

LOCATING DANGEROUS GOODS WITH CONSTANT AND VARIABLE IMPACT RADII

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Summary:

Making decisions about dangerous goods positioning is crucial when it is necessary to minimize environmental risks. In this paper, a specific problem of locating various kinds of dangerous goods (with different characteristics) has been considered. Such goods should be located in a known discrete set of potential storage sites, under condition of the minimum safety distance (MSD) between selected locations. The existence of the MSD is a consequence of the possibility that dangerous goods transfer their undesirable effects to the objects in the neighborhood. The objective here is to maximize the quantity of different kinds of dangerous goods stored meanwhile respecting MSDs. For some dangerous goods, the MSD may be determined as a constant value, which depends only on the dangerous goods' characteristics. On the other hand, the MSD may vary depending on quantity and characteristics of particular dangerous goods. Mixed integer linear programming models are proposed for these two types of MSDs. The spirit of the anti-covering location problem (ACL P) is present in the proposed formulations and thus these models can be viewed as a modification and extension of the ACL P. Finally, a randomly generated numerical example has been used to verify and illustrate the proposed models.

Key words: *spray coatings, repairs, plasmas, engines, deposits, coating.*

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This paper represents the extension of authors' previous research (Dimitrijević et al, 2013).

Introduction

Various widely used goods can be dangerous. Different kinds of gases, liquids, and explosives represent some examples of dangerous goods. Such goods generate different undesirable effects which can be felt over a certain geographical area, so making decisions about their positioning is crucial when it is necessary to minimize all types of risks.

In this paper, the specific problem of storing dangerous goods in a known discrete set of potential storage sites has been considered. This problem is modeled and solved as a location problem. In this process, the minimum safety distance (MSD), both among the storage sites themselves and among the storage sites and other neighboring objects, should be respected. The existence of the MSD is a consequence of the possibility for dangerous goods to impact the objects in the neighborhood. These impacts spread spherically from the source within a certain radius called the MSD. For some dangerous goods, the MSD can be determined as a constant value, which depends only on the dangerous goods' characteristics, and for some others, the MSD is not a constant value, but depends on quantity and other characteristics of dangerous goods. In this paper, both versions of MSDs are considered; therefore, two types of location problems have been analyzed and formulated: the location problem with MSDs as constant radii, and the location problem with MSDs as variable radii. The objective in both location problems is to maximize the quantity of different kinds of dangerous goods stored, meanwhile respecting their different requirements related to MSDs.

The contributions of this paper are threefold. First, we made a comprehensive literature review, with the effort to include all the most relevant papers for the considered problem. Second, for the location problem with MSDs as variable radii, the mathematical formulation given in our previous research outcome (Dimitrijević et al., 2013) is improved. Finally, we proposed a mathematical formulation for the problem with MSDs as constant values.

The paper is organized in seven sections. Two following sections are devoted to literature review related to undesirable facility locations in general and the anti-covering location problem relevant for this research. In the subsequent sections, a detailed problem description, problem formulations and computational examples are given. The concluding remarks are presented in the last section.

Literature review

Numerous single undesirable facility location models use maximin or maxisum objectives. The maximin objective is to find a location of the undesirable facility such that the least (weighted) distance to all associated nodes is maximized (Drezner and Wesolowsky, 1980), (Tamir, 1991), (Berman and Drezner, 2000), while the maxisum objective is to site a facility so as to maximize the (weighted) sum of the distances from the facility to all associated nodes (Church and Garfinker, 1978), (Brimberg and Weselowsky, 1995). For the multiple facilities case, there are many models, depending on how one defines the objective function. For example, one version of the maximin problem is the p -dispersion problem, in which there are p facilities to be located on the network in a way that the minimum distance between any two facilities is as large as possible (Moon and Chaudhry, 1984). Another version is the maxisum dispersion problem which maximizes the sum of minimum separation distances, with one separation distance defined for each facility, while locating p -facilities, called the p -defense problem (Moon and Chaudhry, 1984). Kuby (Kuby, 1987) expanded this concept to a problem that maximizes the sum of all separation distances between all pairs of facilities. A very comprehensive review of distance maximization models for undesirable single facilities as well as multiple facility locations can be found in (Erkut and Neuman, 1989). Later on, Erkut and Neuman (Erkut and Neuman, 1991) considered all previous dispersion problems adding a fourth p -facilities location problem in which each facility is represented by the sum of separation distances to the other $p-1$ facilities and where the objective is to maximize the smallest of these sums. Curtin and Church (Curtin and Church, 2006) proposed general forms of problems which involve the location of different types of facilities, where the interaction between different types has a defined repulsion weight. Lei and Church (Lei and Church, 2013) have shown that all four models compared by (Erkut and Neuman, 1991) can be viewed as special cases of a general dispersion model using a concept based on vector assignment.

