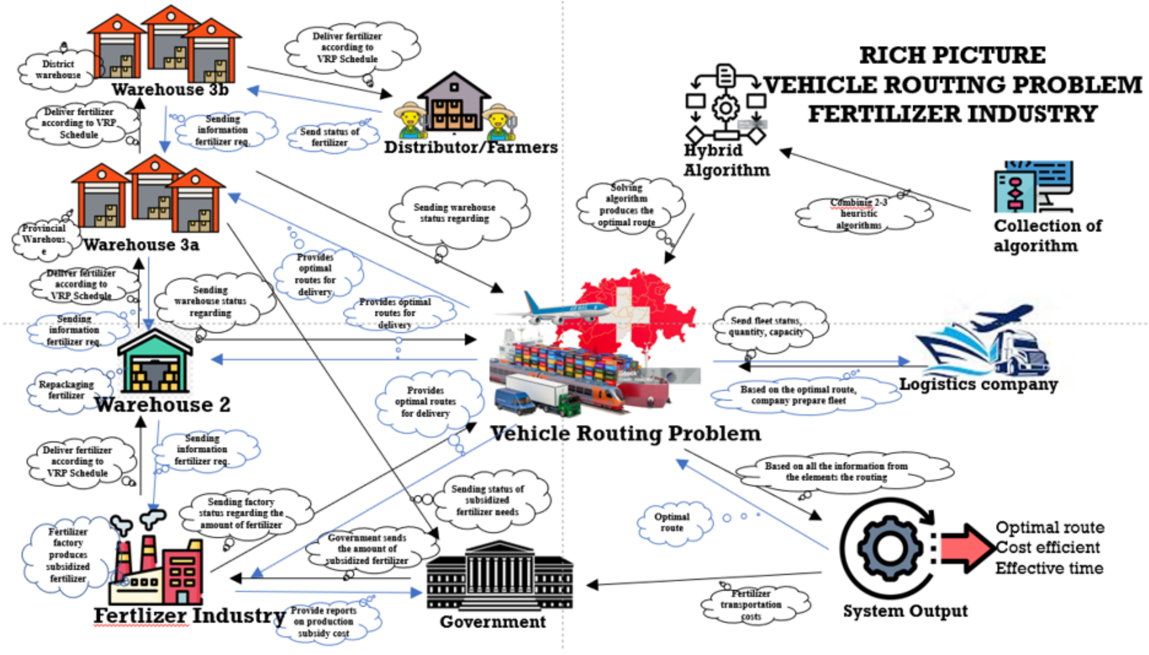

Fig. 3. Rich Picture of VRP Fertilizer Industry in Indonesia

Based on Fig. 3, the rich picture does not merely describe distribution flows, but reveals structural tensions and systemic inefficiencies within the fertilizer supply chain. First, there is a coordination gap between production planning and distribution execution. While the fertilizer industry claims to produce according to government allocation targets, farmers experience shortages at the cooperative level. This indicates that the core issue may not lie in production capacity, but in routing efficiency and inter-echelon synchronization. Second, the multi-echelon structure introduces cumulative delay risks. Each echelon performs localized scheduling decisions without integrated route optimization across echelons. This fragmented decision-making increases lead time variability and creates bottlenecks. Third, institutional constraints imposed by subsidy regulations limit flexibility in route design, vehicle allocation, and cost adjustments.

As a result, logistics companies must operate within strict budget ceilings, which may reduce responsiveness to demand fluctuations. Fourth, stakeholder interests are not fully aligned. The government prioritizes budget control and equitable allocation, the fertilizer industry prioritizes production fulfillment, logistics providers prioritize operational efficiency, and farmers prioritize timely availability. These differing worldviews generate systemic tension within the distribution network. Public complaints regarding fertilizer scarcity at the farmer level indicate that delivery delays and long supply chains contribute to the problem. Although production levels follow government requests, inefficiencies in routing and scheduling across echelons may cause mismatches between supply and demand timing. Thus, the problem situation expressed in the rich picture highlights that the VRP in this context is not solely a mathematical optimization problem, but a socio-technical system involving regulatory control, multi-level coordination, and competing stakeholder objectives. This analytical interpretation provides the foundation for developing the root definition and CATWOE analysis in Stage 3, ensuring that the conceptual model captures both technical routing efficiency and institutional complexity. The stakeholders involved in this VRP in the fertilizer industry are shown in Table 1.

