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Agriculture and Agricultural Science Procedia 7 (2015) 87 – 93
Agriculture and Agricultural Science Procedia

Farm Machinery and Processes Management in Sustainable Agriculture, 7th International Scientific Symposium

System supporting location of service works in agriculture on example of vehicle recycling network

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Abstract

The paper presents a decision support system for the selection of locations of dismantling stations in a vehicle recycling network. The system uses genetic algorithms effectively. Locations were optimized according to the following criterion: minimization of costs connected with transport, storage and dismantling of end-of-life vehicles as well as costs connected with transport of parts and materials. The proposed system is universal and may be used in agriculture to determine locations of a different kind of facilities organized in a network, on any given area.

Peer-review under responsibility of the Centre wallon de Recherches agronomiques (CRA-W)

Keywords: decision support system; location problem; genetic algorithms; service works in agriculture.

1. Introduction

The location problem has been known for a long time, and it is discussed in the process of planning and management networks of a certain kind of facilities (objects). When designing a network, we wish to select the locations of the objects that belong to the network so as to optimize the function that characterizes the location of all the objects in a network. Due to huge variety of networks, the solution to the problem is sought for each case individually. The development of IT techniques created new possibilities concerning the optimization of the location of objects in the spatial structure of the system being designed or managed. There are various models and methods of

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Peer-review under responsibility of the Centre wallon de Recherches agronomiques (CRA-W)
doi:10.1016/j.aaspro.2015.12.039

optimization, including linear programming and sophisticated heuristics, depending on the complexity of the problem. The paper proposes a simulation method using genetic algorithms for the location of objects of the network, with a limited site selection. Here, location is understood as a spatial organization of objects of the network in the topographical sites to choose from, within the specified industrial/administrative area (country/macroregion).

Recently, there have been a lot of publications concerning the location problem, e.g. location of product distribution centers with respect to selected parameters of the process, most frequently minimization of the distance. There were developed models taking into account a different number of products (multi-product) Nozick and Turnquist (2001) and different methods of distribution Nonås and Jörnsten (2007) and Weiwei Gong et al. (2007). Daskin et al. (2002) and Zuo-Jun et al. (2007) formulated this problem in the form of a nonlinear integer programming model and used Lagrangian relaxations. Different tools were used to solve the model depending on the degree of the model complexity Shu et al. (2005) - Column Generation Method. Ek Peng Chew et al. (2002) used genetic algorithms to solve the problem of location and took into consideration the cost of distribution process and the quantity of stocks. Given random changes of distribution process parameters, the quantity of stocks may be assessed using computer simulation, Miranda and Garrido (2006) and Monte Carlo methods, Kwilosz (2011).

Naturally, increased motorization and mechanization is accompanied by the process of systematic increase in end-of life cars. In Poland, there are still a lot of old vehicles. Unfortunately, the average age of a car registered in Poland increases every year. In 2010, 30% of all registered cars were older than 15 years. This is the reason why there is a problem of end-of-life vehicles recycling, and why it will aggravate. It applies both to vehicles used in rural areas as well as large cities. Scrapped vehicles are a source of recyclable materials or environmental pollution. Solving the problem of recycling is consistent with new regulations concerning waste management in accordance with the Directive 2000/53/EC of the European Parliament and of the Council of 2000. This directive contains detailed regulations concerning recycling. It sets out that, no later than 1 January 2015, for end-of-life vehicles, the recovery of materials shall be increased to a minimum of 95% of their weight.

Therefore, the goal of this work was to design a decision support system that facilitates the selection of optimum locations of objects in a specified area, and the implementation of the system for dismantling stations in vehicle recycling network. Genetic algorithms, due to their advantages as a method of complex tasks optimization in the location problem Li Jin et al. (2010), Rui Song et al. (2002), Taniguchi Jyunichi et al. (2005), were used in the developed system. The developed decision support system, facilitating the selection of location of objects that belong to a network, was tested for its sensitivity to changes of input data.

