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OPTIMIZATION OF BULK ROOT-CROP TRANSPORTATION: A LITERATURE REVIEW AND A CONCEPTUAL MODEL FOR UKRAINE

This paper reviews Vehicle Routing Problem (VRP) approaches for bulk root-crop transportation and proposes a conceptual model adapted to Ukrainian inter-regional logistics. The review covers the operational specifics of farm-to-plant flows, relevant VRP variants, and dominant solution methods. Building on these foundations, the paper formulates a conceptual model in which Ukraine-specific factors – accelerated plant consolidation, an extended hauling shoulder, plant-gate queueing, a heterogeneous and aged truck fleet, and pavement-quality dependent travel costs – modify the classical VRP and tighten its operational constraints. The principal contribution is to move the discussion beyond the observation that no Ukrainian VRP study exists for bulk root crops, towards a concrete characterisation of how such a model should differ from its Serbian, Egyptian, Thai, or Australian analogues.

Keywords: vehicle routing problem, bulk root crops, sugar beet, agricultural logistics, metaheuristics, Ukrainian context.

У роботі представлено огляд підходів до задачі маршрутизації транспорту (Vehicle Routing Problem, VRP) у контексті перевезення навалочних плодових культур та запропоновано концептуальну теоретичну модель, адаптовану до української внутрішньорегіональної логістики. Огляд охоплює операційні особливості потоків «поле – переробне підприємство», релевантні варіанти VRP та переважаючі методи їх розв'язання. На цій основі сформульовано концептуальну модель, у якій українські специфічні чинники – прискорена консолідація переробних підприємств, подовжене транспортне плече, черги на прийомних пунктах, однорідний та зношений автопарк, а також залежність витрат на перевезення від якості дорожнього покриття – модифікують класичну постановку VRP та посилюють її експлуатаційні обмеження. Основна суть огляду полягає в переході від простої констатації відсутності українських VRP-досліджень для навалочних плодових культур до конкретної характеристики того, чим така модель має відрізнятися від її сербських, єгипетських, тайських та австралійських аналогів.

Ключові слова: задача маршрутизації транспорту, навалочні плодові культури, цукровий буряк, агрологістика, метаевристики, український контекст.

Introduction

Bulk root crops – sugar beet first of all, alongside potato and onion – combine three properties that make their transportation a classic operations-research problem. The harvesting campaign is short, quality decays within hours of lifting, and a small set of processing plants must absorb large volumes under tight intake schedules. Routing decisions translate directly into hauling cost and into product losses at the plant gate. The Vehicle Routing Problem (VRP), introduced by Dantzig and Ramser in 1959 [1] and matured into a broad family of variants and algorithms [2], is the natural framework. International literature has applied it intensively to sugar beet and sugarcane campaigns. Ukrainian work on the subject is essentially absent. This review summarises the relevant literature and then formulates a conceptual VRP model that reflects Ukrainian operating conditions.

Bulk Root-Crop Logistics and Relevant VRP Variants

Bulk root-crop transportation has three features that drive model selection. The campaign concentrates peak demand for trucks into a few weeks. The product deteriorates: every hour of delay between lifting and slicing costs sucrose and dry matter. The network is many-to-few – many pickup piles serve a small number of plants, each with strict per-shift intake capacity. These features map onto specific VRP variants: a capacitated base case, time-window constraints on plant intake and harvest freshness, multi-depot structure across plants, and multi-trip operation during peak days. Field-logistics work by Bochtis and Sørensen established the link between operational VRP and agricultural machinery, treating field traversal and service-unit coordination as routing decisions [3].

Country-level case studies confirm the value of formal optimisation. Higgins solved a road-vehicle scheduling problem at an Australian sugar mill using mixed-integer programming, achieving substantial real-

fleet savings [4]. Anokić and colleagues formulated Serbian sugar beet transport as a vehicle scheduling problem and cut campaign transportation time with metaheuristics [5]. Fikry, Gheith and Eltawil integrated production, logistics and crop-rotation decisions for Egyptian sugar beet supply chains, showing that decisions taken in isolation leave measurable value on the table [6]. Pitakaso and Sethanan attacked the same problem on the Thai sugarcane side with an Adaptive Large Neighborhood Search algorithm for harvester assignment and routing under shared field resources [7]. Every major beet- or cane-producing country has produced its own VRP-based study. Ukraine has not such number of completed researches and implemented solutions in this field.

Solution Methods

VRP is NP-hard, so exact methods scale poorly beyond toy instances. For realistic campaigns the literature relies on heuristics and metaheuristics: the Clarke-Wright savings algorithm as constructive baseline [8], and Variable Neighborhood Search, GRASP, Adaptive Large Neighborhood Search and Genetic Algorithms as the dominant improvement frameworks [5, 7]. A recent systematic review of VRPTW literature (2018–2022) confirms the pattern: approximate methods dominate, and hybrid algorithms now account for roughly forty per cent of studies [9]. For bulk root crops hybridisation is particularly attractive because the problem combines truck-to-pile assignment, route sequencing, and timing within plant intake windows – three sub-problems with different algorithmic affinities.

The Ukrainian Context: Industry Dynamics

Three structural shifts make the Ukrainian VRP problem qualitatively different from its peers. First, plant consolidation. The number of operating sugar factories has fallen from over a hundred in the 1990s to twenty-seven in the 2025 campaign, and industry forecasts point to eighteen–twenty in the medium term. Closures concentrate the remaining plants in the Vinnytsia, Khmelnytskyi, Ternopil and Poltava regions. Second, the hauling shoulder has lengthened. Fields that previously delivered to a local plant now serve a more distant one, which sharpens the trade-off between travel time and sucrose loss. Third, the operating environment is harder: an aged and heterogeneous truck fleet, road surfaces of uneven quality, plant-gate queueing during peak shifts, and wartime fuel-price volatility. Existing Ukrainian transport-optimisation research has focused on grain export, where rail-to-port logistics dominate and the planning horizon is months rather than hours [10]. That work is methodologically valuable but operationally distant from the root-crop case.

5. A Conceptual VRP Model for Ukrainian Conditions

Building on the reviewed literature, a Ukraine-adapted VRP for bulk root crops should retain the capacitated multi-depot multi-trip backbone but extend it along five lines. The objective should minimise total campaign cost – fuel, driver, and plant-gate idle time – augmented by a quality-loss penalty proportional to the delay between lifting and processing, in line with the sucrose-decay logic central to [5] and [6]. Time-window constraints should be two-sided: a freshness window at the field side and an intake-shift window at the plant side, with the latter narrowed by realistic queueing rather than treated as a hard gate. Travel cost should be road-class dependent rather than purely distance-based, reflecting Ukrainian pavement heterogeneity and its effect on average speed and fuel burn. The fleet should be heterogeneous: capacity, fuel consumption and availability differ across truck classes, which most international studies abstract away. Finally, the post-consolidation network – fewer plants, longer arcs – should be the structural premise of the instance design, not an afterthought. None of these extensions is individually novel; their combination is what makes the model Ukrainian.

Conclusion

VRP and its agricultural extensions are a mature toolkit for routing bulk root crops, with proven gains in international practice. Metaheuristic and hybrid algorithms are the operational standard. The principal gap is not the absence of a Ukrainian VRP study in isolation, but the absence of a problem formulation that captures plant consolidation, longer hauling shoulders, queueing, fleet heterogeneity and road-quality effects together. The conceptual model proposed here is a step in that direction and a basis for subsequent computational work on real fleet and plant data.

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