Table 1. Stakeholder identification

No.	Status	Stakeholder
1	Problem owner	Government
2	Problem customer	Farmers
3	Problem user	Fertilizer industry
4	Problem solver	IT Team/Consultant

3.3. Stage 3: Formulating the Relevant Root Definition

The relevant system is define using CATWOE analysis to ensure that all essential elements of the problem situation are systematically considered. Root definition: A government-regulated fertilizer distribution system that is operated by logistics companies and warehouse personnel to transform fragmented and inefficient routing decisions into optimized multi-echelon vehicle routes, within regulatory and infrastructural constraints, in order to deliver subsidized fertilizer to farmers in a timely, cost efficient, and reliable manner. Based on the root definition, the route planning system is grouped using CATWOE.

1. C (Customer): farmers who receive deliveries (timely or delayed); logistics company that experience efficiency gains or efficiency losses depending on routing performance.
2. A (Actors): logistics company (driver/logistics staff); warehouse staff (warehouse, 3a, 3b); VRP analyst responsible for route optimization.
3. T (Transformation process): transforming dispersed delivery demand and routing inefficiencies into optimized vehicle routes that minimize cost and delivery time.
4. W (Worldview): fertilizer distribution must operate within government subsidy limits while achieving the lowest feasible logistics cost and ensuring timely delivery to farmers.
5. (Owners): management of logistics companies and fertilizer industry; government (subsidy regulation).
6. E (Environmental constraints): road condition, transportation regulations, weather.

3.4. Stage 4: Building a Conceptual Model

At this stage, a causal loop diagram (CLD) is used to construct a conceptual model of the VRP system. The CLD was developed using the Vensim PLE v.32 tools, as shown in Fig. 4. Based on Fig. 4, three loops are visible: one reinforcing loop (R) and two balancing loops (B). Each loop has its own characteristics an interconnected variable. The following explains the meaning if each loop: Reinforcing loop (R1) represents a virtuous cycle between VRP solution efficiency, cost reduction, profitability, and reinvestment. Improved VRP efficiency reduces total mileage and transportation costs, which increases logistical profitability. Higher profitability enables further investment in optimization tools and technological improvements, which again enhance VRP efficiency.

This loop indicates a growth mechanism that can continuously improve system performance. However, without regulatory or budget constraints, excessive focus on cost efficiency may lead to underinvestment in service quality or capacity resilience. Thus, R1 reflects both an opportunity for performance improvement and a potential risk of over-optimization under strict subsidy limits. Balancing loop (B1): explains how demand growth interacts with service capacity. Increased fertilizer demand raises route complexity and total travel time. Longer travel time reduces customer satisfaction, which may suppress future demand. This loop functions as a stabilizing mechanism, preventing uncontrolled demand growth.