Each end-of-life machine, device and vehicle is a source of valuable recyclable materials. Recycling is an environment friendly and cost-effective way of end-of-life vehicles utilization.

The concept of recycling may be understood in two ways Oprzędkiewicz and Stolarski (2003):

1. Recycling of a vehicle involves its complete processing by shredding and reuse of materials obtained in this way in other processes. This method is preferred by such countries as France and Belgium.
2. Recycling of vehicles is divided into two stages. First, all components, parts and materials either for direct reuse, recondition or rework are dismantled. The remaining waste materials may be used in other processes. This method is promoted by Germany, Italy, Sweden and Great Britain.

Although the cost of dismantling makes up a significant percentage of the total cost of recycling, it is still technically justified and allows for better compliance with the Directives of the European Union. Dismantling stations organized in a network, supported by information technology, logistics and appropriate marketing are self-sufficient and make profit. An example may be a system organized by FIAT within the external FA.RE. programme (Fiat Auto Recycling). Based on the second approach, the authors assumed 3-level organization of a recycling network (fig.1). The network consists of the following objects: vehicle collection points (CP_N), dismantling stations (DS_J), and processing facilities (PF_K). The cost of recycling depends on the cost of transport of vehicles, parts and materials between the facilities (objects) of the system. Therefore, the location of each object should be correlated with the locations of other objects of the network.

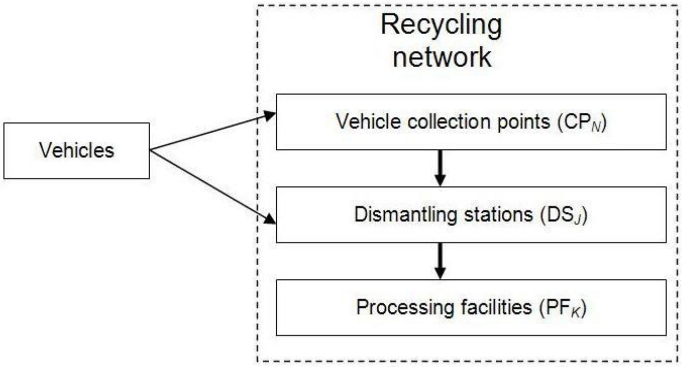

Fig.1. A relational model of a three-level recycling network

2. Formulation of the optimization task

Initial assumptions were formulated as regards the decision support system for the selection of location of dismantling stations in a vehicle recycling network:

1. Location of a dismantling station is sought considering the location of the existing processing facilities, and suggested location of vehicle collection points.
2. The number of vehicle collection points depends on the selected area as well as the assumed territorial and legal conditions.
3. Vehicles collected in collection points are transported to the nearest dismantling station.
4. The concentration of dismantling station depends on demand. However, the distance from the collection points should also be taken into consideration.
5. The network should include at least one processing facility.
6. The vehicle recycling network is designed on a specified, limited area.

The sought solution of the optimization task, with the above assumptions, is the number and location of vehicle dismantling stations. The optimization task, concerning the location of dismantling stations, was formulated relative to minimization of the objective function:

$$F = \sum_{n=1}^{N} \sum_{j=1}^{J} K_{S_{nj}}(Q_n) + \sum_{j=1}^{J} K_{m_j}(q_j) + \sum_{j=1}^{J} K_{d_j}(q_j) + \sum_{j=1}^{J} \sum_{k=1}^{K} K_{C_{jk}}(S_k) \rightarrow \min \quad (1)$$

with the following constraints:

$$K_S, K_m, K_d, K_C \geq 0 \quad (2)$$

$$1 \leq N \leq N_{\max} \quad (3)$$

$$1 \leq J \leq N \quad (4)$$

$$1 \leq K \quad (5)$$

where:

