Optimizing Airport Construction Site Layouts to Minimize Wildlife Hazards

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Optimizing Airport Construction Site Layouts to Minimize Wildlife Hazards

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Abstract: Construction operations in airport expansion projects often attract wildlife species to critical airport traffic areas leading to an increase in the risk of wildlife–aircraft collision accidents. Airport operators and construction planners need to carefully consider and minimize these wildlife hazards during the planning of construction site layouts in order to comply with Federal Aviation Administration recommendations. This paper presents the development of an advanced optimization model for planning airport construction site layouts that is capable of minimizing the hazards of wildlife attractants and minimizing the site layout costs, simultaneously. The model incorporates newly developed concepts and performance criteria that enable (1) quantifying, controlling, and minimizing the hazards of construction-related wildlife attractants near airport traffic areas; and (2) minimizing the travel cost of construction resources and the cost of devices installed to control wildlife on airport construction sites, while complying with all relevant aviation safety constraints. The model is developed using a multiobjective genetic algorithm and an application example is analyzed to demonstrate the use of the model in optimizing airport construction site layouts and its unique capability of generating optimal trade-offs between wildlife control and site layout costs.

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Introduction

The populations of many wildlife species (e.g., pigeons, gulls, and deer) have increased markedly in urban and suburban areas in the last few years [Federal Aviation Administration (FAA 2004b)]. Some of these species are attracted to human-made environments and often exist on and around airport operation areas. The increase in wildlife populations, the use of larger aircraft engines, and the increase in air traffic have all contributed to increase the risk and severity of wildlife–aircraft collisions in recent years, as shown in Fig. 1 (FAA 1997, 2004b). The presence of construction activities and temporary facilities near airport operations can attract more wildlife and further increase this risk of wildlife–aircraft collisions (FAA 2003a). For example, trash produced by construction activities, grass seeds stored on site, and/or ponded water, are capable of attracting wildlife, and hence, can create hazardous conditions during airport construction operations (FAA 2003a). Furthermore, unprotected structures such as temporary construction facilities can attract the formation of bird nests near airport operation areas, leading to an increased risk of birds being ingested by aircraft engines (FAA 2002).

The annual cost of wildlife–aircraft collisions to the U.S. civil aviation industry is estimated to be in excess of $500 million in monetary losses and almost 600,000 h of aircraft downtime (FAA 2004b). In addition, wildlife–aircraft collisions have caused the loss of hundreds of lives during the past century (FAA 1997). In order to minimize these hazards, the FAA recommends planners to use effective wildlife control strategies and techniques such as (1) habitat modification; (2) exclusion; and (3) repelling and harassment (FAA 1997, 2002). To ensure aviation safety, these FAA recommendations need to be carefully considered and complied with during the planning of airport construction site layouts, which typically involves identifying, sizing, and locating temporary construction facilities on site such as storage areas, stockpiles of excavation, site offices, and fabrication shops (Yeh 1995; Hegazy and Elbeltagi 1999). For construction projects in general, site layout planning is essential to promote safe and efficient op-

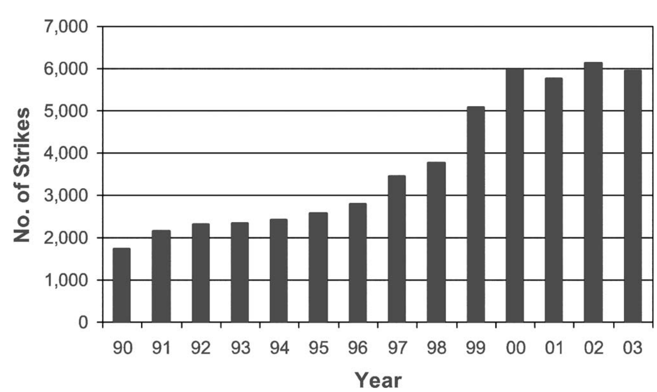

Fig. 1. Wildlife-aircraft strikes in the United States (data from FAA 2004b)

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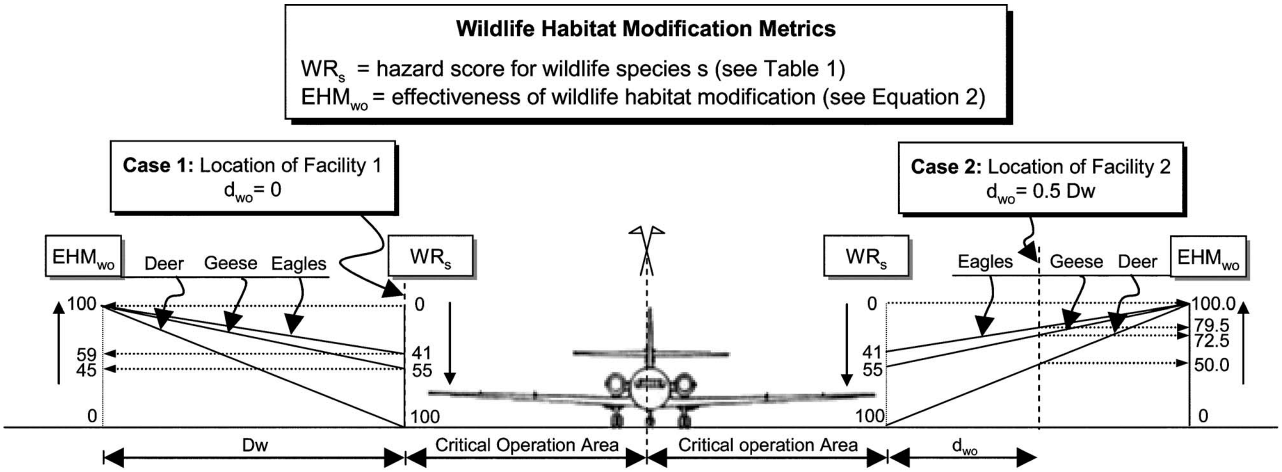

Wildlife Attracted by Facility 1	Deer	Geese	Eagles
WR_s	100%	55%	41%
EHM_{wo} for facility 1	0%	45%	59%

Wildlife Attracted by Facility 2	Deer	Geese	Eagles
WR_s	100%	55%	41%
EHM_{wo} for facility 2	50.0%	72.5%	79.5%

Fig. 2. Impact of facility location on wildlife habitat modification criterion

erations, minimize travel time of construction crews, and decrease material handling costs. For airport construction projects in particular, site layout planning is indispensable as it can play a vital role in minimizing wildlife hazards during construction operations by maximizing compliance with all FAA wildlife safety recommendations.

