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Research in Automating Weather Templating Procedures for Aerial Intelligence Preparation of the Battlefield (AIPB): Final Report

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13. ABSTRACT *(Maximum 200 words)*

This document describes a prototype software system that automates the generation of weather related templates used in the Aerial Intelligence Preparation of the Battlefield (AIPB) process. The software system is called the Terrain and Weather IPB Software Toolkit (TWIST). The primary purpose of the prototype is to demonstrate that software using artificial intelligence technology can be developed to effectively integrate weather, terrain, and doctrinal information and to accurately generate AIPB templates.

TWIST consists of two major modules. One module serves as the user interface and performs weather and terrain analyses that generate gridded data bases covering the battlescale region of interest. The second module combines the information to create templates that can, among other things, define the Air Avenues of Approach.

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1. Introduction

The Weather and Doctrinal Information Fusion (WADIF) system and the Mercury heuristic terrain and weather analyses system were developed together with the objective of exploring the use of artificial intelligence (AI) techniques for automating weather and terrain templates used in the intelligence preparation of the battlefield (IPB) process. The combined software system is called Terrain and Weather IPB Software Toolkit (TWIST). Most recently, TWIST was adapted for automating weather and terrain templating procedures used for aerial intelligence preparation of the battlefield (AIPB).

The overall goals of the project are to incrementally produce prototypes that demonstrate the integration of terrain and weather effects and to use AI reasoning techniques to solve some of the many difficult problems that arise during the AIPB process. The project is a multiyear effort funded by the Army Space Technology and Research Office, the U.S. Army Research Laboratory's Battlefield Environment Directorate (BED), and the Topographic Engineering Center (TEC). BED defines the weather effects, software integration, and overall program coordination. TEC coordinates terrain reasoning products and information. The New Mexico State University Computer Science Department was contracted for software design and programming support.

2. Background

TWIST integrates terrain and weather information relevant to operational level activities with doctrinal information. The Mercury module supplies the weather and terrain information while the WADIF module determines the acceptability of aerial maneuvers given terrain and weather factors and doctrinal specifications of capability and acceptability. To accomplish this objective, WADIF uses the well-tried expert system technology of deductive inference using a modular, rule-based knowledge base to describe the effects of varying weather and terrain conditions on Army maneuvers.

In decision support, expert systems technology provides an effective means of specifying and organizing domain rules of thumb (heuristics) for explanation and prediction. Without a tool like WADIF, heuristics alone would likely remain ill-specified and would not be applied in a systematic manner in the noise of a dynamic and evolving situation. Systematic application is, of course, very important with heuristics because of their inherent uncertainty. The WADIF system provides such a decision envelope to assist intelligence analysts with the planning and management of aerial activities. The decision envelope is the determination of how the expected weather and terrain affects the creation of Air Avenues of Approach (AAAs).

Determining AAAs is a complex and time-consuming process when undertaken manually because of the wide variety of assets that appear on the battlefield and because of the wide range of operational combinations that may be assembled to address unit designs of AAAs. Automation of the doctrinal level assessment of terrain and weather effects allows a more rigorous and detailed application of conventional wisdom, while reducing the manpower and time resources needed to complete the AIPB process. The ability to reason about assets in more detail allows battlefield resources to be used more efficiently. The more detailed planning possible increases the effectiveness of other resources such as satellite and telemetry information by identifying areas on the battlefield that the satellites should scan to provide the most useful information.

A major enhancement to the WADIF program in 1993 was the ability to operate on an aerial battlefield (especially WADIF's ability to define AAAs). The realization that various components of an asset change from ground to air motivated the integration of aerial knowledge with weather, terrain, and asset capability.

An analyst may use WADIF to transition from a review of weather and terrain effects on individual assets to the determination of asset suitability for specific aerial missions within a particular AAA. Comparisons of these assessments allow the analyst to experiment through what if specifications using different combinations of terrain and weather. The analyst may accordingly examine best- and worst-case scenarios and propose most probable scenarios.

3. The TWIST Architecture

Figure 1 is an overview of the TWIST architecture.

