Rich Vehicle Routing Problems – Challenges and Prospects in Exploring the Power of Parallelism

The globalization of the economy generates a rapidly growing exchange of goods and commodities on our planet. The emerging transportation amount, the high cost pressure induced by raising energy prices and the growing relevance of ecological impacts increase the importance of efficient logistics networks.

A seminal approach to face the inherent complexity of logistics systems is the integration of Model-Based Optimization Methods into Interactive Decision Support Systems or Assistant Systems that can combine both the experience and competence of human logistics experts with the capabilities of modern modeling and optimization methods. In this context applicable optimization methods have to fulfill a multiplicity of different requirements. Many case studies have shown that Metaheuristics are promising candidates to meet these challenges.

An important and economical relevant class of logistics problems is the class of Vehicle Routing Problems (VRP). Practice-oriented Vehicle Routing Problems are hard optimization problems with demanding challenges appearing on both modeling and optimization duties.
This talk presents an integrated modeling and optimization approach that can be used to implement powerful Metaheuristics for practice-oriented Vehicle Routing Problems.

The modeling component is inspired by following vehicle- and process-oriented view: A vehicle is interpreted as an abstract machine or processor; and a vehicle route is specified by a sequence of basic service actions (basic commands, elementary transformation functions) induced by the service requests of the customers. Starting from an initial state, each route is served by a different vehicle being restricted by several vehicle specific constraints (i.e. upper limit of load capacity, tour length, time windows, LIFO loading and unloading, multiple compartments, precedence relations, etc.). The service actions are executed on a set of status or resource variables expressing the remaining potential of the vehicle at each step of its service process. In this general model, many cost, demand and constraint types can be represented elegantly with special resources and suitable transformation functions.
Based on this model, the optimization task is finding a set of valid vehicle routes, which processes all necessary service demands of the customers with minimum overall costs.

The optimization component is realized as an expandable framework that is based on a set of standard neighborhoods for Vehicle Routing Problems (i.e. one customer move, two customer exchange, Cross Exchange, Path Exchange, 2-Opt, 3-Opt, 4-Opt, etc.). All considered elementary neighborhoods are special cases of the Path Exchanging operator and, therefore, allow the use of efficient 'Super-Customer' data structures and Fast Delta Function Evaluations for many cost and constraint types.
The elementary neighborhoods are used in an upgradeable set of predefined templates to implement more complex operators and Metaheuristics (i.e. Multi-Step Neighborhoods, Large Neighborhoods, Mutation Operators, Neighborhood Search, Variable Neighborhood Search, Evolutionary Algorithms, etc.).

The applicability and efficiency of the integrated modeling and optimization approach was substantiated on both industrial (i.e. the highly constrained large scale distribution network of a big supermarket chain, the supplier network of a big automobile manufacturer) and scientific Vehicle Routing Problems (i.e. CVRP, MDVRP, MDVRPTW, PTSP, PVRP, OVRP, OVRPTW, VRPBH, etc.).

The described framework was used to implement Hybrid (1+1)-Evolutionary Strategies for the considered problems by combining concepts from Evolutionary Strategies, Variable Neighborhood Search, Iterative Local Search and Dynamic Adaptive Decomposition Strategies. The efficiency and solution quality produced by these implementations were evaluated on several hundred benchmark instances taken from the related literature. Best known solutions were computed for nearly all considered benchmark instances and new best solutions for more than 50% of them.

Four important policies were fundamentally used in these sequential implementations to handle the complexity of practice-oriented Vehicle Routing Problems:

- The use of multiple Neighborhood Generating Operators
- The integration of Multiple Neighborhoods into different Metaheuristics and their orchestration to Hybrid Metaheuristics
- The use of decomposition methods and strategies (divide and conquer)
    - Decomposition in Sub-Neighborhoods
    - Decomposition in partial problems and sub-problems
    - Large Neighborhood Search
- The re-use of partial work that has already been done before on following levels:
    - Objective function level (Fast Delta Function Evaluation)
    - Neighborhood level (Overlapping Neighborhoods and Sub-Neighborhoods)
    - Sub-Problem level (Common Sub-Problems)

Supplementary, decomposition methods and strategies are excellent sources for the utilization of parallelism that is nowadays available with standard PCs and that is supposed to be a major driving factor for the speed-up of future computers. To address this speed-up potential, this talk will point out connections to parallel methods and extensions that can take advantage of different kinds of parallelism.