Minimizing Construction-Related Security Risks during Airport Expansion Projects

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2 authors:

Ahmed Khalafallah
Kuwait University

Khaled El-Rayes
University of Illinois, Urbana-Champaign

MINIMIZING CONSTRUCTION-RELATED SECURITY RISKS DURING AIRPORT EXPANSION PROJECTS

By

Ahmed Khalafallah[1], and Khaled El-Rayes[2], Member, ASCE

ABSTRACT:

Airport expansion projects often require the presence of construction personnel, material and equipment near airport secure areas/ facilities leading to an increase in the level of risk to airport security. Construction planners and airport operators need to carefully study this challenge and implement active measures in order to minimize construction-related security breaches and comply with all relevant Federal Aviation Administration guidelines. This paper presents the development of an advanced multi-objective optimization model for planning airport construction site layouts that is capable of minimizing construction-related security breaches while minimizing the site layout costs, simultaneously. The model incorporates newly developed criteria and performance metrics that enable evaluating and maximizing construction-related security level in operating airports. The model is developed using a multi-objective genetic algorithm and an application example is analyzed to demonstrate the use of the model and its unique capability of generating a wide spectrum of optimal trade-offs between construction-related airport security and site layout costs.

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[1]Assistant Professor, Department of Civil and Environmental Engineering, University of Central Florida, Orlando, Florida 32816-2450, Email: khalafal@mail.ucf.edu

[2]Assistant Professor, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, Email: elrayes@uiuc.edu

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INTRODUCTION

A large number of major airport construction and expansion projects are either on-going or being planned in order to meet the current and expected increases in air traffic demand (ACS 2001). These projects include new construction as well as expansion of existing terminals, runways and taxiways. One of the significant challenges in managing construction sites in this type of projects is caused by the close proximity of construction resources, such as equipment, material and personnel, to critical airport areas leading to an increased risk to airport security. To minimize this risk, the Federal Aviation Administration (FAA) sets forth guidelines for airport security in a number of advisory circulars and reports including (1) *Recommended Security Guidelines for Airport Planning, Design and Construction* (FAA 2001); and (2) *Aviation Security* (FAA 1972). Construction engineers and planners need to carefully consider and comply with these guidelines, especially during construction site layout planning which typically requires identifying the locations of all temporary facilities (e.g. security fences, site offices, and hazardous material storage facilities) on site. Although a number of research studies have been conducted to optimize construction site layout planning, they all focused on minimizing the travel distances and costs of resources on site and they did not consider the impact of construction operations on the security of nearby operational airports.

Existing site layout planning models adopted a wide range of methodologies including: linear programming (e.g. Armour and Buffa 1963, Dawood and Marasini 1999), genetic algorithms (e.g. Tam 1992, Li and Love 1998, Hegazy and Elbeltagi 1999, Mawdesley et al. 2002, Osman et al. 2003, Elbeltagi et al. 2004), artificial neural networks (e.g. Yeh 1995), simulation (e.g. Dawood and Marasini 2001, Tawfik and Fernando 2001), and knowledge-based systems (e.g. Kumara et al. 1988, Hamiani 1989, Tommelein et al. 1991, Tommelein and Zouein 1993). Despite the significant contributions of these models, they were all designed for general construction projects and they focused only on minimizing the travel cost of resources on site. There is little or no reported research studies that considered airport security as an important and independent optimization objective during the planning of airport construction site layouts despite its importance to both aviation and construction industries (Berg and Hinze 2005). To overcome this limitation, this paper presents the development of a multi-objective optimization model that can be used to consider and comply with relevant FAA security guidelines during site layout planning of airport expansion projects, as shown in Figure 1.

OBJECTIVE

The main objective of this study is to develop a model for multi-objective optimization of site layouts that is capable of maximizing construction-related airport security while minimizing site layout costs which include the costs of security systems and travel of construction resources on site. To accomplish this objective, the model is developed in three main phases: (1) identifying the FAA security guidelines for airport expansion projects; (2) formulating planning variables and optimization objectives; and (3) implementing the model as a multi-objective genetic algorithm. The following sections provide more detailed description of these three development phases.

