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Solving a Pickup and Delivery Problem with Sequencing Constraints

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Motivation and Background

As congestion is an ever-growing problem on the roads of Europe, intermodality plays an increasingly important role in the transportation of goods. Furthermore, the complexity of the planning problems thus induced presents additional requirements to the tools available to planners.

This project was initiated in cooperation with a software company producing computer systems for operation and fleet management in small and medium-sized transportation companies. The software company presented a problem that is intriguing, in that it does not seem to have been previously mentioned in the literature, at the same time as it is conceivingly simple.

Problem description

A number of items must be transported from individual addresses in one region to individual addresses in another region, i.e. a set of orders is given, each one consisting of a pickup address and a delivery address. The two regions are far apart, and thus there is some long-haul container transport involved between the pickup and delivery depots. This long-haul transport is not part of the problem considered here. What remains are the two geographically separated problems of picking up and delivering the items in a feasible and suitable way with regard to container loading and routing.

The pickups are performed by a truck carrying a container, and the items are placed into this container as they are picked up. After visiting the final pickup point the container is returned to the depot where it is locked and sent on unopened to another depot from which the delivery starts, without any opportunities to repack.

Subsequently all items are delivered at their respective delivery points in an order such that each item is accessible from the back of the container when its delivery point is reached, i.e. the items must be delivered in the "opposite" order of that in which they were picked up. The loading/unloading of the container thus follows a (variation of the) last-in, first-out (LIFO) principle. The objective of the problem is to find the combined cheapest possible route for pickup and delivery.

The modification imposed on the LIFO principle in this problem, is that the items can be placed in one of several "rows" in the container that each individually obeys this principle, but with no mutual constraints.

Thus a solution to a given problem consists of a pickup route, a delivery route, and a row assignment, which for each item tells which container row it should be placed into.

The items considered here are identical Euro Pallets, which fit 3 by 11 on the floor area of a 40-foot pallet container, thus providing three individually accessible rows available for loading.

The solution

An obvious feasible solution to the problem can be found by solving the problem with strict LIFO conditions. In this case the pickup and delivery orderings must be exactly eachother's opposites, and the solution can then be obtained by adding the two graphs and solving a regular TSP for the resulting graph. This opens an opportunity to use some existing methods, and in the case at hand this has been done by a savings algorithm, producing an initial solution to the problem.

Subsequently the problem has been solved heuristically using both a tabu search (TS) and a simulated annealing (SA) approach, where a combination of different neighbourhood structures has been applied.

The first neighbourhood structure considered for the heuristics only performs changes to the routing of the two tours, and leaves the row assignments untouched. In this case the neighbourhood consists of all possible swappings of two neighbouring items on a route. During this operation it is additionally necessary to consider whether the two items are placed in the same row, and in that case also swap their positions in the opposite route to maintain a feasible solution.

Furthermore a neighbourhood has been implemented which is based on changes to the row assignment, considering each possible pair of items that are currently assigned to different rows, and swapping their positions (both in the row assignment, and in each of the routes).

The final implementation of the solution algorithm uses a combination of the two neighbourhood structures.

Results

The results obtained so far indicate that the primal bound obtained by letting the problem obey strict LIFO conditions and heuristically solving the regular TSP for the added graphs is quite weak, as the results are typically around 60% above the best known solution.

For further testing and comparison the SA-algorithm has been implemented in such a way that it can take the running time as an input parameter and calculate the temperature reduction factor based on this. Each of the two heuristics has been tested on a set of randomly generated problems with Euclidean distances, with running times of 10 and 180 seconds. The results show that with a running time of 180 seconds the SA-algorithm produces objective values that are around 10-12% of that of the best known solution, while this ratio for the TS-algorithm is 15-20%. For running times of 10 seconds, the corresponding numbers are around 20% and 25-30%.