Successive evolution of charging station placement

Helge Spieker*, Alexander Hagg*, Alexander Asteroth*, Stefanie Meilinger*, Volker Jacobs† and Alexander Oslislo‡
*University of Applied Sciences Bonn-Rhein-Sieg
{helge.spieker,alexander.hagg}@inf.h-brs.de, {alexander.asteroth,stefanie.meilinger}@h-brs.de
†International Centre for Sustainable Development, University of Applied Sciences Bonn-Rhein-Sieg, volkerjacobs@arcor.de
‡University of Bonn, s6alosli@uni-bonn.de

***Abstract*—An evolving strategy for a multi-stage placement of charging stations for electrical cars is developed. Both an incremental as well as a decremental placement decomposition are evaluated on this Maximum Covering Location Problem. We show that an incremental Genetic Algorithm benefits from problem decomposition effects of having multiple stages and shows greedy behaviour.**

I. INTRODUCTION

Although car manufacturers and electricity companies have started introducing the necessary infrastructure for electrical cars, coverage rates are still too low to support a significant shift towards non-petroleum based private transportation. The German government's environmental strategy aims to get 1 million electric cars onto national roads by 2020 [1]. In order to reach this ambitious goal, regional efforts to distribute a charging station infrastructure are indispensable. As demand for such infrastructure is still being anticipated, increasing the amount of available charging stations serves as a major incentive to encourage local commuters to move to this alternative form of transportation. As such, the roll out consists of intermediate stages, each expanding total coverage, over the next five years. At every stage, coverage maximization must be targeted, focusing on achieving a near optimal coverage in the final stage.

The Bonn-Rhein-Sieg University of Applied Sciences, together with the municipality of Bonn, the Rhein-Sieg-Kreis region and a number of national and regional energy suppliers were called upon to develop a strategy for a long term roll out of e-charging stations in the region. This strategy will provide recommendations for the political, financial and economic decision process. Because of the number and variety of involved partners with different political, public and private interests, a large number of requirements cannot be set beforehand. Rather than that, the goal of this work is to provide an initial solution that starts a downstream micro-analysis phase. In this phase, decisions will be taken on the exact placement of the charging stations, which is dependent on the availability of technical infrastructure and energy capacity.

This optimization problem can be described as a multi-stage *Maximal Covering Location Problem* (MCLP) [2] in which a fixed number of demand locations need to be optimally covered by a fixed number of supply stations over a fixed number of stages, each growing in size. This problem is known to be NP-hard [3]. To solve this, classical, exact approaches such as dynamic programming or branch and bound algorithms are commonly used [4]. Both suffer from exponential complexity. In our case the final stage contains 935 charging stations with two charging points per station. This is derived from the German government's projective figures on the total necessary number of charging stations [5] and projections of the total car stock in Germany [6] and the region [7] in the year 2020. The number of charging stations and *Points of Interest* (POI) (5,062) in this case is so high that an exact solution becomes intractable.

Instead of focusing on an exact solution, the target region is subdivided into cells which underlie municipal traffic planning. A subset of these traffic cells is depicted in Figure 1. It also shows POI that cover a large range of locations from airports and public transportation transitions to museums and parking lots. The POI were selected based on an expected length of stay that is long enough to allow charging batteries up to 80%. Pre-existing charging stations are a fixed part of the solution. Traffic flow will be taken into account in a second downstream project.

We use *genetic algorithms* (GA) to approximate a near-optimal solution. In the first approach we optimize every stage sequentially, taking the result of the last stage as a starting point for the optimization of the next. The latter approach consists of an optimization step of the final stage and then gradually working back towards the first stage by reducing the number of charging stations in the solution. Suboptimal intermediate solutions must be justifiable, but in the long run the focus is on the last roll out stage. We examine the final as well as intermediate results and compare the results to independently calculated solutions. Results will be shown for the sample region, depicted in Fig.1, consisting of multiple municipal cores and large low-density areas. The figures mentioned in this section are reduced accordingly in the evaluation. In the next section we provide more details about requirements that need to be fulfilled.

II. PROBLEM DESCRIPTION

The optimization of this multi-stage MCLP targets a maximal coverage of POI, thereby taking into account weighted demand based on aforementioned projections of the German government. A strategy for successive placement of stations is developed, whereby each successive stage takes the solution from the former stage as fixed.

