An efficient genetic algorithm to solve the intermodal terminal location problem

Mustapha Oudani [a,b*], Ahmed El Hilali Alaoui [a], Jaouad Boukachour [b]

[a] Sidi Mohamed Ben Abdellah University, Fez, Morocco

[b] Le Havre University, Le Havre, France

Abstract

The exponential growth of the flow of goods and passengers, fragility of certain products and the need for the optimization of transport costs impose on carriers to use more and more multimodal transport. In addition, the need for intermodal transport policy has been strongly driven by environmental concerns and to benefit from the combination of different modes of transport to cope with the increased economic competition. This research is mainly concerned with the Intermodal Terminal Location Problem introduced recently in scientific literature which consists to determine a set of potential sites to open and how to route requests to a set of customers through the network while minimizing the total cost of transportation. We begin by presenting a description of the problem. Then, we present a mathematical formulation of the problem and discuss the sense of its constraints. The objective function to minimize is the sum of road costs and railroad combined transportation costs. As the problem is NP-hard, we propose an efficient real coded genetic algorithm for solving. Our solutions are compared to CPLEX and also to the heuristics reported in the literature. Numerical results show that our approach outperforms the other approaches. A realistic cost approximation of intermodal transportation is used to validate the experimental results.

Keywords: Intermodal transportation; Terminal; Genetic algorithm; Metaheuristic; Rail-truck; Optimization.

* Corresponding author email address: mustapha.oudani@usmba.ac.ma

1. Introduction

Globalization requires integrated and intermodal transportation systems. Generally, Multi-modal Transportation means transportation using several modes. Intermodal or combined transportation is a special case of multimodal transportation with certain interoperability between modes. It requires a unified logistic aspect including the transfer between the modes. It is important to identify the transportation mode or combination of modes, including the most appropriate transfer points, to give the "best" overall level of performance. The driver of intermodal transportation has undoubtedly been the container, which permits easy handling between modal systems. The use of containers shows the complementarities between freight transportation modes by offering a higher fluidity to movements and a standardization of loads. The container has substantially contributed to the adoption and diffusion of intermodal transportation, which has led to profound mutations in the transport sector. Through reduction of handling time, labor costs, and packing costs, container transportation allows considerable improvement in the efficiency of transportation. Nevertheless, the Intermodal Transport is far from being an economical alternative because of the fragility level of infrastructure and connectivity of modes. To improve the attractiveness of Intermodal Transport, the location of intermodal terminals plays a decisive role (Sörensen, 2012). The remainder of this paper is organized as follows: in Section 2, we discuss related works. This section is composed of three subsections. The first one deals with the hub-and-spokes networks, the second addresses multiple propositions of definitions for intermodality and related terms as co/synchro-modality, the third deals with the most Intermodal Transportation issues and Section 3 presents a description of the problem. The mathematical formulation of the problem is given in Section 4. We propose a realistic cost evaluation for Intermodal Transportation in Section 5. Our approach based on genetic algorithms is detailed in section 6 , we test and compare four genetic operators. The numerical results are reported in Section 7, we conclude with some research perspectives.

2. Literature review

In recent years, the number of published papers proves growing interest in Multimodal Transport. Research in this area involves the three levels of planning problems: the strategic concerns, in this case, the location of platforms, called intermodal transshipment hub, hubs, or consolidation's centers. Operational/ tactical is to determine the routes of each commodity demand and determine the appropriate characteristics of these routes (mode, frequency, scheduling). We can classify related works in those dealing with the definition of intermodality and the relevant terms, those focusing on the issues of intermodality as environment benefits, competitiveness and security/reliability for transportation of dangerous goods, etc. or those presenting models or resolution of specific problems. We should notify that the genealogy of terminals location problems is essentially based on the hub location literature.

2.1. Hub and spoke networks

Although the intermodal location problem has its own context, this problem is closely related to the hub location problem. The first well-known work in hub location is made by O'Kelly (1987),

in which he presents the first basic mathematical formulation for the hub location problem. Since that, rich scientific literature about location hubs was growing, including state-of-arts, and several research articles. Hubs are defined as special facilities that serve as switching, transshipment and sorting point in many-to-many distribution systems (Crainic, 2006). Instead of serving each origin-destination pair directly, hub-and-spoke networks concentrate flows in order to take advantage of economy of scale (Racunica, 2005). that we do not report details of hub location literature here for brevity. Further details about single/multiple, location/allocation, p-hub median can be found in (Campbell, 2012, 2002, 1996, 1994), (O'Kelly, 1986, 1998), (Alumur, 2008). The interest of hub literature is that the researchers were inspired by hub literature to build models for intermodal location networks by making an analogy between a hub and an intermodal terminal.

