# AUTOMATED EXPLOSIVE SITE PLANNER
## A Software System for Siting Explosives

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## ABSTRACT

The **AUTOMATED EXPLOSIVE SITE PLANNER (AESP)** is a software system developed at Headquarters Air Force Logistics Command (HQ AFLC) to tackle many of the problems encountered with developing an explosives site plan and completing AFLC FORM 333, **EXPLOSIVES AUTHORIZATION FOR SITED MUNITIONS FACILITY.** This system consists of 3 separate, but coordinated, programs that:

- maintain a site database containing information on structures in and around the explosives storage area (ex: structure identification, type, location, etc).
- establish minimum quantity-distance separations (QDS) between the proposed structure and surrounding structures based on Air Force regulation 127-100, chapter 5.
- identify previously sited structures whose maximum net explosive weights must be reduced due to the introduction/placement of the proposed structure.
- complete AFLC FORM 333.

Programs 1 and 3 of this system were designed using "conventional" techniques and coded in a "conventional" programming language (TURBO Pascal). Program 2 employs artificial intelligence techniques and was coded using expert system development software (M.1).

This paper explains why this project was undertaken, how it was approached, and the rationale behind the approaches taken. It also provides a general discussion of the site planning process and detailed discussions on both program functions and system operation.

# INTRODUCTION

The development of explosive site plans within the Air Force Logistics Command (AFLC) has always been shadowed by the ominous cloud of hidden errors that have somehow managed to circumvent the closest scrutiny of developers and reviewers alike. Although many of these errors can be categorized as quite insignificant, others have the potential to be catastrophic in terms of cost, facility damage, loss of life and/or impairment of mission capability during conflict. While we have learned from our mistakes, some lessons have been lost or forgotten due to personnel turnover, infrequent plan development, or random miscommunication.

In the late 1980's, AFLC instituted an initiative known as Total Quality Management (TQM) to improve products and processes throughout the command. Process action teams (PATs) were formed to examine selected processes and make recommendations on how to improve them. One such team was formed to examine the explosive site planning process. After analyzing the planning process and the problems typically encountered, the team determined that errors introduced into explosive site plans were primarily attributed to:

- the complexity of Air Force regulation (AFR) 127-100 (Explosive Safety Standards).
- misinterpretation of AFR 127-100 by the planner.
- misapplication of AFR 127-100 tables and footnotes.
- variations in training and experience levels of planners and reviewers.
- planner and reviewer proficiency deterioration due to the decreasing need to develop site plans.
- deficiencies in maps used in the planning process.

The PAT concluded that there were no "quick fixes" which would improve the planning process to meet the safety and operational needs of the Air Force; however, automating the planning process would solve the vast majority of the problems encountered.

Although efforts at HQ USAF and DOD levels were underway to design and develop a comprehensive automated site planner, the PAT concluded that AFLC could not wait several years for the system to materialize. In April 1989, the AFLC Weapons Safety Office (AFLC/IGFW) launched an effort to develop the Automated Explosive Site Planner (AESP). This system would focus exclusively on AFLC explosive site planning and would complete AFLC FORM 333, **EXPLOSIVES AUTHORIZATION FOR SITED MUNITIONS FACILITY** (appendix 1).

System design and development efforts were limited by a variety of factors such as insufficient funding and a lack of manpower. These limits precluded a full-time design/development effort; therefore, AFLC/IGFW assets were used as available. During system design, it became evident that automating the process of establishing quantity-distance separations (QDS) using AFR 127-100 would be difficult, if not impossible, for IGFW personnel. Developing software to interpret and act upon the multitude of footnotes and exceptions found in this regulation was beyond their level of programming expertise. For this reason, help was requested from AFLC's Artificial Intelligence Support Center (AISC). The AISC provided system design and programming assistance on an ad hoc basis until October 1989 when they formally joined IGFW in the development effort.

## GENERAL DISCUSSION

<u>THE PLANNING PROCESS:</u> Explosive site planning at Air Force Logistics Command (AFLC) bases is manually accomplished by weapons safety personnel working in cooperation with base civil engineers. This planning process can be divided into three phases:

1. **PREPARATION:** In the preparation phase, the proposed structure is tentatively plotted on a map depicting the explosives storage area and its surroundings. All structures within a radius specified by AFR 127-100 are located and classified by structure type (igloo, operating location, inhabited building, etc). Next, the closest existing structure of each type is identified and the shortest distance to the proposed structure is recorded. Finally, the orientation of each closest structure is established relative to the proposed structure.