FAA SECURITY GUIDELINES FOR AIRPORT EXPANSION PROJECTS

The FAA establishes guidelines for airport security in a number of advisory circulars and reports including (1) *Recommended Security Guidelines for Airport Planning, Design and Construction* (FAA 2001); and (2) *Aviation Security* (FAA 1972). In order to control and minimize construction-related security breaches that may originate during airport expansion projects, construction planners and airport operators need to study and comply with all relevant FAA security guidelines in these advisory circulars. In these documents, the FAA recommends implementing two site layout planning measures to maintain the security on operating airports during construction, namely: (1) utilizing security response distances; and (2) installing physical security systems (FAA 2001, FAA 1972, FAA 1988).

First, the implementation of security response distances is an important requirement in the security planning of operational airports to insure an adequate and secure distance between potential sources of security breaches and the secure area/facility. For example, the distance between a construction site fence and a nearby secure facility plays an important role in determining the security level of that facility. Locating the fence very close to a secure facility would not allow for a suitable response to potential breaches originating from the construction site. Accordingly, increasing the separation distance provides greater flexibility to put in place systems, measures and procedures which will detect, delay, and allow for a suitable security response (FAA 2001).

Second, the FAA requires installing physical security systems to insure that authorized construction personnel have limited access to only the construction site and that they do not have access to airport secure areas. These physical security systems are grouped into two groups: FAA required systems and FAA recommended systems, as illustrated in Table 1. The FAA required systems include the use of (1) physical barriers such as security fences; and (2) access control systems such as keypad entry and fingerprint scan. The FAA recommended systems include the use of (1) anti-intrusion systems such as Closed Circuit TV (CCTV) and motion detectors; (2) detection technologies such as X-ray scanning and explosives detection; and (3) security lighting systems (FAA 1972, FAA 1988), as shown in Table 1. These systems play a major role in preventing unauthorized access to the construction site and in detecting potential airport security breaches that may originate from the construction site.

SITE LAYOUT PLANNING VARIABLES AND OPTIMIZATION OBJECTIVES

In order to minimize construction-related security breaches, the impact of the aforementioned site layout measures needs to be evaluated and modeled. In this decision making problem, the main goal of the planner is to maximize compliance with relevant FAA guidelines and minimize construction-related security breaches at the least possible cost, as shown in Figure 1. To accomplish this, all relevant site layout planning variables are identified and grouped in three sets: (1) the planned distance to separate each secure area/facility from the construction site fence; (2) the types of security control systems that are planned to be installed on site; and (3) the locations of temporary facilities on site (see Figure 1). The first and the second set of variables directly affect the control of construction-related security breaches, while the second and third sets directly influence site layout costs. The following subsections discuss these three sets of decision variables and their impact on the optimization objectives.

Variable 1: Security Response Distance

The distance separating each secure facility from the construction site plays an important and direct role in determining the effect of the site layout plan on the level of controlling construction-related security breaches and an indirect role on the cost of the site layout plan. First, sufficient separation distances between the construction site fence and secure facilities are needed to establish buffer zones around secure facilities in order to provide airport operators with the opportunity of placing systems, measures, or procedures that detect, delay, and allow for a response to security breaches (FAA 2001). Second, the location of the construction site fence determines the available space for locating temporary facilities on site. Accordingly, a change in the fence layout will produce changes in the locations of temporary facilities on site leading to a possible change in the travel distances and cost of construction resources among the site facilities (El-Rayes and Khalafallah 2005).

Variable 2: Security Systems Utilized

The Federal Aviation Administration recommends utilizing efficient security control systems in order to control and minimize security breaches that may originate from the construction site (FAA 1972, FAA 1988). These systems include: security fences, access control technologies, security lighting, and anti-intrusion systems. Each of these systems is associated with a certain cost and effectiveness, as shown in Table 1. As such, there is a need to optimize the selection and utilization of these systems in order to minimize construction-related security breaches while keeping the site layout costs at a minimum.

Variable 3: Temporary Facilities Locations

The planned locations of all temporary facilities on site directly affect the travel distance and cost of construction resources on site. These locations are determined by the developed model based on the available space defined by the site fence. Accordingly, the location of security fences around construction sites will not only affect the level of controlling construction-related security breaches but also will influence the travel cost of resources on site.

Objective 1: Maximizing Airport Security

Two innovative criteria are newly developed to support decision makers in maximizing the performance of security arrangements in and around airport construction sites. The two new criteria are designed to measure and evaluate the impact of site layout decisions on satisfying the earlier described FAA guidelines that require establishing security response distances around secure areas/facilities and the utilization of security systems to prevent construction-related security breaches. As shown in Figure 2, the model uses a weighted average method to combine these two newly developed criteria in order to evaluate the overall construction-related security level on site.