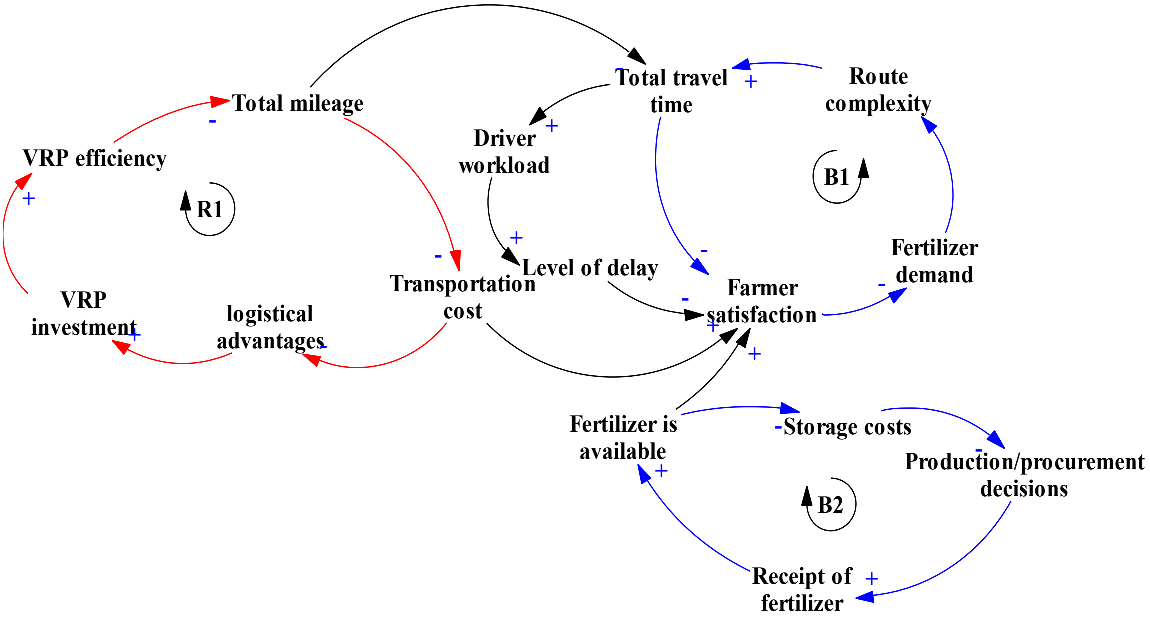

Fig. 4. Causal loop diagram of VRP Fertilizer Industry

However, it also reveals a structural vulnerability: if routing capacity is not upgraded proportionally with demand growth, the system may enter a degradation cycle characterized by service delays and declining trust from farmers. This insight directly links to the problem situation identified in Stage 2, where farmer complaints arise despite adequate production levels. Balancing loop (B2) regulates stock levels through production and procurement analysis. Low fertilizer availability triggers higher production or procurement, increasing warehouse receipts and restoring inventory levels. However, high storage costs suppress excessive procurement decisions. This loop prevents overstocking but may also create oscillation effects if production decisions lag behind demand signals. In a multi-echelon structure, such delays can amplify upstream variability, contributing to supply inconsistency at lower levels.

When R1, B1, and B2 interact, the system exhibits the characteristics of a constrained growth structure in which efficiency improvement, service limitations, and inventory control simultaneously influence overall performance. While R1 drives efficiency growth through continuous reinvestment and cost reduction, B1 restricts performance expansion due to service capacity constraints that emerge as demand increases, and B2 further limits system expansion through cost-based inventory control mechanisms. The combined interaction of these loops indicates that fertilizer scarcity at the farmer level is unlikely to stem from insufficient production capacity alone, but rather from structural misalignment between routing efficiency, service capacity, and inventory regulation policies across the multi-echelon distribution network. Next, a causal-and-effect table is created to provide additional information about the relationship between each variable involved. This can be seen in Table 2 of the causes and effects of VRP.

Table 2 illustrates the causal relationships between variables in a fertilizer distribution system based on the VRP. Overall, the efficiency of the VRP solution reduces travel distance and transportation costs, ultimately increasing profits and encouraging reinvestment in the system, forming a positive reinforcing loop. Conversely, increasing fertilizer demand increase route complexity and travel time, which can decrease customer satisfaction and create a balancing loop.

Furthermore, high storage costs exert pleasure on production decisions, while human factors such as driver fatigue influence delays and satisfaction. These relationships demonstrate that the fertilizer distribution system is a dynamic system with interplay between logistics efficiency, customer satisfaction, and resource constraints.

Table 2. Causal relationship of VRP variables

No.	Causal variables	Consequence variables	Type of influence	Loop	Relationship description
1	VRP solution efficiency	Total mileage	Negative	R1	Good route optimization reduce distance (Sulemana et al., 2019).
2	Total mileage	Total travel time	Positive	R1, B1	The longer the distance, the longer the travel time (Malichová et al., 2022).
3	Total travel time	Transportation cost	Positive	R1	The longer the distance, the higher the transportation costs (Pu et al., 2022).
4	Transportation cost	Logistical advantages	Negative	R1	High cost margins (Yang & Tao, 2023).
5	Logistical advantages	VRP investment	Positive	R1	Increased profits enable technology investments in VRP (Giaglis et al., 2004).
6	VRP investment	VRP solution efficiency	Positive	R1	Investment will improve the quality of VRP solutions (Khan, 2022).
7	Fertilizer demand	Route complexity	Positive	B1	The large number of orders adds to the complexity of planning (Raza et al., 2022).
8	Route complexity	Total travel time	Positive	B1	Complicated routes slow down the delivery process (Russo & Comi, 2021).
9	Total travel time	Level of satisfaction	Negative	B1	Long time will decrease the level of satisfaction (Qin et al., 2019).
10	Level of satisfaction	Fertilizer demand (future)	Positive	B1	High satisfaction encourages repeat orders (Majeed et al., 2022).
11	Fertilizer demand (future)	Storage costs	Positive	B2	Large stocks will increase storage costs (Rijal et al., 2023).
12	Storage costs	Production/procurement decision	Negative	B2	High storage costs drive down production/ procurement (Rijal et al., 2023).
13	Production /procurement decision	Receipt of fertilizer	Positive	B2	Production decisions determine the rate of fertilizer input (Shokouhifar et al., 2023).
14	Receipt of fertilizer	Fertilizer is available	Positive	B2	The inflow will increase the fertilizer stock (Shokouhifar et al., 2023).
15	Total travel time	Driver workload	Positive	Additional relationship	Long travel time increase fatigue (Rostami et al., 2021; Srivatsa Srinivas & Gajanand, 2017).
16	Driver workload	Delay rate	Positive	Additional relationship	Tired drivers are prone to making mistakes/being late (Osorio-Mora et al., 2021).
17	Delay rate	Level of satisfaction	Negative	Additional relationship	Delay can reduce satisfaction (Monsuur et al., 2021).

