The International Journal of
TRANSPORT & *LOGISTICS*
Medzinárodný časopis
DOPRAVA A LOGISTIKA

ISSN 1451-107X

FIXED AND FLEXIBLE ZONING STRATEGIES FOR PARCEL DISTRIBUTION IN UNCERTAINTY ENVIRONMENTS

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Abstract: *Problem observed in this research is inspired by distribution of parcels in courier service where city area is divided into service zones based on the historical data of deliveries intensities and city structure. Each service zone is served by own vehicle of known limited capacity. Number of deliveries per zone varies between days, where average intensity is known in advance. Additionally, total number of deliveries can exceed capacity of the vehicle. All exceeded deliveries in service zones must be served by the "sweep" vehicle. Main idea of our paper is to evaluate the impact of fixed and flexible zoning strategies on total traveled distance of vehicles in the parcel distribution. In fixed zoning strategy deliveries cannot be transferred, whereas in flexible zoning these deliveries can be transferred between zones. For the purpose of solving problems of realistic size we use heuristics approach, while Mixed Integer Programming (MIP) model was developed to solving the small scale problems.*

Key words: *zoning, routing, optimization, heuristics*

1 INTRODUCTION

Parcel distribution in highly populated city area represents one of the most complicated transport problems because of the large number of nodes that needs to be serviced by relatively large fleet of small vehicles. Additionally, transport network consists of thousands of arcs and nodes where demands can appear in stochastic manner. Daganzo *et al.* in their paper [1] described issues that must be taken in consideration in planning and designing logistics systems in uncertain environment and propose modeling steps. In one segment they observed zoning strategies. Usually, demands in parcel distribution can be presented as quantity, weight and volume where all these values can be in sense of capacity constraint, which also adds to the problem complexity.

The vehicle routing in the area divided in zones is not (in general) flexible to the stochastic nature of parcels' delivery. Nevertheless, courier companies insist on this kind of organization (Sorensen *et al.* [2]). Main reason for that lies in simplicity and time savings related with implementation of zone based organization. Namely, driver's knowledge of a zone layout and his familiarity with the traffic conditions has great impact on vehicle driving time. Additionally, mutual driver to client trust can significantly reduce procedures associated to parcel handover. Therefore, in practice, distribution area is divided into zones to which all vehicles are allocated. In average, zones have similar surplus of the daily demands. Surplus demands that cannot be satisfied with the local vehicle (due to some stochastic pikes) must be served by vehicles from nearby zones or by vehicles in reserve, so called sweep vehicles. Specifically, because parcels are being distributed on costumers' home address and those addresses are sometimes hard to find, dispatchers have tendency of being reserved to sending a driver from dedicated to another nearby zone.

In the available literature there are only few research papers that consider parcel distribution problem with stochastic demands. Parcel distribution problem with zones was observed by Zhong *et al.* [3] where they solved the problem by use of two-stage vehicle routing model and the concept of "cell", "core area" and "flex zone". Schneider *et al.* [4] developed a model for quantifying effects of vehicle routing in fixed area for the parcel delivery under time window constraints. Additionally, for the case of stochastic demands, the authors proposed a two-phase approach to solving the vehicle routing problem. Importance of the service zones design motivated Wong [5] to propose alternative approaches regarding territory design in parcel distribution, as one possible area of further research.

Main idea of our paper is to evaluate impact of fixed and flexible zoning strategies on total traveled distance of vehicles in parcel distribution. In fixed zoning strategy deliveries cannot be transferred between zones, whereas in flexible zoning these deliveries can be transferred. For purpose of solving the problems of realistic size we use heuristics approach, while Mixed Integer Programming (MIP) model was developed to solving the problems of smaller size. Most recent paper that describes application of various heuristics in vehicle routing is done by Derigs *et al.* [6], where our heuristics model was developed according to some key ideas of their paper regarding to construction and improvement of vehicle routes. Especially, in case of large number of service zones, we develop heuristic approach of concentrating all surplus demands in service zones around depot. In this way we wanted to limit the sweep route to smallest possible area and therefore minimize travel distance of the sweep vehicle. Another benefit would be that driver of sweep vehicle would work in fewer service zones and therefore would be more familiar with delivery addresses.