The first newly developed criterion is named Security Response Distance Criterion (SRDC). SRDC can be used by construction planners to specify two types of buffer zones around each secure facility, namely: the Required Buffer Zone and the Recommended Buffer Zone, as shown in Figure 3. The purpose of the Required Buffer Zone is to ensure that the specified zone is free of any potential sources of security risks to the secure facility. The role of Recommended Buffer Zone, on the other hand, is to establish a security response distance (df_e) which is needed to detect, delay, and allow for a response to security breaches that may originate from the construction site (FAA 2001), as shown in Figure 3. The FAA suggests at least a distance of 3 – 9 meters (10 – 30 feet) clearance in order to allow for the detection of a fence breach (FAA 2001), while specifications in the UK recommends a separation distance of 30 meters between the source of risk and the secure facility (e.g. an airport terminal). These recommended distances should allow for detecting security breaches and responding by closing the secure facility before further penetration (FAA 2001).

The newly developed criterion (SRDC) utilizes two variables to measure and evaluate the effectiveness of separating secure areas/facilities from the construction site. These variables are: (1) the planned distance (df_e) which separates each secure area/facility (e) from the construction site fence; and (2) the recommended security response distance (d_e) needed for each and every secure area/facility (e) on site. SRDC uses the ratio between these variables to identify a security rating score for each secure facility on site, as shown in Figure 3 and Equation 1. For example, Case 1 in Figure 3 represents a layout where the planned fence separation distance (df_e) equals half of the recommended security response distance (d_e), and accordingly the Response Distance

Rating is calculated to be 50% (see Equation 1). Similarly, Case 2 in Figure 3 represents the most secure case where the fence is located completely outside the recommended buffer zone leading to a perfect score in the Response Distance Rating (i.e., RDR_e = 100%). SRDC is then used to calculate the overall security control rating for all secure areas/facilities in the neighborhood of construction site (SRDC) by averaging the response distance ratings for all secure areas/facilities on site, as shown in Equation 2.

$$\text{Response Distance Rating } (RDR_e) = \begin{cases} \dfrac{df_e}{d_e} \times 100\% & (df_e \leq d_e) \\ 100\% & (df_e > d_e) \end{cases} \quad (1)$$

$$\text{Security Response Distance Criterion (SRDC)} = \frac{\sum_{e=1}^{E} RDR_e}{E} \quad (2)$$

Where

df_e = planned separation distance between security area/facility e and the construction site fence;

d_e = recommended security response distance of secure area/facility e; and

E = total number of secure areas/facilities.

The second criterion is named Security Systems Criterion (SSC) and is developed to evaluate the effect of installing security control systems on improving security arrangements in airport construction site layouts. As shown in Table 1, each security system is associated with a qualitative effectiveness rating which can be obtained from available security studies (FAA 1972, GAO 2002, EPA 2006). These qualitative security ratings can be used as a guide for planners in estimating quantitative effectiveness scores, as shown in Table 1. SSC utilizes the weighted sum of effectiveness scores of all security systems selected for a site layout plan as a measure for evaluating the security level provided by the entire set of utilized security control systems on site, as shown in Equation 3. Table 2 provides a simple example to illustrate the required computations for this newly developed criterion. To calculate the Security Systems Criterion in this simple example, the weighted effectiveness of each selected security control system needs to be evaluated by multiplying the effectiveness of each of these systems (E_U) by its relative significance weight (w_u). For example, the weighted effectiveness of Fence Type III is calculated to be w_u x E_u = 0.3 x 100% = 30%, as shown in Table 2. Second, the results of these weighted multiplications are summed up to get the SSC rating (i.e. SSC = 30% + 18% + 15% + 15% = 78%), as shown in Equation 3 and Table 2. It should be noted that the FAA required systems should be assigned relatively higher significance weights (w_u) to distinguish them from the relatively less important recommended systems, as shown in Table 2. In this example, the collective weight of the FAA required systems is assumed to represent 60% of the SSC rating.

$$\text{Security Systems Criterion (SSC)} = \sum_{u=1}^{U} w_u E_u \qquad (3)$$

Where

w_u = relative significance weight of security system u;

E_u = effectiveness of security system u that ranges from 0 to 100%; and

U = total number of security system categories analyzed.