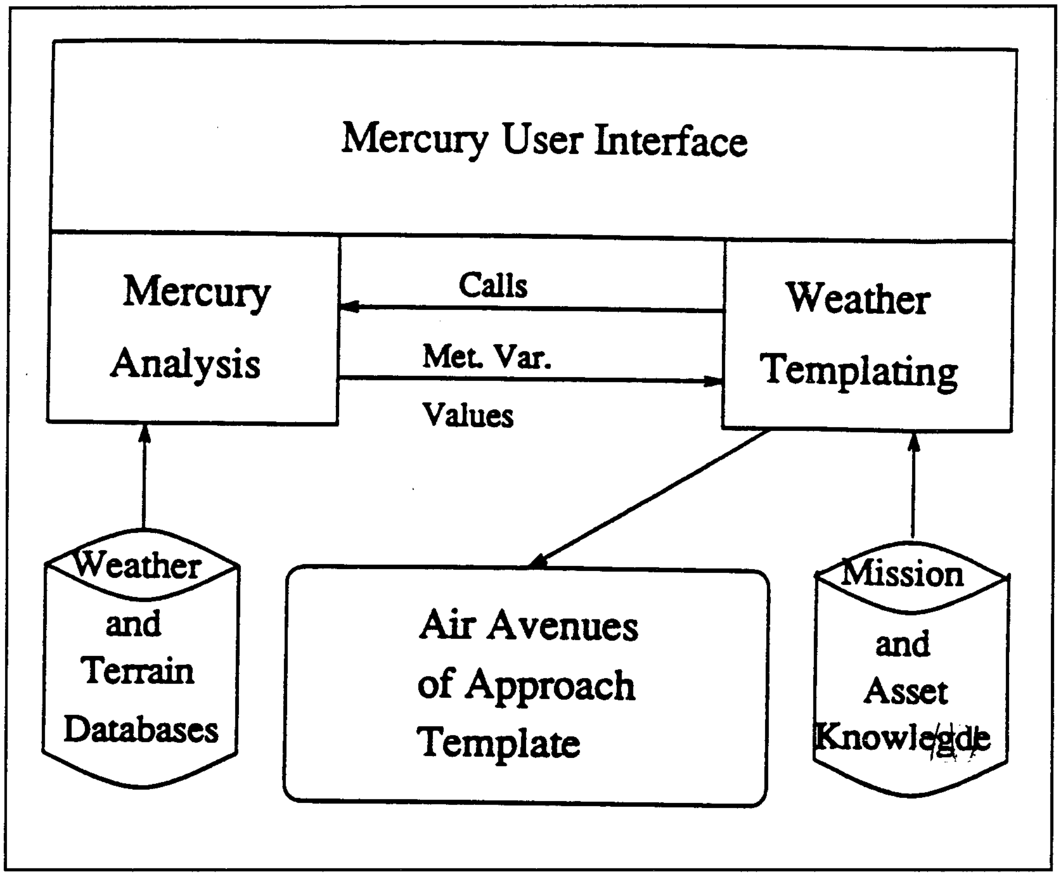

Figure 1. TWIST architecture.

The TWIST software design gives high priority to portability and modularity. Portability is addressed by implementing all of the software in C and using X-windows and the Unix operating system. Modularity is achieved by organizing the system around the user interface. The interface provides all of the basic functions under user control (section 6). Within TWIST, Mercury is an AI-based weather analyses system that spreads weather analyses and effects over a gridded area of interest despite complications of complex terrain and sparse data. The WADIF module currently computes AAAs using weather and terrain effects as input. The TWIST system combines these two modules to produce the reasoning approach in figure 2.