A number of models have been proposed in the literature to facilitate the planning of construction site layouts using a variety of approaches including artificial intelligence (Tommelein et al. 1992), annealed neural networks (Yeh 1995), dynamic layout planning (Tommelein and Zouein 1993; Zouein and Tommelein 1999), geographic information system (Cheng and O'Connor 1996), and genetic algorithms (Li and Love 1998; Hegazy and Elbeltagi 1999). Despite the significant research efforts and contributions of the above models, they all focused on maximizing the efficiency of general construction projects. As such, the application of existing models to plan airport construction site layouts is limited due to their inability to consider the effect of wildlife on aviation safety and the impact of relevant FAA guidelines on the optimization process. New and expanded site layout optimization models are, therefore, needed to enable minimizing the hazards of wildlife attractants near airport critical areas while improving the productivity of construction operations.

Objective

The objective of this paper is to present the development of a robust optimization model for planning airport construction site layouts. The model is designed to assist airport operators and construction planners in generating optimal construction site layouts that maximize compliance with all FAA wildlife safety recommendations and minimize site layout-related costs. In order to strike an optimal balance between these two conflicting optimization objectives, the present model utilizes a multiobjective genetic algorithm that is used to search for and identify optimal site layout plans for airport construction projects. The model incorporates newly developed metrics and functions in order to (1) minimize the hazards of wildlife attractants near airport operation areas (FAA 2003a); (2) minimize site layout-related costs; and (3) provide full compliance with FAA aviation safety constraints. The following sections provide a brief description of these three newly developed metrics and functions.

Minimizing Hazards of Wildlife Attractants

The present model is designed to quantify the impact of site layout planning on the degree of compliance with FAA recommendations in order to minimize the hazards of wildlife attractants in airport construction projects. To accomplish this, the present model is designed to search for and identify site layout plans that maximize compliance with the aforementioned three FAA recommendations on: (1) wildlife habitat modification; (2) wildlife exclusion; and (3) wildlife harassment (FAA 1997, 2002). The following subsections discuss each of these three wildlife control criteria in more detail.

Wildlife Habitat Modification

The FAA recommends providing adequate separation between wildlife attractants (e.g., facilities that can provide food, water, and/or cover for wildlife) and airport operation areas in order to minimize the risk of serious wildlife–aircraft collisions, especially during construction operations (FAA 2002). In order to aid planners in complying with these FAA recommendations, the present model utilizes a newly developed performance metric named wildlife habitat modification criterion (WHMC). This criterion (WHMC) is designed to measure and aggregate the effectiveness of wildlife habitat modification measures (EHM_{wo}) implemented for all wildlife attracting facilities on site ($w=1$ to W), as shown in Eq. (1). This performance metric (EHM_{wo}) enables planners to measure and quantify the effectiveness of wildlife habitat modification for each facility (w) as a function of (1) the degree of hazard posed by the attracted type of wildlife, which is represented by a hazard score (WR_s) that depicts the potential severity of wildlife–aircraft accidents; and (2) the planned separation dis-

Table 1. Relative Hazard Scores for Wildlife Species (Data from FAA 2003b, 2004a)

Species group/type (s)	Relative hazard score (WR_s)
Deer	100
Vultures	64
Geese	55
Cormorants/pelicans	54
Cranes	47
Eagles	41
Ducks	39
Osprey	39
Turkey/pheasants	33
Herons	27
Hawks	25
Gulls	24
Rock pigeon	23
Owls	23
H. lark/s. bunting	17
Crows/ravens	16
Coyote	14
Mourning dove	14
Shorebirds	10
Blackbirds/starling	10
American kestrel	9
Meadowlarks	7
Swallows	4
Sparrows	4
Nighthawks	1

tance between the wildlife attracting facility and critical operation area (d_{wo}) and its ratio to the maximum mobility distance of wildlife species on site (Dw), as shown in Eq. (2)

$$\mathrm{WHMC} = \frac{\sum_{o=1}^{O} \frac{\sum_{w=1}^{W} (\mathrm{EHM}_{wo})}{W}}{O} \tag{1}$$

$$\mathrm{EHM}_{wo} = 100 - \mathrm{WR}_s \times \frac{Dw - d_{wo}}{Dw} \tag{2}$$

where W=total number of facilities that can attract wildlife; O=total number of critical airport areas; WR_s=hazard score for wildlife species s; Dw=maximum mobility distance of the most critical type of wildlife on site; and d_{wo}=distance separating wildlife attracting facility w from critical airport operation area o.

The first factor that influences the effectiveness of wildlife habitat modification (EHM_{wo}) in the present model is the degree of hazard posed by the attracted type of wildlife. FAA advisory circulars assign hazard scores to various types of wildlife species (e.g., deer 100) to represent the degree of damage that each of these species can cause to an aircraft in case of an accident, as shown in Table 1 (FAA 2003b, 2004a). These relative hazard scores were developed by the FAA based on a study that investigated 52,493 wildlife–aircraft strikes. Accordingly, the present model identifies and assigns a wildlife hazard score (WR_s) to each facility on site to represent the degree of hazard posed by the most critical type of wildlife (s) it is capable of attracting (e.g., deer or black birds), as shown in Table 1 and Fig. 2. In the present model, a construction planner needs only to specify the typical species of wildlife encountered in the vicinity of the airport construction site and the model automatically identifies its corresponding hazard score (WR_s), as shown in Table 1 and Fig. 2.