As there is currently neither the demand nor the necessary resources to realize a full-sized deployment of charging stations at once, it is planned to have a successive, multi-stage deployment from 2016 to 2020, where the final number of 935 charging stations is known. This has to be reflected in

978-1-4673-7751-5/15/$31.00 ©2015 IEEE

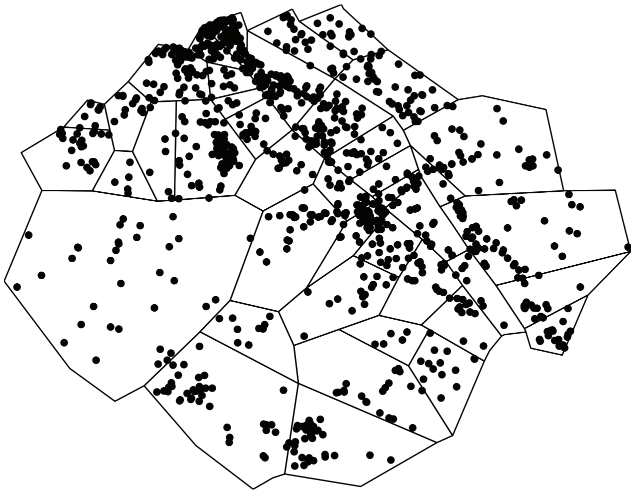


Fig. 1. Sample target area with Points of Interest.

the placement process of the charging stations, covering more important regions of expected demand first.

An *independent* placement strategy consists of independently optimizing every stage, not taking into account the placement of the previous or next stage. An *incremental* strategy is defined to be stagewise, with every stage taking the solution of the previous as a fixed part of the solution. The placement of another batch of charging stations added to this fixed solution is optimized. Vice versa, a *decremental* placement strategy starts with an optimized final solution. A subset of the final placements is then removed to arrive at the solution for the former stage.

The optimization goal for this work is set explicitly to maximize the coverage in all stages. Economical costs are not taken into account, as the needed data is not available and this project does not aim to produce exact placement locations but much rather approximate ideal locations. The accompanying cost for station relocation is therefore not calculable. This constraint prohibits the use of an independent placement approach, as intermediate solution sets are not subsets of the next stage's solution.

Because we will only look at public POI locations, we will only distribute Mode II (up to 22 kW [8]) charging stations, not take into account traffic density directly, but instead define five demand categories with attached weights (1 to 5), expressing the importance of every POI, based on expected traffic density [9], the *modal share* (percentage of commuters using a particular type of transportation) and a number of exclusion criteria that were defined in an earlier phase of the project and are mostly based on the targeted consumer groups, which consist mostly of commuters. The coverage radius of one charging station is set to 300 m [10], as this corresponds to a 5 minute walk. All currently existing charging stations are taken into the solution.

III. RELATED WORK

The MCLP was introduced by Church and ReVelle in 1974 [2]. From there on it was broadly discussed in literature and there are many different solution approaches. A recent review of the problem and available approaches can be found in Berman, Drezner, and Krass [11] and Farahani, Asgari, Heidari, *et al.* [12].

GA are a class of optimization algorithms inspired by natural and evolutionary concepts. They were first presented by Holland [13]. The main idea is to gradually improve a set of initially random solutions (a population consisting of several individuals) measured by a performance measure. In each generation, individuals are selected as parents to create a new offspring individual by recombination and mutation. A fitness value is assigned to each individual, representing how good this solution solves the problem, which is then taken into account to derive a better population in the next generation.

As the standard implementation of a GA is generic and not directly dependent on the field of application, GAs can be used in a broad range of applications. Amongst other things, GAs have already been used to optimize the placement of charging stations. Lim and Kuby applied a GA for the Flow-Refueling Location Model [14], which optimizes the placements to minimize traffic flow interruption and give individual drivers the possibility to charge on route when needed - in contrary to the MCLP used in this paper, which tries to optimize the availability of charging opportunities for parked vehicles. Hess, Malandrino, Reinhardt, *et al.* combined a GA with a traffic simulator to evaluate each individual according to a traffic model [15], targeting traffic flow optimization. A cost-focused approach regarding the construction costs of the charging infrastructure was described by Jin, Shi, Zhang, *et al.* [16]. This approach does not apply to our concrete problem, as was mentioned in Section II.

The concrete application of GAs to optimize MCLP was discussed by Zarandi, Davari, and Sisakht [17] in which they presented a customized GA for a large scale MCLP with 2,500 nodes. Their approach was based on a discretized problem in which possible locations where fixed, which is not an option in our case.