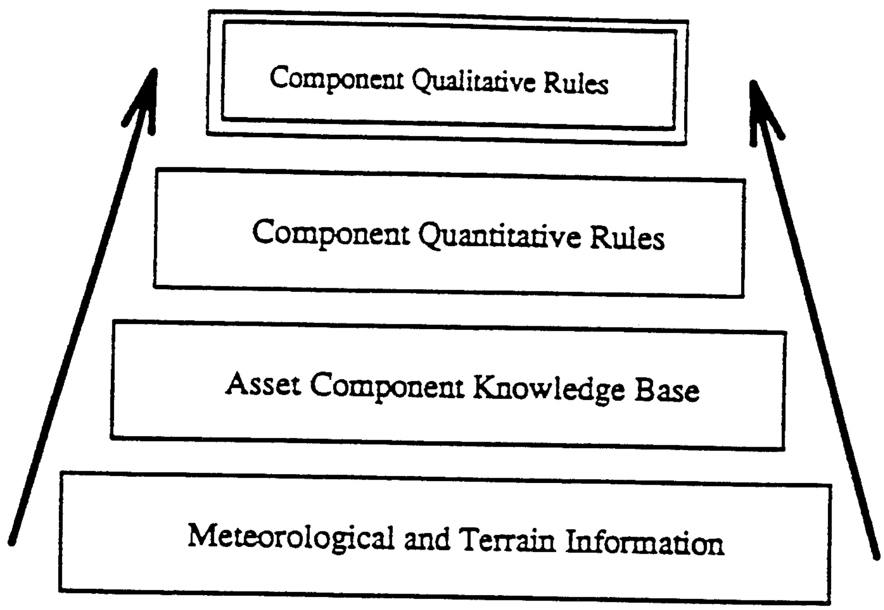

Figure 2. Reasoning system.

4. Reasoning Advances in Mercury

4.1 Data Structure Considerations

The key requirement for a data structure is that it must be efficient for the different types of operations frequently required of it. To choose an effective data structure for a particular problem, one must intensively study the types of problems most often encountered by the programs being developed. Optimizing the data structures for the high-use problems should increase the overall performance of the system. A secondary consideration when designing a data structure is that it should promote modular design and easy maintenance of the code written around it.

4.2 Basic Reasoning Methodologies

There are different types of basic reasoning methodologies. Two of the methodologies available are quantitative and qualitative reasoning.

Quantitative reasoning is known as the mathematical models of numeric processing. The amount of data necessary for processing is very important with quantitative reasoning. If the standard data base tables (or incoming terrain/weather data) have sufficient information, a straight query from those tables (data) may be adequate. However, if all data are not available, the missing data may be numerically computed from available data. Quantitative reasoning may or may not be heuristical depending on whether or not heuristics are needed for computing numeric thresholds.

A new situation arises when some of the data information is missing or cannot be directly computed from factual information. In this situation, a quantitative methodology may not be appropriate, and an incremental approach may be taken by using qualitative methodologies.

Qualitative reasoning is based on relationship decisions. These decisions are considered artificial in nature and are referred to as AI techniques. When data is missing from the data base tables or incoming data, relationships between items and their components or items and other items may assist in computing the needed information.

The following are a few of the relationships that may be used in answering a query:

a. temporal - the relationship between time and other factors, or other time spacing between values of the same elements

b. spatial - the relationship of the object locations between elements

c. causal - the relationship between cause and effect of events

d. heuristic - the relationship between two objects or concepts

Temporal, spatial, causal, heuristic, and other relationships may be used to fill or evaluate possible values for missing data in qualitative reasoning. The kind of reasoning to use depends on the data missing; also the kind of technique to use depends on the relationship between that data and other available data.

4.3 Weather Analyses

The primary purpose of the Mercury meteorological analyses system is to provide accurate weather data for areas in which there are very limited data. To accomplish its mission, Mercury must take available meteorological data, gathered from various point sources, and interpolate between them.

The problem of meteorological analyses over a battlefield is that the commander may have little control over where to place weather sensors. Frequently, the real area of interest for the analyses will reside in enemy territory.

Given the expectation that there will be an inadequate number of data points and each point may uncomfortably reflect local conditions that do not apply to the operational area, it is difficult to project measurements on anything but a qualitative basis.

The basic data structure chosen is a simple grid of points representing the battle area. It was chosen because the battlefield weather domain is characterized by large volumes of data that flow from a sparse set of data sources. Using this simple approach makes it relatively easy to apply a rule-based reasoning approach to interpolate between the data points. Three kinds of rules are used within the rule-based reasoning approach: 1) quantitative rules that translate numerical thresholds to value; 2) qualitative rules that specify contribution of station data to other points within the grid; and 3) quantitative/qualitative rules that integrate quantitative and qualitative results.

The weather grid generated by the weather analyses system may support interpolation across variables within each cell, representing factors such as surface met conditions, cloud conditions, fog, and approximated wind vectors. Moreover, by using separate grid structures for terrain, weather, and asset location information, interpolations within these information domains may progress independently and at a computationally low cost in response to individual queries. The actual interpolation is done by taking surface reports and heuristic rules from the rule base and spreading the data across the whole grid. The heuristics allow a more intelligent spreading of data than using only objective analyses.