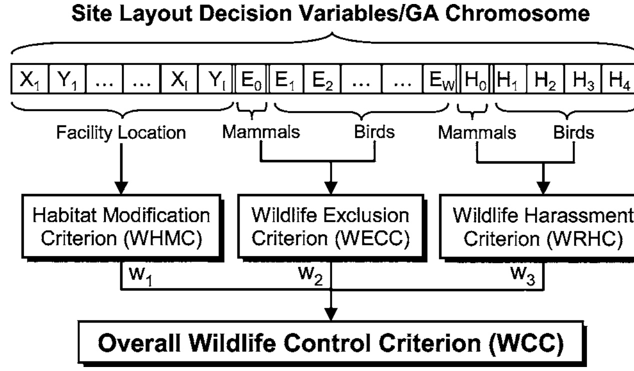

Fig. 3. Site layout objectives and decision variables

The second factor that affects EHM_{wo} in the present model is the planned separation distance (d_{wo}) between the wildlife attracting facility (w) and critical operation area (o) and its ratio to the maximum mobility distance (Dw) of wildlife species on site. As shown in Fig. 2 and Eq. (2), increasing the separation distance (d_{wo}) leads to improved effectiveness of wildlife habitat modification (EHM_{wo}) until it reaches a point of diminishing return when the separation distance becomes equal to or greater than the maximum wildlife mobility distance ($d_{wo} \geqslant Dw$). It should be noted that the location of each facility and its separation distance from critical areas (see Fig. 2) are automatically generated and evaluated by the present model; however, the maximum mobility distance (Dw) needs to be specified by the planner based on the most critical type of wildlife encountered on site.

The present model considers and quantifies the impact of the aforementioned two site layout planning factors on the overall performance of the analyzed site layout in the wildlife habitat modification criterion, as shown in Eqs. (1) and (2). To accomplish this, the present model is designed to (1) generate a set of site layout solutions where each designates a planned location for each facility (X_i, Y_i), as shown in Fig. 3; (2) calculate the distance between each facility and critical airport operation areas (d_{wo}) in each generated site layout, as shown in Fig. 2; (3) compute the effectiveness of wildlife habitat modification for each wildlife attracting facility (EHM_{wo}), as shown in Eq. (2); and (4) calculate the overall performance of the entire site layout in the wildlife habitat modification criterion by obtaining an average of all the calculated effectiveness scores (EHM_{wo}), as shown in Eq (1).

Wildlife Exclusion

The FAA recommends the utilization of wildlife exclusion techniques such as the installation of physical barriers, especially if wildlife attractants cannot be fully eliminated by the aforementioned habitat modification measures (FAA 2002, 2004a). The recommended type of physical barrier primarily depends on the type of wildlife on site (i.e., mammals or birds), and they include chain-link fences, electric fences, netting, overhead systems, plastic sheeting door curtains, and porcupine wire, as shown in Table 2. To assist planners in selecting the most effective and suitable type of physical barrier for the airport construction site layout being planned, the present model utilizes a newly developed per-

Table 2. Wildlife Exclusion Techniques

Wildlife	Exclusion technique (t)	Description	Qualitative effectiveness[a]	User-specified quantitative effectiveness (ME_t/BE_t)
Mammals[b]	1	No fence	—	$ME_1=0\%$
	2	Chain-link fence with barbed wire	Less effective	$ME_2=70\%$
	3	Electric fence	Effective	$ME_3=100\%$
Birds[c]	1	No technique	—	$BE_1=0\%$
	2	Netting or overhead system	Effective	$BE_2=35\%$
	3	Plastic sheeting door curtains	Effective	$BE_3=30\%$
	4	Porcupine wire	Effective	$BE_4=35\%$

[a]Data from Transport Canada 2002.

[b]Exclusion techniques for mammals are used for entire site.

[c]Exclusion techniques for birds are used for each facility.

formance metric named wildlife exclusion control criterion (WECC). This metric (WECC) is capable of measuring and quantifying the impact of the installed barriers on the safety of airport operation areas by (1) computing a wildlife exclusion effectiveness score (ETE_w) for each wildlife attracting facility (w); and (2) calculating the average of all these scores for all wildlife attracting facilities on site, as shown in Eq. (3). The present model is designed to quantify the impact of site layout planning on the effectiveness of wildlife exclusion (ETE_w) as a function of (1) the effectiveness of the selected technique(s) to exclude mammals and/or birds from the construction site (ME_t and BE_t); and (2) the relative hazard caused by the attracted mammals and/or birds to each facility (hm_w and hb_w), as shown in Eq. (4)

$$\mathrm{WECC} = \frac{\sum_{w=1}^{W} (\mathrm{ETE}_w)}{W} \tag{3}$$

$$\mathrm{ETE}_w = (hm_w \times \mathrm{ME}_t) + \left(hb_w \times \sum_{t=1}^{T} \mathrm{BE}_t \right) \tag{4}$$

$$hm_w = \frac{\mathrm{MWR}_s}{\mathrm{MWR}_s + \mathrm{BWR}_s} \tag{5}$$

$$hb_w = 1 - hm_w \tag{6}$$

where ETE_w=overall effectiveness of all exclusion techniques utilized in facility w; hm_w=relative hazard caused by the attracted mammals to facility w; hb_w=relative hazard caused by the attracted birds to facility w; ME_t=effectiveness of utilized mammals exclusion technique t; BE_t=effectiveness of utilized birds exclusion technique t; MWR_s=relative hazard score of the most critical mammal attracted to facility w; and BWR_s=relative hazard score of the most critical bird attracted to facility w.

In the present model, the effectiveness of wildlife exclusion (ETE_w) primarily depends on the selected type of wildlife exclusion technique for each facility (w). A number of studies have been conducted to estimate the effectiveness of various mammals and birds exclusion techniques in controlling wildlife access to critical airport operation areas (Transport Canada 2002; Schmidt and Knight 2000). As shown in Table 2, these studies provided qualitative assessment of typical wildlife exclusion techniques, which can be used by construction planners to specify equivalent quantitative effectiveness values (ME_t or BE_t). The specification of these quantitative effectiveness values should consider the practical implementation of these techniques on site, which may require the selection of only one exclusion technique for mammals and one or more for birds from the set of feasible options stored in the model database. Accordingly, the specified quantitative effectiveness values in Table 2 are shown for illustrative purposes only and, therefore, they can be slightly varied by other construction planners to better represent the unique conditions of their specific airport construction site.