2.2. Definitions

There is no consensus definition of intermodal transportation despite the growing in intermodal transportation by industry and government. Intermodal transportation can be interpreted in several ways. It means many things for many people (Crainic, 2006). Nevertheless, the literal meaning is transportation of goods or passengers using more than two modes in the same trip. Multimodal and Intermodal or combined transportation is often used as synonyms, although the words are not entirely interchangeable (Pederson, 2005). It is defined *as the movement of goods using two or more modes of transport but in the same unit or the same road vehicle, and without stuffing or unloading* (UNECE, 2009).

The Multimodal Transport is defined in (UNECE, 2009) as the transport of goods by at least two different modes of transport. Multimodal Transport is developed mainly because of the need to ensure the continuation of the terrestrial ocean freight simplifying dock. An illustrative example of a network of Intermodal Transportation is the growing traffic between container terminal from maritime port to their hinterlands where several millions of containers are transferred to road, rail or waterway. Several governmental organisms and companies proposed their definitions. Indeed, in 1991, The United States department of Transportation showed in ISTEA (Intermodal Surface Transportation Efficiency Act) that: *The National Intermodal Transportation System shall consist of all forms of transportation in a unified interconnected manner, including the transportation systems of the future, to reduce energy consumption and air pollution while promoting economic development and supporting the Nation's preeminent position in international commerce.* (Jones, 2000) CNC transport, a French company specializing in intermodal transportation and logistics services presents the following definition for intermodal transportation : *The conveyance of goods via a combination of at least two transport modes within the same transport chain, during which there is no change in the container used for transport and in which the major part of the journey is by rail, inland waterway, or by sea, whereas the initial and final part of the journey is by road and is as short as possible* (Jones, 2000). The United States Department of Transportation (USDT) defines intermodal Transportation as: *Use of more than one type of transportation e.g. transporting a commodity by barge to an intermediate point and by truck to destination.* Recently, relevant terms were appeared like: co-modal transportation, which can be defined as the transportation which focuses on the efficient use of different modes on their own and in combination. Co-modality is defined by the Commission of the European Communities (CEC, 2006) as the use of two or more modes of transportation, but with two particular differences from

multimodality: (i) it is used by a group or consortium of shippers in the chain, and (ii) transportation modes are used in a smarter way to maximize the benefits of all modes, in terms of overall sustainability (Verweij, 2011). Synchromodal transportation is positioned as the next step after intermodal and co-modal transportation, and involves a structured, efficient and synchronized combination of two or more transportation modes. Through Synchromodal transportation, the carriers or customers select independently, at any time, the best mode based on the operational circumstances and/or customer requirements (Verweij, 2011).

2.3. Intermodal Transportation issues

To insure sustainable development, a logistic system must be competitive, viable and without ecological externality. For this raison, several researchers propose solutions including:
   • Effective attractiveness to build competitive networks
   • Environment respect by promoting modal shift from road transportation to nonpolluting and consolidated modes
   • Confirmed safety where the main concern is to profit from the safety of certain mode for the transport of hazardous materials (hazmat)
These three issues are the most important subjects in the intermodal transportation literature.

2.3.1. Building competitive networks

Macharis and Bontekoning (2004) provide an overview of the most important researches in the field of operations research. Ishfaq and Sox (2006) provide an overview of several models in the literature. Arnold et al. (2001) proposed a mathematical formulation of the intermodal transshipment centers location problem. They suggest, first, a generic formulation of the problem and extensions with the situations most often encountered in the practice of Multimodal Transport as the introduction of fixed costs to cover the investment costs associated with the implementation of transshipment centers, the minimization of the cost of transportation and another case in which they fixed the maximum cost of transport. Artmann et al. (2003), studied if the shift of traffic from road to rail TRANSITECTS creates sustainable intermodal solutions to fit changing markets—especially combined transport products for transalpine freight traffic. Limburg et al. (2009) proposed an iterative procedure based on the p- median problem of hubs and the problem of multimodal assignment. Their objective function includes the transport cost of road, transfer via terminals and rail. Arnold et al. (2004) proposed a new formulation based on the problem of multi-commodity fixed cost. K. Sörensen et al. (2012) studied the model of Arnold et al. (2001). They showed that the problem is an NP-hard problem as an extension of the facility location problem with capacity and they used two different heuristics: ABHC (Assigns Base Hill Climber) and GRASP procedure (Greedy Randomized Adaptive Search Procedure). Tsamboulas et al. (2013) proposed the development of a methodology with the necessary tools to assess the potential of a specific policy measure to produce a modal shift to intermodal transport. Recently, Lin et al. (2014) proposed a simplification of K. Sörensen modeling and proposed two heuristics for solving the problem.