$F=K_{rec}$ - the objective function denoting total cost of vehicles recycling,
J - number of vehicle dismantling stations,
K - number of processing facilities,
N – number of vehicle collection points,
N_{max} – maximum assumed number of locations of objects,
K_S – cost connected with transport of vehicles from the collection point to the dismantling station,
K_m – cost of storing vehicles in the dismantling station,
K_d – cost of dismantling vehicles in the dismantling station,

K_C – cost of transporting parts and materials from the dismantling station to the processing facilities,
Q_j – daily stream of vehicles received by the j-th dismantling station,
Q_n – daily stream of vehicles received by the n-th collection point,
S_k – daily stream of parts and materials in the k-th processing facility,
j, k, n – summing indexes.

It is at the dismantling stations that the main part of the process takes place, namely: dismantling of vehicles as well as storing both vehicles and dismantled parts to be transported to processing or utilizing facilities.

It was assumed that the cost of storing vehicles at a dismantling station K_m is considered only when the number of cars deposited at the station is greater than the daily throughput of the station.

The cost of dismantling K_d depends on the scope of work and is calculated for each vehicle in each station. The cost includes the following:

- cost of dismantling work that depends on the labour cost, investment costs and depreciation, fixed (operational) cost, and internal transport cost,
- cost of utilization of non-recyclable waste material.

The cost of transport K_S and K_C depends on the distance between potential locations of a given dismantling station and other objects that belong to the recycling network, the weight and type of transported cargo as well as the method of transport. The input data must be the distances between potential locations of the dismantling station and other objects that belong to the recycling network. They are determined based on the road map and presented in the form of a matrix. The remaining dependences may be represented by the identified unit cost of transport.

The solution of the above optimization task requires using the original method as the components of the objective function, namely, the cost of recycling, are non-linear functions of the scrapped vehicle stream. The number of vehicles changes randomly, and the optimum solution is sought in a limited space. Additionally, the cost of recycling depends on many factors that are difficult to express using numbers or it is not possible to present their influence on cost using mathematical formulae. Due to the optimization properties of genetic algorithms, one of the methods of Artificial intelligence (AI), the following research assumptions were made in the paper: "Simulation techniques based on genetic algorithms may be an effective tool to support decision-making concerning the locations of vehicle dismantling stations due to the optimization of cost connected with recycling". As a result, there was proposed a system for the analysis of the cost of recycling to support decision-making as regards spatial location of vehicle dismantling stations using genetic algorithms.

3. Structure of the decision support system

The principle of operation of the system supporting the selection of the location of vehicle dismantling stations is presented in fig. 2.

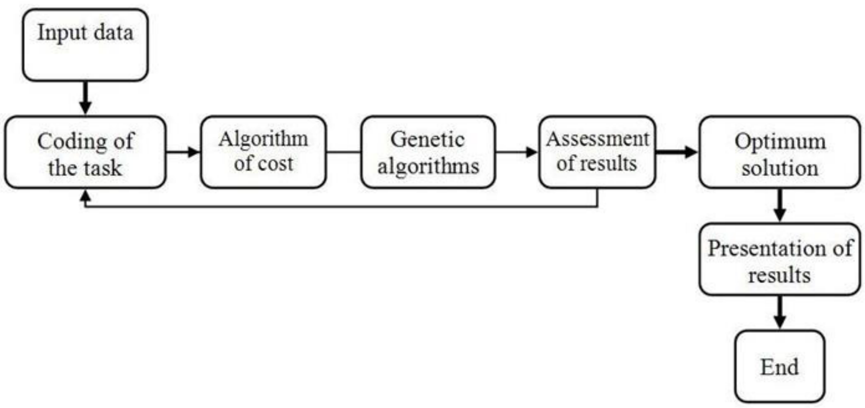

Fig. 2. The principle of operation of the system supporting decision-making concerning the location of vehicle dismantling stations

Input data – is a module where data about the objects of the recycling network (e.g. J, K, N, …), and the matrix of distance between them for a selected area are input, and numbers Q_i of vehicles to be recycled are generated. Coding of the optimization task– each variant of the number and location of the dismantling station being analysed in the system is coded in the form of an ordered binary sequence, called a chromosome. Recycling cost is calculated for each chromosome. Cost determination algorithms are responsible for the calculation of all costs that make up the total recycling cost, and the objective function with constraints.Optimization using genetic algorithms is the most important module of the system that finds the optimum solution - the number of the dismantling stations as well as their topographic location.