“Coverage” of the node assumes the existence of a facility within a pre-specified coverage radius. In the cases when the idea is to locate the desirable facilities in networks, analysts try to cover the clients' demand as much as possible. Farahani et al. (Farahani et al., 2012) presented a comprehensive review of models, solutions and applications related to the covering problem. Undesirable facility location problems with a covering concept are called Minimum Covering Location problems. Drezner and Wesolowsky (Drezner and Wesolowsky, 1994) considered the Minimum Covering Location problem on the plane. Berman et al. (Berman et al., 1996) studied the

problem on a network and presented an algorithm to solve the problem. They also analyzed the sensitivity of the coverage radius. Berman et al. (Berman et al., 2003) investigated the Minimum Covering Location problem which they called Problem 2 of the Expropriation Location Problem on a network and generalized the search for the optimal solution to a dominant set of points. They defined all demand nodes as covered if the weighted distance from the facility is less than a pre-specified radius. Plastria and Carrizosa (Plastria and Carrizosa, 1999) formulated a bi-objective undesirable facility location problem in the plane. In this problem, an undesirable facility must be located within some feasible region; the region can have any shape in the plane or on a planar network. The objective functions of the problems are: maximization of a radius of influence and minimization of the total covered population. Berman and Huang (Berman and Huang, 2008) investigated the Minimum Covering Location Problem with Distance Constraints (MCLPDC). The objective function minimizes the total demand covered through locating a fixed number of facilities with distance constraints on a network. The major constraint of this problem is that no two facilities are allowed to be closer than a pre-specified distance. Another location problem with the same distance constraint but with the aim to find maximally weighted set of location sites is the Anti-Covering Location Problem (ACLP) (Moon and Chaudhry, 1984), (Murray and Church, 1997). A brief description and formulation of the ACLP will be given in the following section, since its spirit appears in location models presented in this paper.

The Anti-covering location problem

The ACLP, introduced by Moon and Chaudhry (1984), belongs to the class of discrete location problems and could be defined in the following way: for a given set of potential facility location sites, a maximally weighted set of facilities is located in such a way that no two placed facilities are inside a pre-specified distance of each other. In the case of ACLP, the total number of facilities to be sited is not given in advance.

There are a few mathematical formulations of the ACLP proposed in literature (Moon and Chaudhry, 1984), (Murray and Church, 1997).

Let us introduce binary variables x_i defined in the following way:

$$x_i = \begin{cases} 1 & \text{if node } i \text{ is chosen to be a facility location site} \\ 0 & \text{otherwise} \end{cases}$$

Consider the following notation:

n – total number of potential location sites,

w_i – potential location site's weight (benefit associated with the use of location i)

d_{ij} – the shortest distance between potential location sites i and j ,

R – pre-specified minimum distance, and

$\pi_i = \{j | d_{ij} \leq R \wedge i \neq j\}$ – locations that are at a distance less than or equal to R , excluding a particular location site i

M – a large positive number.

The following mathematical formulation of the ACLP is proposed by Moon and Chaudhry (1984):

$$\max Z = \sum_i w_i x_i \quad (1)$$

$$Mx_i + \sum_{j \in \pi_i} x_j \leq M, \forall i \quad (2)$$

$$x_i \in \{0,1\}, \forall i \quad (3)$$

The objective function (1) maximizes the total weighted selection of the location sites. Constraints (2) are referred as Neighborhood Adjacency Constraints (NAC). If the location site i is selected (i.e. $x_i = 1$), then the term Mx_i equals the right hand side term, M , and forces

$\sum_{j \in \pi_i} x_j = 0$. Thus, if the location site i is used, then all sites j within the R

distance, in the neighborhood of the site i , π_i , are restricted from use. Constraints (3) define problem binary variables. Other mathematical formulations of the ACLP (Murray and Church, 1997) differ from the original ACLP formulation in the specification of the NAC (2), because of the impact that the NAC structure has on problem solvability.

Niblett (Niblett, 2014) proposed a new and improved optimization model for the ACLP when applied to a discrete set of points in the Cartesian plane using a combination of separation conditions called core-and-wedge constraints. Equally, he developed a new model when less than optimal sites are employed in a dispersive pattern called the Disruptive Anti-Covering location model. Carrizosa and Tóth (Carrizosa and Tóth, 2015) analyzed and solved the continual Anti-Covering Location Problem. They formulated a bi-objective optimization model which minimizes a sum of "facility - individual" interactions, and a sum of "facility - facility" interactions. Atypically, in this problem, individuals affected by facility placement are not located at a finite number of known points.