The paper is organized as follows. Problem description is given in Section 2. Section 3 contains description of MIP formulation. Description of the proposed heuristic is given in Section 4. Test examples and computational results are presented in Section 5. Finally, Section 6 contains concluding remarks and direction for future research.

2 PROBLEM DESCRIPTION

Problem observed in this paper can be described as Multiple Traveling Salesmen Problem (MTSP) with fixed and flexible zoning strategies where all routes are open (vehicle starts from depot but finishes its route in one of the demand nodes). At the beginning of the day all parcels that have been picked up on previous day are being delivered to their addresses and this is the process that we are analyzing. For detailed insight in various MTSP formulations see overview paper [7] from Bektas. When vehicle finishes delivery of the last parcel, it is being sent to collect all parcels that need to be delivered next day, and therefore vehicle does not return to depot. Also, it is the reason why we observe open MTSP. Entire delivery area is divided in multiple zones where each zone is serviced with a single vehicle ($\boldsymbol{k} \in \{1,2,...,\boldsymbol{K}\}$). Vehicle fleet is homogeneous and vehicle capacity $\boldsymbol{V}$ is defined as maximal number of demand nodes that can be served. Shape of zones is based on the excepted demand quantities which are stochastic in nature and can vary between days. Therefore, some zones have surplus of demand that cannot be served with an allocated vehicles and additional vehicle must be employed (sweep vehicle), denoted as $\boldsymbol{k}$=0. In the model we observe only cases where these surpluses can be served with a single sweep vehicle (for all zones) of capacity $\boldsymbol{V}$. Total number of demands are denoted as $\boldsymbol{I}$. Depot is starting point of each route and is denoted as $\boldsymbol{i}$=0 ($\boldsymbol{i}\in\{0,1,2,...,\boldsymbol{I}\}$). If we would apply fixed zoning strategy, vehicles can serve only demands from its dedicated zone. On other hand, we can apply flexible zoning strategy where allocation of demands between zones is allowed. Both of these zoning strategies are evaluated with MIP model and heuristics. Goal is to minimize total travel distance of all vehicles.

3 MIP MODEL

To obtain the optimal solution for small scale problem instances we use MIP model, which represents modification of classical multi vehicle routing formulation. Objective function is given by (1) and consists of arcs $\boldsymbol{Y_{ijk}}$ between nodes $\boldsymbol{i}$ and $\boldsymbol{j}$ that can be visited by vehicle $\boldsymbol{k}$ (takes value 1 if nodes $\boldsymbol{i}$ and $\boldsymbol{j}$ are serviced with the vehicle $\boldsymbol{k}$) and cost of travel between these nodes $\boldsymbol{C_{ij}}$ (equal to travel distance between node $\boldsymbol{i}$ and $\boldsymbol{j}$). Because each vehicle have its service zone, we use a penalty coefficients $\boldsymbol{P_{ijk}}$ that are used to increase travel costs between demand nodes from different service zones (if nodes $\boldsymbol{i}$ and $\boldsymbol{j}$ are from the same zone as the vehicle $\boldsymbol{k}$ than $\boldsymbol{P_{ijk}}$=1, otherwise $\boldsymbol{P_{ijk}}$ takes some predetermined value greater than 1). Each zone $\boldsymbol{k}$ has its non-overlapping covering area and each demand $\boldsymbol{i}$ has its coordinates that determines to which zone it belongs. Arcs of sweep vehicle are denoted as $\boldsymbol{Y_{ij0}}$ where this vehicle can serve all demand nodes without the penalty cost between different zones.

$$\text{Minimize} \rightarrow \sum_i \sum_j \sum_{k\in K\setminus 0} Y_{ijk} \cdot C_{ij} \cdot P_{ijk} + \sum_i \sum_j Y_{ij0} \cdot C_{ij} \tag{1}$$