2.3.2. Ecological alternative

The transport sector is responsible for over 30% of all CO_2 emissions. In addition, road transport remains the most polluting with 71 % of all CO_2 emissions from transportation (UIRR, 2009). The strategic importance of Intermodal Transport as an ecological alternative to the heavy use of road transport is evidenced by a simple example that a barge can replace more than 300 trucks. The Modal Shift aims, in this case, to achieve environmental sustainability by the suggestion of new logistics plans without technological improvements. Macharis et al. (2010) studied the impact of fuel price increasing on the market area of unimodal road transport compared to the intermodal transport in Belgium. They analyzed the internalization of the external cost (i.e. taking into account impacts on environment and society in transportation cost) as recommended by European commission.

2.3.3. Hazmat Transportation

Verma et al. (2010), presented a bi-objective optimization model for rail-truck intermodal transportation, where intermodal route selection is driven by the delivery-times specified by customers and they proposed an iterative decomposition based solution for solving the problem. The same authors Verma et al. (2012) studied the problem of truck-train transportation for regular and dangerous goods: the problem is to determine the best routing plan of the hazardous material and regular material. They propose a bi-criteria formulation of the problem to minimize the cost of transportation on the one hand and the risk associated with transport of dangerous goods on the other hand. Xie et al., proposed a non-linear multimodal hazmat location and routing model. They convert the initial non-linear model to a mixed integer linear form and they tested the model in a small and medium size networks. Jiang et al. (2014) presented a multi-objective and multimodal model for optimization of transfer yard locations and hazmat transportation routes. They tested their model in a highways and railways network in the Northeast of China.
To our knowledge, this is the first study to use the new genetic operators in the fields of Intermodal Transportation and used a realistic assessment of the cost of intermodal transport.

3. Position of the problem

The research problem is to determine the best routing of a set of demands through a network with, especially two modes (road and rail). This planning will include first, opening a set of terminals chosen from a set of candidate sites (potential sites). The goods request to a group of customers may be transported by road (by trucks) or use a combination truck- train (Intermodal Transport). So, solving the problem is to determine the amounts to carry unimodal and quantities to carry on an intermodal way. The figure below shows a network of three customers and two intermodal terminals.
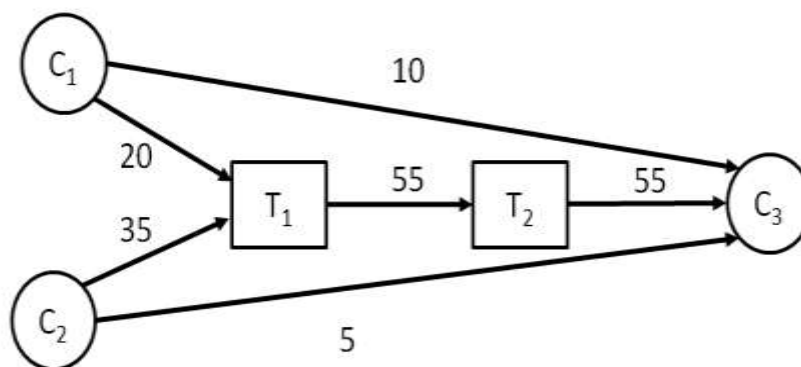
Figure 1: small intermodal network

Figure 1 shows that for transporting goods, we can take unimodal and/or intermodal circuit. The three customers c_1, c_2, c_3 are associated to a set of demands (asymmetric in this case) that can be routed directly or through terminals T_1, T_2.

Unimodal circuit: goods are transported directly by trucks from the origin to destination.

Intermodal circuit: It is occurred in three segments: transportation of goods by trucks from origin to the first terminal (pre-haul), the rail transfer from the first to the second terminal (long-haul) and the transportation by road from the second terminal to destination (end-haul).