Available choices for mammal exclusion techniques, for example, may include the construction of no fence, barbed-wire chain link fence, or electric fence for the entire site layout, and accordingly the corresponding quantitative effectiveness values for these alternatives can be specified as shown in Table 2. Similarly, available options for bird exclusion techniques may include various combinations of netting, plastic door curtains, and/or porcupine wire (strips of spike barrier installed on surfaces to repel birds). Due to the possibility of combining more than one option for excluding birds in each facility, the overall effectiveness of utilizing bird exclusion techniques is obtained by adding up the effectiveness values (BE_t) of all the utilized techniques. For example, utilizing the two techniques of netting and porcupine wire in a field office will yield an effectiveness level of 65% for excluding birds compared to a level of 100% when a combination of the three techniques of netting, porcupine wire, and plastic door curtains are used (see Table 2).

The second factor that affects ETE_w is the relative hazard caused by the attracted mammals and/or birds (hm_w and/or hb_w) to each facility (w), as shown in Eq. (4). In the present model, the planner needs only to specify the most critical wildlife (mammal and/or bird) that each facility is capable of attracting, and the model automatically calculates its corresponding relative hazard values (hm_w and/or hb_w), as shown in Eqs. (5) and (6). For example, if the planner specifies that deer and geese are the most critical mammal and bird species attracted to site facilities, then the relative hazard scores of these species are automatically obtained by the model from its database shown in Table 1 (i.e., $MWR_s=100$ and $MBR_s=55$) and applied in Eqs. (5) and (6) to calculate the relative hazard caused by these species (i.e., $hm_w=65\%$ and $hb_w=35\%$).

Wildlife Harassment

The FAA recommends utilizing repellent and harassment techniques as habitat modifications and exclusion techniques will never completely rid an airport of problem wildlife (FAA 2002). These techniques typically involve utilizing chemical, audio, and visual repellents to make the area desired by wildlife unattractive, or to make the wildlife uncomfortable or fearful. In order to aid planners in complying with this FAA recommendation, the present model utilizes a new performance metric named wildlife repelling and harassment criterion (WRHC). This performance metric (WRHC) enables planners to measure and quantify the effectiveness of wildlife repelling and harassment as a function of (1) the effectiveness of the selected technique(s) to repel and harass mammals and/or birds from the construction site (MR_t and BR_t); and (2) the average relative hazard caused by the attracted mammals and/or birds (hm_{avg} and hb_{avg}), as shown in Eq. (7)

Table 3. Wildlife Repellent Techniques

Wildlife	Repelling technique (t)[a]	Description	Qualitative effectiveness[b]	User-specified quantitative effectiveness (MR_t/BR_t)
Mammals	1	No audio repellents	—	$MR_1=0\%$
	2	Audio repellents	Effective	$MR_2=100\%$
Birds	1	No technique	—	$BR_1=0\%$
	2	Audio repellents	Most effective	$BR_2=70\%$
	3	Chemical repellents	Limited	$BR_3=10\%$
	4	Visual repellents	Limited	$BR_4=10\%$
	5	Radio-controlled model aircrafts	Limited	$BR_5=10\%$

[a]Techniques are used for entire site.

[b]Data from Transport Canada 2002.

$$\mathrm{WRHC} = (hm_{\mathrm{avg}} \times \mathrm{MR}_t) + \left(hb_{\mathrm{avg}} \times \sum_{t=1}^{T} \mathrm{BR}_t\right) \tag{7}$$

$$hm_{\mathrm{avg}} = \frac{\sum_{w=1}^{W} (hm_w)}{W} \tag{8}$$

$$hb_{\mathrm{avg}} = 1 - hm_{\mathrm{avg}} \tag{9}$$

where hm_{avg}=average relative hazard caused by mammals attracted to all facilities on site; hb_{avg}=average relative hazard caused by birds attracted to all facilities on site; MR_t=effectiveness of utilized mammals repelling technique t on site; and BR_t=effectiveness of all utilized birds repelling techniques (t=1 to T) on site.

In the present model, the wildlife repelling and harassment criterion is influenced by the effectiveness of the selected technique to repel wildlife species out of the construction site. As in the case with the earlier discussed exclusion techniques, a number of studies have been conducted to estimate the effectiveness of various techniques to repel and harass mammals and birds out of critical airport operation areas (Transport Canada 2002). As shown in Table 3, these studies provide qualitative assessments of typical wildlife repelling and harassment techniques and can also be used by construction planners to specify equivalent quantitative effectiveness values (MR_t or BR_t) in a similar way to that earlier described for exclusion techniques. For example, available choices for mammal repelling techniques may include a binary decision to either install audio repellents for the entire site layout or not. Similarly, available options for birds repelling techniques may include various combinations of audio repellents, visual repellents, chemical repellents, and/or radio-controlled model aircrafts for the entire site. The second factor that affects WRHC in the present model is the average relative hazard posed by all the attracted mammals and birds (hm_{avg} and hb_{avg}) in the entire site, which is automatically computed by the model using Eqs. (8) and (9).

Overall Wildlife Control

The overall impact of utilizing the three aforementioned important criteria (WHMC, WECC, and WRHC) to control wildlife attractions in airport construction sites is depicted by the overall wildlife control criterion (WCC). The WCC utilizes a weighted average approach to enable construction and airport planners to specify the relative importance of each of the three criteria and its contribution to the overall wildlife control effectiveness, as shown in Fig. 3 and Eq. (10). It should be noted that WCC is the main objective function which the present model seeks to maximize in order to minimize the hazards of wildlife attractants

$$\mathrm{WCC} = w_1 \times \mathrm{WHMC} + w_2 \times \mathrm{WECC} + w_3 \times \mathrm{WRHC} \tag{10}$$

where w_1=planner-specified relative importance/weight of habitat modification criterion; w_2=planner-specified relative importance/weight of exclusion control criterion; and w_3=planner-specified relative importance/weight of harassment criterion.