5. Reasoning Advances in WADIF

5.1 Weather/Terrain Effects

Weather and terrain data effects can be twisted to give more of a complete picture of the desired area by using the weather grid just computed and applying information about terrain data for the same area. Moreover, using separate grid structures for terrain and weather interpolations within these information domains allows independent and low-cost responses to individual queries and allows analyses of effects from integrating grid information together.

5.2 AIPB Processing

When TWIST receives a query concerning AIPB processing, it combines terrain and weather effects information with doctrinal constraints. To create the rules needed for the constraint processing, one must first understand the basic AIPB operational processing requirements. A study was done in aviation deployment, air attack, and air defense to understand the doctrinal rules of operation for AIPB. Given these observations, heuristics can be generated for creating relationship trade-offs. For example, in analyzing an area of interest to produce possible AAAs, there is a relationship between the flight path of the asset (currently this is a rotary-wing aircraft) and the amount of fuel used to travel this path. There are times that the path will be longer in length but at the same time safer because of where the asset travels.

Each of these trade-offs is considered a parameter to the system. AIPB parameters are considered to be independent or dependent (figure 3).

The independent parameters are

a. line of sight - computing visibility of attacking aircraft

b. land use - how land use helps, hinders, or does not affect the choices of attack

c. weather - how the known weather affects the mission

d. air defense - where the air defenses are and where they can move to

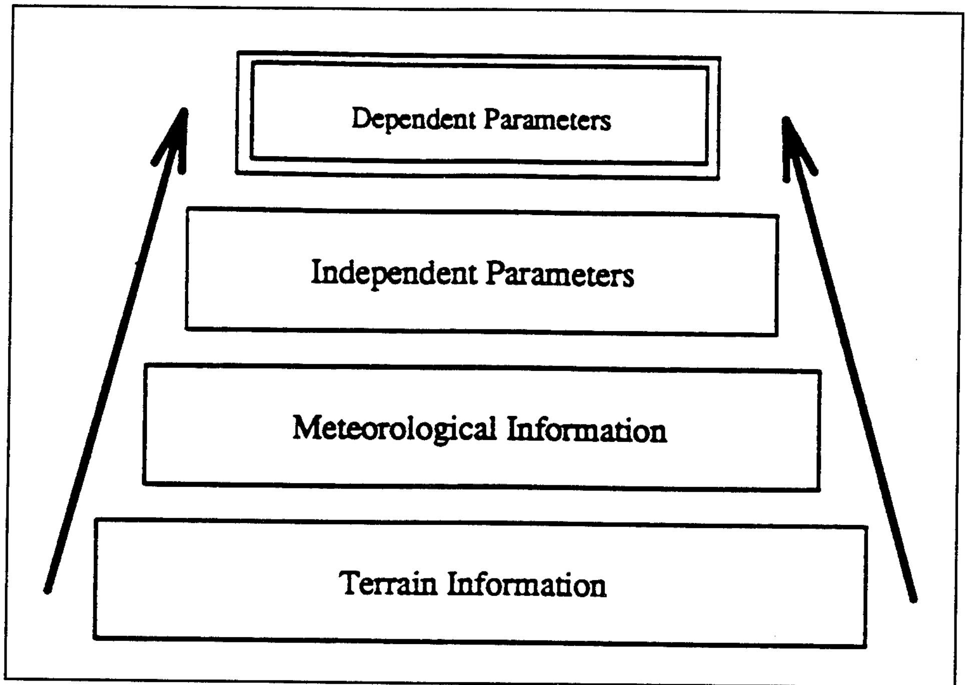

Figure 3. WADIF processing.

The emphasis of the independent parameters is on accurate spreading across the whole grid.

The dependent parameters are

a. start location - where the attacking aircraft starts from

b. target location - the location of target desired

c. fuel consumption - the amount of fuel available and how important is it to be saved

d. risk factor - how risky the path is to travel

e. target zones - the attack area around the target

The computation time with each dependent parameter is more important than the perfect answer. Each factor cannot be done until the actual mission assessment is performed.

6. Current Status

The current TWIST system is a proof-of-concept prototype capable of integrating terrain, weather, and doctrinal information to produce aerial IPB templates. The latest development tasks include the following.

6.1 System Architecture Design

The system architecture was designed toward continuing development in the coming years. The resulting open-ended architecture can produce a fully effective AIPB analyst tool.