The overall Construction-Related Security Level (CSL) can then be calculated using the weighted average of SRDC and SSC, as shown in Figure 3 and Equation 4. SRDC can be given a higher relative weight than SSC as it represents the fundamental concept in security planning (FAA 2001). In the present model, CSL is maximized (see Equation) to ensure the selection of the most effective security arrangements in and around airport construction sites.

$$\text{Maximize Construction-Related Security Level} = \text{Max: } [w_{s1}\,SRDC + w_{s2}\,SSC] \qquad (4)$$

Where

w_{s1} = relative weight/significance of Security Response Distance Criterion; and

w_{s2} = relative weight/significance of Security Systems Criterion.

Objective 2: Minimizing Overall Site Layout Cost

The overall site layout cost in this model is grouped into two main categories: (1) the travel cost of resources among temporary facilities which is affected by the planned locations of these facilities as well as the location of the selected security fence; and (2) the cost of installing security control systems on site. As shown in Equation 5, this overall cost is minimized as the second main objective function in the present multi-objective optimization model, which is described in more details in the following section.

$$\text{Minimize Overall Site Layout Cost} = \text{Min: } \sum_{i=1}^{I-1}\sum_{j=i+1}^{J} C_{ij}\,d_{ij} + \sum_{u=1}^{U} c_u\,Cc_u \qquad (5)$$

Where

C_{ij} = travel cost rate of resources in $/meter of distance traveled between facilities i and j.

d_{ij} = distance in meters between facilities i and j;

I = total number of temporary facilities on site;

J = total number of temporary and fixed-location facilities on site;

c_u = binary variable to represent the utilization of security system u to control security on site; and

Cc_u = cost of installing, operating and maintaining security system u on site.

MULTI-OBJECTIVE OPTIMIZATION MODEL

The present optimization model is implemented as a multi-objective genetic algorithm (Deb et al. 2000) in order to enable the generation of optimal site layout plans that maximize construction-related airport security while keeping the overall site layout cost at a minimum. The earlier described three sets of site layout planning variables are represented in this model by a genetic algorithm chromosome (string of variables), as shown in Figure 1. The optimization calculations in the present model (see Figure 1) are performed in four main steps: (1) generate an initial set of random site layout solutions; (2) evaluate and rank the generated solutions based on non-domination criteria (Deb et al. 2000); (3) select the best solutions to perform crossover and mutation operations and generate the next generation of solutions; and (4) repeat the second and third steps over a number of cycles until the generated solutions converge to an optimal/near optimal set of site layout solutions.

APPLICATION EXAMPLE

An application example is analyzed to illustrate the use of the present model and demonstrate its capabilities in optimizing construction site layouts and generating optimal tradeoffs between the level of construction-related airport security and the overall site layout costs (see Figure 4). In order to enable examining the performance of the model in a real-life setting, the airport layout is formulated to closely resemble that of an existing airport (AirNav 2005). The example involves the construction of a new building in close proximity to a secure facility in an operating airport, exposing the facility to possible security breaches that can originate from the construction site. The construction of this building requires the utilization of 17 temporary construction facilities such as parking lots, field offices, workshops and lay down areas, as shown in Table 3. In this example, the present model is used to support construction planners to search for and identify optimal site layout plans that specify an optimal location for the security fence, optimal location for each temporary facility on site and an optimal use of security control systems on site. The two main optimization objectives in this site layout planning problem are (1) maximizing construction-related airport security by controlling breaches that may originate from the construction site; and (2) minimizing the site layout costs which include the cost of security control systems and resource travel cost on site.

In order to carry out the optimization of site layout planning in this example, the present model requires construction planners to specify and input the following parameters: (1) the dimensions (Lx, Wy, H_i) of each temporary facility as shown in Table 3; (2) the estimated travel cost rate of traveling crews between facilities (C_{ij}), as shown in Table 4; (3) the various options for the location of the security fence, as shown in Table 5; (4) the location and dimensions of each secure area/facility near the construction site, as shown in Figure 5; (5) the recommended security response distance that should separate the secure area/facility from the required buffer zone (30 m in this example); and (6) the estimated effectiveness and cost of utilizing available security control systems, as shown in Table 1.

