# MODELING ALLOCATION OF HIVES

## Juraj Pekár [a], Marian Reiff [a,*], Ivan Brezina [a]

[a] University of Economics in Bratislava, Slovakia

**Abstract:** *The contribution of insect pollinators to the economic output is obvious. Several alternative bee species have been identified to be capable of replacing or at least supplementing decreasing number of honey bees. Our research aim to deal with location of nesting aids for solitary bees in orchards using mathematical programming models for determining the optimal location of nesting aids and thus can be used to optimize the management of solitary bees.*

*Keywords: hive location, pollination management, crop pollination, Osmia cornuta.*

## 1. INTRODUCTION

Insect pollination is important service for agriculture crops, many field crops require an operating pollination system, influencing the productivity of approximately 75% crop species (Klein et al., 2006) and 80% of all flowering plant species rely on animal pollinators (Kluser & Peduzzi, 2007). The area of insect pollination crop has grown substantially in recent decades, resulting in greater demand for pollination services (Aizen, Garibaldi, Cunningham, & Klein, 2008). A worldwide decline of pollinators abundance and diversity is recorded over the last years and fueled the debate of sustainability of the current intensive farming (Hole et al., 2005). Insufficient pollination is a common case of a poor yield for example of pears (Soltész, 1996), (Monzón, Bosch, & Retana, 2004).

Although honey bees (*Apis mellifera*) can be used as a pollinators in in large commercial orchards to improve productivity (Delaplane, Mayer, & Mayer, 2000). A number of other insects, notably solitary bees (e.g. *Osmia spp. Andrrena spp.*) and bumblebees (*Bombus spp.*) have been studied as alternative pollinators and demonstrated to be effective pollinators of for example apple, pear, cherry, pear orchards and in some cases more effective than honeybees (Martins, Gonzalez, & Lechowicz, 2015). Possible advantages of alternative pollinators are temperature when pollinators are active, preference for foraging and stigma contact by floral visitor.

Temperature and relative humidity do not effect *Osmia cornuta* presence in the orchard (Vicens & Bosch, 2000b) (B. Maccagnani, Ladurner, Tesoriero, Sgolastra, & Burgio, 2003).

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* marian.reiff@euba.sk

Commercial yields in Osmia pollinated orchards are achieved even in yields with poor weather during bloom (Bosch & Kemp, 1999), (Bosch & Kemp, 2001).

The promising pollinator species should preference for foraging on flowers of the target crop (Márquez, Bosch, & Vicens, 1994). *Osmia cornuta* bees do not look for other food sources in case of pollen decline in pear orchard in contrast with honeybees (Bettina Maccagnani, Burgio, Stanisavljevic, & Maini, 2007). Also pollination influence numbers of seeds and seed sets is important factor in pear commercialization. Parthenocarpic fruits are often smaller than seeded ones, and size is important factor in terms of customer preference. Pears with high numbers of seeds tend to be larger, and have better shape and flavor (Sedgley & Griffin, 2013). High rates of stigma contact by floral visitor are strongly related to the pollinator's behavior on flower. It is well known that honey bees behavior results in low rates of stigma contact, whereas pollen collectors (e.g. *Osmia*) are much more efficient pollinators of the crops (Free, 1993), (Bosch & Blas, 1994), (Vicens & Bosch, 2000a). Rates of stigma contact are sometimes also related to body size of the pollinator relative to the size of the crop flower. Also in orchards with non- *Apis* bees, the foraging behavior of honey bees changed and the pollination effectiveness of the single bee visit was greater than in orchard where non *Apis* bees where absent. The change translated to a greater proportion of fruit sets in these orchards (Brittain, Williams, Kremen, & Klein, 2013).

The contribution of insect pollinators to the economic output is obvious. Several alternative bee species have been identified to be capable of replacing or at least supplementing decreasing number of honey bees (Kremen, Williams, & Thorp, 2002), (Rader et al., 2009). Literature review how to establish and manage bee species as a crop pollinators can be found for example (Bosch & Kemp, 2002), (Gruber, Eckel, Everaars, & Dormann, 2011). Our research aim to deal with location of nesting aids for solitary bees in orchards using mathematical programming models for determining the optimal location of nesting aids and thus be used to optimize the management of solitary bees in orchards. The current practice with honey bees can be described as follows, beehives are kept together on trailer on the edge of the field or orchard where the plants to pollinate are. This location is convenient for the beekeeper, but some distant parts of the orchard can be left not covered, not pollinated because bees need to fly longer distances or will forage on another crop that is closer. In the case of solitary bees, the problem can become more obvious because solitary bees can fly smaller distance compared to honey bees. In the next part of the paper mathematical programming model for determining the optimal location of nesting aids is proposed.

## 2. MATHEMATICAL PROGRAMMING MODELS FOR DETERMINING THE OPTIMAL LOCATION OF NESTING AIDS

Suppose, the trees that need to be pollinate are randomly located and distances between threes are known. Assume that the nesting aids, hives can be located under the any tree and total number of nesting aids is given. The aim is to pollinate all the trees at a minimum total distance flown by the insect. The basic problem is known as *P*-median problem (ReVelle & Swain, 1970). In our research, we modified this model to the problem of minimal total distance needed to be flown in the case when the total number of nesting aids is given. The constraint for maximum distance the bee can fly is also introduced.