4. Mathematical formulation

Arnold et al. (2001) proposed the first mathematical modeling of the Intermodal Terminal Location Problem. Sörensen et al. proposed an improved modeling as follows:

Problem parameters:

- I: set of all customers,

- K: set of all potential locations,

- q_{ij}: total quantity of goods to be routed from i to j,

- c_{ij}: the unit cost of transportation by route from i to j,

- c_{ij}^{km}: the unit cost of transporting of a fraction of

  commodity i to j through the terminals k and m,

- C_k: maximum capacity of the terminal k,

- F_k: fixed installation cost of the terminal k.

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Decision variables:

- y_k: a binary variable equal to 1 if k is a terminal, 0 otherwise,
- w_{ij}: fraction q_{ij} transported directly from i to j,
- x_{ij}^{km}: the fraction of q_{ij} routed from i to j via terminals k and m.

$$Min \sum_{i,j \in I} \sum_{k,m \in K} C_{ij}^{km} x_{ij}^{km} + \sum_{i,j \in I} C_{ij} w_{ij} + \sum_{k \in K} F_k y_k \tag{1}$$

Subject to:

$$x_{ij}^{km} \leq q_{ij} y_k, \forall k, m \in K, \forall i, j \in I \tag{2}$$

$$x_{ij}^{km} \leq q_{ij} y_m, \forall k, m \in K, \forall i, j \in I \tag{3}$$

$$\sum_{k,m \in K} x_{ij}^{km} + w_{ij} = q_{ij}, \forall i, j \in I \tag{4}$$

$$\sum_{i,j \in I} \sum_{k \in K} x_{ij}^{km} + \sum_{i,j \in I} \sum_{m \in K} x_{ij}^{km} \leq C_k, \forall k, m \in K \tag{5}$$

$$x_{ij}^{kk} = 0, \forall i, j \in I, \forall k \in K \tag{6}$$

$$w_{ij} \geq 0, x_{ij}^{km} \in \{0,1\}, \forall i, j \in I, \forall k, m \in K \tag{7}$$

The objective is to minimize the total cost of the goods transportation as the sum of unimodal cost, intermodal cost and cost of opening the terminal. Constraints (2) and (3) ensure that the goods must be transported via the terminal k if this terminal is open. Constraint (4) ensures that the sum of the goods routed directly and transported via the terminals is equal to the demand associated with each origin/destination pair. Constraint (5) takes into account the limited capacity of terminals. Constraint (6) requires the use of two different terminals. Constraints (7) ensure that the quantities of goods transported by road via terminals are nonnegative and that y_k takes two values 0 or 1. This program is linear with binary and real variables (Mixed Integer Program.) if we assume that |I|=|J|=|K|=n …., the problem becomes large and highly constrained in case of large values of *n*. K. Sörensen et al. (2011) showed, using a polynomial reduction to the problem of the location of facilities with capacity that the problem is NP-hard, so there is no exact deterministic algorithm that can solve this problem in polynomial time (in reasonable time since now). Recently, Lin et al. (2014) proved that the three constraints (2), (3), (5) can be merged to the sole constraint (8):

$$\sum_{i,j \in I} \sum_{k \in K} x_{ij}^{km} + \sum_{i,j \in I} \sum_{m \in K} x_{ij}^{km} \le C_k y_k, \forall k, m \in K \tag{8}$$

The last introduced constraint makes a significant simplification of the problem. For this reason, we consider, in this paper, the model as presented in Lin et al. (2014) but with a new cost evaluation that we introduce in the next section.

5. Intermodal Cost Evaluation

A transportation chain is basically partitioned in three segments: pre-haul (or first mile for the pickup process), long-haul (intermediate transfer of containers), and end-haul (or last mile for the delivery process). In most cases, the pre-haul and end-haul transportation are carried out via road, but for the long-haul transportation, road, rail, air and water modes can be considered. Example:
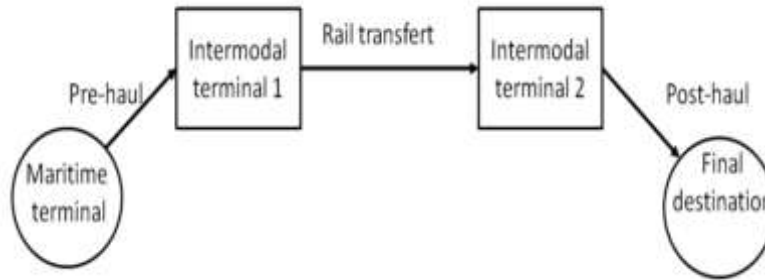