Constraints (2) define that vehicle can travel only once between two different nodes. In case where vehicle serves only one demand node in its route, this constraint is excluded (case when the sweep route has only one node to visit).

$$Y_{ijk} + Y_{jik} \le 1 \quad \forall i,j \in I, i \ne j,\ \forall k \in K \tag{2}$$

All demand nodes must be serviced with single vehicle and this condition is defined by constraints (3) where each demand node must have one incoming and one outgoing arc. Naturally, the depot must have multiple vehicle and connected arcs since it represents starting point of all routes. Therefore constraints (3) are applied for $\boldsymbol{i}$>0 (depot is denoted with 0). To be able to include depot in vehicle routes we use constraints (4).

$$\sum_j \sum_k \left(Y_{ijk} + Y_{jik}\right) = 2 \quad \forall i \in I \setminus \{0\}, i \ne j \tag{3}$$

$$\sum_{i\in I\setminus 0} Y_{i0k} = 1 \quad \forall k \in K \tag{4}$$

Variable $\boldsymbol{X_{ik}}$ denotes what vehicle serves which demand node. It is defined by constraints (5) where $\boldsymbol{X_{ik}}$ takes values 1 if there exists an arc with vehicle $\boldsymbol{k}$ and node $\boldsymbol{i}$, otherwise it takes value 0. Constraint (6) defines that each demand node can be serviced exactly by one vehicle.

$$\frac{1}{I} \cdot \sum_j Y_{ijk} \le X_{ik} \le \sum_j Y_{ijk} \quad \forall i \in I, i \ne j, \forall k \in K \tag{5}$$

$$\sum_{i \in I \setminus 0} X_{ik} = 1 \quad \forall k \in K \tag{6}$$

Each vehicle allocated to service zones must be completely loaded. In other words, vehicle must visit ***V*** demand nodes. Because we observe cases with surplus of demands, this constraint can be applied and are given by (7). As for the sweep vehicle, it can serve up to ***V*** demand nodes and this constraint is given by (8).

$$\sum_{i \in I \setminus 0} X_{ik} = V \quad \forall k \in K \setminus \{0\} \tag{7}$$

$$\sum_{i \in I \setminus 0} X_{i0} \le V \tag{8}$$

Total number of departures from depot must be equal to total number of vehicles (including the sweep vehicle) which is represented by constraint (9). Finally, binary nature of the variables Y_{ijk} and X_{ik} are defined by (10).

$$\sum_{k} X_{0k} = K + 1 \tag{9}$$

$$Y_{ijk}, X_{ik} \in \{0,1\} \quad \forall i, j \in I, i \neq j, \forall k \in K \tag{10}$$

Note that mathematical formulation of traveling salesman problem should contain the sub-tour elimination constraint, but since we use the MTSP formulation that can be applied only to small scale problems (multiple vehicles where each route can have no more than 3 stops) these sub-tours are not possible to occur and therefore it is not necessary to include them in our model.

4 HEURISTICS MODEL

Since MTSP is NP-hard problem and therefore not practically solvable by use of optimal techniques, we developed heuristics model that is based on: two widely used route construction heuristics, Clark-Wright (CW) and Nearest Neighborhood (NN); and two widely used local search techniques, 2OPT by deletion of two arcs in single route and node interchange between two routes. Since we observe two zoning strategies, we have developed heuristic model for fixed zoning strategy and modified it to be applicable to flexible zoning strategy.