2. **QUANTITY-DISTANCE SEPARATION (QDS) DETERMINATION:** In this phase, AFR 127-100 is used to establish the minimum QDS values between the proposed structure and the closest existing structure of each type (as established in phase 1). This is done for each explosive hazard class/division. QDS determination is always performed once, but may be performed twice:

   - QDS values from existing potential explosion sites (PES) to the proposed structure are established for the closest PES of each structure type (igloo, module, etc).

- If the proposed structure will house explosives, a second set of QDS values is established by treating the proposed structure as the PES and all other structures as exposed sites (ES).

3. **LIMITS DETERMINATION AND CONFLICT IDENTIFICATION:** In this third and final phase, limits on the amount of net explosive weight (NEW) to be stored in the proposed structure are established. These maximum NEW values are calculated using the QDS values established by Program 2. Additionally, the QDS values are also used to calculate NEWs (where appropriate) for all existing structures involved in the site plan. These calculated NEWs are compared against their counterparts found in the existing structure's site plan (on file). If a calculated NEW is less than its counterpart on file, a conflict has occurred. (In other words, introduction of the proposed structure has **reduced** the NEW authorized for the previously sited structure). Identified conflicts are resolved by either moving the proposed structure so as to increase the distance between it and the existing structure, and/or by reducing the NEW authorized at the existing structure. After all conflicts are resolved, the NEWs calculated for the proposed structure are used to complete AFLC FORM 333.

**PROBLEMS:** As was mentioned previously, the opportunity for error abounds in this manual planning process...

- In the **preparation phase**, inaccurate maps, inaccurate measurements, and/or incorrect determination of the shortest distances are common sources of error. Problems have also arisen around determining the orientation of one structure to another as specified by AFR 127-100.

- In the **QDS determination phase**, discrepancies in AFR 127-100 chapter 5, misinterpretation of the regulation, misapplication of the various tables and footnotes, and skipping some possible ES/PES combinations have all caused problems at one time or another.

- With every repetition of the planning process due to conflict resolution, planner fatigue, confusion, and frustration increase the chances of missing conflicts and/or of making additional mistakes.

- When questions arise during the review of the site plan by AFLC/IGFW, it is difficult (and sometimes impossible) for the planner to recall exactly how AFR 127-100 was applied and footnotes/exceptions interpreted.

The AESP system addresses and resolves virtually all of the problems above by automating each of the site planning phases. In the next section, each of the 3 programs that comprise the AESP will be discussed individually. How they address the aforementioned problems will be described as well.

## PROGRAM DESCRIPTIONS

PROGRAM 1: This TURBO Pascal program automates the preparation phase and resolves (or reduces) problems associated with it as described below:

- INACCURATE MAPS: All structure location information in the form of map coordinates will be placed into a site database. These coordinates will be provided by base civil engineers using their computerized map system. Program 1 provides menu-driven functions to create, maintain, and print/display this site database. For more information on the site database, please refer to appendix 2.

- INACCURATE MEASUREMENTS AND INCORRECT DETERMINATION OF SHORTEST DISTANCE: Using the coordinates in the database, Program 1 will mathematically determine the shortest distance between any 2 given structures.

- INCORRECT DETERMINATION OF STRUCTURE ORIENTATION: This program establishes the ES/PES orientations (front-to-side, rear-to-front, etc) using AFR 127-100 specifications.

PROGRAM 2: This M.1 program is the knowledge-based portion of the system and it automates the QDS determination phase of the site planning process. It reduces or eliminates the following problems normally associated with this phase:

- DISCREPANCIES WITHIN AFR 127-100: AFR 127-100 chapter 5 was methodically scrutinized during the development of Program 2. As a result, numerous discrepancies were identified and eliminated.

- MISINTERPRETATION OF AFR 127-100: Program 2 enforces the requirements of AFR 127-100 as interpreted by HQ AFISC/SEWV. Because AESP will be used to generate all site plans within AFLC, a uniform interpretation of the regulation is achieved.