3.1. Coding and solving the optimization task

A binary location vector that represents chromosomes in the applied genetic algorithm was used to code potential locations of all dismantling stations (DS) in the recycling network. The number of the vector's coordinates is equal to the number of vehicle collection points; in the analysed case N=37. The coordinate xn of the location vector (n=1, …, N) provides information as to whether there is a dismantling station (DS) in the n-th vehicle collection point (CP). The value equal "1" denotes that a dismantling station is located in the place, and the value equal "0" denotes that there is no such station. Uniqueness of this information results from the initial assignment of the chromosome coordinates to the CP locations, e.g. chromosome (1, 0, 1, 0, 1, 0) denotes that dismantling stations are located in the first, third and fifth location of all six locations being analysed. The shortest distance criterion is used to indicate the CP points from which the vehicles are transported to these three DS stations. Hence, in the distance matrix $[a_{jn}]$, values:

$$x_{1n_1} = \min a_{1n}, \quad x_{2n_2} = \min a_{2n}, \quad x_{6n_6} = \min a_{6n}$$

are sought for n=1,3,5. Indexes $n_1, n_2, \ldots, n_6$ indicate the number of the place of location of the station (DS). The example below presents the assignment of vehicle dismantling stations (DS) locations to vehicle collection points (CP). In the example N=6, symbols A,B,…, F denote locations of vehicle collection points (CP).

Table 1. An example of coding and finding solution of the task.

Place of location, matrix $[a_{jn}]$	**A** a_{j1}	**B** a_{j2}	**C** a_{j3}	**D** a_{j4}	**E** a_{j5}	**F** a_{j6}
A, a_{1n}	0	182	196	106	125	84
B, a_{2n}	182	0	191	105	126	96
C, a_{3n}	196	191	0	91	88	142
D, a_{4n}	106	105	91	0	52	56
E, a_{5n}	125	126	88	52	0	75
F, a_{6n}	84	96	142	56	75	0
Chromosome $[x_n]$	**1**	**0**	**1**	**0**	**1**	**0**

Locations of CP	**Locations of DS selected by the chromosome**			$x_{jn_j} = \min_{n=1,3,5} a_{jn}$
	A	**C**	**E**	
A	0	196	125	$n_1=1 \Rightarrow x_{11}$
B	182	191	126	$n_2=3 \Rightarrow x_{23}$
C	196	0	88	$n_3=2 \Rightarrow x_{32}$
D	106	91	52	$n_4=3 \Rightarrow x_{43}$
E	125	88	0	$n_5=3 \Rightarrow x_{53}$
F	84	142	75	$n_6=3 \Rightarrow x_{63}$

As the example shows, six CP points were assigned a DS located in A, C and E. Fig. 3 presents the assignment; namely, to which dismantling station (DS) the vehicles from the vehicle collection points (CP) will be transported. Each chromosome contains information about the number of vehicle dismantling stations and their locations in a given area.