The ACLP, as the convenient NP-hard problem (Garey and Johnson, 1979), is solved by various heuristic and meta-heuristic algorithms: Greedy Heuristic algorithms (Chaudhry et al., 1986), Lagrangian relaxation (Murray and Church, 1997), Genetic Algorithm (Chaudhry, 2006), Column Generation (Ribeiro and Lorena, 2008), Greedy Randomized Adaptive Search (Cravo et al., 2008) and Bee Colony Optimization meta-heuristic (Dimitrijević et al., 2012).

A wide variety of particular applications of the ACLP can be found in literature. The applications include forest management (Barahona et al., 1992), telecommunications (Balas and Yu, 1986), military defense location and various planning problems (Moon and Chaudhry, 1984), (Chaudhry et al., 1986). The spirit of anti-covering restrictions appears in the literature examining separation or dispersion of entities as well, such as land management areas, solution selection, franchise distribution, etc. (Murray and Church, 1997). Grubestic and Murray (Grubestic and Murray, 2008) proposed its use in analyzing policies that dictate the separation of sex offender residences from each other as well as from selected fixed elements on the landscape. Downs et al. (Downs et al., 2008) used the ACLP to analyze the carrying capacity of a population of sandhill cranes. Williams (Williams, 2008) employed a separation distance in the selection of biological reserve sites. Church (Church, 2013) has used the ACLP in estimating the size and extent of a core habitat. Grubestic et al. (Grubestic et al., 2012) analyzed the impacts of alcohol outlet distribution in Philadelphia based upon the ACLP.

Dimitrijević et al. (Dimitrijević et al., 2012) presented an illustration of the ACLP application in a dangerous goods' warehouse location problem. They showed that when the MSD is given as a constant value and only one type of dangerous goods has to be located in warehouses, with the aim to maximize its quantity, then the "classical" ACLP formulation is suitable for the problem description. Dimitrijević et al. (Dimitrijević et al., 2013) considered a specific version of the ACLP through its modifications and extensions, whose objective is to locate the maximum quantity of different kinds of dangerous goods, with safety distances as variable radii, in the existing storage sites. A Mixed Integer Linear programming model is proposed for this kind of problems. Meanwhile, in this paper, M (M = sufficiently large number) is removed from constraints from the previous approach, which improves the problem solvability. This paper also introduces a formulation of the problem with the same objective function but with safety distances as constant radii of undesirable effects.

Thus, this research focuses on one class of real problems dealing with the distribution of maximum quantities of different kinds of dangerous goods in the existing storage sites. The undesirable impact of different kinds of dangerous goods imposes restriction requirements

between storage sites. These requirements are different MSDs, both with constant and variable radii. Since the ACLP has been characterized by the presence of “interactions” between locations sites, its basic principles are used in our problems formulations. Consequently, a classical ACLP is significantly upgraded so as to sustain the above mentioned requirements and to enable solving the described problems in case when dangerous goods are different kinds of explosives. Similar problems (storing other dangerous goods including dangerous waste, parking vehicles carrying different kinds of dangerous goods, etc.) require small adjustments to the models presented hereafter.

Problem description

Storing and keeping dangerous goods like explosives, flammable materials and compressed gasses is characterized by the opportunity to transfer undesirable effects to the objects in the neighborhood thus causing destruction, serious damage and fire in these areas. Those effects spread spherically from the source, reaching the surrounding objects within a certain radius known as the MSD. In this paper, MSD values correspond to explosives' type and/or amount.

In case when the MSD depends on the quantity of explosive stored, it can be calculated in the following way (AFMAN 91-201, 2011):

$$R = P \cdot Q^{1/3} \quad (4)$$

where: R is the minimum safety distance required; P is the protection factor depending on the degree of risk assumed or permitted; Q is the net explosive weight for the given quantity of certain explosive.

There are a few types of safety distances related to explosives (AFMAN 91-201, 2011): inhabited building distance (IBD)¹, public traffic route distance (PTRD)², intraline distance (ILD)³ and intermagazine distance (IMD)⁴. They differ in the value of the protective factor P . Very often the IBD, PTRD and ILD have the same P and are larger than the IMD. That is why

¹ This is the minimum distance required to protect facilities and personnel not directly related to explosives storage and operations.

² This is the minimum distance required to protect public traffic routes and other designated exposures. At this distance, damage and personnel injury is expected.

³ This is the minimum distance required to protect activities associated with explosives storage and operations.

