SUPPORTING REAL-TIME DECISION-MAKING IN LOGISTICS AND TRANSPORTATION BY COMBINING SIMULATION WITH HEURISTICS

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ABSTRACT

Supporting decision making in logistics and transportation is one of the most fruitful application areas of simulation and optimization techniques. In a global world, many enterprises need to perform complex procurement and delivery activities. Usually, these problems have an intricate nature, being NP-hard in most cases, which means that heuristic-based optimization approaches are necessary to deal with real-life and large-scale instances whenever a high-quality solution is needed in a short amount of time. Examples of these problems include many variants of the well-known vehicle routing problem, the facility location problem, and the arc routing problem. We will discuss here the role played by Monte Carlo simulation in a suitable mixture with skewed probability distributions to enrich the performance developed by heuristic-based constructive methods. Some examples will highlight the efficiency of this simple yet powerful approach.

Keywords: Logistics and Transportation, Simulation, Heuristics, Biased Randomization.

1 INTRODUCTION

Decision-making process in real-life logistics and transportation are usually complex and, at the same time, they need to be completed in reasonably short times. A considerable number of them can be modeled as combinatorial optimization problems. Typical examples are: the vehicle routing problem (Toth and Vigo, 2014), the arc routing problem (Corberan and Laporte, 2015), or the facility location problem (Chan, 2011). All these problems are NP-hard in nature, meaning that the space of potential solutions grows very fast (exponential replication of the number of feasible solutions) as the size of the instance is increased. For that reason, using exact methods is not always the most efficient strategy in order to solve these problems, especially when considering large-size instances for which high-quality solutions are needed in relatively short computing times. Under these circumstances, heuristic-based approaches constitute an excellent alternative to exact methods. Hence, a large number of heuristic and metaheuristic algorithms have been developed during the last decades to solve NP-hard problems in a myriad of practical scenarios, ranging from transportation and logistics to supply chain management and services optimization (Faulin et al., 2012; Longo, 2012; Merkuryeva et al. 2011).

Monte Carlo simulation (MCS) can be combined with the use of skewed or asymmetric probability distributions in order to easily improve the performance of the heuristic algorithms along with the quality of the solutions generated by them. Having the purpose of generating a suitable good solution, most of these procedures make use of a greedy behavior which consist of choosing the 'best next step' from a list of potential constructive movements. Typically, this selection is based on a certain logic that tries to take advantage of the specific characteristics, which usually are subject to uncertainty, corresponding to the optimization problem being considered. In this context, the main idea behind our approach is to introduce a slight modification in the greedy constructive behavior, in such a way that the constructive process is still based on the heuristic logic but, at the same time, some degree of randomness is introduced. This random effect tries to take benefit to the internal structures (usually unknown and subject to uncertainty) of the problem to solve by means of the biased selection of solutions generated by a skewed statistical distribution (Figure 1).

Some initial steps in the process of combining MCS with heuristic approaches were done by Faulin and Juan (2008), who designed a MCS with entropy control to solve the Capacitated Vehicle Routing Problem. Using this simulation-based approach it is possible to easily enhance the quality of the solutions generated by the original heuristic. Also, it is important to notice that using a uniform probability distribution instead of a skewed one, this improvement would very rarely occur since the logic behind the constructive heuristic would be destroyed and, accordingly, the process would be random but not correctly oriented (Figure 1).

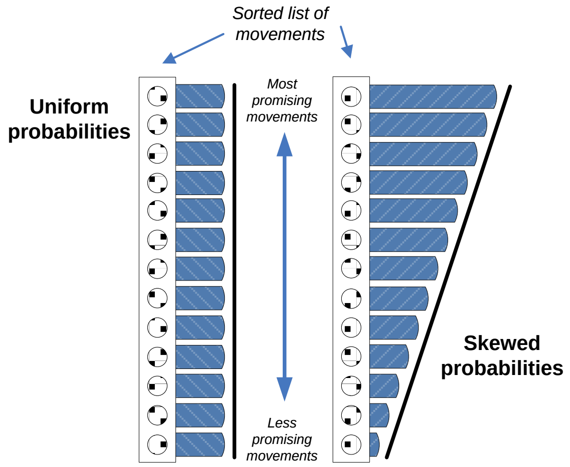

Figure 1: Ways to introduce randomness into heuristics.