3.5. Stage 5: Comparison Between Conceptual Model and Reality

Comparing the conceptual model from the previous stage with the real world will help understand the dynamics of the problem and systemic changes, allowing for deeper analysis and recommendations. The CATWOE is used to identify six critical elements of the system to be considered. The comparison of the conceptual model with reality is displayed in the form of a table based on the previously prepared CATWOE.

Table 3. Real world analysis

CATWOE	Root Definition	Real World	GAP
Customer	Distributors/farmers achieve high delivery satisfaction.	Customer satisfaction is highly sensitive to delivery time and delay rate (see Loop B1).	The measurement of delivery performance and customer satisfaction is not systematically integrated into routing evaluation.
Actors	Logistics companies apply VRP solutions to plan and schedule fertilizer deliveries.	The multi echelon structure increase coordination complexity and limits the effectiveness of isolated VRP applications.	Limited integration of real-time warehouse and demand data into the routing algorithm.
Transformation	Routing decisions generate cost efficient and time effective distribution performance.	Operational trade-offs prevent simultaneous optimization of cost and delivery speed. Driver workload and travel time remain constraints (Loop B1).	Absence of explicit prioritization between efficiency oriented (R1) and service oriented (B1) objectives.
Worldview	Distribution operates at minimum feasible cost while ensuring timely fertilizer availability.	Field operation reveal persistent tension between cost control and service reliability.	Strategic policy direction regarding cost service trade-offs is not clearly articulated.
Owner	Fleet and warehouse capacity are aligned with operational demand.	Fleet size and warehouse capacity frequently become during peak planting seasons.	Infrastructure capacity does not fully accommodate seasonal demand variability.
Environment	The routing system adapts to geographical, regulatory, and traffic conditions.	Demand fluctuations driven by planting cycles and policy adjustment increase routing complexity times.	Limited system responsiveness to sudden regulatory or demand shifts.

The Table 3 above shows that there is still a gap between the root definition and the real-world situation. This demonstrates the need for in-depth study of CATWOE in the fertilizer industry`s VRP and opens up opportunities for further research. Determining the trade-off between efficiency and service is the most important gap to be studied in this fertilizer industry`s VRP.

3.6. Stage 6: Identification of Feasible and Desirable Changes

The gap identified in Stage 5 indicate the need for structural and operational improvements within the fertilizer distribution system. One critical change involves the integration of the routing optimization system with real-time operational data, including traffic conditions, weather disruptions, and warehouse inventory levels. The incorporation of dynamic data inputs would enhance the responsiveness of the VRP model and reduce delays caused by environmental uncertainty, thereby improving alignment between efficiency objectives (R1) and service stability mechanisms (B1).

In addition to technological integration, organizational readiness must be strengthened. This requires systematic training programs for logistics operators and warehouse personnel to ensure effective use of advanced routing software. Without adequate human capability development, technological upgrades may not produce the intended performance improvements. Another feasible change concerns the adjustment of vehicle allocation strategies based on seasonal demand variability and warehouse capacity constraints. Given that peak fertilizer demand typically coincides with planting periods, flexible fleet allocation mechanisms would help mitigate bottlenecks identified in Stage 5 and reduce service delays during high-demand periods.

Furthermore, the incorporation of explicit delivery duei-date constraints into the VRP formulation is necessary to balance cost efficiency with service reliability. By embedding time-window or due-date considerations within the optimization model, the system can prevent excessive prioritization of cost minimization at the expense of delivery punctuality. Finally, the potential establishment of additional transit warehouses may be considered in regions characterized by long transportation distances or high routing complexity. Such infrastructure adjustments could shorten delivery routes, reduce travel time, and increase overall system resilience, particularly in geographically dispersed distribution networks.

3.7. Stage 7: Action to Improve the Situation

The proposed changes are operationalized through the development of an integrated conceptual framework for subsidized fertilizer distribution as illustrated in Fig. 5.

