Metaheuristics for Transport and Logistics

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Metaheuristics for the optimisation and management of Transport and Logistics

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Abstract

IDSIA, Istituto Dalle Molle di Studi sull'Intelligenza Artificiale is a research institute active in both theoretical and applied research in the field of Operations Research and Artificial Intelligence. Since 1996 IDSIA has capitalized on the results obtained in theoretical research fields applying them to real world logistic and transport problems. In this short communication we outline the major results we have obtained in combinatorial optimisation problems and their applications to real-world problems. We also show how the real world provides a source of continuous inspiration to define new theoretical problems whose solutions can later have an impact on real problems.

Keywords

Logistics systems, optimisation, simulation, metaheuristics– 2nd Swiss Transport Research Conference – STRC 2002 – Monte Verità

1. Metaheuristics and hard combinatorial optimisation problems

Most problems faced by logistics operators have been known for centuries, think of the Chinese postman problem, first formulated by Euler in 1736. These problems have the displeasing (for what it concerns the attainability of a solution) characteristic of being combinatorial, that is, all the possible combinations of the decisions and variables must be explored to find a solution of the problem. Thus, as the number of decisions and variables increase, the time required to find a solution becomes rapidly unaffordable, since in real world problems it is quite easy to encounter problems with hundreds, if not thousands, of variables.

Heuristics methods have been devised to limit the search to some parts of the search space, concentrating where an improvement of the objective function is more probable, thus reducing the time required to obtain a solution, maybe sub-optimal, but already a good and sensible improvement from the initial situation. A heuristic method makes use of peculiar characteristics of a problem and exploits them to find such a solution. Other empirical methods do not exploit only the problem characteristics but the analogy with other optimisation methods found in nature. Such heuristic methods, independent of the problem, are called *metaheuristcs*.

In the following we explain how we match theory with practice in order to bring to real world problems the results of theoretical research.

2. Methodological investigation

The research topic of the metaheuristics has been investigated in many projects supported by the Swiss National Science Foundation and the European Commission. In particular IDSIA is currently involved in the “Metaheuristics Network”, a Research and Training Network project funded by the European Commission within the Improving Human Potential Program (2000-2004). The project studies the use of metaheuristics in the solution of difficult combinatorial optimisation problems. The metaheuristics instances under investigation are Simulated Annealing, Tabu Search, Ant Colony Optimization, Genetic Algorithms, Iterated Local Search. The Metaheuristics Network will study these metaheuristics from both theoretical and experimental points of view with the aim of improving our understanding of how they work, and to make easier their effective application to the solution of important practical optimization problems. The optimization problems under investigation are: Scheduling Problems, Vehicle Routing Problems, Quadratic Assignment Problems, Max-Sat Problems and Timetabling Problems. The results obtained from this investigation will be used to develop a “theory” to match metaheuristics components to problem characteristics. This will allow us to achieve the following engineering-oriented goal: the definition of guidelines that can be used to help choosing which metaheuristics, or metaheuristic components, to use when a new problem is faced.

One of the metaheuristic under investigation is ant colony optimization (ACO) (Dorigo *et al*. 1999). ACO is based on the observation that real ants find the optimal path between a food source and their nest food by depositing chemical traces (pheromones) on the ground. A computer analogy has been implemented where a large number of simple artificial ants are able to build good solutions to hard combinatorial optimization problems via low-level based communications based on artificial pheromone. The system is able to learn from previous experiences by dynamically adapting the search of in relation to the solutions computed by the colony. ACO has been deeply investigated in three projects funded by the Swiss National Science Foundation (SNSF): the project “Cooperation and Learning for Combinatorial Optimization” (1996-1998) was the first world-wide funded project on the ant colony approach. In this project the basic principles and the basic methodologies of ACS (Gambardella and Dorigo, 1996, Dorigo M., Gambardella, 1997), a very effective ACO based algorithm have been defined and applied to the travelling salesman problem. In the following SNSF project “Dynamic Memory for Combinatorial Optimization” (1998-2000) we started to analyze the use of ACS in the solution of more complex combinatorial problems like the sequential ordering problem (HAS-SOP, Gambardella and Dorigo, 2000) and vehicle routing problems (MACS-

VRPTW, Gambardella *et al.* 1999). In these domains the developed algorithms are among the best currently available and for many benchmark instances they have found new best known solutions. Lastly, in the SNSF project “On-line Fleet Management” (2000-2002) we decided to move from static to dynamic environment putting ACO to work on the solution of on-line vehicle routing problems where the information about activities, costs and vehicles dynamically change over time.

Our knowledge in the use of metaheuristic approach to the solution of combinatorial problems has been enlarged with the study of scheduling problems where the main focus is on the efficient allocation of one or more resources to activities over time. The SNSF project “Resource Allocation and Scheduling in Flexible Manufacturing Systems” (1998-2002) give us the possibility to develop the state of the art algorithms for the flexible job shop scheduling problem (Mastrolilli and Gambardella, 2000). The competence in scheduling problems comes from our practical attempt to solve a real problem in loading and uloading containers from ships in the LSCT project presented in the following section.