2 SOME CLASSICAL ROUTING PROBLEMS AND HEURISTICS

In the vehicle routing problem, a set of customers' demands must be satisfied by a fleet of capacitated vehicles that typically begin from a central depot. Moving vehicles between any two nodes (customers or depots) in the map has a distance-based cost. The goal is to find the set of vehicle routes that minimizes the delivery cost while serving all demands and taking into consideration the vehicle capacity constraints. One popular procedure for solving this problem is the savings heuristic (Clarke and Wright, 1964), whose acronym is CWS. In that procedure, an initial dummy solution is built by sending a virtual vehicle from the depot to each customer. Then, the list of edges connecting each pair of nodes is considered. This list is sorted according to the savings criterion that would be obtained by using the corresponding edge to merge two routes in the dummy solution. Thus, merging edges associated with higher savings are located at the top of the list, while edges with lower savings are located at its bottom. At this point, the sorted list of edges is traversed from the top to the bottom, and new route merges are carried out whenever the corresponding edge can be used to merge the two routes it connects without violating any constraint. A similar savings-based heuristic, called SHARP, was developed by Gonzalez et al. (2012) for solving the arc routing problem. The arc routing problem is similar to the previously described vehicle routing problem, but it differs in several details: to start with, the demands are not located on the nodes, but on the edges connecting these nodes; also, only some nodes are directly connected among them (i.e., the associated graph related to this problem is not complete). Again, the SHARP heuristic makes use of a dummy initial solution and a sorted list of connecting edges to merge those routes that provide the highest possible savings at each step without violating any problem constraint.

3 A SIMULATION-BASED APPROACH FOR ENHANCING HEURISTICS

Most constructive heuristics make use of a list of potential movements, then sort that list according to some problem-specific criterion, and finally traverse the sorted list selecting, at each step, the element at the top of the list. By following this greedy behavior, which tries to select the next 'most promising' movement according to the sorting criterion, these heuristics are expected to generate a high-quality solution once the entire list is traversed. Notice, however, that this is a somewhat 'myopic' behavior, since the heuristic selects the next movement without being able to consider how this selection would affect subsequent selections as the list is processed downwards. What is even worse, this behavior is also deterministic: once the heuristic has been run, further runs of this deterministic process make no sense since they all will provide the same output. Knowing that running a heuristic might take only a few seconds –or even less in a modern computer if the heuristic is correctly implemented and the problem size is not very large (for instance, less than 100 customers for a routing problem)–, one might consider to introduce some type of randomness in the heuristic's behavior, in such a way that it can be run several times –either in sequential mode or in synchronous mode by using different computers–, and then select the best of the stochastic outputs. However, this is not always true: if uniform randomization is introduced inside the heuristic without any further modification of the original list of candidates, the logic behind the sorting criterion is lost and, therefore, the probabilities that any stochastic solution improves the original one provided by the heuristic are almost non-existent. To avoid that, GRASP algorithms (Feo and Resende, 1995) introduce uniform randomization on a restricted candidate list, which is composed of the first *n* elements (*n* being an algorithm parameter) in the original list. Instead of following the GRASP approach, our methodology proposes to use the entire sorted list of potential movements, but then use a skewed probability distribution (e.g., a geometric or a descending triangular one) in order to assign different probabilities of being selected to each of the elements in the list. Then, direct Monte Carlo simulation can be used at each stage of the solution constructive process to select the next element from the list according to the desired probabilities. In the particular case of the vehicle routing problem, some computational results obtained with this strategy can be found in Juan et al. (2009). This approach can easily generate solutions that improve the original ones provided by the heuristic in short computing times, which represents an interesting alternative to the use of more complex metaheuristics.

4 EXPERIMENTAL RESULTS

We implemented in Java the previously described heuristics and their corresponding skewed-randomized versions. A series of classical benchmarks were then run on a desktop computer (Intel Core i3 CPU M 370 @2.40GHz on Windows 7). Each instance was run once for a maximum of 30 seconds, and then a comparison was made between the heuristic value (h) and the best value obtained with the skewed-randomized version (rh). This comparison was given by the perceptual gap between both solutions, computed as: gap = $(rh - h) / h$. We have calculated these gaps for a set of classical instances (Kelly instances) for the vehicle routing problem, which are publicly available at http://neo.lcc.uma.es/vrp/vrp-instances/capacitated-vrp-instances/. The results are that in 16 out of 20 cases the solution provided by the skewed-randomized version of the heuristic (RandCWS) outperformed the solution provided by the original version of the heuristic (CWS-Clarke and Wright's savings procedure), with an average improvement gap of -2.45% and a maximum improvement gap of about -13.17% for the Kelly08 instance (Table 1). In this case, a Geometric distribution with parameter 0.2 was used to randomize the selection of potential movements from the sorted list of edges.

Table 1: Results for the vehicle routing problem.