Minimizing Site Layout Costs

Site layout planning decisions such as identifying facility locations and utilizing various wildlife control devices have a direct impact on site costs. The present model is designed to minimize these site layout costs (SLC) using an objective function designed to compute (1) the travel cost of resources as a function of the distance between facilities; and (2) the cost of devices installed to control wildlife, as shown in Eq. (11)

$$\mathrm{SLC} = \mathrm{TCR} + \mathrm{CDC} \tag{11}$$

where TCR=total travel cost of resources on site; and CDC=wildlife control devices cost.

Travel Cost of Resources on Site

The travel cost of construction resources (e.g., material, equipment, and labor) can be minimized by efficiently planning the location of facilities on site such that travel distances (d_{ij}) of these resources are minimized, as shown in Eqs. (12)–(14) (El-Rayes and Khalafallah 2005). In these equations, the user has to specify the travel cost rate of construction crews (C_{ij}) among site facilities, which can be estimated using (1) the hourly cost of traveling crew (c_r); (2) the speed of the crew (s_r); and (3) the frequency of traveling between facilities (f_r), as shown in Eq. (13). While the hourly cost and speed of each traveling crew can be directly estimated according to the crew formation, the frequency of traveling between facilities (f_r) can be calculated based on the total amount of work and the capacity of the crew. For example, to transport 13 tons of brick between a storage facility and a construction site, a construction crew consisting of an operator and a forklift with a capacity of 1.3 ton will need 20 one-way trips to finish the job (i.e., $f_r=13/1.3\times 2=20$ one-way trips)

$$\mathrm{TCR} = \sum_{i=1}^{I-1} \sum_{j=i+1}^{J} (C_{ij} \times d_{ij}) \tag{12}$$

$$C_{ij} = \sum_{r=1}^{R} \left(\frac{f_r \times c_r}{s_r}\right) \tag{13}$$

$$d_{ij} = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2} \tag{14}$$

where C_{ij}=travel cost rate in \$/m of distance traveled between facilities i and j; d_{ij}=distance in meters between facilities i and j; f_r=the frequency of one-way traveling for construction crew r between facilities i and j during the lifecycle of the site layout plan; c_r=hourly cost of traveling crew r in \$/h; s_r=speed of traveling crew r in m/hr; X_i, Y_i=coordinates of center of gravity of facility i; X_j, Y_j=coordinates of center of gravity of facility j; I=total number of temporary facilities on site; and J=total number of all facilities on site.

Wildlife Control Devices Cost

The use of various wildlife control devices (e.g., repelling and harassment products) entails additional installation and maintenance costs that need to be considered during the site layout planning phase. The present model minimizes these costs by carefully inspecting various combinations of devices and selecting those providing the maximum overall wildlife control at the least possible cost, as illustrated in Eq. (15)

$$\mathrm{CDC} = \sum_{q=1}^{Q} c_q \tag{15}$$

where c_q=cost of installing, operating and maintaining wildlife control device q; and Q=total number of wildlife control devices utilized.

FAA Safety Constraints

The planning of construction work in and around airport operational areas needs to fully comply with a number of aviation operational safety constraints such as (1) limiting the heights of temporary facilities such as construction equipment and/or stockpiled materials in airport construction zones in order to eliminate the risk of collisions between these facilities and operating aircrafts; (2) protecting underground utilities and facilities from the excessive weight that can be produced by heavy construction equipment and/or facilities; and (3) prohibiting the presence of construction equipment and/or material in a number of restricted areas around operational runways and taxiways in order to ensure aviation safety during construction operations (FAA 1987, 2003a). The developed model is designed to fully comply with all of these constraints using a multiobjective genetic algorithm, which is described in more detail in the following section.

Multiobjective Optimization Model

A multiobjective optimization model is developed to: (1) enable the simultaneous optimization of the earlier described objectives (i.e., minimize hazards of wildlife attractants and minimize site layout costs); and (2) fully comply with FAA operational safety constraints. The model is developed using a multiobjective genetic algorithm (Deb et al. 2000; El-Rayes and Kandil 2005; Kandil and El-Rayes 2005) in order to optimize all relevant site layout planning variables including (1) the location of each temporary facility on site, which is represented by the coordinates (X_i, Y_i) of its center of area; (2) the selection of one of the available alternatives for wildlife exclusion techniques, which is represented by variables (E_0-E_w); and (3) the selection of one of the available alternatives for wildlife harassment techniques, which is represented by variables (H_0-H_4), as shown in Fig. 3. In the present model, these variables are represented by an artificial genetic algorithm chromosome to enable the model to evaluate the impact of various site layout decisions on wildlife control and site layout costs. As shown in Fig. 3, this chromosome is composed of five main categories in order to represent (1) the location and coordinates of each temporary facility on site using $(2\times I)$ integer

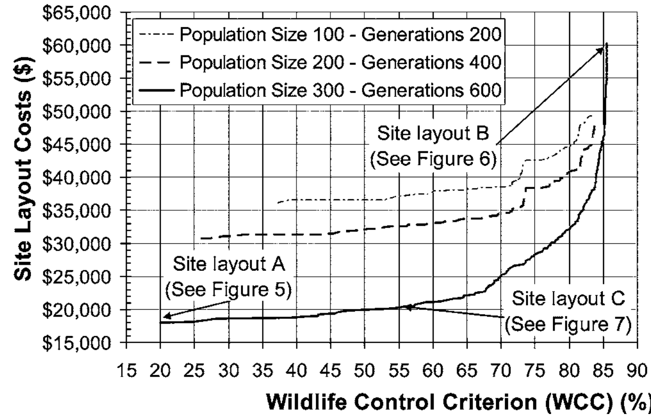

Fig. 4. Trade-off between wildlife control and site layout costs

variables $(X_i, Y_i, \ldots, X_I, Y_I)$; (2) the utilization of mammals exclusion techniques in the entire site layout using one integer variable (E_0); (3) the selection of birds exclusion techniques for each wildlife attracting facility on site using W integer variables (E_1-E_W); (4) the utilization of mammals harassment techniques in the entire site layout using one binary variable (H_0); and (5) the selection of birds harassment techniques in the entire site layout using four binary variables (H_1-H_4). The planner needs to provide the dimensions of temporary facilities and the available wildlife control systems to be investigated, while the model is used to search for and identify optimal locations of temporary facilities and the best combinations of wildlife control devices to be utilized.