The above data were utilized as input to the present model in order to perform a series of optimization runs designed to generate optimal site layout solutions that provide optimal and non-dominated tradeoff between maximizing construction-related airport security and minimizing overall site layout costs (See Figure 4). The tradeoff exists because controlling construction-related security breaches often requires: (1) increased separation distances between construction facilities and secure areas/facilities leading to an increase in the travel cost of construction resources on site; and/or (2) additional costs to utilize more effective security control systems. For example, site layout A (see Figures 4 and 5) provides the least site layout cost which is estimated at $63,648 and the least security level. The security level of solution A can be significantly improved to reach a perfect performance level (i.e., 100%) at a higher site layout cost of $122,789 as shown in solution B in Figure 4.

In this application example, site layout A (see Figure 5) was capable of minimizing the overall cost of site layout by (1) reducing the travel distances among all temporary facilities on site especially those associated with high travel cost rates such as facilities 14–17 and 15–17; and (2) limiting the utilization of costly security control systems on site. This site layout plan, however, led to a reduction in the overall construction-related airport security as a result of locating the security fence within the recommended security buffer zone of the secure facility and utilizing limited security control systems as shown in Figure 5. On the other end of the spectrum, site layout B (see Figure 6) maximizes construction-related airport security to 100% by (1) providing adequate security response distance due to locating the security fence outside the recommended security buffer zone of the secure facility; and (2) utilizing an optimal combination of the most effective security control systems to reduce the possibility of breaches from the construction site.

The above analysis of the application example highlights the unique capabilities of the developed model and illustrates how it can be effectively used to search for and identify a wide spectrum of optimal site layout plans, where each provides a unique and optimal tradeoff between maximizing the level of construction-related airport security and minimizing the overall site layout costs as shown in Figure 4. Construction planners can then evaluate these generated optimal tradeoffs and select an optimal site layout that satisfies the specific requirements of the project being planned.

SUMMARY AND CONCLUSION

A robust multi-objective optimization model is developed to address the pressing need for maximizing compliance with FAA security guidelines during airport expansion projects. The model enables construction planners and airport operators to simultaneously (1) minimize the risks of security breaches that may originate from construction sites; and (2) minimize site layout costs including the cost of security systems and travel cost of resources on site. The model is implemented using a multi-objective genetic algorithm and is capable of specifying optimal locations for temporary facilities on site, optimal locations of security fences, and optimal utilization of security control systems whenever needed to prevent the risk of security breaches from construction sites. An application example is analyzed to illustrate the use of the model and demonstrate its unique capabilities in generating a wide spectrum of optimal tradeoffs between construction-related airport security and site layout costs. These new capabilities should prove useful to construction planners and airport operators and can lead to significant improvements in the optimization of site layout plans in airport expansion projects.

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NOTATION

Ccu = cost of installing, operating and maintaining security system u on site.

C_{ij} = travel cost rate of resources in $/meter of distance traveled between facilities i and j.

c_u = binary variable to represent the utilization of security system u to control security on site;

d_e = recommended security response distance of secure area/facility e;

df_e = planned separation distance between security area/facility e and the construction site fence;

d_{ij} = distance in meters between facilities i and j;

E = total number of secure areas/facilities;

E_u = effectiveness of security system u (ranges from 0 – 100%);

I = total number of temporary facilities on site;

J = total number of temporary and fixed-location facilities on site;

U = total number of security system categories analyzed;

w_{s1} = relative weight/significance of Security Response Distance Criterion;

w_{s2} = relative weight/significance of Security Systems Criterion; and

w_u = relative significance weight of security system u.

Subscripts and Superscripts

i = temporary facility counter (from i = 1 to I); and

u = security system category (from u = 1 to U).

LIST OF TABLES

TABLE 1. Effectiveness and Cost of Security Systems

Category (u)	Security Control Technology	Qualitative Effectiveness[a]	User-specified Quantitative Effectiveness (E_u)	Average Cost[b] (Cc_u)
FAA Required Systems				
1- Physical Barriers	Fence Type I[c]	Reliable	50%	[f]
	Fence Type II[d]	More Reliable	75%	[f]
	Fence Type III[e]	Most Reliable	100%	[f]
2- Access Control	Magnetic Swipe Cards	Less Reliable	60%	150
	Keypad Entry	Less Reliable	60%	200
	Fingerprint Scan	Reliable	80%	1,500
	Retina Scan	Most Reliable	100%	2,000
FAA Recommended Systems				
3- Anti-Intrusion	Closed Circuit TV	Less Reliable	75%	480
	Motion Detectors	Reliable	100%	1,080
4- Detection Technologies	X-ray Scan	Less Capable	60%	14,000
	Explosive Detectors	Most Capable	100%	18,000
5- Security Light	Security Lighting	Recommended	100%	1,500