An important aspect for charging station placement planning is multi-stage optimization, where the final placement plan is reached over intermediate stages. This is a common problem decomposition method in applications where it is unreasonable or not possible to realize the optimal solution at once. Reininger, Iksal, Caminada, *et al.* discussed this problem for the planning of a mobile radio network on a discrete set of fixed possible locations, their solution is based on GAs and they evaluate different approaches to reach the maximum stage [18], allowing for relocalization of intermediate solutions. This latter option is explicitly excluded in our problem. Furthermore, Canel, Khumawala, Law, *et al.* present a branch and bound algorithm for a dynamic multi-stage facility location problem [19] and Albareda-Sambola, Fernández, Hinojosa, *et al.* further formulate it as a multi-period incremental service facility location problem (MISFLP) for which they present a Lagrangean formula [20]. Chung analysed a multi-period planning problem of charging station placement for Korean expressways, also based on a Flow-Refueling Location model [21]. The three latter approaches can be excluded by us, as we solve a static problem and do not take into account queue times or station blocking.

The large scale and continuous multi-stage MCLP as defined in our case does not allow us to use any of the beforementioned approaches. Although a fine grained discretization grid would allow using the algorithm introduced by Zarandi, Davari, and Sisakht [17], this option is explicitly excluded by our project clients, as the possible locations are unknown beforehand. In the following section, we will explain different approaches that cater to the explicit multi-stage and continuous character of the placement strategy at hand.

IV. METHOD

There are different approaches to realize a successive multi-stage strategy, depending on influence factors and the quality expectations in the beginning or the end. The first approach is to work incrementally from the first, minimal stage and calculate the optimal placements. Each further stage is then based on the results of the former stage as a fixed part of the solution.

The second approach is to calculate the final stage first and afterwards select a partial set for the next smaller solution and repeat this for each stage (a decremental approach). Therefore, the final result is calculated without the constraints of already fixed partial solutions and can adapt more freely to an optimal solution. For the intermediate stages it is afterwards reduced to a subset of the larger stage.

The third approach, which is mainly used for comparison, is to calculate each stage independently without a dependency on a former or latter stage. This allows the algorithm to optimize for each specific number of charging stations, but it is not applicable for the problem as charging stations would have to be relocated after each stage, which is explicitly forbidden (see Section III).

In general, there is a possible use case for each of the planning approaches, depending on the scenario at hand. As the incremental approach starts with an optimized solution for only few placements, it has an advantage at the early stage, but there is the risk of limiting the optimization possibilities at later stages due to the initial placements. This would cause the incremental approach to be stuck in a local optimum. On the other hand, due to problem decomposition, in the incremental approach only a small number of placements have to optimized compared to the independent approach.

For the decremental approach this is vice versa. The final stage solution should be optimized, because there are no constraints on the placements, but as this solution specifies the possible locations for the further process, the solutions for all smaller stages have to be a partial set of this solution, which is a constraint on the freedom of the solution. This means the best solution for each stage is bounded by the former, larger stage.

TABLE I. GENOTYPE REPRESENTATIONS

	Incremental/Independent		Decremental
Station #	x	y	Active
1	3.6	4.2	1
2	0.5	11.1	0
3	8.6	5.5	1

TABLE II. GENETIC ALGORITHM PARAMETERS

Parameter	Incremental/Independent	Decremental
Population Size	90	90
Selection	Tournament	Tournament
Selection Pressure	2	2
Crossover Probability	95%	95%
Mutation Probability	25%	10%
Mutation Distance	3,500 m	1 station
Chance of new individual	5%	5%

The genetic algorithms use different representations (see TABLE I). The genotype of the independent and incremental approaches consists of the charging station positions represented by Latitude and Longitude in the Gauss-Krüger coordinate system. All individuals are initialized with the coordinates of existing POI, so they always cover some POI in the beginning. Recombination is done by fitness-weighted uniform crossover. Mutation consists of randomly moving a charging station in the target area. The mutation distance is drawn from a Gaussian distribution with standard deviation of 3,500 meters, which was determined experimentally to be a useful standard deviation for the problem size (the target area has a range of about 25 km in each direction) with regard to the overall fitness and convergence speed.

