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Solving Multiple Tour Multiple Traveling Salesman Problem with Evolutionary Programming

László Kota[1], Károly Jármai[2]

[1] University of Miskolc, Institute of Logistics, Hungary, altkota@uni-miskolc.hu
[2] University of Miskolc, Institute of Logistics, Hungary, altjar@uni-miskolc.hu

1. Abstract

Nowadays in the field of globalized production and service industry the significance of the tightly integrated logistic systems are increasing. In the service industry the technical inspection and maintenance systems has a great importance, because they provide safety and reliable operation of production and service facilities. The reliable, accident free, and economic operation require periodic technical inspections and maintenances. In these systems the inspection generally require specialized knowledge, sometimes it even requires special certificate. At elevators, which inspection and maintenance are very important from the aspect of life protection, there are governmental regulations available.

The paper describes a single phase algorithm for the fixed destination multi-depot multiple traveling salesman problem with multiple tours (mmTSP). This problem widely appears in the field of logistics mostly in connection with maintenance networks. In the first part we show the general model of the technical inspection and maintenance systems, where this problem usually emerges. We propose a mathematical model of the system's object expert assignment with the constraints like experts minimum and maximum capacity, constraints on experts' maximum and daily tours. In the second part we describe the developed evolutionary programming algorithm which solves the assignment, regarding the constraints introducing penalty functions in the algorithm. In the last part of the paper the convergence of the algorithm and the run times are presented.

2. Keywords: heuristics, optimization, evolutionary programming.

3. Introduction

The significance of the technical inspection and maintenance systems are increasing in the field of globalized service industry. These systems ensure the safe and reliable operation of the production and service systems and they are important in the field of residential services like communal services, water, sewage, electricity, telecommunication services, monitoring and measuring devices, critical network control device or even elevator maintenance systems. The reliable, accident free and economical operation of these types of systems requires periodical inspections and maintenance requirements on site. The technical inspection tasks and maintenance in most cases require special knowledge and specially trained people. For example of the elevator inspection and maintenance systems where the technical inspection and maintenance are vital, and the proper operation can save lives; thus there are governmental regulations available [1].

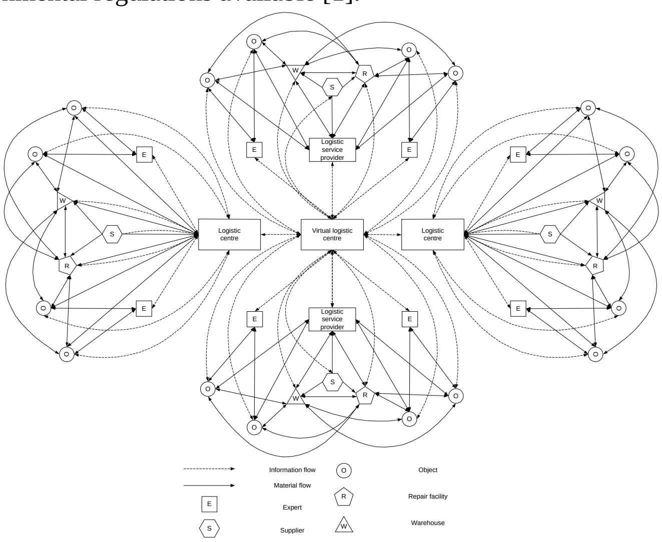

Figure 1: General structure of a technical inspection and maintenance system

The network like technical inspection and maintenance systems (Figure 1) can extend a city, a region, a country, continent wide, or even worldwide. The duties of these systems are a regular supervision of the objects in a defined time period and maintenance and/or repair the parts of the objects [2]. The effective realizations of the maintenance tasks is ensure by one or more scattered raw material and tool warehouses and repair facilities.
The role of the logistic system is to ensure the availability of the resources - experts, raw materials, tools- required by the technical inspection and maintenance tasks.
The system is controlled by a virtual logistic center [3] (Fig. 1.), but in smaller scale – regional or country wide systems – the core of the system, the controller facility could be a logistic center where the information processing and the material flow is simultaneously present. The virtual logistic center which controls the system uses complex mathematical models and optimization processes, where it minds the operational requirements, governmental regulations and many other conditions as constrains [4].