⁴ This is the minimum distance between potential explosion sites required to prevent one potential explosion site from simultaneously detonating an adjacent potential explosion site.

the MSD is divided into distances between the storage sites (internal safety distance - ISD), and distances between the storage sites and the neighboring objects (external safety distance - ESD). The ESD is larger than the ISD in the cases of other dangerous goods, as well as in situations when their MSDs are constant values. One example is shown in Figure 1.

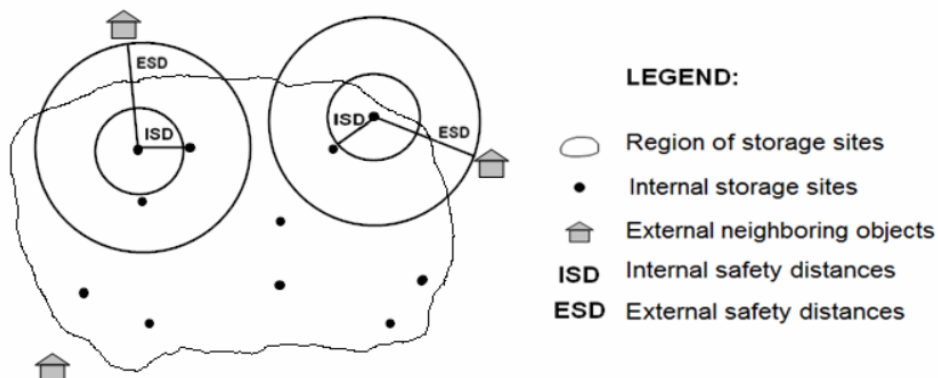


Figure 1 – Potential storage sites and external objects
 Рус. 1 – Потенциальные местоположения для складирования и объекты вблизи
 Slika 1 – Potencijalne lokacije skladišta i objekti u njihovoj okolini

Usually when there are several types of dangerous goods, it is necessary to respect (apply) certain rules regarding compatibility groups' requirements.

According to (AFMAN 91-201, 2011), compatibility groups are also used for segregating explosives on the basis of similarity of function, features, and accident effects potential. In developing the various compatibility groups, these factors are considered: chemical and physical properties, design characteristics, inner and outer packaging configurations, hazard class and division, net explosive weight, rate of deterioration, sensitivity to initiation, and effects of deflagration, explosion, or detonation. The compatibility group assigned to explosives indicates what can be stored with the explosive without increasing significantly either an accident's probability or, for a given quantity, the magnitude of an accident's effects. Explosives of different compatibility groups may only be mixed in storage as indicated in the storage compatibility mixing chart. For a mixture of compatible explosives with variable MSDs, the MSD depends on the total net explosive weight and the largest P among them.

The problem considered in this paper can be defined in the following way: elect storage location sites to be used, and determine the type and quantity of dangerous goods to be stored in these locations, in a way to maximize the total amount of stored dangerous goods, while respecting safety and compatibility constraints.

Problem formulations

Let $N = \{1, \dots, i, j, \dots, n\}$ be the set of all locations relevant for this problem and d_{ij} ($i, j \in N$) the Euclidean distance between them. The set N is partitioned into two subsets $N = N_I \cup N_E$, where N_I represents a set of sites inside a designated area which are candidates for storing dangerous goods (internal storage sites), and N_E represents a set of external objects that must be kept at a safe distance from the dangerous goods stored in internal sites. To each $i \in N_I$, is associated C_i , which represents potential storage or location's capacity restriction or the maximum quantity of dangerous goods that can be stored in a specific location. Let $D = \{1, \dots, k, r, \dots, m\}$ be a set of different types of dangerous goods. Two scalars R_k^I, R_k^E are associated to each dangerous good $k \in D$, which represent the ISD and the ESD, respectively, and $R_k^E > R_k^I$. In the case when the MSD depends on the quantity of explosives stored, R_k^I and R_k^E are calculated by relation (4), shown in the previous section. It is assumed that the protection factor P , for each explosive $k \in D$, has two values: P_k^I and P_k^E , for the ISD and the ESD, respectively, and $P_k^E > P_k^I$. Also, for practical reasons, for each type of dangerous goods, we defined the minimum quantity that must be stored and denoted with q_k^{min} . Finally, let I_{kr} be the compatibility index which takes a value of 1 if explosives $k \in D$ and $r \in D$ can be stored at the same location, otherwise it takes a value of 0.