The GA for the decremental approach is based on a bit-string representation, where each bit represents whether one of the formerly fixed charging stations is set for the current stage. Due to the discrete solution space it is possible to calculate the covered POI of each possible placement upfront and store them in a lookup table. The actual fitness evaluation can then be reduced to simple matrix calculations, which is significantly faster than the former, iterative approach where each POI has to be checked for each individual. Two individuals are recombined by their conjunction where the result is filled with missing placements drawn randomly from the parent individuals. The parents' fitness ratio is used as the probability of each gene to be drawn. Mutation is done by randomly flipping two bits - both from 0 to 1 and vice versa to assure the individual stays valid.

An overview of the parameters used for both GAs is presented in TABLE II. They where experimentally chosen for the representative target region of the evaluation, based on the parameter set of the larger problem.

V. EVALUATION

The primary motivation for the following comparisons is the need for a reasonable and applicable approach regarding the actual charging station placement problem described above. Therefore, the evaluation is not based on synthetic examples but rather on a representative part of the actual target area and its characteristics, having both high and low POI density areas (see Fig. 1). The sum of the weight values of all 1,230 POI in the target area is 1,678. One main aspect is to see how the results from the three approaches differ, measured by the fitness in each stage as well as of the final solution. To examine the differences in the quality of the results not only the absolute fitness numbers are compared, but also the distribution of the placements and how the overall fitness is compounded from the individual placements' contributions.

POI only need to be covered by one charging station. Multiple coverage is neither necessary nor restricted, but does

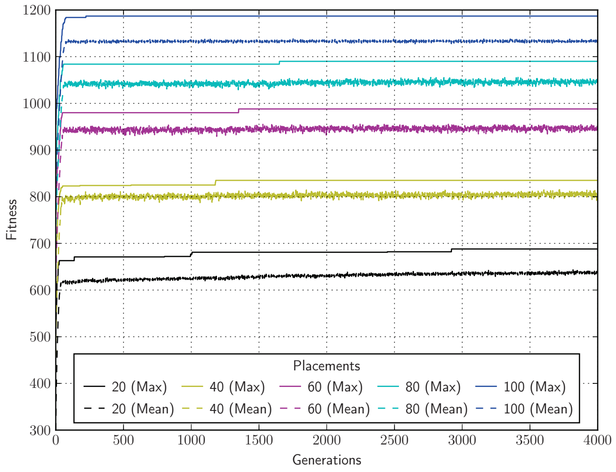


Fig. 2. All independent runs leading to an approximate convergence time of 1,000 generations, reaching 98% of the respective final fitness values

TABLE III. SCENARIO OVERVIEW

Scenario	Approach	Initial Stage	Intermediate Stages	Final Stage
One-step	Incremental	50	./.	100
	Decremental	100	./.	50
Two-step	Incremental	50	./.	75
	Decremental	100	./.	75
Multi-stage	Incremental	20	40, 60, 80	100
	Decremental	100	80, 60, 40	20
	Independent	20	40, 60, 80	100

not count towards the optimization goal.

An overview of the scenarios discussed in the following is stated in TABLE III. In all scenarios the initial stages where calculated by the independent approach. For comparability and statistical relevance the presented results are averaged over 32 runs. All runs were stopped after 1,000 generations, as they have then reached 98% of the maximum fitness after 4,000 generations (see Fig. 2).

On a single CPU core of a Intel(R) Xeon(R) CPU with 2.60 GHz the incremental and independent approach take in average 2.8 seconds per generation, where the decremental approach takes only 0.6 seconds per generation.

A. One-step Comparison

To evaluate the actual behaviour of the successive approaches, two further scenarios are created, which only consider one step of each successive approach. In this one-step comparison it is shown how the incremental and the decremental approach differ due to problem decomposition. The result of the successive calculations are compared to the independently calculated solution for that stage.

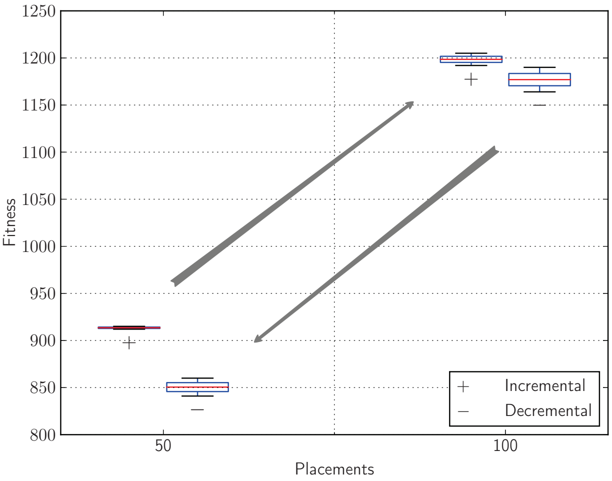


Fig. 3. Comparison of fitness values based on a single step, comparing both approaches with the independent calculation. Starting conditions for the incremental and decremental approaches determined by respective independent solutions for 50 and 100 placements.