Figure 2: Maritime terminal-Hinterland logistics system

The intermodal transportation cost function can be written as: $\phi(x, z)$, where x is a flow variable and z is a location variable. This cost depends on the amount of goods (x) and on the transshipment cost in intermodal terminals located at z (handling costs). Despite the scale economy for large amount of x (in the second segment), the punctual cost must be considered for the handling operations in each opened terminal z. In most cases, as in the example above Figure 2, we can make a minimum economy of 75 % in rail transfer comparing to road mode especially in long distances (up to 300 Km which is the relevance threshold of rail transport). Sörensen et al. (and Lin al. later) considered that we can approximate the intermodal cost by: $C_{ijkm} = C_{jk} + \dfrac{1}{2} C_{km} + C_{kl}$

Nevertheless, pre and post haul are constrained by handling cost in terminal, ecologic and other limitations especially in urban distribution areas. For this reason, we propose a more realistic approximation for the intermodal transportation cost as follows:

$$C_{ijkm} = \alpha_1 C_{ik} + \alpha_2 C_{km} + \alpha_3 C_{mj} \tag{9}$$

Where $\alpha_1, \alpha_3 > 1, \alpha_2 < 1$. For numerical tests, we suppose $\alpha_1 = \alpha_3 = 1, \alpha_2 = 0.75$. These supposed parameter values are an average approximation for the combined transport cost in France.

6. Solving by genetic algorithm

Inspired by population genetics, genetic algorithm (GA) is a stochastic search algorithm of good solutions (Goldberg, 1989). In this paper, we use mixed coding solutions since this type of coding is naturally best suited to the problem and the fact that several authors have highlighted in the literature the performance of this type of coding that goes beyond binary coding in some cases. The choice of operator's crossover and mutation used is justified by the fact that these operators have shown their effectiveness in solving a class of mixed integer optimization problems including our problem.

6.1. Chromosome representation

The success of a genetic algorithm depends on the manner in which the solutions are coded. We use the mixed coding. The variables y_k are encoded in binary, while other variables are encoded using the real coding already the most natural in this case, these variables are treated as a vector of numbers belonging to the continuous domain. In our approach, each chromosome (solution) consists of two tables: *Location Array* and *Routing Array*. *Location Array* length is equal to the number of potential locations of the terminals. It contains 0 and 1, where 1 indicates that the site is a terminal and 0 otherwise. *Routing-Array* contains fractions of the goods to be routed from i to j, a unimodal way or intermodally.

6.2. Initial Population

A predefined number of initial solutions are randomly generated using the following heuristic (Algorithm 1). In the initialization phase, one begins by randomly generating a site of terminals among candidate sites, when all goods are transported by truck for all origins/destinations. Then we compare the costs: c_{ij} and c_{ijkm}, if $c_{ij} > c_{ijkm}$, intermodal alternative is chosen, otherwise the unimodal alternative is chosen.

Initialization:

Generate a random number *nbr_ter* among potential sites,

$for \quad i, j \in I \quad do$

$\quad w_{i,j} \leftarrow q_{ij}$

$\quad for \quad k, m \in K \quad do$

$\quad \quad x_{ij}^{km} \leftarrow 0$

$\quad end$

end

Routing goods :

$while \quad c_{ij} \geq c_{ij}^{km} \quad do$

$\quad if \quad y_k == 1 \quad then$

$\quad \quad for \quad i, j \in I \quad do$

$\quad \quad \quad for \quad k, m \in K, k \neq m \quad do$

$\quad \quad \quad \quad x_{ij}^{km} \leftarrow \dfrac{q_{ij}}{c_k c_m}$

$\quad \quad \quad \quad w_{ij} \leftarrow q_{ij}\left(1 - \sum_{k,m \in K} \dfrac{1}{c_k c_m}\right)$

$\quad \quad \quad end$

$\quad \quad end$

$\quad end$

end

Algorithm 1: Initial population procedure

6.3. Crossover Operator

The crossover operators provide better exploration of the search space. The importance of this operator lies in the inheritance by children of genetic information. A standard crossover is applied for the Location Array table. For the Routing Array we test two crossover operators: Laplace Crossover and Arithmetic Crossover. Deep et al. (2007) recently proposed the Laplace Crossover (LX). This crossover works in the following way:

Given two parents:

$$\begin{cases} x^{(1)} = (x_1^{(1)}, x_2^{(1)}, ..., x_n^{(1)}) \\ x^{(2)} = (x_1^{(2)}, x_2^{(2)}, ..., x_n^{(2)}) \end{cases}$$