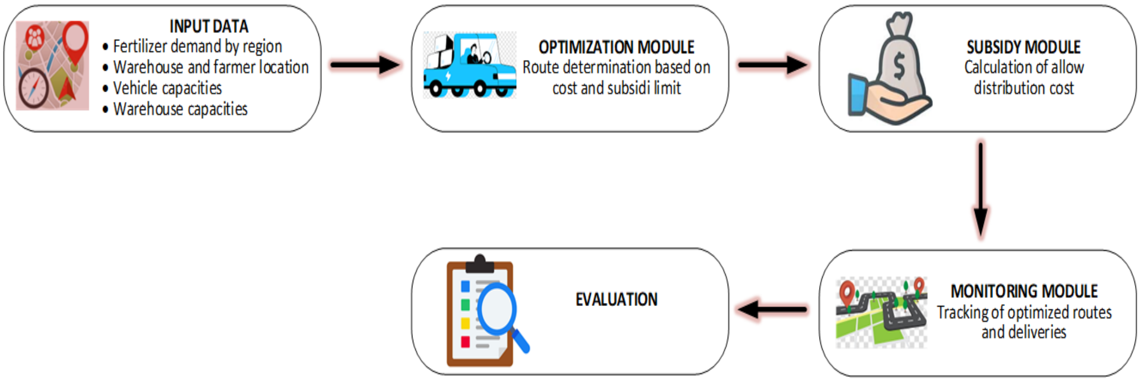

Fig. 5. Conceptual Framework of VRP Fertilizer Industry

Fig. 5 present a multi-module VRP-based framework that integrates routing optimization, subsidy constraints, monitoring mechanisms, and evaluation feedback into a unified decision-support structure. Unlike conventional VRP implementations that primarily focus on minimizing distance or transportation cost, this framework explicitly incorporates government subsidy limits as binding systemic constraints. The framework consists of five interrelated modules. The input module collects structured operational data, including regional fertilizer demand, warehouse and farmer locations, vehicle capacity, warehouse capacity, and subsidy budget allocation. The optimization module processes these inputs using a VRP algorithm that minimizes distribution cost while respecting capacity and distance constraints (Arvianto et al., 2025).

A distinguishing feature of this framework is the inclusion of a subsidy control module, which evaluates whether optimized routing outcomes remain within the government's subsidy ceiling. If budget thresholds are exceeded, the routing solution is recalibrated to maintain fiscal feasibility. The monitoring module provides real-time visibility of routes, schedules, and delivery performance, enabling transparency and accountability within the subsidized distribution system. Finally, the evaluation module compares actual performance indicators such as delivery punctuality, cost realization, and service coverage against predefined efficiency and policy targets. Through this structure, the framework operationalizes the systemic insights derived from the SSM stages, transforming conceptual analysis into an implementable governance-oriented VRP architecture.

The Primary novelty of this study lies in the integration of Soft Systems Methodology (SSM) with a constrained VRP optimization structure under government subsidy regulation. While existing VRP frameworks predominantly emphasize algorithmic improvement such as metaheuristics, hybrid algorithms, or computational efficiency this study embeds routing optimization within a socio-technical governance context. Unlike conventional VRP models that treat cost minimization as the primary objective, the proposed framework introduces subsidy ceiling control as an institutional constraint. This shifts the VRP formulation from a purely operational optimization problem to a policy-constrained decision system. Furthermore, the integration of monitoring and evaluation modules extends the framework beyond static optimization, enabling continuous performance feedback and adaptive control.

Most VRP studies focus on improving algorithmic performance metrics such as solution quality, convergence speed, or computational complexity. In contrast, this framework addresses systemic alignment across multi-echelon coordination, service reliability, and regulatory compliance. VRP studies focus on improving algorithmic performance metrics such as solution quality, convergence speed, or computational complexity. In contrast, this framework addresses systemic alignment across multi-echelon coordination, service reliability, and regulatory compliance.

Although the case study focuses on the Indonesian fertilizer industry, the proposed framework is structurally adaptable to other subsidized or regulated distribution systems, such as: Pharmaceutical distribution under public health budgets, Food assistance logistics, and Energy subsidy distribution networks. The modular structure comprising input, optimization, constraint control, monitoring, and evaluation components enables adaptation to different regulatory environments and distribution scales. Thus, the framework demonstrates methodological generalizability beyond the fertilizer industry context.

Theoretically, this study contributes by bridging Soft Systems Methodology with quantitative VRP modeling, demonstrating how qualitative problem structuring can inform constrained optimization design. Methodologically, the study illustrates how CLD analysis can identify leverage points prior to algorithm formulation, thereby preventing misalignment between mathematical optimization and systemic realities. This integration addresses a research gap in VRP literature, where algorithmic development often proceeds independently from stakeholder analysis and institutional constraints.

4. Conclusion

This study proposes a systemic conceptual framework for Vehicle Routing Problem (VRP) modeling by integrating Soft Systems Methodology (SSM) into a subsidy-constrained logistics context. Through the seven stages of SSM, supported by VOSviewer analysis, rich pictures, CATWOE, and causal loop diagrams, the research identifies key variables and feedback structures that explain the trade-off between cost efficiency and service reliability in subsidized fertilizer distribution. The study contributes to the SSM literature by demonstrating how qualitative problem structuring can inform quantitative optimization design, and to VRP modeling by embedding institutional and fiscal constraints into routing formulation rather than focusing solely on cost minimization. It further advances logistics systems thinking by linking systemic feedback analysis with operational decision models. Methodologically, the study offers a structured pathway from systemic diagnosis to optimization architecture, while practically providing a governance-oriented framework for managing efficiency service trade-offs under regulatory limits. However, the framework remains conceptual and has not yet been empirically validated through computational implementation. Future research should focus on algorithmic development, empirical testing with real distribution data, and comparative analysis between subsidy-constrained and conventional VRP models to strengthen generalizability and theoretical robustness.