3. Integrating optimisation problems at different levels: the LSCT project

Metaheuristics are a powerful tool to solve combinatorial optimisation problems that are so frequent in logistics and transports, but they cannot be applied blindly. It is only with a judicious combination of old and new methods that we have been able to solve the problem of improving the performance of the intermodal container terminal in La Spezia in the contest of a CTI/KTI sponsored project. The scale of the problem, involving many decision makers at different levels (yard managers, ship planners, resource allocation managers), made the problem intractable, even by the most advanced optimisation methods currently available. Our approach was based on a decomposition of the problem at different levels, on different time scales. We focused on the ship loading and unloading process, but first we formulated the resource allocation problem as a network flow problem: how many quay cranes and yard cranes are necessary to sustain a flow of container from the ship to the yard (and back) to unload and load the ship within the deadline? Once this problem has been solved, with the traditional mixed integer programming approach, we concentrated on the scheduling of the load/unload sequence, devising a new job-shop heuristics to solve this hard problem (Gambardella *et al.* 2001). The found solution, composed of the allocation of resources to load and unload vessels, together with the detailed scheduling, container by container, of load and unload operations, was then put to test in a discrete event simulation environment, facing various scenarios. This enables us to communicate to the port manager the robustness of the solution, since we showed the feasibility against real world data. The improvement of the terminal management could be measured to a reduction of operating costs of approximately 30%.

Among the techniques used in this project we find: time series analysis, mixed integer programming, flexible job-shop scheduling, discrete event simulation.

This project has been developed in collaboration with ContShip La Spezia Container Terminal and Data Systems and Planning in Lugano. The project was financed by the Swiss CTI.

4. Simulation and optimisation: PLATFORM

Simulation also played a major role in the EC-sponsored project "PLATFORM: Computer-controlled freight platforms for a time-tabled rail transport system" an European DGVII transport project (1998-2000). The objective of the work was to evaluate the impact of advanced logistics systems in rail-road intermodal hubs. The experience of PLATFORM (Rizzoli *et al.*, in press) showed how simulation can be used to provide to the logistic managers a very detailed model of the process they manage, when many of the assumptions used to formulate a traditional optimisation problem must be neglected. It has been observed that these assumptions are often rejected by the terminal managers since they think that they impose an over-simplification the problem. On the basis of this objection, their next step is to refuse any kind of management policy based on the assumptions. Simulation can provide the common ground where managers and operations research specialist converge to a shared vision of the problem.

In the framework of the PLATFORM project we designed a model of an intermodal rail-road terminal made of rail and road gates, platforms for loading and unloading, shunting areas to compose and decompose trains. The model was then populated by agents such as train wagons, trucks and the drivers, terminal cranes and the terminal operators. Simulations were run under different truck arrival scenarios and hypothesising different loading and unloading machinery. Monte Carlo simulations have shown possible alternatives to improve the terminal throughput, thus increasing the performance of the combined rail-road network.

5. ACO for vehicle routing: the DYVO project

The Ant-colony optimisation metaheuristic finds an application to the problem of heating oil distribution in Canton Ticino (Casagrande *et al*, 2001). This CTI/KTI sponsored project "DYVO: Dynamic Vehicle Routing and Dispatching by using Optimization, Forecasting and Simulation" aims at the development of a software prototype able to employ ACO to the solution of the vehicle routing problem with time windows and with a non-homogeneous fleet of vehicles. Pina Petroli SA, located in Grancia, is the commercial partner in this project and provided the test site while DIE-SUPSI is working on the integration of the different modules. IDSIA have developed an application which, accessing the company's database of customers' orders, returns a distribution plan, which is the list of customers to be visited over a given time horizon, minimising the travelled distance. The tool has been designed in order to let the human decision maker (the Tour Planner) to experiment with the computer generated solutions, to quickly compute a new solution in face of changed conditions (a truck breakdown, a road blockage, an urgent customer request) thanks to the extreme rapidity of the ACO metaheuristic in finding a new solution (only 2 minutes for a whole week of deliveries, with more than 100 orders). The application is complemented by an order forecasting module, which estimates when each customer will be likely to need a refill, on the basis of the customer's reorder pattern and on the average daily temperature. Distribution plans can then be simulated in front of various situations and to assist the Tour Planner in the assignment of urgent orders, which must be satisfied on the spot (i.e. customers who have unexpectedly run out of fuel). The use of these applications allows Pina Petroli to reduce the number of urgent deliveries thanks to the forecasting module and to increase the truck performances by 20% on average.

In this project we applied the following techniques: Ant Systems, Local Search, Forecasting, On-line Planning

6. Dynamic and time dependent VRP: the MOSCA project

IDSIA is currently taking part in a European project, codenamed "MOSCA, Decision Support System For Integrated Door-To-Door Delivery: Planning and Control in Logistic Chains", which aims at the design and implementation of a decision support system for the delivery of goods in urban environments. Most traffic management systems do not take into account commercial traffic in their models and this can lead to substantial errors in estimating travel times on the road network, due to the ignorance of slow downs caused by delivery operations in front of shops. MOSCA aims at improving the management of urban traffic providing assets to both commercial transport operators and to city traffic managers. The former will be able to access state-of-the-art vehicle routing algorithms which make use of privileged traffic information provided by the city administration. The latter will use the information on planned deliveries to mitigate the effects and smooth the traffic flow, reducing both the economical and the environmental impact. The role of IDSIA is to develop vehicle routing algorithms which are customised to the urban situation, where travel times on road segments are highly variable and the knowledge of this variability must be capitalised and used efficiently.

This project is financed by the EU Commission and allows us to explore techniques such as stochastic and minmax optimization, together with on-line planning. Among our partners we find the CRTL-PTL (commission for public transport in the Lugano area), PTV a major German firm specialised in software for transport engineering, ENEA, the Italian agency for energy and the environment, the city of Stuttgart, the intermodal node of Padua, the universities of Karlsruhe and Cambridge.

7. Conclusions

In the last years we have seen a great effort in the integration of logistics with the existing data exchange infrastructure. We think that this integration and data availability brings great opportunities to make an intelligent use of the data and Operations Research techniques such as the metaheuristics developed at IDSIA are ready to take this chance.

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