They produce two offspring:

$$\begin{cases} y^{(1)} = (y_1^{(1)}, y_2^{(1)},..., y_n^{(1)}) \\ y^{(2)} = (y_1^{(2)}, y_2^{(2)},..., y_n^{(2)}) \end{cases}$$

As follows:

> *Begin*
>
> Uniformly generate a random number $u \in [0,1]$
>
> Generate β according to Laplace distributi on function as follows :
>
> *if* $u \le \dfrac{1}{2}$ *then*
>
> $\quad | \quad \beta = a - b.\log(u)$
>
> *else*
>
> $\quad | \quad \beta = a + b.\log(u)$
>
> *end*
>
> Generate the offsprings by the equation :
>
> $$\begin{cases} y_i^{(1)} = x_i^{(1)} + \beta \left| x_i^{(1)} - x_i^{(2)} \right| \quad (1) \\ y_i^{(2)} = x_i^{(2)} + \beta \left| x_i^{(1)} - x_i^{(2)} \right| \quad (2) \end{cases}$$

Algorithm 2: The Laplace Crossover (LX)

According to the equations (1) and (2), and for smaller values of b, children are like their parents.

Given values of a and b, the Laplace Crossover leaves children proportional to the difference between the parents, for example if the parents are close to each other, then children are also close to each other because : $y_i^{(1)} - y_i^{(2)} = x_i^{(1)} - x_i^{(2)}$

In arithmetic crossover, two parents produce two offspring as follows:

> *Begin*
>
> Uniformly generate a random number $u \in [0,1]$
>
> Generate α according to Laplace function as follows :
>
> Generate the offsprings by the equation :
>
> $$\begin{cases} y_i^{(1)} = \alpha x_i^{(1)} + (1 - \alpha) x_i^{(2)} \\ y_i^{(2)} = \alpha x_i^{(2)} + (1 - \alpha) x_i^{(1)} \end{cases}$$

Algorithm 3: The Arithmetic Crossover (AC)

α is a fixed parameter. It makes offspring a weighting of their parents.

These operators were applied to table Routing Array and a correction phase is applied to eliminate unfeasible individuals.

6.4. Mutation operator

The mutation operators offer random population diversity, they also prevent premature convergence of the algorithm when it encounters local optima. We test two mutation operators: MPT mutation and Power Mutation. In the first, we use the mutation MPTM (Makinen and Periaux Toivenen Mutation) proposed by Makinen et al. (2007). We consider the table as a vector $x=(x_1, x_2,\ldots, x_n)$ the mutated vector $x'=(x_1', x_2',\ldots, x_n')$ is created as follows:

Begin

Uniformly generate a random number $r_i \in [0,1]$

Calculate t_i as follows :

$$t_i = \frac{x_i - x_i^t}{x_i^u - x_i}$$

if $r_i < t_i$ *then*

$$t_i' = t_i - t_i \left(\frac{t_i - r_i}{t_i} \right)^{b_m}$$

else

$$t_i' = t_i + (1 - t_i) \left(\frac{r_i - t_i}{1 - t_i} \right)^{b_m}$$

end

The mutated vector is given by :

$$x_i' = (1 - t_i')x_i^l + t_i' x_i^u$$

Algorithm 4: The MPT Mutation (MTPM)

For the Power mutation, let *f* be the function defined by $f(x) = px^{p-1}, 0 \le x \le 1$
Its density function is given by: $F(x) = x^p, 0 \le x \le 1$

Begin

Uniformly generate a random number $r \in [0,1]$

Generate s following power distibutio n mentionned above

Calculate t_i as follows :

$$t_i = \frac{x_i - x_i^l}{x_i^u - x_i^l}$$

The mutated vector is given by :

if $t_i < r$ *then*

$\quad x_i' = x_i - s(x_i - x_i^l)$

else

$\quad x_i' = x_i + s(x_i^u - x_i)$

end

Algorithm 5: The Power Mutation (PM)

This mutation is used to create a solution x$'$ in the vicinity of a parent solution. The strength of this mutation is governed by the index of the mutation p. For small values of p, fewer disturbances in the solution is expected. For large values of p, more diversity is achieved. The probability of producing a mutated solution x$'$ on left (right) side of x is proportional to distance of x from l(u) and the muted solution is always feasible.