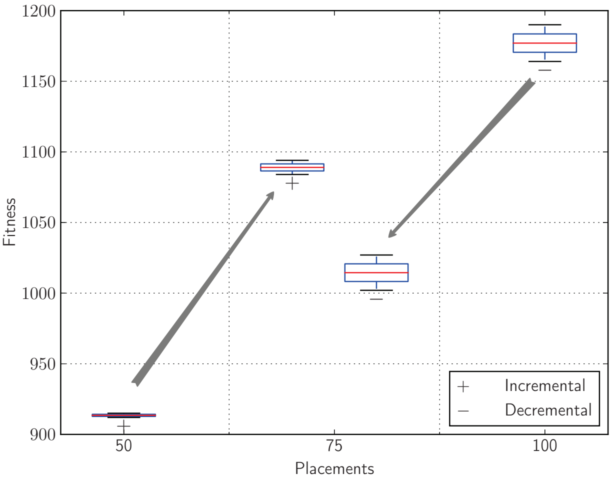


Fig. 4. Comparison of fitness values based on a single target stage with 75 placements, allowing a direct comparison with similar starting conditions, which are determined by the independent approach.

As can be seen in Fig. 3, the incremental solution is able to produce a significantly better result than the independent approach, which can be explained by the fact that the latter, having to optimize all 100 placements at once, is more prone to run into a local optimum. The independent solutions are generally better than in the decremental case, as the upper bound for the latter is set by the best solution found by optimizing directly. The upper bound will only be reached in certain unique cases, with equally distributed POI and in general, decremental will perform worse.

B. Two-step Comparison

Fig. 4 shows a direct comparison of the incremental and decremental approaches, where the actual problem is simplified to a single intermediate target stage of 75 charging stations, with fixed initial solutions for both algorithms. The incremental approach's fixed solution, marked with + in the lower left corner, was calculated by using the independent approach for 50 charging stations. The initial solution for the decremental approach, marked with − in the upper right corner, was calculated for 100 charging stations also by the independent approach.

At the intermediate stage the incremental approach reached a significantly higher fitness than the decremental approach.

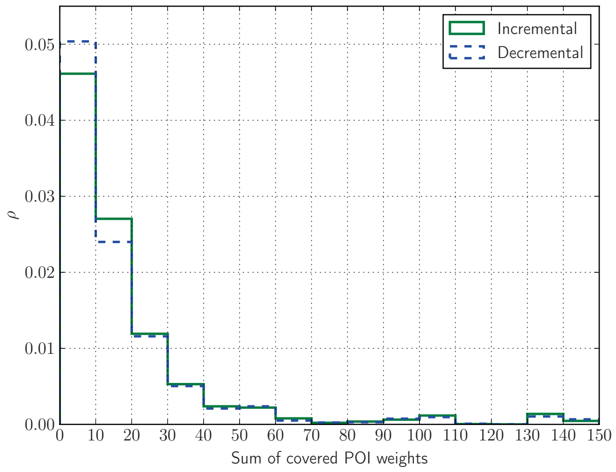


Fig. 5. Density histogram comparison between incremental and decremental approach at intermediate stage with 75 charging stations

Both results vary in their variance, where the incremental approach, which generally has more freedom in the solution space, shows a smaller variance than the decremental approach. This indicates that the incremental approach's runs tend to find a certain optimum for 75 placements, whereas the subset of the decremental approach's initial solution includes a certain range of possible placements leading to similar, but varying fitness values.

Fig. 5 shows the density distribution for both approaches. This distribution categorizes the charging stations with respect to their fitness share. We can conclude that the incremental approach is generally better at avoiding placing charging stations that have hardly any effect on the total fitness. This can be derived from the fact that the amount of charging stations in the most left bin is significantly lower for the incremental approach. A significant number of placements are moved from the first to the second bin. On the other hand, the decremental approach is confined to a mere subselection of placements from the final stage. The approach does not seem to have any visible influence on the solutions' variance, which only holds true for large numbers of charging stations.

C. Multi-stage Comparison

Besides the comparison of single steps it should further be investigated how the approaches develop results for a number of subsequent stages. The scenario for this evaluation is based on a successive placement strategy with five stages and a final number of 100 placements in the target area (see TABLE III).

