Metaheuristics for cleaning debris in urban networks after major disasters

Thiago Jobson Barbalho, Andréa Cynthia Santos, Dario José Aloise

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Thiago Jobson Barbalho[1], Andréa Cynthia Santos[1], Dario José Aloise[2]

[1] Normandie Université, UNIHAVRE, UNIROUEN, INSA Rouen, LITIS, 76600 Le Havre, France

{thiago-jobson.barbalho, andrea-cynthia.duhamel}@univ-lehavre.fr

[2] Universidade do Estado do Rio Grande do Norte, DI, 478 rue Almino Afonso, 59.610-210, Mossoró, Brazil

aloisedj@gmail.com

Keywords : *disaster relief, scheduling, urban network.*

Every year, a large number of lives and economic losses are caused by natural, industrial and technological disasters. For instance, 15,080 people died due to natural catastrophes in 2020, with an estimated economic loss of 171.3 billion dollars [4]. In the aftermath of disasters, the number of casualties may increase due to interruptions on the access to essential services such as water, food, drugs and shelter as a result of the network state.

The problem focused here consists in scheduling work-troops to clean urban networks blocked by debris from collapsed buildings over a discrete time horizon. The transportation network is defined as a graph with nodes representing crossroads, depots and nodes where the population gathers; arcs correspond to roads, blocked or not. The homogeneous fleet of work-troops leaves and returns to depots, respectively, at the beginning and ending of working days. The objective is to minimize the sum of shortest paths between each destination and its nearest depot, weighted by population. Although this problem is often associated with natural disaster, it can also appear after technological or industrial events in urban areas, as for the explosion at Beyrouth Port, Liban, 2020.

An interesting entry point reviewing operations research and management science problems on humanitarian logistics is found in [5]. A related study dealing with allocation of limited resources to improve accessibility of rural networks is found in [3]. In [2], interruptions in a transportation network, known in advance, are scheduled, and the network is reconfigured in such a way it remains strongly connected. The authors in [6] proposed deterministic heuristics for solving the Work-troops Scheduling Problem in a large scale.

In this study, we extended the work of [6] by developing a dedicated local search coupled with a procedure able to repair infeasibility (see [1]). In fact, defining local moves which ensure feasibility is not an easy task. This is mainly due to some difficult constraints such as the availability of paths to route work-troops to blocked roads. Moreover, a Greedy Randomized Adaptive Search Procedure (GRASP) and an Iterated Local Search (ILS) were also proposed. These metaheuristics were tested using a set of 240 theoretical instances and a large instance of Port-au-Prince, Haiti, after an earthquake in 2010 and were compared with results obtained by [6]. Considering the theoretical instances with known optima, both metaheuristics were able to improve up to 50% of the existing results from [6]. In addition, GRASP obtained 228 out of 240 optima, while ILS found 235 out of 240 optima solutions in the test set. For the instances where optimal solutions were not found, GRASP and ILS produced gaps at most 0.03% and 0.01% away from optimal value, respectively.

The most interesting results on Port-au-Prince case study is summarized in the following. The graph of the network consisting of $16,657$ nodes, $19,558$ edges, 536 blocked roads, 62 destinations, 8 work-troops distributed among 3 depots and a time horizon of 106 working days. For this instance, the first schedule of work-troops is crucial for achieving good results, allowing the majority of *optimal* shortest paths to be cleared by the end of the first working day. In the following working days, little improvements on distances are obtained.

Both methods start with similar solutions produced by the constructive heuristics. In Table 1, we compare improvements of the final solutions with the initial ones in terms of total distance. GRASP and ILS reduce in, respectively, 13.2km and 18.5km after 1h of execution. Subsequently, the gaps between the two metaheuristics tends to decrease hour by hour and converge to similar solutions after 5h.

Execution time	GRASP Path reductions	ILS Path reductions
1h	13.2	18.5
2h	23.6	23.9
3h	28.2	28.3
4h	29.6	29.7
5h	29.7	29.7

TAB. 1: Improvements on the sum of paths during working days, in km.

The metaheuristics results highly improved the ones found in the literature. Moreover, this study opens several avenues of research. For instance, the problem can be extended by adding priority areas in the urban network. Another direction of research is to reformulate the problem with precedence constraints between blocked roads.

Acknowledgments

The LIS project is founded by Normandie region, FEDER FEDER-FSE/IEJ program, Haute Normandie, France.

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