- MISAPPLICATION OF AFR 127-100 TABLES/CHARTS: Program 2 determines the correct table/chart to use, when to use it, how to use it, and how to interpret and apply any referenced footnotes/exceptions. The planner is only prompted for necessary information, only at the time it's needed, and only when the information is not in the database. As long as the planner provides AESP with correct information, Program 2 will use the various tables and charts within AFR 127-100 correctly.

- INABILITY TO RECREATE THE PLANNING PROCESS: An audit log is kept of every footnote and/or exception that influences QDS value determination. When necessary, a transcript of the entire dialogue between Program 2 and the planner can be generated.

- SKIPPING POSSIBLE ES/PES COMBINATIONS: Program 1 "tells" Program 2 when to treat the proposed structure only as an exposed site (ES) and when to treat it as both an ES and a potential explosion site (PES). Program 2 checks all relevant ES/PES combinations.

PROGRAM 3: This third and final program, written in TURBO Pascal, automates the **limits determination and conflict identification phase**. If/when no conflicts are found, Program 3 completes AFLC FORM 333.

## PROGRAM DESIGN RATIONALE

As mentioned in the program descriptions, the **preparation** and **limits determination phases** were automated using TURBO Pascal. TURBO Pascal was the "language of choice" for a variety of reasons:

- Both phases are very math oriented.

- Both phases are completed in a logical, methodical (ie: procedural) manner

- Turbo Pascal graphics capabilities supports diagram generation and display

- Turbo Pascal creates executable (.COM) programs that run on Z248s (or compatible). These programs can be distributed freely throughout the command (ie: no run-time costs involved).

- Turbo Pascal can allocate/release computer memory on the fly.

- Turbo Pascal was available; funds to purchase anything else were not!

Unlike the preparation and limits determination phases of the site planning process, QDS determination is neither math oriented nor procedural in nature. The emphasis in Phase 2 is on the interpretation of information as per AFR 127-100 rather than on data manipulation. A software package called M.1 (M1) was used to automate the QDS determination phase because:

- it is a rule-based, non-procedural language.

- M1 applications will run on the Z248 or compatible (as required by AFLC/IGFW).

- M1 was available and applications can be distributed freely throughout AFLC (ie: no run-time cost).

- M1 expertise was readily available.

- it uses a technique called "backward chaining" which is well suited to the problem of QDS processing. Backward chaining is advantageous for solving problems where it is easier to work backward rather than forward. For example, it is often easier to work from the center of a maze toward the outside than vice versa.

## SYSTEM OPERATION

PRELIMINARY WORK: Before developing a site plan, the planner must use Program 1 to create and populate the site database. Program 1 prompts the planner for all needed structure information, much of which is obtained from the base civil engineer's computerized base mapping system. (See appendix 2 for the information required by the database.) Data on every structure in and around the explosives area must be entered. Additionally, every structure having an AFLC Form 333, Explosives Authorization for Sited Munitions Facility, on file will have the information on the form transcribed into the database. At present, this is a manual, time consuming process; however, it need only be done once. After initial data entry, Program 1 database maintenance functions can be used to add new structures, delete old structures, and/or change information in the database.

CREATING A SITE PLAN - PART(1): The creation of a site plan begins with the planner working with the base civil engineer (BCE) to tentatively plot the proposed structure on the BCE's computerized mapping system. Location information for the proposed structure (ie: map coordinates) provided by the BCE system will be needed by

Program 1. With this location information in hand, the planner starts the AESP system on his/her Z248 computer (or compatible). Program 1 is automatically started and a menu of options is displayed. The planner selects the option that allows him/her to develop a site plan. Next, the planner is prompted for information about the proposed structure. Once Program 1 has all of the information it needs, it performs preparation phase tasks which include:

- Determining the shortest distance between the proposed structure and all other structures (components) in the database. (See **appendix 2** for an explanation of structure components.)

- Selecting the structure (component) of each AFR 127-100 structure type that is closest to the proposed structure.

- Establishing the orientations of the existing structure (component) and the proposed structure relative to each other.

Information about the proposed structure is placed in a **STRUCTUR.NEW** file. Similar information about all <u>relevant</u> existing structures (components) is written to a **STRUCTUR.OLD** file. Other information such a building orientation, "actual" (map) distances, etc. are written to other files so that this information is available to programs 2 and 3. With all of this accomplished, Program 1 ends and Program 2 takes over.