6.2 Interface With Mercury

The interface with Mercury is completed and fully functional. The quick development of an interface between WADIF and Mercury is due to the modular design of the Mercury system. An example of this interface program using Mercury is shown in the appendix. WADIF uses a simple function call to query Mercury for the values of the meteorological variables.

6.3 Develop and Implement a Map Server

The first priority was to develop a map server to address the purely practical problem of displaying the results produced by WADIF. The generic user interface functionality of the Mercury program provided the basic framework on which to build the map server. While the current map server provides basic functionality, other products that may provide more functionality and efficiency need to be explored.

6.4 Reasoning About AIPB Problems

TWIST, when applied to AIPB problems, can now determine AAAs for three different regions. The regions include an area in South Korea (37.0° to 37.5° N. lat., 127.2° to 127.7° E. long.), the Fulda Gap region of Germany (50.0° to

52.0° N. lat., 8.5° to 11.5° E. long.), and the Los Angeles Basin (33.0° to 35.0° N. lat., 117.0° to 119.0° W. long.)

The knowledge base of the WADIF module implements a subset of the traditional Army weather factor analyses matrix. It also uses slope, land use, and major obstacle information when determining the performance acceptability of an asset. This information is critical for all query types, but especially for queries that determine AAAs.

The Mercury module provides the meteorological data required by the weather factor analyses matrix. The gridded meteorological data and related information provided by Mercury for the AAA application include the following:

Latitude (degrees)
Longitude (degrees)
Date (yymmddhh)
Elevation (meters above sea level)
Temperature (degrees Fahrenheit)
Dew Point (degrees Fahrenheit)
Relative Humidity (percent)
Wind Direction (degrees)
Wind Speed (knots)
Pressure (millibars)
Visibility (miles)

Mercury also provides the terrain data needed for the AAA determination. Mercury's terrain data bases include digital terrain elevation data level 1, arc digitized raster graphics (ADRG) data, and land-use data derived from Landsat imagery. At the present time, Mercury only has ADRG and Landsat data for the South Korean location.

TWIST is currently able to create and reason about using AAAs for target missions in enemy areas within the AIPB problem domain.

7. Future Work

The following enhancements would greatly improve the TWIST system.

7.1 Proposed Artificial Neural Network Approach to Reasoning

An artificial neural network approach was proposed as a new architecture for TWIST. This is a multiple-layer (terrain, weather, decision support, and other constraints) architecture with grid-style processing elements.

Each layer has processing elements that have within-layer (intralayer) and lateral (interlayer) connections. The weights for within-layer connections (grid weights) are initially loaded from a cost matrix precomputed from independent information or from a current cost matrix made up of independent/dependent mission information. The weights between the layers are established by functional relationships. For example, a weather layer has a functional relationship to a terrain layer. The functional relationships are defined by a set of functional weighted links (loaded or learned) between the layers.

Figure 4 shows that the activations of each individual layer are represented by spatially oriented variables. The set of weights that define the matrix (grid) relationships within the layer is loaded onto that layer. For example, the current weather and terrain information is imposed on those layers and the decision layer is loaded after information is observed over time, which allows spatial questions to be addressed across a single layer. The single layer also can address questions within that realm of information, which means the terrain layer can address questions relating to mountains, valleys, etc.

The layers also have functional relationships between each other. The relationships are defined by a set of functional weighted links between the layers. The terrain layer is the layer that tries to fuse information from all the other layers. It is this layer that takes into account all the effects of the layers above. Figure 5 looks more closely at the functional relationships between the