6.5. General Outline

The wheel selection is used: parents are selected based on their performance, a good chromosome is more likely to be selected and the best individuals can be drawn several times and the worst have a low chance to be selected. We propose to test four different GA versions with different genetic operators. We denote by a = LX, b = AC crossover operators and by 1 =MPTM, 2 = PM mutation operators, so GA(a, 1) is the genetic algorithm with Laplace Crossover and MPT Mutation, GA(b, 2) is the algorithm with the Arithmetic Crossover and Power Mutation, etc.

7. Computational results

To test our algorithm, we use instances randomly generated by K. Sörensen, these instances can be found in the following link: http://antor.ua.ac.be/intermodal

The parameters of a genetic algorithm should be set carefully for good results. These parameters are:

- The probabilities of crossover and the mutation
- Parameters in genetic operators as: scale parameter in LX
- The generation number and the size of the population.

To find the suitable parameters, we made several tests. The number of generations is determined by comparing the cost of each solution after independent executions. The maximum number of

generations is set if there is no significant improvement. This is how we set 100 iterations as criterion stopping because the cost becomes almost constant after this value. For the crossover probability, it attempts to intensify the search by choosing a high rate of crossover to better scan the search space, while the mutation is applied sparingly to diversify the solutions and to avoid premature convergence to local optima. Thus, we set the values of the following parameters:

- Setting the location to the CL, a = 1
- Setting scale parameter for CL, b = 0.5
- Setting the mutation, b_m = 2
- Number of individuals 50
- Number of iterations 100
- Crossover rate 40 %
- Mutation rate 10 %

The algorithm is implemented in the language C/C++ in a PC with Windows 7 CPU@2.20Ghs operating system, Intel(R) Core(TM) i3-2230m (4CPUs) RAM: 4 Ghs.

Table 1: Comparison of GA versions

Instance	Exact solution	GA(a,1) $(\times 10^7)$	GA(a,2) $(\times 10^7)$	GA(b,1) $(\times 10^7)$	GA(b,2) $(\times 10^7)$	Gap 1 (%)	Gap 2 (%)	Gap 3 (%)	Gap 4 (%)
10C10L	9.540	9.883	9.947	10.483	10.557	3.59	4.26	9.88	10.66
10C20L	9.083	9.238	9.198	9.328	9.238	1.70	1.26	2.69	1.70
10C30L	9.167	9.464	9.574	9.841	10.611	3.23	4.43	7.35	15.75
10C40L	8.807	9.125	9.845	9.849	9.882	3.61	11.78	11.83	12.20
10C50L	8.390	8.66	8.841	8.481	8.647	3.21	5.37	1.08	3.06
10C60L	7.475	9.33	9.741	9.777	8.542	24.81	30.31	30.79	14.27
10C70L	7.637	8.480	7.802	8.846	8.148	11.03	2.16	15.83	6.69
10C80L	7.955	9.682	9.142	9.559	9.846	21.70	14.92	20.16	23.77
10C90L	8.678	9.523	9.145	9.956	9.623	9.73	5.38	14.72	10.88
10C100L	8.398	10.180	9.980	11.885	10.380	21.21	18.83	41.52	23.60
20C10L	50.916	51.263	52.183	52.833	51.263	0.68	2.48	3.76	0.68
20C20L	45.968	45.974	51.554	51.584	52.015	0.01	12.15	12.21	13.15
20C30L	46.358	46.461	55.261	47.461	48.481	0.22	19.20	2.37	4.57
20C40L	40.123	40.458	42.154	47.774	45.554	0.83	5.06	19.06	13.53
20C50L	34.403	34.887	41.137	36.807	38.147	1.40	19.57	6.98	10.88
20C60L	41.174	42.577	43.177	42.333	48.487	3.40	4.86	2.81	17.76
20C70L	33.559	35.473	40.363	44.145	41.142	5.70	20.27	31.54	22.59
20C80L	36.024	37.123	38.583	39.789	41.541	3.05	7.10	10.45	15.31
20C90L	32.626	36.740	41.456	44.189	46.864	12.60	27.06	35.44	43.64
20C100L	38.512	44.547	50.184	50.184	54.795	15.67	30.30	30.30	42.28
30C10L	111.66	115.72	117.12	112.72	113.14	3.63	4.88	0.94	1.32
30C20L	104.16	105.19	105.51	112.48	111.49	0.98	1.29	7.98	7.037
30C30L	103.31	104.03	114.84	114.99	114.51	0.69	11.16	11.30	10.84
30C40L	80.470	80.713	91.713	91.495	92.954	0.30	13.97	13.70	15.51
30C50L	89.726	90.88	102.02	101.33	100.54	1.28	13.70	12.93	12.05
30C60L	88.521	89.268	103.15	114.26	104.84	0.84	16.52	29.07	18.43
30C70L	90.509	90.753	111.53	102.01	101.03	0.26	23.22	12.70	11.62
30C80L	75.126	79.557	89.164	81.462	89.051	5.89	18.68	8.43	18.53

We compare four versions of GA to exact solutions found by Gurobi and reported by Sörensen et al. (2012). We note that for a meaningful comparison we consider intermodal cost evaluation

like in Sörensen et al. (2012). Taking into account deviation values, we remark that the efficient algorithm version is GA (a, 1). The next table reports our result using these versions with a comparison to exact solutions found by CPLEX.