The model starts the optimization process by generating a set of random site layout solutions and then runs through a series of evaluation, modification and combination of good solutions, attempting to reach a set of optimal solutions that satisfy the design objectives and comply with the set constraints. The model was tested on a number of application examples to validate its use as described in more details in the following section.

Application Example

An application example is analyzed to illustrate the use of the model and demonstrate its capabilities in minimizing wildlife hazards on airports during construction operations, and in generating optimal trade-offs between minimizing wildlife hazards and minimizing the total site layout costs, as shown in Fig. 4. In order to enable examining the performance of the model in a real-life setting, the airport layout in this example is selected to closely resemble that of an existing airport (AN 2005). The example involves the design of a site layout for constructing a new airport building that requires the utilization of 12 temporary construction facilities such as field offices, workshops, and lay down areas, as shown in Table 4. The presence of the construction site in close proximity to an operational runway and one of its parallel taxiways (see Fig. 5), can attract wildlife to the utilized temporary construction facilities, and accordingly can create hazardous conditions to ongoing airport traffic operations.

The present model requires the planner to input (1) the temporary facilities dimensions (see Table 4); (2) the site boundaries (see Fig. 5), (3) the relative importance of the three wildlife control criteria (in this example, $w_1=w_2=w_3=33.33\%$); (4) the location and dimensions of the critical airport operation areas shown in Fig. 2 (e.g., an area 60 m in width measured from the taxiway

Table 4. Temporary Construction Facilities and Available Exclusion Techniques

							Relative hazard		Birds[a] exclusion		
Facility number	Facility name	Length L_x (m)	Width W_y (m)	Height H_i (m)	Typical attracted mammal	Typical attracted bird	hm_w	hb_w	Technique (t)	Effectiveness BE_t (%)	Cost c_q (dollars)
1	Field office (a)	20	5	2.7	—	Blackbirds	0	1	2	35	200
					—				3	30	15
					—				4	35	950
2	Field office (b)	20	5	2.7	—	Blackbirds	0	1	2	35	200
					—				3	30	15
					—				4	35	950
3	Field office (c)	20	5	2.7	—	Blackbirds	0	1	2	35	200
					—				3	30	15
					—				4	35	950
4	Lay down area (a)	10	12	3	—	Geese	0	1	2	100	240
5	Lay down area (b)	10	12	3	—	Geese	0	1	2	100	240
6	Storage facility (a)	10	10	4	Coyotes	Vultures	0.18	0.82	2	35	200
									3	30	80
									4	35	760
7	Storage facility (b)	20	20	6	Coyotes	Vultures	0.18	0.82	2	35	800
									3	30	80
									4	35	1,520
8	Workshop (a)	5	4	3	Coyotes	Vultures	0.12	0.75	2	35	40
									3	30	15
									4	35	340
9	Welding shop	5	5	3	Coyotes	Vultures	0.12	0.82	2	35	50
									3	30	15
									4	35	380
10	Toilets	5	6	3	Deer	Turkey	0.75	0.25	3	50	5
									4	50	418
11	Parking lot	30	30	3.5	[b]	[b]	—	—	—	—	—
12	Crane	10	6.5	25	—	Vultures	0	1	2	100	280

[a]Mammals exclusion: Chain-link fence with barbed-wire outriggers (70% effective with expected cost of $6.2/m) or electric-fence (100% effective with expected cost of $8.7/m).

[b]Temporary facility does not attract wildlife.

centerline); (5) the maximum wildlife mobility distance (e.g., $Dw = 500$ m); (6) the most critical wildlife mammal and bird attracted to each temporary facility as illustrated in Table 4; (7) the effectiveness and cost of various wildlife exclusion techniques as shown in Table 4; (8) the effectiveness and cost of various wildlife harassment techniques (see Table 5); and (9) the unit travel cost of resources among facilities (see Table 6). The model also gives the planner the flexibility to modify the automatically calculated relative hazard values of attracting mammals and birds (hm_w, hb_w, hm_{avg}, and hb_{avg}) to each temporary facility (see Table 4). In order to enable the evaluation of the model in a real-life and practical setting, the costs of wildlife exclusion and repellent techniques in this example are obtained from recent prices provided by various suppliers and research studies (Schmidt and Knight 2000; AS 2005; BCE 2005; EB 2005; EPA 2005; MS 2005; NL 2005; WCT 2005). These data are necessary in order for the model to search for and identify optimal site layout plans that simultaneously (1) minimize the hazards of construction-related wildlife attractants; (2) minimize site layout costs; and (3) comply with all relevant aviation safety constraints in airport expansion projects (FAA 1997, 2002). These data are readily avail-

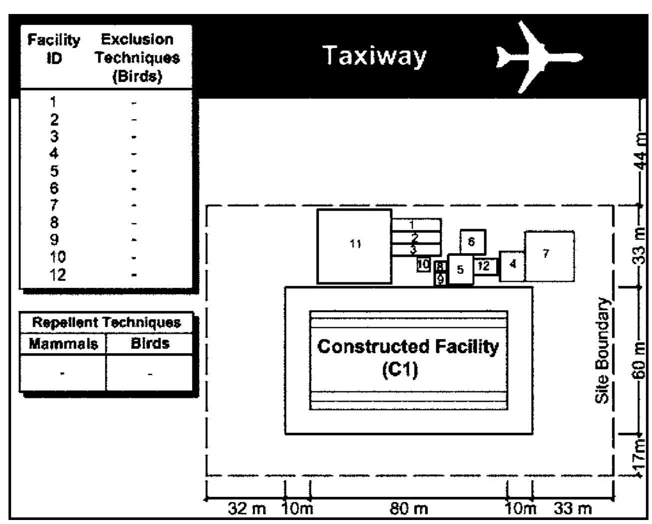

Fig. 5. Site layout with least costs

Table 5. Effectiveness and Costs of Available Repellent Techniques

Wildlife	Repellent technique (t)	Effectiveness BR_t (%)	Total cost c_q (dollars)
Mammals	1	100	700
Birds	1	70	1150
	2	10	3,267
	3	10	320
	4	10	450

able and the model can be effectively used to import, update, and reuse the data from previously completed projects.