Acknowledgements: The author would like to express his gratitude to all the promoters in the Industrial Engineering Doctoral Program at Trisakti University for their guidance, direction an input. To all parties involved in the discussion and analysis process related to this article. This research is the initial part of a doctoral dissertation, so it is possible that there will be further publications of this research.

Author Contribution: Tombak Gapura Bhagya, the first author, conceived and design research, conducted data collection analysis, and drafted the initial manuscript. Rahmi Maulidya, the second author, contributed to methodology, supervision, result discussion, oversight. Parwadi Moengin, the third author, contributed to review writing and editing, final text approval. Sally Cahyati, the fourth author, contributed to review writing and editing, final text approval.

Funding Statement: The researchers fully funded this study themselves, without receiving any financial assistance form any party, whether in the form of grants, or other forms of financial support.

Conflict of Interest: The author declares no conflict of interest regarding the publication of this article.

References

Abdirad, M., & Krishnan, K. (2022). Examining the impact of E-supply chain on service quality and customer satisfaction: a case study. *International Journal of Quality and Service Sciences*, *14*(2), 274–290. https://doi.org/10.1108/IJQSS-08-2020-0131

Anokic, A., Stanimirovic, Z., Stakic, D., & Davidovic, T. (2021). Metaheuristic approaches to a vehicle scheduling problem in sugar beet transportation. *Operational Research*, *21*(3), 2021–2053. https://doi.org/10.1007/s12351-019-00495-z

Arvianto, A., Cahyani, D. C., & Saputra, D. W. N. (2025). Optimizing Container Repositioning Using a Sequential Insertion Algorithm for Pickup-Delivery Routing in Export-Import Operations. In *Spektrum Industri*. https://doi.org/10.12928/si.v23i1.349

Fahmid, I. M., Jamil, A., Wahyudi, Agustian, A., Hatta, M., Aldillah, R., Yofa, R. D., Sumedi, Sumaryanto, & Susilowati, S. H. (2022). Study of the impact of increasing the highest retail price of subsidized fertilizer on rice production in Indonesia. *Open Agriculture*, *7*(1), 348–359. https://doi.org/10.1515/opag-2022-0087

Fatorachian, H., & Kazemi, H. (2021). Impact of Industry 4.0 on supply chain performance. *Production Planning & Control*, *32*(1), 63–81. https://doi.org/10.1080/09537287.2020.1712487

Firmansyah, F., Mawengkang, H., Mujib, A., & Mathelinea, D. (2022). A Decision Model to Plan Optimally Production-Distribution of Seafood Product with Multiple Locations. *Mathematics*, *10*(18), 3240. https://doi.org/10.3390/math10183240

Giaglis, G. M., Minis, I., Tatarakis, A., & Zeimpekis, V. (2004). Minimizing logistics risk through real-time vehicle routing and mobile technologies. *International Journal of Physical Distribution & Logistics Management*, *34*(9), 749–764. https://doi.org/10.1108/09600030410567504

Gilbert, J., & Pratt-Adams, S. (2022). Systems Thinking and Soft Systems Methodology. In *Soft Systems Methodology in Education* (pp. 3–34). Springer International Publishing. https://doi.org/10.1007/978-3-030-99225-5_1

Jaboob, A. S., Awain, A. M. B., Ali, K. A. M., & Mohammed, A. M. (2024). *Introduction to Operation and Supply Chain Management for Entrepreneurship* (pp. 52–80). https://doi.org/10.4018/979-8-3693-1846-1.ch004

Khan, A. S. (2022). Multi-Objective Optimization of a Cost-Effective Modular Reconfigurable Manufacturing System: An Integration of Product Quality and Vehicle Routing Problem. *IEEE Access*, *10*, 5304–5326. https://doi.org/10.1109/ACCESS.2021.3137563

Konstantakopoulos, G. D., Gayialis, S. P., & Kechagias, E. P. (2022). Vehicle routing problem and related algorithms for logistics distribution: a literature review and classification. *Operational Research*, *22*(3), 2033–2062. https://doi.org/10.1007/s12351-020-00600-7

Kumari, M., De, P. K., Chaudhuri, K., & Narang, P. (2023). Utilizing a hybrid metaheuristic algorithm to solve capacitated vehicle routing problem. *Results in Control and Optimization*, *13*, 100292. https://doi.org/10.1016/j.rico.2023.100292