<u>**CREATING A SITE PLAN - PART (2):**</u> Program 2 begins by reading the **STRUCTUR.NEW** and **STRUCTUR.OLD** files. It takes one structure (component) at a time out of the **STRUCTUR.OLD** file, pairs it with the proposed structure to form an ES/PES set, and processes the ES/PES set to obtain QDS values for all explosive hazard classes. Next, it switches the ES/PES roles of the proposed and existing structures in an attempt to obtain a second set of QDS values. When all processing is complete, the next structure in the **STRUCTUR.OLD** file is paired with the proposed structure and the entire process repeats. This cycle continues until all components in the **STRUCTUR.OLD** file have been paired with the proposed structure.

At the beginning of every cycle, the proposed structure is treated as the ES and the existing structure (component) as the PES. (For the moment, let's assume that the existing structure will contain explosives and thus qualifies as a PES.) Initial AFR 127-100, Table 5-1 (Quantity-Distance Separation Criteria) row and column designations are assigned to the ES and the PES, respectively, based upon:

1. the structure classification assigned to them by Program 1

2. barricade information supplied by the planner.

Next, any footnotes referenced by Table 5-1 for the row number assigned to the ES are processed in order of appearance. Each footnote is a knowledge-based program that collects information from the database and/or the user as needed. When a footnote alters the ES designation, the new row number is assigned immediately and an annotation is made in an audit log. Both the footnote causing the change and the new row number being assigned are recorded. Processing of the footnotes associated with the new row then begins. This cycle continues until all footnotes for the given row have been processed and the ES designation has stabilized (ie: no other row changes occur). In cases where row footnotes create an infinite cycle, the original ES row designation is used.

Once a final ES designation (ie: row number) is established, the same type of processing occurs to arrive at a final PES designation (ie: column number). Program 2 uses these final Table 5-1 row/column designations to establish a default QDS value for hazard class 1.1 explosives by performing a simple table look-up. Next, any footnotes that affect the QDS value are applied. For every change to the QDS value, the footnote causing the change, and the change itself are recorded in the audit log.

After a final QDS value for hazard class 1.1 explosives is established for the given ES/PES set, the same methods are used to establish QDS values for all other hazard classes. All results are then written to a file for subsequent processing by Program 3.

When processing of the current ES/PES set is complete, or if the existing structure (component) was not a valid PES (ex: inhabited building, public traffic route, etc), the roles of the proposed structure and the existing structure are reversed. The proposed structure is treated as the PES and the existing structure (component) is treated as the ES. All of the processing described above will occur to generate a second set of QDS values only if 2 conditions are met:

1) The proposed structure is a valid PES.
2) Program 1 "informed" Program 2 that this role reversal should occur.

<u>CREATING A SITE PLAN - PART (3)</u>: At the conclusion of Program 2, all relevant proposed/existing structure combinations have been evaluated and the QDS values for each have been written to a QDS file. Program 3 takes this information and begins the limits determination and conflict identification phase. Assuming that the proposed structure will house explosives (ie: acts as a PES), maximum net explosive weights (NEWs) are established for hazard classes 1.1 through 1.4 using the QDS values derived by Program 2

and the inter-structure distances calculated by Program 1. (REMEMBER! When 2 sets of QDS values are derived for a proposed/existing structure pair, the more restrictive of the 2 values is used.) Next, Program 3 calculates NEWs for all previously sited structures involved in the site plan and compares these calculated NEWs to their counterparts on file. Program 3 provides the planner with information on every conflict found (ie: when the calculated NEW is found to be less than the NEW on file). With this information in hand, the planner must take corrective action(s). This usually involves relocating the proposed structure and/or reducing the authorized NEW in the "offending" existing structure. After corrective action is taken, the AESP system must be run again using the new information.

| REVISION NUMBER | EXPLOSIVES AUTHORIZATION FOR SITED MUNITIONS FACILITY | SITE PLAN NUMBER | ORGANIZATION | FACILITY NUMBER |
|---|---|---|---|---|
| | | | | |