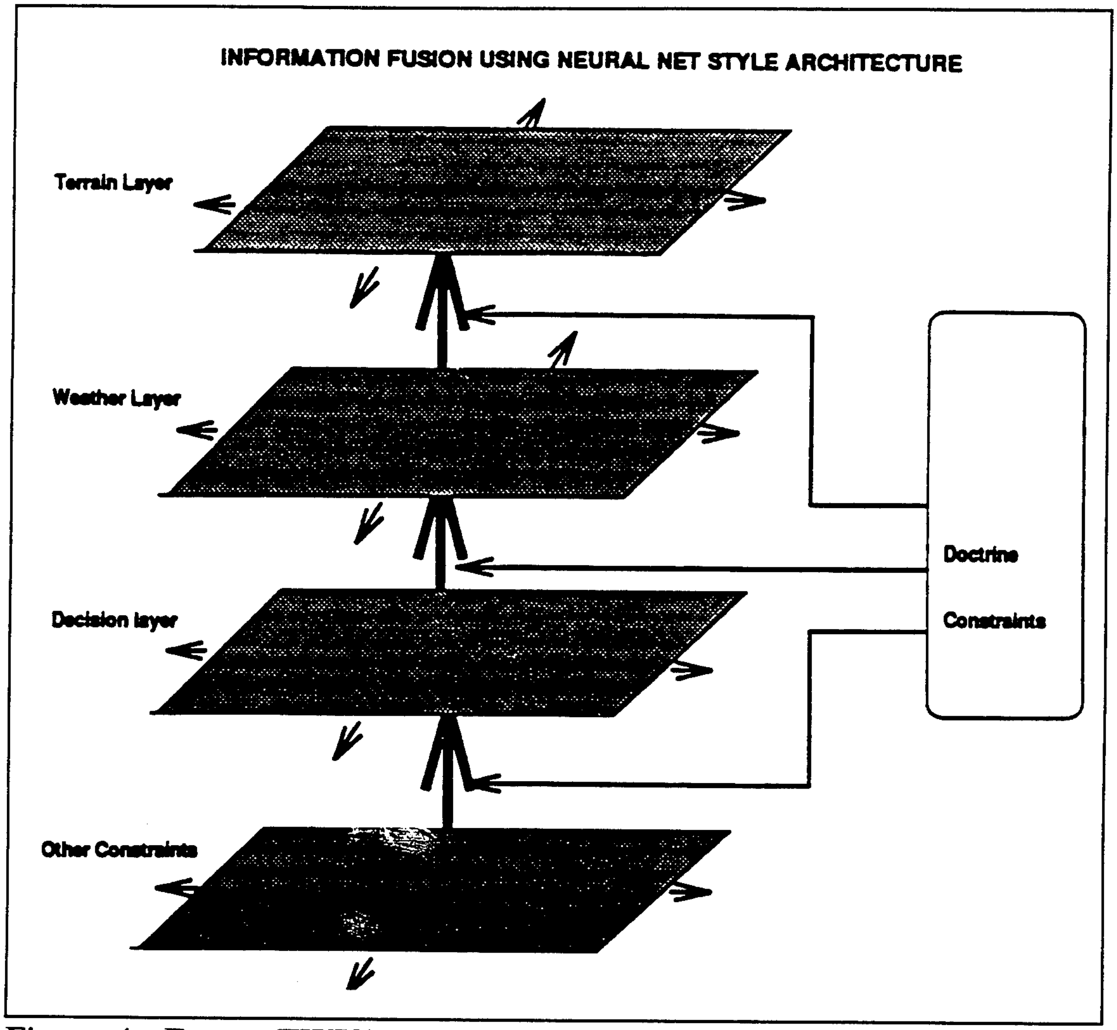

Figure 4. Future TWIST architecture.

layers. For a particular task, the set of weights that define the relationship between the layers is loaded for every pair layer onto the functional weighted (interlayer) links. These weight matrices represent the functional relationships between the different layers and eventually to the task. For example, we will have weight matrices defining the relationship between the weather and terrain for assessment movement. Also, we can have a set of weights between the weather layer and the decision support layer.

When terrain, current weather, and decision information is imposed on the layers, the activations from these layers represent the current weather, terrain, and decision information for the whole network. The activations from the layers interact with each other through the functional weight matrix related to