In MTSP with fixed zoning strategy, all demands must be satisfied with vehicles that are allocated to zones or by global sweep vehicle. Therefore, our first step is to construct local routes for all zones by use of the CW or the NN heuristics. If there is more demands than can be served by the vehicle of given capacity than these construction heuristics will stop when vehicle has full load and all surplus demands will be allocated to sweep vehicle. When all local routes are initially constructed, then we apply local search for improvement of these routes by use of 2OPT heuristic. 2OPT heuristics selects two arcs from one route, deletes them and finds best reconnection of the route. Steepest descent logic is applied, where all combinations of arcs are evaluated and if there is improvement of the route, search is stopped, original route is updated and search starts all over from the first possible combination. If there is no improvement of route with all combinations checked, 2OPT local search is finished. Next step is construction of global sweep route and its local search, where these two operations are the same as in the construction of local routes per each service zone. Finally, when we have constructed all routes we can try to improve the solution by interchanging one node from local routes and one from global sweep route. This improvement is also based on the steepest descent logic, where we evaluate all possible interchanges and if improvement exists, search is stopped, solution updated and search starts all over from the first possible interchange. If there is no improvement of the solution with all possible interchanges checked, we have obtained the final solution from heuristics model. Steps of heuristics model for parcel distribution with fixed zoning strategy are outlined in Algorithm 1.

ALGORITHM 1: *Heuristics model with fixed zoning strategy*

1. Construction of routes per each zone (NN or CW heuristics)
2. Improvement of zone routes by use of the local search technique (2OPT arc)
3. Construction of sweep route (NN or CW heuristics)
4. Improvement of sweep route by use of the local search technique (2OPT arc)
5. Improvement of solution by use of the node interchange between each zone route and sweep route

When flexible zoning strategy is applied, demands from one service zone can be allocated to another zone, which means that all surplus demands from one zone can be serviced with the vehicle of another zone (nearby zone) or with the global sweep vehicle. This must be incorporated in the heuristics model as additional step of solution improvement by use of the node interchange between all routes. Procedure is the same as in the final step of Algorithm 1 except that interchange between local routes are also allowable. Furthermore, flexible zoning allows us to reallocate demand nodes before we start to construct routes with the main goal of spatial grouping of all demands and converging all surplus demands near the depot which will result in significantly shorter travel distance of the sweep vehicle. For this purpose we have developed heuristic which is based on the set of allowed demand moves between service zones. Heuristic starts by grouping the demand nodes in zones that are furthers from the depot in following manner: if there is surplus of demands in observed zone then these demands are moved to neighborhood zones; if there is less demands than capacity of vehicle than demands are moved from neighborhood zones (that have surplus demands) to observed zone. Heuristics stops if surplus demands are concentrated in zones that are nearest to the depot (these zones are defined by predetermined rules). Basic steps of heuristics model for parcel distribution with flexible zoning strategy are outlined in Algorithm 2.

ALGORITHM 2: *Heuristics model with flexible zoning strategy*

0. Demand nodes reallocation between service zones
1. Construction of routes per each zone (*NN or CW heuristics*)
2. Improvement of obtained routes by use of the local search technique (*2OPT arc*)
3. Construction of sweep route (*NN or CW heuristics*)
4. Improvement of sweep route by use of the local search technique (*2OPT arc*)
5. Improvement of solution by use of the node interchange between each zone route and sweep route
6. Improvement of solution by use of the node interchange between all routes

5 TEST EXAMPLES AND COMPUTATIONAL RESULTS

Testing of proposed model is realized on two sets of test examples: small scale problems which are solved optimally by MIP model and by heuristics model; moderate scale problems which are solved only by use of heuristics model. Both of these problems are solved on 100 instances with two zoning strategies (fixed and flexible).

Small scale problems have following characteristics: four service zones ($\boldsymbol{K}$=4) where each zone is of the same size and shape (square 50x50 units); zones are located around depot; vehicle capacity is $\boldsymbol{V}$=3; demand nodes are randomly generated within zones where total number of demands in single zone can take value from [$\boldsymbol{V}$, $\boldsymbol{V}$+2] (while total surplus of demands must be in range [1, $\boldsymbol{V}$]); MIP model will be tested with penalty coefficients $\boldsymbol{P_{ijk}}$ values from range [1, 2, 5, 50, 100] (value 1 represents model with totally flexible zoning strategy as if zones does not exist at all, value 100 means extremely high penalties of demand moves between zones and therefore this model represents fixed zoning strategy, all other values represents variations between these extremes).