4. Mathematical model and the optimization problem

The main optimization problem in these systems is the assignment of the object have to be supervised and the experts who is doing the supervision. The system main parameter is the path matrix L, which shows the distances between the system elements. In our case the path matrix is an integrated matrix, built up from several sub-matrixes, the sub-matrices defined by the number of elements in the system.

$$L = [l_{ij}], \tag{1}$$

The assignment matrix Y is one of the main output parameter of the model. The assignment matrix:

$$Y = [y_{ij}] \tag{2}$$

where

- $y = \begin{cases} 1 \\ 0 \end{cases}$ according to the system elements are assigned together (1) or not (0),

Defining the y_{ij} is the assignment task which has to be solved in this complex system.

4.1 Objects

The main parameters of the objects are:

- p: is the number of the objects, it is constant in this model,
- L matrix defines the location of the objects, and the distance from the other system elements,
- $\kappa_{i\ (i=1..p)}$ is the mandatory inspection number per object,

The number of the technical inspections and maintenances could be prescribed by the maintenance plan or even law or governmental regulations in some cases where human life is endangered, like at elevators. The maintenances can't happen in an arbitrary period, there is a time period which has to be defined to every object when the next maintenance task could perform.

$$\tau^m = [\tau_i^m]_{i=1..p} \tag{3}$$

The interval of the inspections fulfil the constraint

$$\tau_i^m * (\varepsilon_i \ - 1) \leq \vartheta, \tag{4}$$

where:

ε_i : is the number of the maintenance tasks of object *i*, and ϑ: is the examination period.

In real life of these systems the inspection and maintenance tasks are performed usually by the same expert so the special knowledge collected at the previous inspections is well utilized, so the maintenance times could be shortened.

3.1 Experts

The parameters for the mathematical description of the experts are the following:

- s: is the number of the experts, this is constant in most cases and in this model we modelled as constant,

The time required to travel between object i and j:

$$\tau_{i,j} = \frac{l_{i,j}}{\bar{v}} \; ; \qquad \begin{matrix} i = 1..p \\ j = 1..p' \end{matrix} \tag{5}$$

where:

- $l_{i,j}$: is the distance between the object i and j,
- p : is the number of the objects,

– $\bar{v}$ is the average speed of the expert.
– P: is the performance of the experts, it shows how much maintenance task is performed by the expert.

Constraints:

The performance of the expert has to be between the defined minimum and maximum values:

$$P_{i\,min} < P_i \quad < P_{i\,max}, \tag{6}$$

where:

$$P_i \quad = \sum_{j=1}^{p} \left(Y_{12\,i,j} * \varepsilon_j \ \right) \tag{7}$$

The cycle time (τ_{max}) - generally one day – is also a constraint, in one cycle the expert visit the objects do the inspection and return to his base location:

$$\tau^t = \tau_{0,1}^f + \tau_1^k + \sum_{i=2}^{c^t} \left(\tau_i^k + \tau_{i-1,i} \right) + \tau_{q,0}^f < \tau_{max}, \tag{8}$$

where:

τ^t: is the interval when the expert start from his base location, visits the objects and return, it is generally one day at the regional or countrywide maintenance systems and:

$$\sum_{i=1}^{T} \tau_i^t = \vartheta,, \tag{9}$$

where:

– T: is the number of cycles in the ϑ interval,
– τ_{max}: time interval of a cycle,
– c^t :: the number of objects has to visit in the cycle t,
– $\tau_{0,1}^f$: the travel time to the first object from the start location,
– $\tau_{q,0}^f$: the travel time from the last object (q) to the experts base location,
– τ_i^k: the average inspection time of the object i.