The above data were utilized as input to the developed model to perform a series of optimization runs designed to generate optimal site layout solution(s) that seek to minimize the hazards of wildlife attractants and site layout costs simultaneously. The results illustrate improvements in the performance of the model with the increase in the genetic algorithm population size and number of generations, as shown in Fig. 4. However, such an increase usually entails additional computational time and cost to run the model, and this trade-off should be considered by planners when they specify these genetic algorithm parameters. The results also indicate that there is a trade-off between the performance in wildlife control and total site layout costs. As shown in Solutions A and B in Fig. 4, the performance in wildlife control in this example can be increased from 20 to 86%. However, this improvement requires an increase in the site layout costs from $17,968 to $60,311. This increase in site layout costs is caused by the implementation of various wildlife control measures on site such as utilizing wildlife exclusion and repellent techniques and/or locating temporary facilities far from critical operational areas, which often leads to an increase in the travel cost of resources on site.

Site Layout A (see Figs. 4 and 5) represents the solution providing the least site layout costs ($17,968) achieved by locating temporary facilities with high travel costs of resources (e.g., Facilities 4, 5, 12, and C1) close to one another and utilizing no wildlife exclusion nor repellent techniques. This site layout plan, however, is associated with the least wildlife control safety score

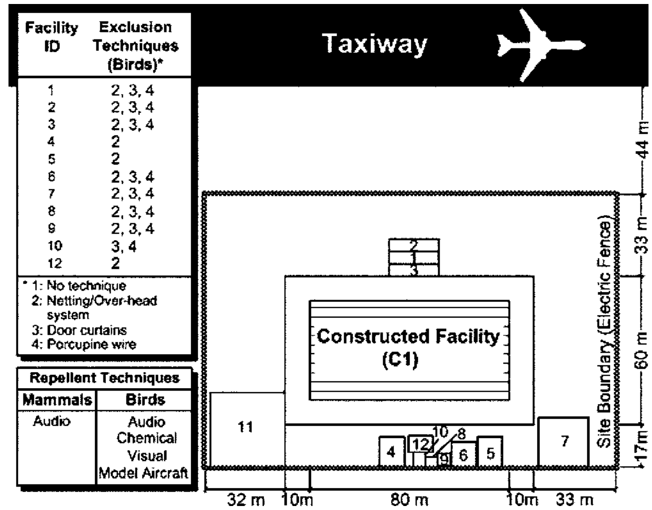

Fig. 6. Site layout with maximum wildlife control

(20%) due to locating hazardous wildlife attractant facilities (e.g., Facilities 6, 7, 8, 9, and 10) in close proximity to the taxiway and utilizing no wildlife preventive techniques to manage the attraction of wildlife to these temporary facilities (see Fig. 5). On the other end of the spectrum, Site Layout B (see Figs. 4 and 6) illustrates the solution that ensures the maximum wildlife control (86%) achieved by locating hazardous wildlife attracting facilities (e.g., Facilities 6, 7, 8, 9, and 10) far from critical operational areas. However, this site layout plan is associated with the maximum site layout costs ($60,311) due to the utilization of several wildlife control techniques and locating temporary facilities away from the construction site (see Fig. 6).

Site Layout C (see Figs. 4 and 7) represents an intermediate solution that provides an optimal trade-off between minimizing site layout costs ($20,317) and maximizing wildlife control (56%). This optimal trade-off between site layout costs and wildlife control is achieved by (1) locating temporary facilities with the highest travel cost of resources (e.g., Facilities 4, 5, 12, and C1) close to each other in one clustered area near the taxiway in order to minimize cost; (2) locating the most hazardous wildlife

Table 6. Travel Cost Rates (C_{ij}) among Facilities

Facility (*i*)	Facility (*j*) 1	2	3	4	5	6	7	8	9	10	11	12	C1
1	0	—	—	—	—	—	—	—	—	—	—	—	—
2	15	0	—	—	—	—	—	—	—	—	—	—	—
3	15	15	0	—	—	—	—	—	—	—	—	—	—
4	2.5	2.5	3	0	—	—	—	—	—	—	—	—	—
5	2.5	2.5	3	0	0	—	—	—	—	—	—	—	—
6	1	2	2	3	3	0	—	—	—	—	—	—	—
7	0	0	0	0	0	8	0	—	—	—	—	—	—
8	1	1	1	8	8	9	0	0	—	—	—	—	—
9	1	1	1	9	9	10	0	10	0	—	—	—	—
10	15	8	8	0	0	0	0	5	5	0	—	—	—
11	1	1	1	0	0	0	0	0	0	0	0	—	—
12	0	0	0	100	100	35	20	5	5	0	0	0	—
C1[a]	15	15	15	10	10	10	0	36	36	0	0	100	0

[a]Constructed facility (80×40 m^2).