Let us introduce the variables:

x_{ik} – quantity of explosive k stored at the location i

$$y_{ik} = \begin{cases} 1 & \text{if any quantity of explosive } k \text{ is stored at the location } i \\ 0 & \text{otherwise} \end{cases}$$

$$t_{ikr} = \begin{cases} 1 & \text{if explosives } k \text{ and } r \text{ are stored at the same location } i \\ 0 & \text{otherwise} \end{cases}$$

$$z_i = \begin{cases} 1 & \text{if any quantity of any explosive is stored at the location } i \\ 0 & \text{otherwise} \end{cases}$$

In this paper, based on previous research by Dimitrijević et al. (2013), in the case when the ISD and the ESD depend on the quantity of explosive stored, the location problem analyzed here, called the Quantity

Dependent ACLP (QDACLP), is formulated as the following improved version of the mixed integer linear programming (MILP) problem:

$$\max \sum_{i \in N_I} \sum_{k \in D} x_{ik} \quad (5)$$

subject to:

$$\sum_{k \in D} x_{ik} - (2 - y_{ir} - z_j) \cdot C_i \leq \left(\frac{d_{ij}}{P_r^I} \right)^3 \quad \forall i \in N_I; j \in N_I; i \neq j; r \in D \quad (6)$$

$$\sum_{k \in D} x_{ik} - (1 - y_{ir}) \cdot C_i \leq \left(\frac{d_{ij}}{P_r^E} \right)^3 \quad \forall i \in N_I; j \in N_E; i \neq j; r \in D \quad (7)$$

$$x_{ik} \leq y_{ik} \cdot C_i \quad \forall i \in N_I; k \in D \quad (8)$$

$$\sum_{k \in D} x_{ik} \leq C_i \quad \forall i \in N_I \quad (9)$$

$$\sum_i x_{ik} \geq q_k^{\min} \quad \forall k \in D \quad (10)$$

$$\sum_{k \in D} y_{ik} \leq z_i \cdot m \quad \forall i \in N_I \quad (11)$$

$$y_{ik} + y_{ir} - t_{ikr} \leq I_{kr} \quad \forall i \in N_I; k \in D; r \in D \quad (12)$$

$$y_{ik} \in \{1, 0\} \quad \forall i \in N_I; k \in D \quad (13)$$

$$t_{ikr} \in \{1, 0\} \quad \forall i \in N_I; k \in D; r \in D \quad (14)$$

$$z_i \in \{0, 1\} \quad \forall i \in N_I \quad (15)$$

The objective function (5) that should be maximized presents the total quantity of explosives stored at selected internal storage sites. Constraints (6) can be referred to as internal NAC which provides that the maximum amount of explosives stored at the observed location i is limited and will not put in danger other internal location sites with explosives stored, and vice versa. Similarly, constraints (7) can be referred to as external NAC which provide that external objects are not put in danger by the maximum amount of explosives stored at any of internal storage sites. Constraints (8) do not allow storing dangerous goods at the observed location i if it is not a chosen candidate for storing

dangerous goods. The quantity of dangerous goods stored at the observed location cannot exceed location's capacity restriction considering constraints (9). The minimum quantity of each explosive type that must be stored internally is determined by constraints (10). These constraints are important in order to prevent storing only explosives with minor MSDs. Constraints (11) enable that the variable z_i takes a value of 1 if any quantity of any explosive type is stored in the observed location i . Constraints (12) allow that compatible explosives can be located at the same storage site. Constraints (13, 14, 15) define variables as binary.

In the case when the ISD and the ESD are constant values (do not depend on the quantity of dangerous goods stored), the location problem called the Quantity Independent ACLP (QIACLP) is formulated in the same manner as the QDACLP. Exceptions are internal and external NAC, (6) and (7), which become as follows, and are denoted as (16) and (17), respectively.

$$(y_{ir} + z_j) \cdot R_r^I \leq d_{ij} + R_r^I \quad \forall i \in N_I; j \in N_I; i \neq j; r \in D \quad (16)$$

$$y_{ir} \cdot R_r^E \leq d_{ij} \quad \forall i \in N_I; j \in N_E; r \in D \quad (17)$$

For a mixture of compatible explosives with different constant MSDs, the ISD takes the value of the largest among ISDs, and the ESD takes the value of the largest among ESDs.

Computational examples

In this section, the proposed MILP formulations for the QDACLP and the QIACLP are tested on one hypothetical numerical example. The input data for a hypothetical numerical example are given in Tables 1, 2, 3, and 4.

The set N_I consists of fifteen storage sites whose (x,y) coordinates and capacities are given in Table 1. The set N_E contains ten external objects, and their (x,y) coordinates are presented in Table 2.