Fig. 6 displays the average fitness values for each approach at each stage. It should be noted that for the first stages, i.e. 20 placements for the incremental and 100 placements for the decremental approach, the fitness values of the successive approaches are equal to the independent approach, because the successive approaches start upon the independent results of their initial stages. From the results statements can be made about the influence of the problem size on the result. The incremental approach can utilize problem decomposition as it has to place only a small number of 20 charging stations upon the existing solution. This seems to work well regarding the dynamics of the GA and results in the best overall fitness at each stage.

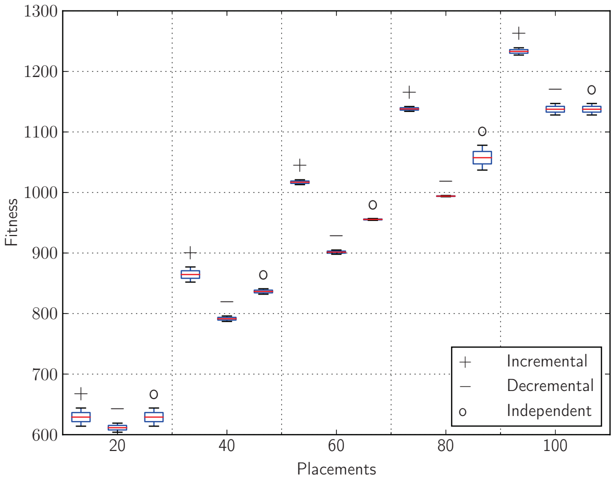


Fig. 6. Comparison of fitness values per approach over five stages

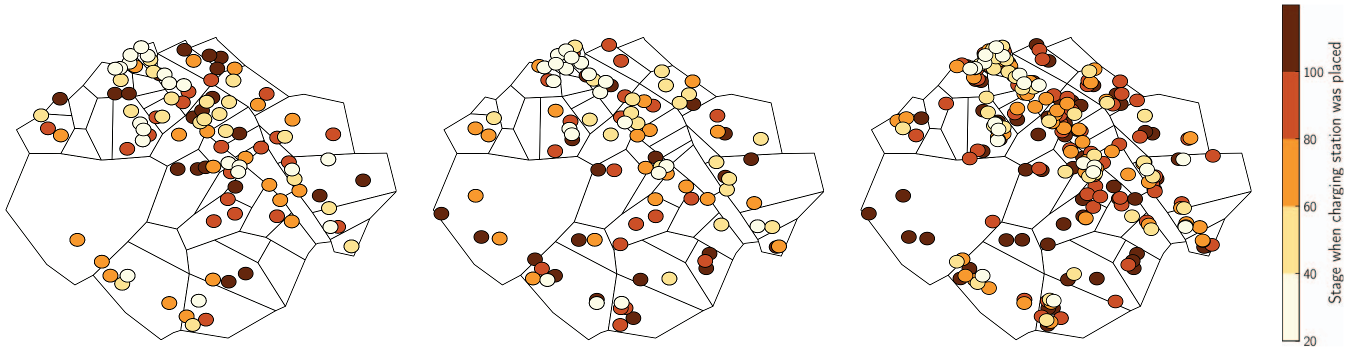
On the contrary, the decremental approach is constrained by the fixed set of options, which hinder the dynamics of the GA, resulting in less fit results at all stages. The difference to the incremental results is especially visible between the incremental results at stage 60 and the decremental results at stage 80, where the placement results of more stations are less optimal than the smaller placement.

For the smallest stage of 20 placements it can be observed, that the fitness values of the different solutions are very similar, even for the reduced decremental approach, indicating a local optimum found by both different GA implementations.

Further differences between the approaches and their successive placement behaviour is depicted by the fitness differences between each subsequent stage. These differences get smaller for each step of the incremental approach as the most valuable points are covered at an early stage and later stages further optimize the result in small additional steps. This is opposed to the decremental approach, where the fitness difference per stage is neither steadily increasing nor decreasing, but changing. From 100 to 80 placements and from 40 to 20 placements the fitness difference for the decremental results is significantly larger than between the intermediate stages, because of the way the initial solution was built. The independent approach directly places all 100 charging stations for the initial stage. That can lead to a state where the complete construction is necessary for the fitness result and is less robust compared to the incremental approach, which is based on partial high-fitness building blocks.

Conclusively, the multi-stage comparison shows the ability of the incremental approach to better adapt to the problem by gradual improvement as well as producing stages containing high fitness placements in earlier stages, fulfilling the requirement of placing important charging stations earlier on.