(a) Data from GAO 2002, FAA 1972.
(b) Data from GAO 2002, Mazzara et al. 2003, EPA 2006, SCSE 2006, SPS 2006.
(c) Fence meeting the FAA minimum requirements, including: No. 10 gauge, galvanized steel, chain link fabric, installed to a height of 2.5 m, and topped with a three strand (12 gauge) barbed wire overhang.
(d) Specifications are the same as Fence Type I with the addition of ground penetration prevention.
(e) Specifications are the same as Fence Type II with the addition of vibration detection.
(f) Average costs of fence types are: \$8.7/m for Type I, \$9.7/m for Type II, and \$11.7/m for Type III.

TABLE 2. Security System Criterion Example Calculation

Category (u)	Relative Significance (w_u)	Selected System	Effectiveness (E_u)	w_u x E_u	Security Systems Criterion (SSC)
		FAA Required Systems			
Physical Barriers	0.30	Fence Type III	100%	30%	
Access Control	0.30	Magnetic Swipe Cards	60%	18%	
		FAA Recommended Systems			30% + 18% + 15% + 15% = 78%
Anti-Intrusion	0.15	Motion Detectors	100%	15%	
Detection Technologies	0.15	Explosive Detectors	100%	15%	
Security Light	0.10	-	-		

TABLE 3. Temporary Facilities

Symbol	Facility Name	Length in m (L_x)	Width in m (W_y)	Height in m (H_i)
F1	Parking lot (a)	30	30	3.5
F2	Field office (a)	20	5	2.7
F3	Field office (b)	20	5	2.7
F4	Field office (c)	20	5	2.7
F5	Field office (d)	20	5	2.7
F6	Workshop (a)	5	4	3
F7	Workshop (b)	6	5	3
F8	Welding shop	5	5	3
F9	Storage facility (a)	10	10	4
F10	Storage facility (b)	12	8	4
F11	Storage facility (c)	10	10	4
F12	Equipment storage (a)	20	20	6
F13	Equipment storage (b)	5	5	3
F14	Lay down area (a)	10	12	3
F15	Lay down area (b)	10	12	3
F16	Toilets	5	6	3
F17	Crane	10	6.5	25

TABLE 4. Travel Cost Rates (C_{ij}) among Facilities

Facility (j)	Facility (i)																
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17
F1	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F2	2	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F3	2	30	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F4	2	30	30	0	-	-	-	-	-	-	-	-	-	-	-	-	-
F5	2	30	30	30	0	-	-	-	-	-	-	-	-	-	-	-	-
F6	0	2	2	2	2	0	-	-	-	-	-	-	-	-	-	-	-
F7	0	2	2	2	2	20	0	-	-	-	-	-	-	-	-	-	-
F8	0	2	2	2	2	20	14	0	-	-	-	-	-	-	-	-	-
F9	0	2	4	4	4	18	6	20	0	-	-	-	-	-	-	-	-
F10	0	2	16	16	16	14	16	14	2	0	-	-	-	-	-	-	-
F11	0	2	16	16	16	6	6	6	6	2	0	-	-	-	-	-	-
F12	0	0	0	0	0	0	10	0	16	16	16	0	-	-	-	-	-
F13	0	2	2	2	2	8	8	8	0	0	0	8	0	-	-	-	-
F14	0	5	5	6	6	16	16	18	6	6	6	0	0	0	-	-	-
F15	0	5	5	6	6	16	16	18	6	6	6	0	0	0	0	-	-
F16	0	30	16	16	16	10	10	10	0	0	0	0	0	0	0	0	-
F17	0	0	0	0	0	10	10	10	70	70	70	40	0	200	200	0	0
C1*	0	30	30	30	30	72	72	72	20	20	20	0	20	20	20	0	200

* Constructed Facility (80 x 40 m^2)

TABLE 5. Options to Construct Security Fence

	Option 1	Option 2	Option 3
Fence Vertices Coordinates	(2265, 2496)	(2290, 2496)	(2315, 2496)
	(2465, 2496)	(2465, 2496)	(2465, 2496)
	(2465, 2606)	(2465, 2606)	(2465, 2606)
	(2265, 2606)	(2290, 2606)	(2315, 2606)