Table 1 – Characteristics of potential internal storage sites (Dimitrijević et al., 2013)

Таблица 1 – Характеристики потенциальных внутренних местоположений для складирования (Dimitrijević et al., 2013)

Tabela 1 – Karakteristike potencijalnih internih lokacija za skladištenje (Dimitrijević et al., 2013)

Characteristics	Internal storage sites									
	No.	1	2	3	4	5	6	7	8	9
Coordinate X	803	761	270	409	755	474	651	309	572	362
Coordinate Y	483	397	603	479	829	466	711	954	367	792
Capacity [kg]	8030	5060	4550	4480	4830	3550	4290	4420	7960	4500

Characteristics	Internal storage sites				
	No.	11	12	13	14
Coordinate X	233	538	605	556	419
Coordinate Y	840	681	676	990	758
Capacity [kg]	5000	9750	4600	4280	7380

Table 2 – Characteristics of external objects (Dimitrijević et al., 2013)
Таблица 2 – Характеристики внешних объектов (Dimitrijević et al., 2013)
Tabela 2 – Karakteristike eksternih objekata (Dimitrijević et al., 2013)

Characteristics	External objects									
	No.	16	17	18	19	20	21	22	23	24
Coordinate X	187	121	418	747	210	298	620	139	119	170
Coordinate Y	217	961	127	131	598	204	136	342	642	521

There are four types (groups) of explosives and their characteristics are given in Table 3. The protection factors should be used in the case of the QDACLP, while internal and external safety distances should be used in the case of the QIACLP.

Table 3 – Characteristics of dangerous goods
Таблица 3 – Характеристики опасных материалов
Tabela 3 – Karakteristike opasnih materija

Characteristics	Explosives			
	1	2	3	4
Explosive types	1	2	3	4
Minimal quantity to be stored [kg]	5000	5000	5000	5000
Internal safety distance [m]	250	190	190	170
External safety distance [m]	280	220	240	210
Protection factor for internal locations	17	11	11	10
Protection factor for external objects	18	16	15	18

Different groups of explosives may only be mixed in storage as indicated in Table 4. Table 4 presents a hypothetical storage compatibility mixing chart in which value 1 at an intersection indicates that explosives may be combined in storage, while 0 stands for prohibited mixing.

Table 4 -- Storage compatibility mixing matrix (Dimitrijević et al., 2013)
Таблица 4 – Матрица комбинирования совместимых взрывчатых веществ при складировании (Dimitrijević et al., 2013)
Tabela 4 – Matrica kombinovanja kompatibilnih eksploziva pri skladištenju (Dimitrijević et al., 2013)

	Explosive 1	Explosive 2	Explosive 3	Explosive 4
Explosive 1	1	0	0	1
Explosive 2	0	1	1	1
Explosive 3	0	1	1	0
Explosive 4	1	1	0	1

The same hypothetical example is used for both cases: QDACLP and QIACLP. These problems are solved by using the academic version of the CPLEX.

In the numerical example, for the QDACLP case, the binary decision variables $z_1, z_3, z_4, z_5, z_8, z_9, z_{11}, z_{12}$ and z_{14} , take a value of 1. Thus, the internal storage sites 1, 3, 4, 5, 8, 9, 11, and 14 should be used for storing dangerous goods. Table 5 shows the quantity of each type of explosive which should be stored in these sites.

Table 5 – Solution of the QDACLP numerical example
Таблица 5 – Решение численного примера QDACLP
Tabela 5 – Rešenje numeričkog primera QDACLP

Internal storage sites	Type of explosive	Stored quantity [kg]
1	2	4343.4
	4	3420.7
3	3	64.7
4	3	3693.5
5	1	3413.8
8	3	1932.4
9	3	3891.3
11	2	656.6
	3	437.7
12	3	9750
14	1	1586.2
	4	1579.3

As shown in Table 5, two types of explosives are located in storage sites 1, 11, and 14, while only one in 3, 4, 5, 8, 9 and 12. For example, 4343.4 kg of type 2 explosive ($x_{12} = 4343.4$), and 3420.7 kg of type 4

explosive ($x_{14} = 3420.7$) should be located in storage site 1, while 64.7 kg of type 3 explosive should be located in storage site 3, etc. The total quantity of dangerous goods stored in all storage sites is 34769.6 kg. An illustration of the solution is depicted in Figure 2.