	CWS Heuristic	**RandCWS**		
Instance	**Cost**	**Cost**	**Time (s)**	**Gap**
Kelly01	5,956.50	5,776.93	22.0	-3.01%
Kelly02	9,880.40	9,696.08	10.3	-1.87%
Kelly03	13,494.43	12,941.51	19.0	-4.10%
Kelly04	68,694.43	68,141.51	23.6	-0.80%
Kelly05	12,000.00	12,000.00	0.0	0.00%
Kelly06	16,800.00	16,800.00	0.0	0.00%
Kelly07	21,600.00	21,600.00	0.0	0.00%
Kelly08	16,927.66	14,698.87	19.8	-13.17%
Kelly09	663.57	630.54	2.7	-4.98%
Kelly10	838.92	802.97	16.8	-4.28%
Kelly11	1,052.13	1,014.97	24.8	-3.53%
Kelly12	1,270.99	1,231.46	29.7	-3.11%
Kelly13	952.74	932.14	5.6	-2.16%
Kelly14	1,221.69	1,194.80	22.6	-2.20%
Kelly15	1,512.66	1,488.47	17.0	-1.60%
Kelly16	1,774.68	1,774.68	0.0	0.00%
Kelly17	771.71	756.10	14.2	-2.02%
Kelly18	1,069.29	1,059.34	20.4	-0.93%
Kelly19	1,466.00	1,459.61	22.8	-0.44%
Kelly20	1,963.47	1,948.69	8.5	-0.75%
Average			*14.0*	*-2.45%*

Likewise, the results of a similar experiment for the arc routing problem are summarized. The set of classical instances used for this experiment (the so called GDB instances) are publicly available at: http://www.uv.es/belengue/carp.html. The solution provided by the heuristic (SHARP) is improved in 14 out of the 15 tested instances, with a maximum improvement gap of -13.82% (gdb12) and an average improvement gap of -6.26%. Again, a Geometric distribution with parameter 0.2 was used here to randomize the selection from the sorted list of edges.

5 CONCLUSIONS AND FUTURE WORK

This work discusses how simulation can be used to easily improve the performance of already existing or new heuristics aimed at solving combinatorial optimization problems in the fields of transportation, logistics, and production systems. By combining skewed probability distributions with direct Monte Carlo simulation, the logic behind the heuristic can be slightly randomized without losing its good properties. This allows transforming the deterministic heuristic procedure into a probabilistic algorithm that can be run several times to obtain several alternative solutions to the original problem, some of them better than the original one provided by the heuristic itself. Several examples of different heuristics and optimization problems contribute to illustrate the potential of the proposed approach. Finally, we would like to highlight that this paper contribution is mainly devoted to explain the good qualities that have the heuristics randomization to provide a suitable set of potential good solutions to the problem to solve, even if it is difficult.

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REFERENCES

Chan, Y. 2011. *Location Theory and Decision Analysis: Analytics of Spatial Information Technology*. Springer.

Clarke, G., and J.W. Wright. 1964. "Scheduling of vehicles from a central depot to a number of delivery points." *Operations Research* 12:568–581.

Corberan, A., and G. Laporte. 2015. Arc Routing: Problems, Methods, and Applications. SIAM

Faulin, J., and A. Juan. 2008. "The ALGACEA-1 method for the capacitated vehicle routing problem." *International Transactions of Operational Research* 15(5):599–621.

Faulin, J., Juan, A., Grasman, S., and M. Fry. 2012. *Decision making in service industries: A practical approach*. CRC Press, Clermont, FL, USA.

Feo, T.A., and M.G.C. Resende. 1995. "Greedy Randomized Adaptive Search Procedures." *Journal of Global Optimization* 6:109–133.

Gonzalez, S., Juan, A., Riera, D., Castella, Q., Munoz, R., and A. Perez. 2012. "Development and Assessment of the SHARP and RandSHARP

Algorithms for the Arc Routing Problem." *AI Communications* 25:173–189.

Juan, A., Faulin, J., Ruiz, R., Barrios, B., Gilibert, M., and X. Vilajosana.2009. "Using oriented random search to provide a set of alternative solutions to the Capacitated Vehicle Routing Problem." In *Operations Research / Computer Science Interfaces Series*, 47:331–345.

Longo, F. 2012. Supply Chain Security: An Integrated Framework for Container Terminal Facilities. International Journal of Simulations and Process Modelling, 7, 159-167. (doi:10.1504/IJSPM.2012.049154).

Merkuryeva. G., Merkuryev, Y., Vanmaele, H. 2011. Simulation-based planning and optimization in multi-echelon supply chains. Simulation, 87(8)-pp. 680-695.

Toth, P., and D. Vigo. 2014. *Vehicle Routing: Problems, Methods, and Applications*. SIAM.

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