In Fig. 7 it is shown for one exemplary run how the different approaches affect the distribution of charging stations. The visualization directly represents which charging station is placed at which stage. For the incremental and decremental



(a) Incremental Placements (b) Decremental Placements (c) Independent Placements

Fig. 7. Exemplary actual charging station placements; the colors depict at which stage a charging station is added or removed, except for the independent where at each stage all charging stations are shown

approaches (see Fig. 7a and Fig. 7b) this corresponds to the stage when a charging station is added or removed. The longer a station exists, i.e. the earlier it is placed or the later it is removed, the brighter its color. For the independent approach at all stages all placed charging stations are displayed. It can be seen that it mostly covers the same, high valuable regions and then further spreads out over the target region to place the additional stations at larger stages.

There are quite differently placed charging stations, but the main placement clusters are similar and according to the POI density distribution (see Fig. 1). However, the independent placements (see Fig. 7c) also show a similar distribution pattern, where some regions are always covered, regardless of the number of placements, which gives the impression of the region to be an important part of a high fitness solution.

VI. CONCLUSION

For a successive, multi-stage charging station placement strategy two different approaches, based on genetic algorithms, are compared and evaluated. On the one hand, the incremental approach starts with a small initial stage and builds stepwise upon this partial solution at each stage. The decremental approach, on the other hand, starts at the final stage and keeps at each smaller stage a subset of the former placements. Those approaches are compared in different scenarios with different numbers of intermediate stages and evaluation focuses. All initial stages results are always based on the same genetic algorithm for an independent placement approach.

It is clear that the decomposition of the placement problem into smaller stages fosters the evolution of an optimized solution. It can be concluded that the GA profits from small, successive optimization goals based on a fixed partial solution. This behaviour, especially in the application of GA on MCLP, is caused by the fact that the high fitness locations, where a single charging station placement can yield a high share on the overall fitness, will be covered first in every case irrespectively of the total number of charging stations to be placed. The approach's outcome caters towards placing high fitness stations in earlier stages, which was part of the requirements. In later stages, the incremental approach is successful at placing those further charging stations which have the highest additional fitness, i.e. it concentrates on high value regions first and later includes missing parts of the target region. This is comparable to a greedy solution, which always places the one charging station with the highest fitness gain next. The incremental approach's risk of finding a local optimum in an early stage and not being able to escape from it at subsequent stages did not seem to have an effect on the results.

Furthermore, the maximum reachable fitness of the decremental approach is constrained by the result of the independent approach for the same stage, as the decremental approach works on a discrete set of locations which are optimized for a larger stage. It can only achieve to select the most valuable subset of these placements, but it lacks the chance to improve the result as it can not move any stations for optimization. In practice this is only acceptable if it can be assured that the final result - i.e. the initial stage - is near the optimum and the project constraints focus more on the final than the intermediate results.

We recommend to consider an incremental approach for charging station placement, not only for a successive, multi-stage placement strategy, but - especially for large scale problems - to exploit the problem decomposition effect and consider it as an alternative to an independent approach for single-stage planning, too. The usage of a decremental approach did not lead to useful results, but it can be started from an optimal initial solution if it is acceptable for the intermediate results to be less optimal it has the advantage of being less computationally expensive than the incremental approach. However, this will usually not be the case for charging station placement strategies.

Based on the discussed observations additional research should be conducted. A comparison of the incremental GA approach with a pure greedy solution should be considered, as the observed characteristics of the former show similarities with the latter. Moreover, for the concrete charging station placement problem, a multi-objective optimization - for example to increase the spread of charging stations in rural areas - in combination with the incremental approach could lead to a better final solution. While the evaluation of this paper is based on a representative part of the problem it could also be investigated whether the approaches scale to larger problems, especially with even more intermediate stages to foster the problem decomposition effect.

ACKNOWLEDGMENT

The authors would like to thank the "Arbeitskreis Starthilfekonzepte Elektromobilität Bonn-Rhein-Sieg" for providing data and financing. Namely we would like to thank the City of Bonn, the county Rhein-Sieg-Kreis and the regional energy infrastructure providers, Energie- und Wasserversorgung Bonn/Rhein-Sieg GmbH, RWE Deutschland AG, Rhein Energie AG, Rhenag - Rheinische Energie AG and Stadtwerke Troisdorf GmbH for sponsoring the underlying project.