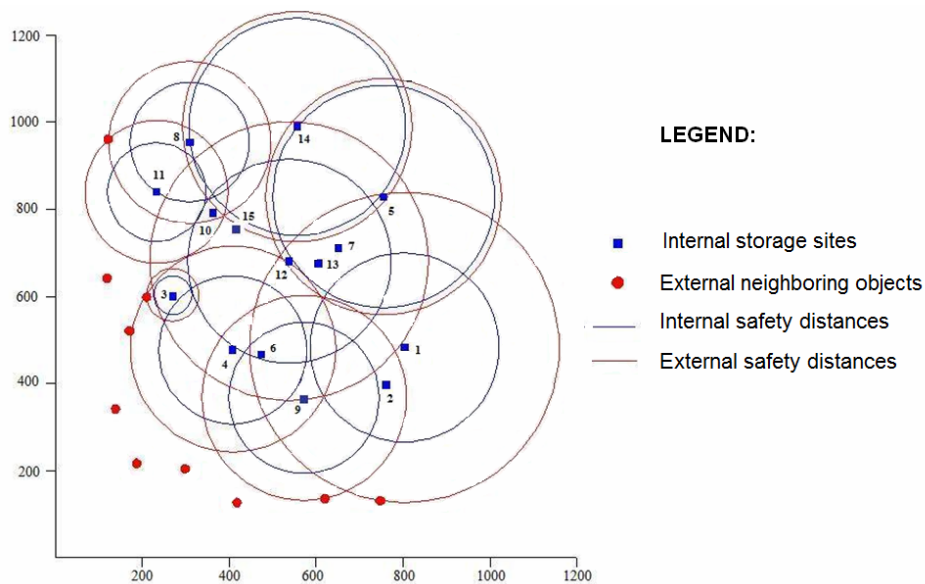


Figure 2 – Illustration of the QDACLP solution
 Рис. 2 – Иллюстрация решения QDACLP
 Slika 2 – Ilustracija rešenja QDACLP

The optimal solution of the numerical example in the case of the QIACLP is shown in Table 6. The decision variables $z_1, z_4, z_5, z_9, z_{10}, z_{12},$ and z_{14} take a value of 1. Thus, internal storage sites 1, 4, 5, 9, 10 and 12 should be used for storing explosives.

Table 6 – Solution of the QIACLP numerical example
 Таблица 6 – Решение численного примера QIACLP
 Tabela 6 – Rešenje numeričkog primera QIACLP

Internal storage sites	Type of explosive	Stored quantity [kg]
1	2	7530
	3	500
4	2	4480
5	1	4830
9	2	7960
10	3	4500
12	4	9750
14	1	4280

As shown in Table 6, two types of explosives are located in storage site 1, while only one in 4, 5, 9, 10, 12 and 14. For example, 7530 kg of type 2 explosive ($x_{12} = 7530$), and 500 kg of the type 3 explosive ($x_{13} = 500$) should be located in storage site 1. Besides, type 2 explosive should be located in storage sites 4 ($x_{42} = 4480$) and 9 ($x_{92} = 7960$), and so on. The total quantity of dangerous goods stored is 43830 kg. The QIACLP solution is illustrated in Figure 3.

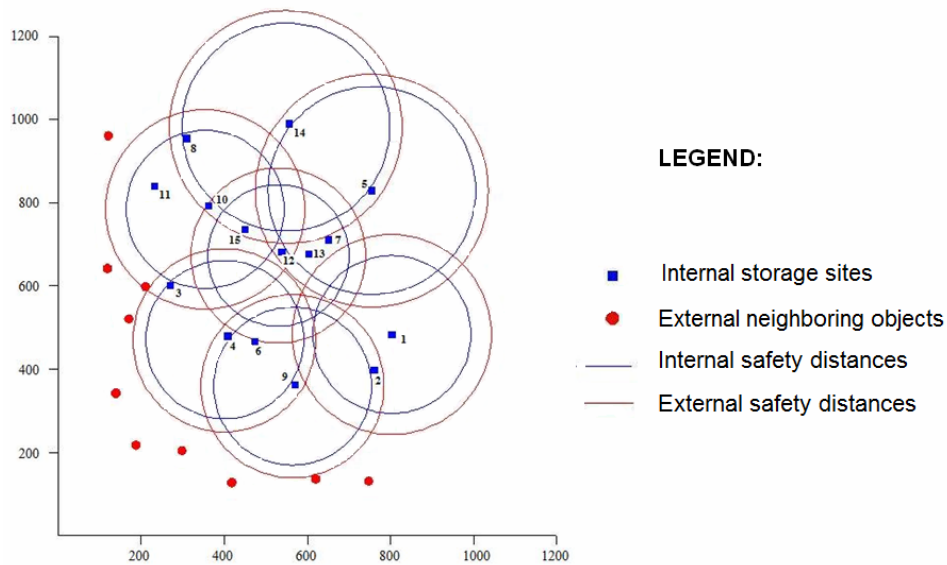


Figure 3 – Illustration of the QIACLP solution

Рис. 3 – Иллюстрация QIACLP

Slika 3 – Ilustracija rešenja QIACLP

Conclusion

In this paper, the authors studied the location problem implemented on storing dangerous goods. A known discrete set of storage sites is used for storing different types of dangerous goods. They are characterized by the opportunity to transfer their undesirable effects to the objects in the neighborhood. These effects define separation distances among objects with dangerous goods called minimum safety distances (MSDs). The observed undesirable effects spread spherically from the sources with constant and variable radii. Some classes of explosives are assumed to be good representatives the MSD of which depends on the quantity and/or characteristics of the activated material.