Results for the small scale instances are presented in Table 1. Comparison of solutions for all 100 instances obtained from different models are shown in Figure 1, where first graph shows comparison of optimal solutions for fixed and flexible zoning, second graph shows comparison between optimal and heuristics model for fixed zoning and third graph shows same comparison for flexible zoning. Solutions of instance 67 are given in Figure 2, where MIP model with $\boldsymbol{P_{ijk}} \geq 5$ gives identical solution for both fixed and flexible zoning. Bolded black lines represents sweep route and grey lines represents local routes.

Tab. 1 *Average values of solutions obtained from 100 instances of small scale problem*

	MIP MODELS					HEURISTICS MODELS							
	Fixed <-------------> Flexible					Fixed zoning				Flexible zoning			
	P_{ijk}=100	P_{ijk}=50	P_{ijk}=5	P_{ijk}=2	P_{ijk}=1	NN+NN	NN+CW	***CW+NN***	CW+CW	NN+NN	NN+CW	CW+NN	***CW+CW***
Total traveled distance of all routes	327.6	327.6	327.3	321.0	316.3	337.3	337.3	***334.0***	334.1	328.4	328.3	327.7	***327.4***
Calculation time [sec]	2.4	2.5	6.7	17.8	1149.7	0.8	0.8	***0.8***	0.8	0.9	0.9	0.8	***0.9***
Local routes length	267.1	267.1	266.7	262.2	262.1	258.7	258.7	***269.4***	269.4	262.2	261.8	271.6	***271.4***
Sweep route length	60.6	60.6	60.5	58.8	54.2	78.7	78.7	***64.6***	64.8	66.2	66.5	56.1	***56.0***

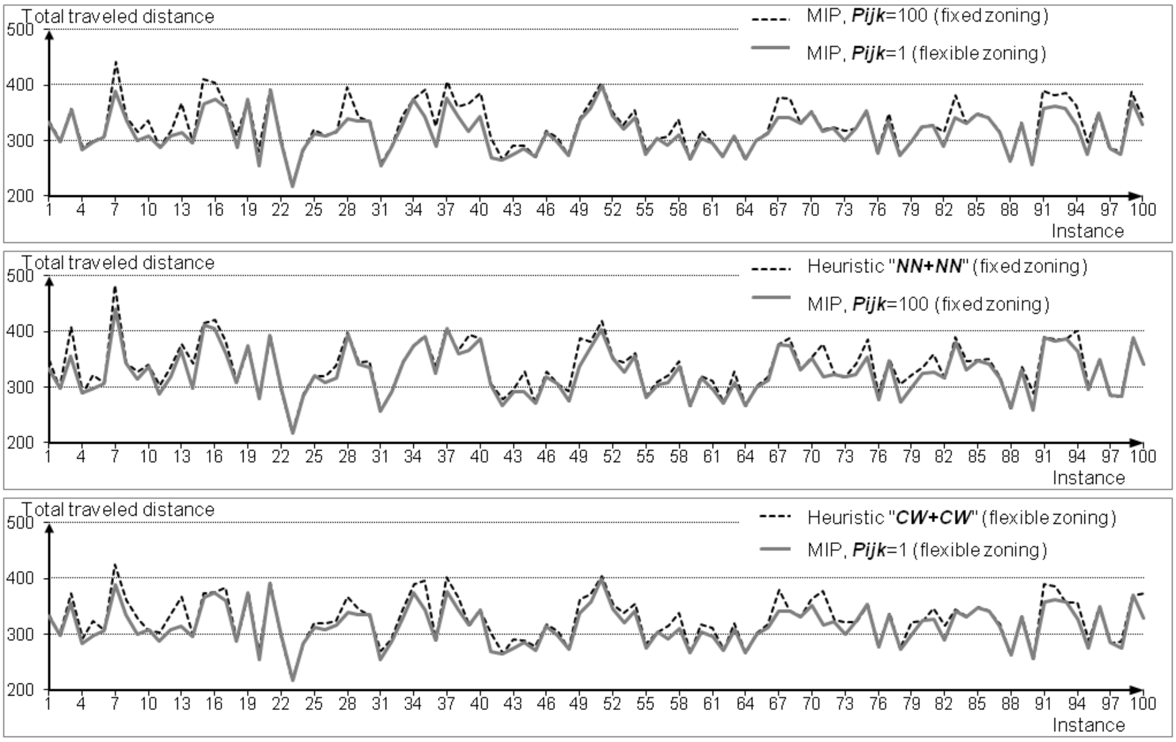
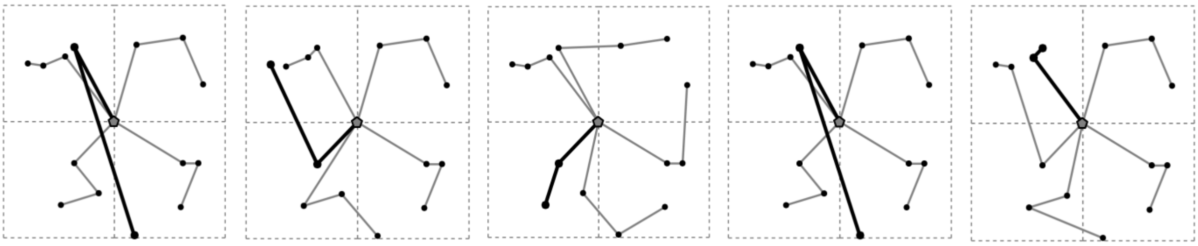