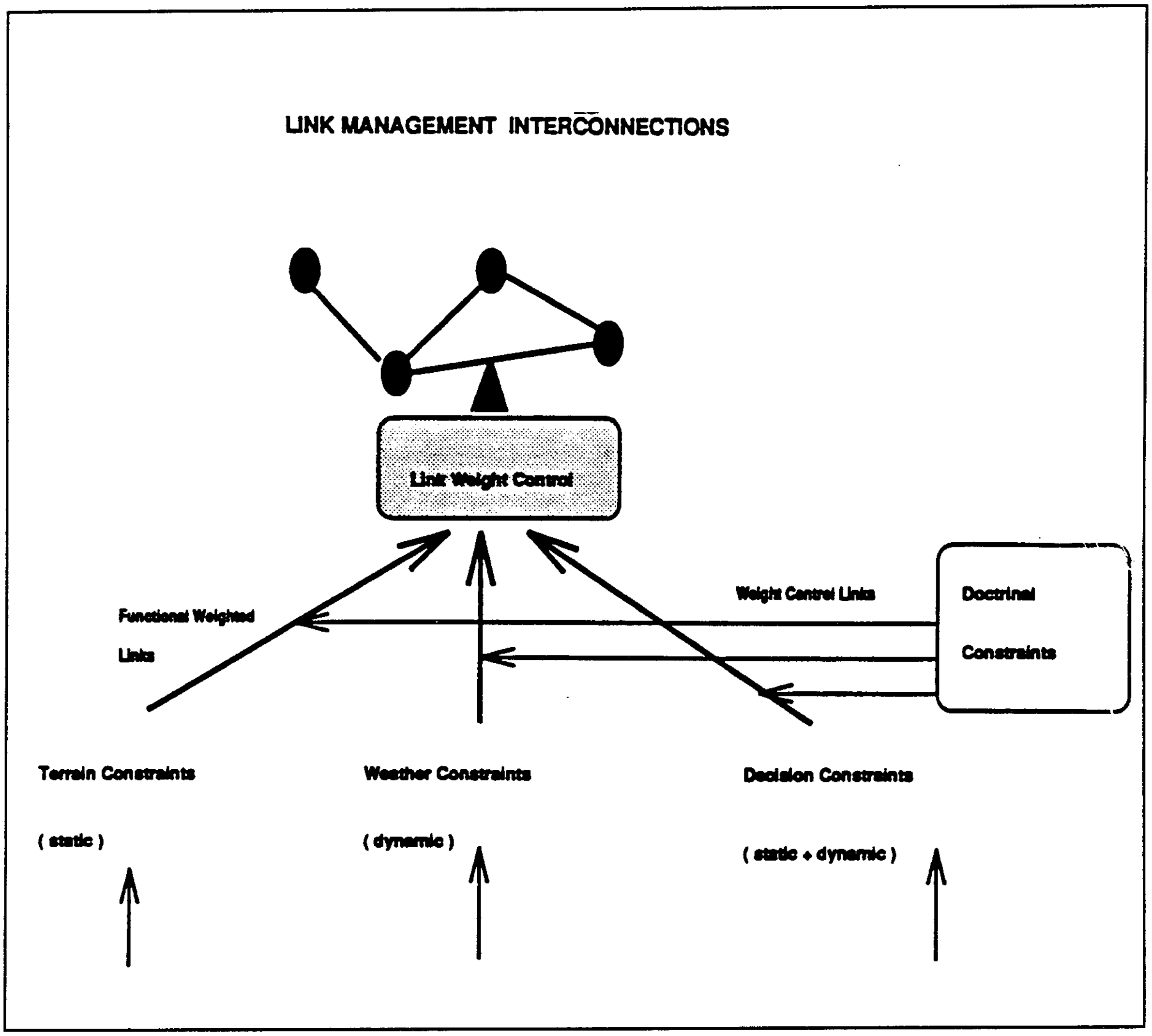

Figure 5. Relational data links between levels.

the asset movement issue. The interaction of activations through the weight matrices determines a set of activations for the terrain layer in which the intralayer connection strengths are mapped according to the fused activation from the other layers. The strength represents the cost function in the spatial dimension for asset movement. The cost function was derived from combining weather, terrain, and decision constraint information and the functional relationships to each other with the asset movement task in mind.

How can these task specific functional weight matrices be developed? The doctrine constraints are represented through the cost matrices. The constraints affect the functional relationships between the layers. The constraints hold basic relationship information between the weather, terrain, and other decision-dependent parameters. For asset movement, the strategy of moving assets from one place to another is applied to the functional weight links by the basic relationships. The doctrine constraints can be learned by the network by presenting prototypical situations or they can be encoded in the form of rules.

The architecture can be used for adding a different or new layer. Adding a new layer only requires a new set of intralayer weight matrices and a suitable set of functional relationships to be added between the new layer and the layers that already exist.