**I. FACILITY DESCRIPTION**

| | |
|---|---|
| A. TYPE CONSTRUCTION STANDARD, NON STANDARD AF DEFINITIVE DWG NUMBER | F. NUMBER OF ROOMS/BAY |
| B. TYPE HEATING | G. NUMBER OF EXITS |
| C. TYPE OF ELECTRIC FIXTURES | H. EXTENT AND TYPE OF BARRICADING |
| D. LIGHTNING PROTECTION | I. DESIGN PURPOSE (MAINTENANCE, X-RAY, STORAGE, ETC.) |
| E. DIVIDING WALLS (NUMBER, SIZE) | J. SPECIAL FEATURES (OVERHEAD CRANE, HOIST, ETC.) |

**II. COMPUTATION DATA**

| NEAREST TARGET THAT REQUIRES A | TARGET IDENTIFICATION B | FROM (PES) / TO (ES) C | K FACTOR D | DISTANCE E | CL DIV 1.1 F | CLASS/DIVISION 1.2 (04) G | (08) H | (12) I | (18) J | CL DIV 1.3 K | CL DIV 1.4 L | OTHER M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAGAZINE DISTANCE | 4083 | 3 / 1 | 2.75/ 0.00 | 1376 | 500000 | PHY CAP (4083 ) | PHY CAP (4083 ) | 500000 (4083 ) | 500000 (4083 ) | 20842283 (4083 ) | PHY CAP | |
| INTRALINE DISTANCE | 4067 | 3 / 8 | 18.00/ 0.00 | 1816 | 500000 | PHY CAP (4067 ) | PHY CAP (4067 ) | 500000 (4067 ) | 500000 (4067 ) | 47911252 (4067 ) | PHY CAP | |
| PTR DISTANCE | 17 | 2 / 24 | 21.00/ 30.00 | 1530 | 186667 | PHY CAP (17 ) | PHY CAP (17 ) | 500000 (17 ) | 500000 (17 ) | 6995268 (17 ) | PHY CAP | |
| INB DISTANCE | 4070 | 3 / 34 | 35.00/ 50.00 | 2393 | 170800 | PHY CAP (4070 ) | PHY CAP (4070 ) | 500000 (4070 ) | 500000 (4070 ) | 109627140 (4070 ) | PHY CAP | |
| OTHER | 4071 | 3 / 5 | 0.00/ 0.00 | 2040 | 50 | PHY CAP (4071 ) | PHY CAP (4071 ) | 500000 (4071 ) | 500000 (4071 ) | 67917312 (4071 ) | PHY CAP | |
| OTHER | | | | | | | | | | | | |

REMARKS

**III. AUTHORIZATION**

| CL/DIV 1.1 A | CLASS/DIVISION 1.2 (04) B | (08) C | (12) D | (18) E | CL DIV 1.3 F | CL DIV 1.4 G | OTHER H |
|---|---|---|---|---|---|---|---|
| 50 | PHY CAP | PHY CAP | 500000 | 500000 | 6995268 | PHY CAP | |

AFLC FORM 333 APR 89 PREVIOUS EDITION IS OBSOLETE

## APPENDIX 2
## - The Site Database -

There is one entry (record) in the site database for every structure component* that must be considered in the site plan as directed by AFR 127-100, when developing a site plan. One set of records will describe the components of the proposed structure, another set will describe the components of all surrounding structures (within the radius specified by AFR 127-100). Each record consists of the following fields:

COMPONENT ID: A unique identifier.

STRUCTURE TYPE: An integer code that identifies the type of structure (igloo, magazine, module, inhabited building, etc) the component belongs to.

COMPONENT SHAPE: An integer code that identifies the geometric shape of component (rectangle, triangle, circle, etc.)

COMPONENT COORDINATES: Cartesian coordinates of each endpoint on a polygonal component. Circular components have their center point and radius recorded.

COMPONENT ATTRIBUTE FLAG: This is a bit-mapped flag used to exchange information between the various parts/programs. Each bit of a 16-bit computer word has a predefined, binary meaning. For example, flag bit #1 indicates whether or not a structure is a non-standard structure ( 0 = no, 1 = yes).

***STRUCTURE COMPONENTS:** To simplify processing, irregularly shaped structures are represented as overlapping and/or adjoining triangular, rectangular, square, and/or circular components. Each component is treated as an individual structure during QDS value determination. Structures having a simple, regular shape are said to have one component. At present, breaking irregularly shaped structures into simple components is a manual process.