Fig. 1 *Graphical comparison of obtained solutions for small scale problem from MIP and heuristics models for fixed and flexible zoning*



MIP model, $\boldsymbol{P_{ijk}}\geq5$ MIP model, $\boldsymbol{P_{ijk}}=2$ MIP model, $\boldsymbol{P_{ijk}}=1$ Fixed zoning heur. Flexible zoning heur.

Fig. 2 *Solutions obtained from one instance of small scale problem*

Moderate scale problems have following characteristics: sixteen service zones (***K***=16) where each zone is of the same size and shape (square 50x50 units); zones are located around depot; vehicle capacity is ***V***=10; demand nodes are randomly generated within zones where total number of demands in single zone can take value from [int(0.8****V***), int(1.4****V***)] (while total surplus of demands must be in range [1,***V***]). Results for moderate scale instances are presented in Table 2. Comparison of solutions for all 100 instances obtained from heuristics models for fixed and flexible zoning is shown in Figure 3. Solutions of instance 87 are given in Figure 4.

Tab. 2 *Average values of solutions obtained from 100 instances of moderate scale problem*

	FIXED ZONING				FLEXIBLE ZONING							
					Without demands reallocation				With demands reallocation			
	NN+NN	***NN+CW***	CW+NN	CW+CW	***NN+NN***	NN+CW	CW+NN	CW+CW	***NN+NN***	NN+CW	CW+NN	CW+CW
Total traveled distance of all routes	3018.8	***3013.7***	3022.0	3015.3	***2940.8***	2942.8	2948.3	2945.6	***2783.9***	2784.1	2813.7	2811.8
Calculation time [sec]	45.6	***29.8***	132.5	32.3	***78.8***	61.9	161.7	63.7	***41.9***	41.1	46.6	40.8
Local routes length	2511.2	***2512.3***	2557.8	2556.8	***2481.9***	2483.1	2524.8	2524.7	***2593.6***	2593.8	2611.9	2611.2
Sweep route length	507.6	***501.4***	464.2	458.5	***458.9***	459.7	423.5	420.9	***190.3***	190.4	201.8	200.6