The set of objects can be defined which have to inspect by the expert c:

$$O_c \ := \left\{ o_i \ | \ Y_{12\,s,i} = 1; i = 1..p \ \right\}, \tag{10}$$

$$\left| O_c \ \right| = P_c \ , \tag{11}$$

and the subsets, the objects have to be inspected in one cycle:

$$O_c^t \ \subseteq O_s \ , \tag{12}$$

where:

O_s : is an ordered set, the objects assigned to the given expert, the ordering function is:

$$o_p \in O_i; o_q \in O_i; o_p < o_q \ where \ t_{o_p} < t_{o_q}, \tag{13}$$

where:

– t_{o_p} is the inspection time of o_p, and $t_{o_q}$is the inspection time of o_q,

so the set is ordered by the visiting time.

$$|O_c^t \ | = c_c^t \leq P_c, \tag{14}$$

$$\bigcup_{t=1}^{T} O_c^t = O_s \ , \tag{15}$$

and

$$\bigcup_{s=1}^{p} O_s^t = O \quad . \tag{16}$$

However the expert performs more than one inspection on an object so the object is counted in the sets defined at (12) as many times as the number of inspection has to be performed.

To determine the interval of the inspections the following distance functions can be applied:

$$d\left(o_i; o_j \middle| o_i \in O_p^t; o_j \in O_q^t \right) = p - q, \tag{17}$$

so based on the constraint in eq. (4):

$$min\left\{ d\left(o_i; o_j \middle| o_i \in O_p^t; o_j \in O_q^t \right) \right\} \geq \tau_i^m. \tag{18}$$

So the path travelled by the expert i in a cycle t can be describe as:

$$l_i^t = l_{0,O_i^t(1)} + \sum_{c=1}^{|O_i^t|-1} \left(l_{O_i^t(c),O_i^t(c+1)} \right) + l_{O_i^t(|O_i^t|),0}, \tag{19}$$

and the total path travelled by the expert i can be described as:

$$l_i^T = \sum_{t=1}^{T}\left[l_{0,O_i^t(1)} + \sum_{c=1}^{|O_i^t|-1}\left(l_{O_i^t(c),O_i^t(c+1)}\right) + l_{O_i^t(|O_i^t|),0}\right] = \sum_{t=1}^{T} l_p^t. \quad (20)$$

The expenditures (C) of the experts (S) in a given period (T) can be described as:

$$C^S = \left[\sum_{j=1}^{s}\left(\sum_{t=1}^{T} l_j^t\right)\right] * c_u + \left[\sum_{j=1}^{s} P_j\right] * c_v \quad (21)$$

where:

- c_u: is the specific cost for one kilometer,
- c_v: the specific cost for an object.

Further in the article the specific cost is calculated with the multiplier 1, so only the distance is considered.
The target of the optimization is:

$$C^S \rightarrow min,, \quad (22)$$

the expenditures has to be minimal.

4. The evolutionary algorithm

The algorithm we developed solves the fixed destination multiple depot multiple route multiple travelling salesman problem and optimize the number of salesman in one phase and can be used for large or very large problems. The one phase algorithms not common in this area, there are only two phase algorithms were presented since then [5, 6], most of them using clustering [7] or partitioning [8] as one phase. As there are multiple salesmen: the experts, multiple depot: all the experts have different locations, fixed destination: all the expert start and return to their initial location, and all the experts do the travel (generally) in one day cycles.
The developed solution method based on a multi chromosome technique [9] which is not widely used in genetic algorithm but it could simply implement in the evolutionary programming. The data structure of the optimization is built as a cascaded structure. The biggest container is the population which consists of defined constant number of individuals, which is an input parameter of the optimization.
The algorithm is an evolutionary programming algorithm which has the following pseudo code:

1. generate the first population, in most cases it is random generated,
2. calculate the population fitness values,
3. while not done
    - 3.1. copy the population into a temporary population,
    - 3.2. run the mutation operators on the temporary population,
    - 3.3. select the survivors for the next population,
4. end while.

In the computer solution first initialize the data, random generator, etc. Then initialize the first population. In heavily constrained problems there are two cases:

- the randomly generated population individual is invalid: it violates the constraints,
- the individual is in the feasible region: but this is a very rare case.