LIST OF FIGURES

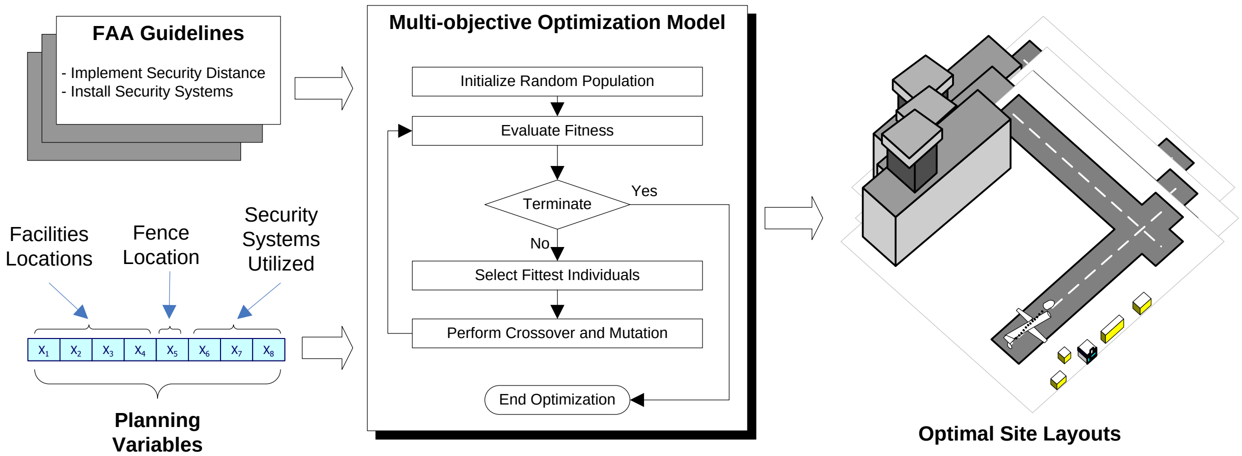

FIGURE 1. Model Formulation

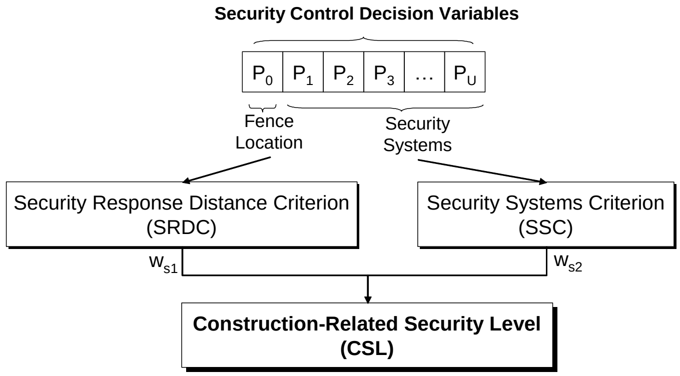

FIGURE 2. Security Control Measures and Decision Variables

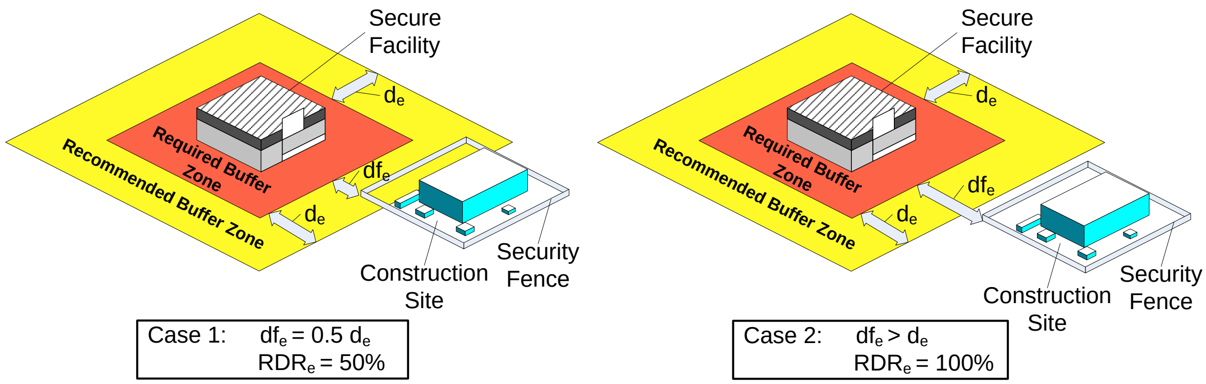

FIGURE 3. Measuring the Performance of Establishing Security Buffer Zones