REFERENCES

[1] Bundesministerium für Verkehr und digitale Infrastruktur, *Szenarien zum Infrastrukturaufbau für Elektromobilität*. 2011.

[2] R. Church and C. ReVelle, “The maximal covering location problem,” English, *Papers of the Regional Science Association*, vol. 32, no. 1, pp. 101–118, 1974.

[3] R. L. Church, D. M. Stoms, and F. W. Davis, “Reserve selection as a maximal covering location problem,” *Biological Conservation*, vol. 76, no. 2, pp. 105–112, 1996.

[4] O. Berman and D. Krass, “The generalized maximal covering location problem,” *Computers & Operations Research*, vol. 29, no. 6, pp. 563–581, 2002.

[5] N. P. Elektromobilität, “Ladeinfrastruktur bedarfsgerecht aufbauen,” Nationale Plattform Elektromobilität, Tech. Rep., 2012.

[6] Kraftfahrt-Bundesamt. (2015). Bestand, [Online]. Available: www.kba.de/DE/Statistik/Fahrzeuge/Bestand/bestand_node.html.

[7] Ministerium für Bauen, Wohnen, Stadtentwicklung und Verkehr des Landes Nordrhein-Westfalen, “Mobilität in Nordrhein-Westfalen - Daten und Fakten,” Tech. Rep., 2013.

[8] Bundesministerium für Verkehr und digitale Infrastruktur, “Öffentliche Ladeinfrastruktur für Städte, Kommunen und Versorger,” Tech. Rep., 2014.

[9] Infas Institut für angewandte Sozialwissenschaft Gmbh, *Alltagsverkehr in Bonn und dem Rhein-Sieg-Kreis*, 2009.

[10] J. Hoffmann, “Raumplanungskonzept für Fahrzeugwechselstationen und Ladeinfrastruktur zur Nutzung der Elektromobilität im intermodalen Personennahverkehr der Stadt Karlsruhe,” PhD thesis, 2013.

[11] O. Berman, Z. Drezner, and D. Krass, “Generalized coverage: New developments in covering location models,” *Computers & Operations Research*, vol. 37, no. 10, pp. 1675–1687, Oct. 2010.

[12] R. Z. Farahani, N. Asgari, N. Heidari, M. Hosseininia, and M. Goh, “Covering problems in facility location: A review,” *Computers & Industrial Engineering*, vol. 62, no. 1, pp. 368–407, Feb. 2012.

[13] J. H. Holland, *Adaptation in Natural and Artificial Systems*, 53. 1975, vol. Ann Arbor, p. 211.

[14] S. Lim and M. Kuby, “Heuristic algorithms for siting alternative-fuel stations using the Flow-Refueling Location Model,” *European Journal of Operational Research*, vol. 204, no. 1, pp. 51–61, 2010.

[15] A. Hess, F. Malandrino, M. B. Reinhardt, C. Casetti, K. A. Hummel, and J. M. Barceló-Ordinas, “Optimal deployment of charging stations for electric vehicular networks,” *Proceedings of the first workshop on Urban networking - UrbaNe ’12*, p. 1, 2012.

[16] M. Jin, R. Shi, N. Zhang, and Y. Li, “Study on Multi-Level Layout Planning of Electric Vehicle Charging Stations Based on an Improved Genetic Algorithm,” pp. 5–10, 2012.

[17] M. F. Zarandi, S. Davari, and S. H. Sisakht, “The large scale maximal covering location problem,” *Scientia Iranica*, vol. 18, no. 6, pp. 1564–1570, 2011.

[18] P. Reininger, S. Iksal, A. Caminada, and J. Korczak, “Multi-stage optimization for mobile radio network planning,” in *Vehicular Technology Conference, 1999 IEEE 49th*, vol. 3, 1999, pp. 2034–2038.

[19] C. Canel, B. M. Khumawala, J. Law, and A. Loh, “An algorithm for the capacitated, multi-commodity multi-period facility location problem,” *Computers & Operations Research*, vol. 28, no. 5, pp. 411–427, Apr. 2001.

[20] M. Albareda-Sambola, E. Fernández, Y. Hinojosa, and J. Puerto, “The multi-period incremental service facility location problem,” *Computers & Operations Research*, vol. 36, no. 5, pp. 1356–1375, May 2009.

[21] S. H. Chung, “Multi-Period Planning for Electric-Car Charging Station Locations : a Case of Korean Expressways,” *European Journal of Operational Research*, vol. 242, no. 2, pp. 1–31, 2012.