There are several methods to get valid individual from simply dispose invalid individuals to create special operators which retain the individual's integrity. But the simplest solution is using penalty function. In the penalty function one can regulate the algorithm which solutions are preferred.

After the creation of the initial population it has to be copied into a temporary population then the mutation operators run on the temporary population. In most cases the high impact mutations have less chance to run and the low impact operators have a bigger chance. After the mutation we have to compute the mutated individuals' fitness value and then choose the survivor individuals to the descendant population which happens with a tournament. One simple way to perform the tournament is choose two random individuals one from the original and one from the mutated population and that will survive which has less (or bigger if the fitness not normalized) fitness value, we have to repeat this until the new population not filled.

4.1. Penalty functions

The penalty function is one of the simplest and fastest way to rate the individual, so the goodness of the actual solution. In this algorithm there are two different levels of penalty functions as it follows the multichromosome paradigm:

- local: the penalty function is applied to the expert,
- global: the penalty function is applied to the whole individual.

4.2 Local penalties

There are three different local penalty functions:

- Number of cycles penalty: when the expert do more route cycles than allowed,

– Few penalty : the expert has to get a minimal number of maintenance events,
– More penalty: the expert cannot get more maintenance events than his maximum capacity,

4.4 Global penalties

There are three different global penalty functions, which calculated after the local penalties:

– Near penalty: the maintenance events of one object cannot be arbitrarily close to each other.
– Scatter penalty: This applied when maintenance events of an object are scattered among several experts.
– Number of expert penalty: The employment of the expert has a fixed cost in this model. The algorithm tries to minimize the number of employed experts due to these penalty functions [10].

5. Results

We present the convergence of the algorithm on two test instances as the paper limits us. In these instances there are three experts and the objects are around them in a perfect circle. This instance can be easily solved by a human but it is hard to solve perfectly with a computer algorithm.

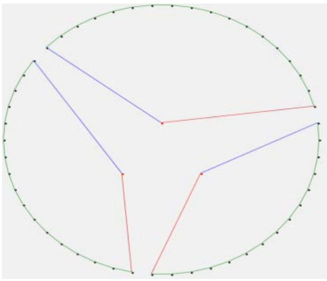

Figure 2: Test instance with 3 experts

Table 1: Running times of the optimization

Iteration number	35457
Run time	48 min 33 sec
Penalty	0
Cost	4484,47
Iteration number	35457

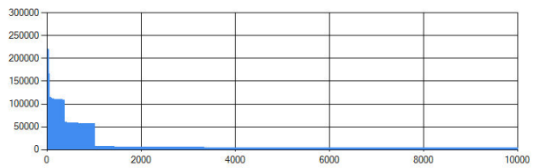

Figure 3: Convergence of the solution

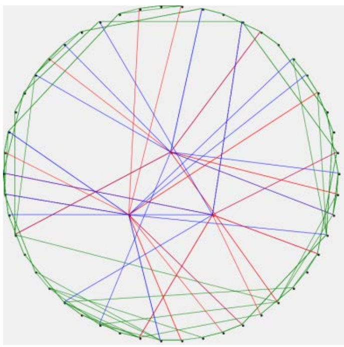

Figure 4: Test instance with 3 experts

Table 2: Running times of the optimization

Iteration number	50000
Run time	1 h 11 min 9 sec
Penalty	5
Cost	760731,64
Iteration number	50000

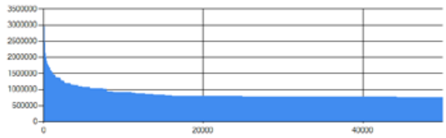

Figure 5: Convergence of the solution

6. Conclusion

The algorithm we designed and presented in this paper is great to solve this kind of problems, like the scheduled inspection and maintenance of any equipment or machines and it is even usable at waste collection systems. The algorithm can take the constraints of these types of systems into consideration and give result even if there are no optimal solution according to the constraints, it will give the least bad solution. The convergence of the algorithm is good and it performed well on large scale instances but at large scale a very high computing capacity computer or computer cloud needed.

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