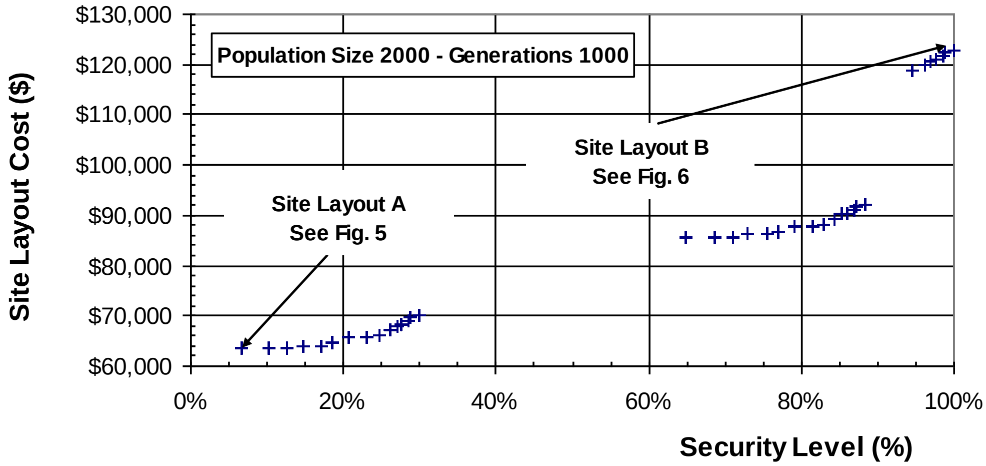

FIGURE 4. Trade-off between Aviation Security and Cost

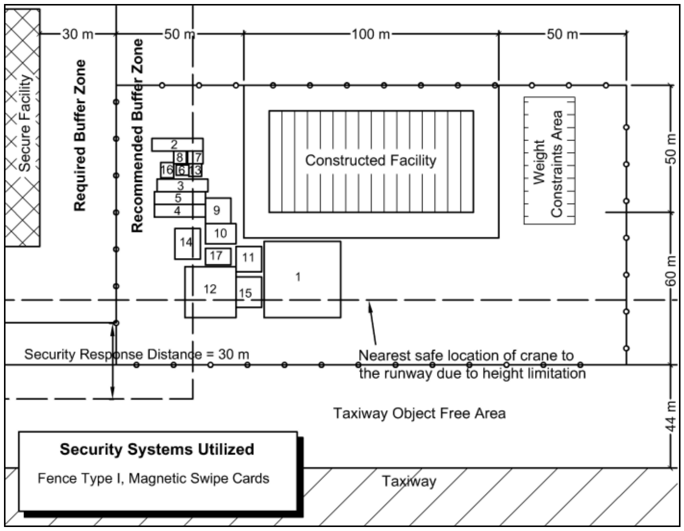

FIGURE 5. Site Layout A: Least Site layout Cost

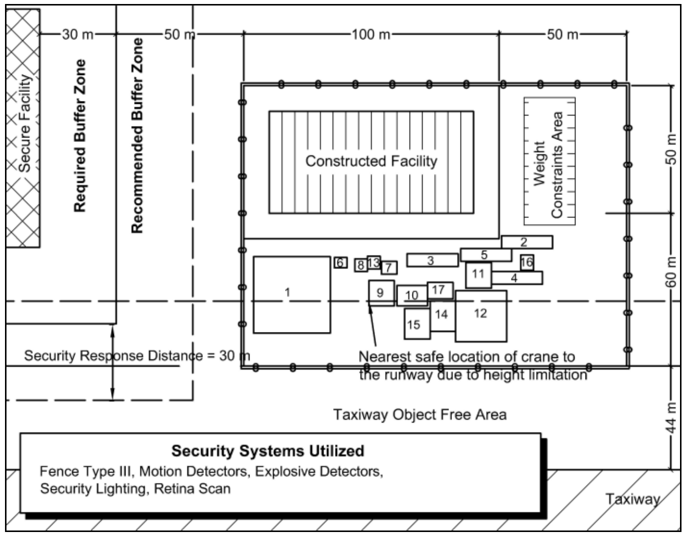

FIGURE 6. Site Layout B: Maximum Construction-Related Security