Lu, W., Choi, S.-B., & Yeo, G.-T. (2022). Resilient route selection of oversized cargo transport: the case of South Korea–Kazakhstan. *The International Journal of Logistics Management*, *33*(2), 410–430. https://doi.org/10.1108/IJLM-11-2020-0445

Majeed, M., Asare, C., Fatawu, A., & Abubakari, A. (2022). An analysis of the effects of customer satisfaction and engagement on social media on repurchase intention in the hospitality industry. *Cogent Business & Management*, *9*(1). https://doi.org/10.1080/23311975.2022.2028331

Malichova, E., Cornet, Y., & Hudak, M. (2022). Travellers’ use and perception of travel time in long-distance trips in Europe. *Travel Behaviour and Society*, *27*, 95–106. https://doi.org/10.1016/j.tbs.2021.12.003

Monsuur, F., Enoch, M., Quddus, M., & Meek, S. (2021). Modelling the impact of rail delays on passenger satisfaction. *Transportation Research Part A: Policy and Practice*, *152*, 19–35. https://doi.org/10.1016/j.tra.2021.08.002

Mor, A., & Speranza, M. G. (2022). Vehicle routing problems over time: a survey. *Annals of Operations Research*, *314*(1), 255–275. https://doi.org/10.1007/s10479-021-04488-0

Nurhasanah, N., Machfud, Mangunwidjaja, D., & Romli, M. (2020). The Application of Soft System Methodology to design the Conceptual Model for Intelligent Supply Chain Model of Natural Fibre Agroindustry. *IOP Conference Series: Materials Science and Engineering*, *847*(1), 012089. https://doi.org/10.1088/1757-899X/847/1/012089

Osorio-Mora, A., Soto-Bustos, M., Gatica, G., Palominos, P., & Linfati, R. (2021). The Multi-Depot Cumulative Vehicle Routing Problem With Mandatory Visit Times and Minimum Delayed Latency. *IEEE Access*, *9*, 27210–27225. https://doi.org/10.1109/ACCESS.2021.3058242

Pak, Y.-J., & Mun, K.-H. (2024). A practical vehicle routing problem in small and medium cities for fuel consumption minimization. *Cleaner Logistics and Supply Chain*, *12*, 100164. https://doi.org/10.1016/j.clscn.2024.100164

Pratiwi, E. B., Prajitno, P., & Kurniawan, E. (2024). ELM-based control system applications: A bibliometric analysis and review. *Journal of Mechatronics, Electrical Power, and Vehicular Technology*, *15*(1), 68–81. https://doi.org/10.55981/j.mev.2024.889

Pu, X., Lu, X., & Han, G. (2022). An improved optimization algorithm for a multi-depot vehicle routing problem considering carbon emissions. *Environmental Science and Pollution Research*, *29*(36), 54940–54955. https://doi.org/10.1007/s11356-022-19370-0

Puspitasari, F. H., & Kurniawan, V. R. B. (2021). Designing Optimal Distribution Routes using a Vehicle Routing Problem (VRP) Model in a Logistics Service Provider. *IOP Conference Series: Materials Science and Engineering*, *1071*(1), 012005. https://doi.org/10.1088/1757-899X/1071/1/012005

Qin, G., Tao, F., & Li, L. (2019). A Vehicle Routing Optimization Problem for Cold Chain Logistics Considering Customer Satisfaction and Carbon Emissions. *International Journal of Environmental Research and Public Health*, *16*(4), 576. https://doi.org/10.3390/ijerph16040576

Raza, S. M., Sajid, M., & Singh, J. (2022). *Vehicle Routing Problem Using Reinforcement Learning: Recent Advancements* (pp. 269–280). https://doi.org/10.1007/978-981-19-0840-8_20

Reynolds, M., & Holwell, S. (Eds.). (2010). *Systems Approaches to Managing Change: A Practical Guide*. Springer London. https://doi.org/10.1007/978-1-84882-809-4

Ricome, A., Barreiro-Hurle, J., & Sadibou Fall, C. (2024). Government fertilizer subsidies, input use, and income: The case of Senegal. *Food Policy*, *124*, 102623. https://doi.org/10.1016/j.foodpol.2024.102623

Rijal, A., Bijvank, M., & de Koster, R. (2023). Dynamics between warehouse operations and vehicle routing. *Production and Operations Management*, *32*(11), 3575–3593. https://doi.org/10.1111/poms.14051

Rodriguez-Ulloa, R., & Paucar-Caceres, A. (2005). Soft System Dynamics Methodology (SSDM): Combining Soft Systems Methodology (SSM) and System Dynamics (SD). *Systemic Practice and Action Research*, *18*(3), 303–334. https://doi.org/10.1007/s11213-005-4816-7