The objective is to maximize the quantity of different kinds of explosives located at existing storage sites, while respecting MSDs.

MILP models for the observed problems (QDACLP and QIACLP) are developed. The spirit of the ACLP is present in the proposed formulations and thus the QDACLP and the QIACLP can be viewed as modifications and extensions of the ACLP.

Future research will include a more comprehensive model testing to establish CPLEX boundaries and potentially to “open the door” to heuristics and meta-heuristics for problem solving. Also, possible uncertainties of MSDs could be considered by introducing appropriate stochastic models.

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РАЗМЕЩЕНИЕ ОПАСНЫХ МАТЕРИАЛОВ С ПОСТОЯННЫМ И ПЕРЕМЕННЫМ РАДИУСОМ ВОЗДЕЙСТВИЯ

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ОБЛАСТЬ: логистика, математическое программирование
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Резюме:

Для минимизации угрозы внешнего окружения необходимо разработать систему решений в области размещения опасных веществ. В данной работе рассмотрены проблемы, касающиеся размещения различных видов опасных веществ (с различными характеристиками).

Опасные материалы должны быть размещены в дискретном пространстве потенциальных местоположений складов, при условии соблюдения минимальных безопасных расстояний между выбранными пунктами.

Минимальное безопасное расстояние рассчитывается на основании вероятности неблагоприятного воздействия веществ на внешнее окружение и прилегающие объекты. Цель работы заключается в максимизации количества складированных материалов, соблюдая минимальное безопасное расстояние.

Минимально безопасное расстояние в случае некоторых видов веществ имеет постоянные значения, которые зависят от характеристик опасных веществ.

С другой стороны, минимально безопасное расстояние может колебаться в зависимости от количества опасных веществ и других характеристик.

Для описанных видов минимально безопасного расстояния предлагаются модели смешанного численного метода программирования. Данные модели основаны на проблеме определении местоположения складов, таким образом их можно считать расширенным дополнением задачи программирования выбора местоположения. Верификация модели выполнена на гипотетическом примере, результаты которого приведены в работе.

Ключевые слова: складирование опасных веществ, безопасное расстояние, проблемы безопасного размещения

LOCIRANJE OPASNIH MATERIJA SA KONSTANTNIM I PROMENLJIVIM RADIJUSIMA UTICAJA

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OBLAST: logistika, matematičko programiranje
VRSTA ČLANKA: originalni naučni članak
JEZIK ČLANKA: engleski

Sažetak:

Donošenje odluka o prostornom raspoređivanju opasnih materija neophodno je zbog minimiziranja rizika po okolinu. U ovom radu razmatran je problem lociranja različitih vrsta opasnih materija (sa različitim karakteristikama). One mogu biti locirane unutar poznatog diskretnog skupa potencijalnih lokacija skladišta, pod uslovom da budu zadovoljena minimalna bezbednosna rastojanja između odabranih lokacija. Minimalno bezbednosno rastojanje je posledica postojanja verovatnoće da opasne materije neželjeno deluju na objekte u okolini. Cilj je da se istovremeno maksimizira uskladištena količina različitih opasnih materija, vodeći računa o minimalnim bezbednosnim rastojanjima. Za neke opasne materije minimalno bezbednosno rastojanje je konstantna vrednost, koja zavisi samo od karakteristika opasnih materija. Sa druge strane, minimalno bezbednosno rastojanje može da varira u zavisnosti od količine opasne materije i njenih ostalih karakteristika. Za ova dva tipa minimalnih bezbednosnih rastojanja predloženi su modeli mešovitog celobrojnog programiranja. Ovi modeli zasnovani su na lokacijskom problemu nepokrivanja, pa se mogu tretirati i kao njegova modifikacija i proširenje. Verifikacija modela sprovedena je i ilustrovana na generisanom hipotetičkom primeru čiji su rezultati prikazani.

Ključne reči: skladištenje opasnih materija, bezbednosno rastojanje, lokacijski problem nepokrivanja.

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