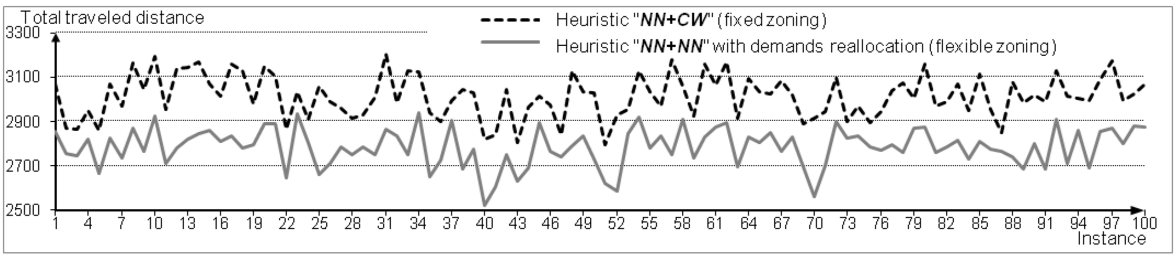
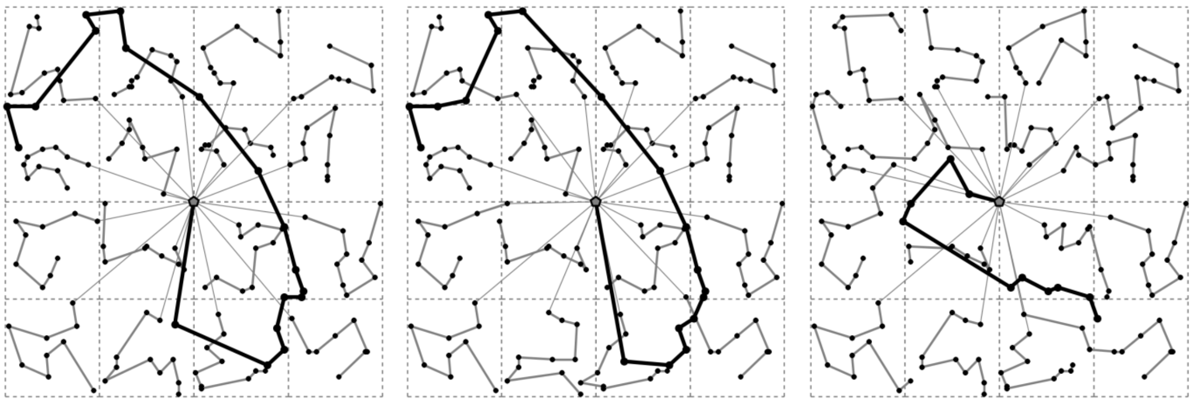


Fig. 3 *Graphical comparison of obtained solutions for moderate scale problem from heuristics models for fixed and flexible zoning*



Fixed zoning Flexible zoning Flexible zoning with reallocation

Fig. 4 *Solutions obtained from one instance of moderate scale problem*

6 CONCLUSIONS

In this paper we compared fixed and flexible zoning strategies in parcel distribution, and introduced modification of flexible zoning strategy (concentration of surplus demands near depot) with purpose of improvement of overall solution. Obtained results from small and moderate size problems indicates that flexible zoning strategy gives better quality of solutions regarding the total traveled distance of all used vehicles than fixed zoning strategy, which was expected. On the other hand we got some interesting results from flexible zoning strategy with grouping of all surplus demands near depot, where we obtained 7.2% shorter total traveled distance than with fixed zoning strategy and 5.3% shorter total traveled distance than with regular flexible zoning strategy (in average for 100 instances of moderate scale problem) as it is shown in Table 2. Furthermore, calculation time necessary for obtaining the solution is the shortest for flexible zoning strategy with demands concentration compared to other two models.

Observed problem represents simplified version of real problem in parcel distribution, mainly concerning vehicle capacity constraints and structure of demands (its number, volume and weight). Furthermore, time constraints are not taken in consideration. This allowed us to develop transparent model with basic search techniques that should be further developed in future for application in more complex and realistic environment.

AKNOWLEGEMENT

This work was partially supported by the Ministry of Science and Technological Development of the Republic of Serbia, through project TR 36006, for the period 2011-2014.

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