Rostami, B., Desaulniers, G., Errico, F., & Lodi, A. (2021). Branch-Price-and-Cut Algorithms for the Vehicle Routing Problem with Stochastic and Correlated Travel Times. *Operations Research*, *69*(2), 436–455. https://doi.org/10.1287/opre.2020.2037

Russo, F., & Comi, A. (2021). Sustainable Urban Delivery: The Learning Process of Path Costs Enhanced by Information and Communication Technologies. *Sustainability*, *13*(23), 13103. https://doi.org/10.3390/su132313103

Sbai, I., Krichen, S., & Limam, O. (2022). Two meta-heuristics for solving the capacitated vehicle routing problem: the case of the Tunisian Post Office. *Operational Research*, *22*(1), 507–549. https://doi.org/10.1007/s12351-019-00543-8

Seki, Y., Sutrisna, M., & Olanipekun, A. O. (2021). Integrating a rich picture diagram and causal loop diagram to model stakeholder engagement in building refurbishment projects. *Engineering, Construction and Architectural Management*, *28*(7), 1929–1951. https://doi.org/10.1108/ECAM-05-2020-0342

Sherif, S. U., Asokan, P., Sasikumar, P., Mathiyazhagan, K., & Jerald, J. (2021). Integrated optimization of transportation, inventory and vehicle routing with simultaneous pickup and delivery in two-echelon green supply chain network. *Journal of Cleaner Production*, *287*, 125434. https://doi.org/10.1016/j.jclepro.2020.125434

Shokouhifar, M., Sohrabi, M., Rabbani, M., Molana, S. M. H., & Werner, F. (2023). Sustainable Phosphorus Fertilizer Supply Chain Management to Improve Crop Yield and P Use Efficiency Using an Ensemble Heuristic–Metaheuristic Optimization Algorithm. *Agronomy*, *13*(2), 565. https://doi.org/10.3390/agronomy13020565

Sihombing, V., Yandri, E., Pramono, K. P., & Ariati, R. (2025). Advances in building energy management systems (BEMS): A comprehensive review with bibliometric analysis and future research directions. *Journal of Mechatronics, Electrical Power, and Vehicular Technology*, *16*(1), 27–41. https://doi.org/10.55981/j.mev.2025.961

Sluijk, N., Florio, A. M., Kinable, J., Dellaert, N., & Van Woensel, T. (2023). Two-echelon vehicle routing problems: A literature review. *European Journal of Operational Research*, *304*(3), 865–886. https://doi.org/10.1016/j.ejor.2022.02.022

Srivatsa Srinivas, S., & Gajanand, M. S. (2017). Vehicle routing problem and driver behaviour: a review and framework for analysis. *Transport Reviews*, *37*(5), 590–611. https://doi.org/10.1080/01441647.2016.1273276

Stowell, F. (2024). The Art of Soft Systems Inquiry: Retracing the Footsteps of Churchman and Checkland. *Systemic Practice and Action Research*, *37*(6), 1123–1140. https://doi.org/10.1007/s11213-024-09689-9

Sulemana, A., Donkor, E. A., Forkuo, E. K., & Oduro-Kwarteng, S. (2019). Effect of optimal routing on travel distance, travel time and fuel consumption of waste collection trucks. *Management of Environmental Quality: An International Journal*, *30*(4), 803–832. https://doi.org/10.1108/MEQ-07-2018-0134

Wilson, B., & Van Haperen, K. (2015). *Soft Systems Thinking, Methodology and the Management of Change*. Macmillan Education UK. https://doi.org/10.1007/978-1-137-43269-8

Xu, G., & Lyu, Q. (2021). Vehicle Routing Problem for Collaborative Multidepot Petrol Replenishment under Emergency Conditions. *Journal of Advanced Transportation*, *2021*, 1–20. https://doi.org/10.1155/2021/5531500

Yang, F., & Tao, F. (2023). A Bi-Objective Optimization VRP Model for Cold Chain Logistics: Enhancing Cost Efficiency and Customer Satisfaction. *IEEE Access*, *11*, 127043–127056. https://doi.org/10.1109/ACCESS.2023.3332145

Zarezadeh, M. (2024). Applying Soft Systems Methodology to implement strategy in the organization: A case study of improving the motivation system of Statistic Center. In *Journal of Systems Thinking in Practice*. jstinp.um.ac.ir. https://doi.org/10.22067/jstinp.2024.86313.1087

Zhang, H., Ge, H., Yang, J., & Tong, Y. (2022). Review of Vehicle Routing Problems: Models, Classification and Solving Algorithms. *Archives of Computational Methods in Engineering*, *29*(1), 195–221. https://doi.org/10.1007/s11831-021-09574-x