Table 2: Results with the new intermodal cost evaluation

Instance	Solution by CPLEX	Sörensen solution	Our solution 1	Our solution 2	Gap 1	Gap 2
10C10L	11.54	10.05	9.883	11.85	2.64	-1.66
10C20L	12.44	9.24	9.23	12.74	2.36	-0.02
10C30L	12.96	9.64	9.46	13.04	0.59	-1.89
10C40L	9.48	9.11	9.12	9.78	3.16	0.12
10C50L	9.51	8.89	8.66	9.63	1.26	-2.66
10C60L	9.54	8.93	9.33	10.16	6.47	4.40
10C70L	9.84	8.44	8.48	9.99	1.52	0.47
10C80L	10.02	9.58	9.682	11.59	15.65	1.04
10C90L	10.84	9.48	9.52	11.01	1.55	0.42
10C100L	15.16	10.12	10.18	15.16	0	0.59
20C10L	51.48	51.56	51.26	51.88	0.77	-0.58
20C20L	48.15	51.75	45.97	49.15	2.07	-11.16
20C30L	47.21	55.66	46.46	48.47	2.67	-16.52
20C40L	45.15	47.76	40.45	45.15	0	-15.29
20C50L	41.28	42.87	34.88	41.36	0.20	-18.63
20C60L	43.18	48.57	42.57	43.21	0.06	-12.33
20C70L	39.84	39.31	35.47	39.91	0.16	-9.76
20C80L	41.16	43.58	37.12	41.48	0.78	-14.82
20C90L	40.87	38.74	36.74	40.88	0.03	-5.16
20C100L	46.14	48.54	44.54	46.45	0.66	-8.23
30C10L	105.19	117.72	115.72	105.48	0.27	-1.69
30C20L	115.95	113.5	105.19	116.15	0.17	-7.32
30C30L	149.61	117.03	104.03	149.74	0.08	-11.10
30C40L	88.16	91.31	80.71	88.41	0.28	-11.60
30C50L	102.15	105.48	90.88	102.49	0.33	-13.84
30C60L	114.16	103.24	89.26	114.46	0.26	-13.54
30C70L	148.12	113.53	90.75	148.84	0.49	-20.06
30C80L	105.33	188.55	79.55	105.55	0.21	-10.17

The second, the fifth and sixth columns represent respectively: the exact solution found by CPLEX, our solution and deviation of our solution to exact solution using the new intermodal cost evaluation. Other columns represent the comparison of our solution to solution reported in (Sörensen, 2012) using the same intermodal cost evaluation reported in their paper. We can remark that our approach is very competitive and our results are close to optimal. It outperforms widely the last results recently introduced in the literature. The introduction of a new intermodal cost evaluation is a very important contribution because it opens the way for more realistic approaches for the transportation problem.

8. Conclusion

We studied the Intermodal Location Problem. This problem is known as NP-hard. Initially, we presented a description of the problem, its mathematical formulation, and we detailed our resolution approach based on genetic algorithms. We proposed a realistic evaluation of intermodal distance to validate our approach.

The problem is interesting from the modeling and algorithmic point of view but does not correspond to the cases encountered in reality. For this reason, we believe it is necessary to build a more realistic model, multi-criteria with other constraints. In addition, a wedding optimization/simulation approach will be very interesting. For this reason, one of the extensions to realize is validation of our model on a real case. This work will test the feasibility of the solutions provided by the optimization algorithms. It will also allow a possible model correction to meet more realistic aspects.

As prospects, we envision to improve solving performance by adapting new heuristics such as Particle Swarm Optimization (PSO), Tabu Search (TS) or Simulated Annealing (SA) to the problem on the one hand and by adjusting the parameters of the algorithm using other more specialized methods in the other hand because often in a meta-heuristic, the selection of good for parameters values significantly affects the quality of solutions.

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