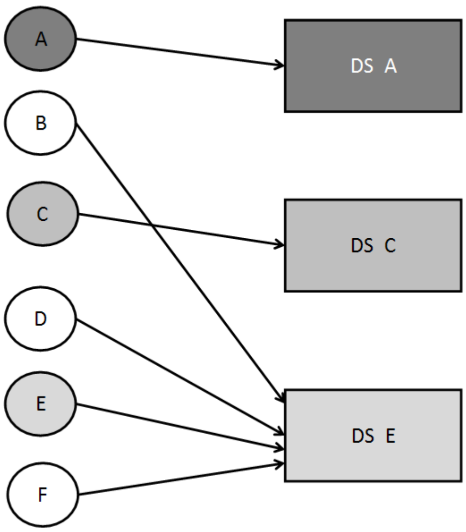

Fig. 3. A diagram presenting optimum assignment of vehicle collection points A,...,F to vehicle dismantling stations A,C and E.

3.2. Optimization using the genetic algorithm

The solution of the optimization task, formulated in the paper, was sought using the developed genetic algorithm (the method of transformation of the population of chromosomes which code the selection of DS considering the minimum cost of recycling). The flowchart of the algorithm is presented in fig. 4.

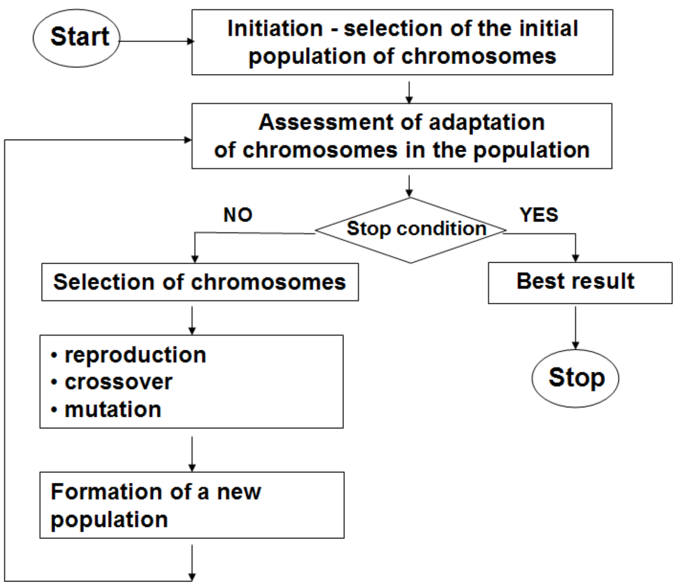

Fig. 4. A flowchart of the genetic algorithm.

The algorithm uses the following genetic operators: mutation, crossover and reproduction:
Gene mutation - the mutation operator was introduced (with probability 1) in the chromosomes which were identical (deterministic selection) in order to introduce diversity in the population, which (at least partially) prevents the premature convergence of the algorithm.
Crossover – the crossover operator was used only in cases of selected individuals (the most promising ones), and the point of crossover is selected at random.
Reproduction - an elite strategy and genetic algorithm with partial exchange of population. The elite strategy involves protection of the best chromosomes in successive iterations. In the genetic algorithm with partial exchange of population, only part of the population which is to forms the next generation, does not undergo any modifications, i.e. crossover and mutation. In this particular case, it applies to the best (fittest) individual from the population.
Selection - the individuals to form the next generation are selected based on the ranking method. Each individual is assigned the number specifying his position on a list - a rank.
Halt condition - no improvement in the adaptation function (minimization of the recycling cost) in ten successive iterations (generations).

The originality of the method used involves automatic formation of new chromosomes (by the developed decision support system) which indicate potentially possible locations for which the cost is calculated. The chromosome, for which it is impossible to significantly improve the calculated objective function (1) of the optimization task, is assumed to meet the optimization criterion.

4. Conclusions

The presented system is universal and may also be used to locate other types of objects on a selected area, e.g. agricultural products collection or distribution centres. The proposed method for optimizing the location of vehicle dismantling facilities using genetic algorithms was developed to include the complexity of the process of recycling. The advantage of the proposed intelligent system that supports decisions concerning the location of dismantling stations is the fact that it allows to obtain solutions for different values of decision variables in a short time, which supports making decisions in changing conditions, while the network is being formed and during its functioning.

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