The problem can be formulated as binary programming problem with variables $y_{ij} \in \{0,1\}$, $x_i \in \{0,1\}$, $i, j = 1, 2, \ldots n$, where $n$ represents the number of the trees in the orchard. The variable $y_{ij} \in \{0,1\}$, $i, j = 1, 2, \ldots n$ represent the event of pollination. The value is equal to 1 if the $j$-th tree is pollinated by bees from $i$-th hive or nesting aid, otherwise the value is equal to 0. The model also deals with binary variable $x_i \in \{0,1\}$, $i = 1, 2, \ldots n$ that represents location of the hive. The value is equal to 1 if the hive, nesting aid is operated under the $i$-th tree, otherwise the value is equal to 0.

The objective deals with parameters $d_{ij}$, $i, j = 1, 2, \ldots n$ that represent minimal distances between all trees in the orchard. Aims is to pollinate all the trees and the objective function of the problem can be formulated:

$$f(\mathbf{x}, \mathbf{y}) = \sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij} y_{ij} \to \min \qquad (1)$$

The first group of conditions represents the need to pollinate all the trees from $i$-th location of the hive.

$$\sum_{i=1}^{n} y_{ij} = 1, \ \ j = 1, 2, \ldots n \qquad (2)$$

Second group models the maximum distance the bee can fly.

$$\sum_{i=1}^{n} d_{ij} y_{ij} \leq K, \ \ j = 1, 2, \ldots n \qquad (3)$$

The conditions that represent the need to operate the hive at $i$-th location, belong to the second group of conditions.

$$y_{ij} - x_i \leq 0, \quad i, j = 1, 2, \ldots n \qquad (4)$$

It is evident that the number of hives must be restricted:

$$\sum_{i=1}^{n} x_i = p \qquad (5)$$

The formulation of the model:

$$f(\mathbf{x}, \mathbf{y}) = \sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij} y_{ij} \to \min$$

$$\sum_{i=1}^{n} y_{ij} = 1, \ \ j = 1, 2, \ldots n$$

$$\sum_{i=1}^{n} d_{ij} y_{ij} \leq K, \ \ j = 1, 2, \ldots n \qquad (6)$$

$$y_{ij} - x_i \leq 0, \ \ i, j = 1, 2, \ldots n$$

$$\sum_{i=1}^{n} x_i = p$$

$$x_i, y_{ij} \in \{0,1\}, \ \ i, j = 1, 2, \ldots n$$

Where

$p$ – represents number of hives,

$d_{ij}$ – represents shortest distance from  $i$-th hive to $j$-th tree or from  $i$-th tree to $j$-th tree. It is assumed that possible location of the hives can is under the any tree.

 $K$ – represents maximum distance the bee can fly.

Below can be seen the source code for the GAMS program to solve the total minimal distance tasks at a specified number of hives:

```
Sets i /1*n/
alias (i,j);
Scalar p /p/
K /K/;
Table d(i,j);
Variables f;
Binary variable y;
Binary variable x;
Equations uf
first(j)
second(i,j)
third
fourth;
uf.. f=e=sum((i,j),d(i,j)*y(i,j));
first (j).. sum(i,y(i,j))=e=1;
second (j) sum(i,d(i,j)*y(i,j)); )=l=K;
third (i,j).. y(i,j)-x(i)=l=0;
fourth sum(i,x(i))=e=p;
Model totaldistance /all/;
solve totaldistance using mip minimizing f;
```

The illustrative results are demonstrated on Figure 1. The blue dots represent the optimal location of nesting aids in the orchard that is represented by trees that need to be pollinated depicted by red circles.


## 3. CONCLUSION


The paper presents the model that aims to locate nesting aids for solitary bees in the orchard in order to pollinate all the trees at a minimum total distance flown by the insect. The problem is NP-hard problem. Small instances can be solved by contemporary computation tools. In cases with more trees problem becomes computationally demanding. In the future, we would like to use evolutionary tools to deal with this problem.
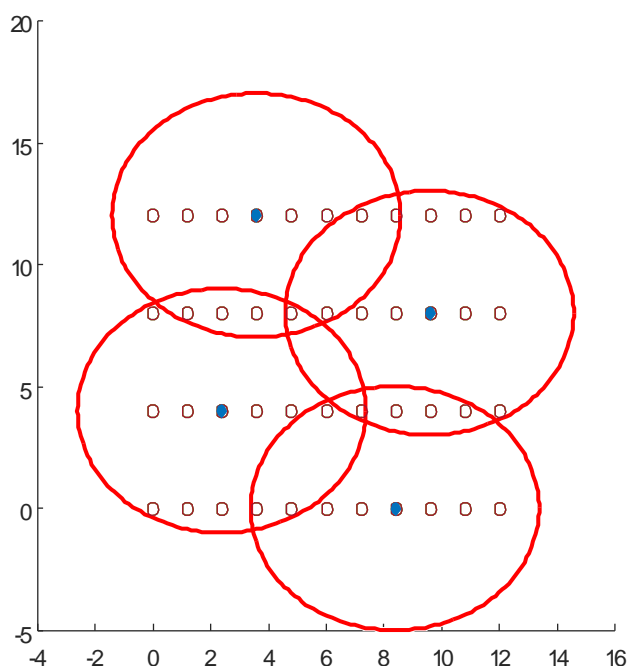
Figure 1. Optimal solution for illustrative example with 44 trees that need to be pollinated

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