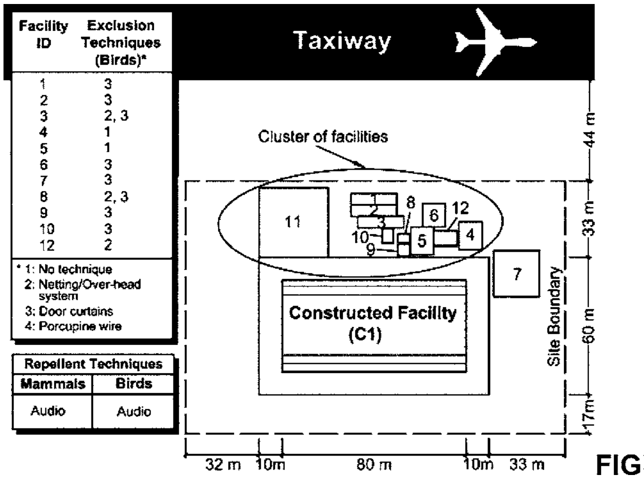

Fig. 7. Site layout C

attracting facilities (e.g., Facility 7) at a greater distance from the taxiway and the clustered area of facilities to maximize wildlife control; and (3) utilizing an optimal and limited number of wildlife exclusion and repellent techniques (e.g., in Facilities 3 and 8) to maximize wildlife control while keeping their additional cost to a minimum, as shown in Fig. 7. This intermediate solution represents an optimal site layout that provides the maximum possible wildlife control level that can be achieved for a site layout cost of $20,317. Identifying this optimal solution ensures that no other site layout can provide a greater wildlife control level for that site layout cost and vice versa. It should be noted that the maximum wildlife control criterion in this example did not exceed 86% (see Fig. 4) due to the close proximity of the construction site to the taxiway, which caused the temporary facilities to be located at distances smaller than the recommended maximum wildlife mobility distance (Dw) and as such the habitat modification effectiveness could not reach 100%. In addition to these three optimal site layouts (A, B, and C), the model was able to generate a wide range of optimal site layout plans, where each provides a unique and optimal trade-off between wildlife control and site layout costs, as shown in Fig. 4.

The results of the application example illustrate that wildlife control can be maximized by (1) locating wildlife attracting facilities far away from critical airport operational areas; and (2) increasing the level of utilizing wildlife exclusion and repellent techniques on site, as shown in Figs. 4 and 6. Similarly, site layout costs in airport expansion projects can be minimized by (1) locating temporary facilities with high travel costs of resources close to one another so as to reduce the travel distance and cost of resources on site; and (2) reducing the level of utilizing wildlife exclusion and repellent techniques on site, as shown in Figs. 4 and 5. The results also illustrate the unique capabilities of the present model in searching for and identifying optimal site layout plans that provide optimal trade-offs between maximizing wildlife control and minimizing site layout costs in airport expansion projects (see Figs. 4–7). Construction planners and airport operators can analyze these optimal trade-off solutions and select an optimal site layout plan that satisfies the specific design requirements of the project being planned.

Summary and Conclusion

A multiobjective optimization model was developed to support planning and optimization of construction sites in operating airport projects. The model is designed to enable the simultaneous minimization of wildlife attractant hazards and site layout costs. In order to enable the minimization of wildlife hazards during airport construction operations, the model incorporates three newly developed performance criteria to measure and quantify the impact of site layout planning decisions on the degree of compliance with relevant federal aviation administration recommendations on: (1) wildlife habitat modification; (2) wildlife exclusion; and (3) wildlife harassment (FAA 1997, 2002). The model is implemented using a multiobjective genetic algorithm and is capable of generating optimal site layout plans that specify an optimal location for each temporary facility on site and an optimal use of wildlife preventive techniques whenever needed to control the attraction of wildlife to critical airport traffic areas. An application example is analyzed to illustrate the use of the model and demonstrate its unique capabilities in generating optimal trade-offs between wildlife control and site layout costs. This should prove useful to construction planners and airport operators, alike and is expected to lead to significant and practical improvements in aviation safety during airport construction operations.

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Notation

The following symbols are used in this paper:

BE_t = effectiveness of utilized birds exclusion technique t;
BR_t = effectiveness of all utilized birds repelling techniques ($t=1$ to T) on site;
BWR_s = relative hazard score of the most critical bird attracted to facility w;
CDC = wildlife control devices cost;
C_{ij} = travel cost rate in $/m of distance traveled between facilities i and j;
c_q = cost of installing, operating, and maintaining wildlife control device q;
c_r = hourly cost of traveling crew r in $/h;
d_{ij} = distance in meters between facilities i and j;
Dw = maximum mobility distance of the most critical type of wildlife on site;
d_{wo} = distance separating wildlife attracting facility w from critical airport operation area o;
E = exclusion technique chromosome variable;
ETE_w = overall effectiveness of all exclusion techniques utilized in facility w;
f_r = the frequency of one-way traveling for construction crew r between facilities i and j during the lifecycle of the site layout plan;
H = repelling and harassment technique chromosome variable;
hb_{avg} = average relative hazard caused by birds attracted to all facilities on site;
hb_w = relative hazard caused by the attracted birds to facility w;

hm_{avg} = average relative hazard caused by mammals attracted to all facilities on site;
hm_w = relative hazard caused by the attracted mammals to facility w;
I = total number of temporary facilities on site;
J = total number of all facilities on site;
ME_t = effectiveness of utilized mammals exclusion technique t;
MR_t = effectiveness of utilized mammal repelling technique t on site;
MWR_s = relative hazard score of the most critical mammal attracted to facility w;
O = total number of critical airport areas;
Q = total number of wildlife control devices utilized;
s_r = speed of traveling crew r in m/h;
TCR = total travel cost of resources on site;
W = total number of facilities that can attract wildlife;
w_1 = planner-specified relative importance/weight of habitat modification criterion;
w_2 = planner-specified relative importance/weight of exclusion control criterion;
w_3 = planner-specified relative importance/weight of harassment criterion;
WR_s = hazard score for wildlife species s;
X_i, Y_i = coordinates of center of gravity of facility i; and
X_j, Y_j = coordinates of center of gravity of facility j.

Subscripts and Superscripts

avg = average value;
i = temporary facility counter (from $i=1$ to I);
o = critical operation area (from $o=1$ to O);
q = wildlife control device (from $q=1$ to Q);
r = traveling crew (from $r=1$ to R);
s = species group/type;
t = exclusion/repelling technique (from $t=1$ to T); and
w = wildlife attractant facility (from $w=1$ to W).

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