7.2 Reasoning With Past Performance

In many instances, the performance of one type of military asset varies between instances of that asset because of individual differences of the crews manning the assets and/or because of the characteristics of the asset itself. Variance is particularly true of intelligence collection assets. An important aspect of crews, that the system designers wish to capture, is the differences in experience of the crews. In assigning assets to a mission, there will be a large difference in the capabilities of an experienced crew versus an inexperienced one. The system designers also wish to capture the differences in individual assets to separate the assets that perform unacceptably because of mechanical considerations.

To capture the differences, the system designers propose to create asset performance histories that capture information relevant to each of the individual assets during the execution of its mission. The mission, weather and terrain conditions, crew, and individual asset information are recorded. When similar missions are being assigned, WADIF looks through the performance histories to find the assets that performed better than others. This knowledge allows the analyst to make recommendations as to the actual assignment of assets to the missions and provide more complete and justifiable performance analyses of the assets assigned.

7.3 Display of Reasoning Process

The reasoning process within TWIST incorporates terrain, weather, and doctrinal analyses as well as knowledge-base processing. At each point within the process, decisions based on multiple inputs are being made. A useful tool for the intelligence analyst would be to be able to display the inputs used at each decision point and the conclusion that was drawn through analyses. This approach allows the analyst to more fully use the mission information projected by TWIST.

8. Conclusion

The TWIST project has made significant steps toward providing time and labor-saving capabilities to the intelligence analyst staff. The utility of such a system was proven by the prototype system. In the future, increases in the scope and depth of knowledge available to the system will provide a more valuable tool for the AIPB process.

Acronyms and Abbreviations

AAA	Air Avenues of Approach
ADRG	arc digitized raster graphics
AI	artificial intelligence
AIPB	aerial intelligence preparation of the battlefield
BED	Battlefield Environment Directorate
IPB	intelligence preparation of the battlefield
TEC	Topographic Engineering Center
TWIST	Terrain and Weather IPB Software Toolkit
WADIF	Weather and Doctrinal Information Fusion

Appendix

Example WADIF Interface Program Using Mercury

This is an Example WADIF interface program using Mercury.

```
/*
** Main module
**
** File name: wad_main.c
**
** This module hides the main routine for WADIF.
**
** Depends on:
**      Mercury/interface/mw
**      Mercury/interface/mm
**      Mercury/interface/pg
**      Mercury/sgx/error
**      Mercury/utility/db_util
**
** Change log:
**      May 13, 1993    hdp
**          Modified to new format.
**
```

```
**      Jan 27, 1992    newberry
**          Created.
*/


#include <Xm/Xm.h>
#include "error.h"
#include "db_util.h"
#include "mm.h"
#include "mw.h"
#include "pg.h"


#include "wad_fm.h"
#include "am.h"
#include "ub.h"
#include "mission.h"


/*
 * Define the name of the program
 */
char *program = "WADIF";
```

```
/*
**  main
**
**  Assemble and start the WADIF GUI.
*/

void
main( argc, argv )
int argc;       /* number of arguments */
char **argv;    /* argument list */
{
    char *area;
    char *db_status;

    /* Setup from the environment
       - this routine MUST be called                                    */
    db_setup_env();

    /* Setup of main windowing environment
       - this routine MUST be called                                    */
    mw_create( &argc, argv );
```

```
/* Setup of 'File' menubar button
   - this routine MUST be called                              */
fm_create( mw_menubar() );

/* Create rest of the menubar buttons                         */
exec_create( mw_menubar() );
mt_create( mw_menubar() );
sym_create( mw_menubar() );
missm_create( mw_menubar() );
as_create( mw_menubar() );

/* Initialize of main windowing environment
   - this routine MUST be called                              */
mw_manage();

/* Gets the 'area of interest' from environment variables
   - can set this from input or hard code, if wish            */
area = db_get_db_area();

/* Loads area terrain                                         */
db_load_ter( area );
```

```
/* Loads area weather                                                    */

db_load_area_wea( area );


/* Turn on weather stations                                              */

toggle_stations();


/* Initializes error processing

   - this routine MUST be called                                         */

sgx_error_noise();


/* Initializes the overlay pics if using the 'Terrain' button            */

pg_init_pics();


/* Setup the map for each area of interest; below are the areas

   being setup according to available areas of interest:


   la view -     disp_set_view_home(33.0, 35.0, -119.0, -117.0 );

   fulda view -  disp_set_view_home(50.0, 52.0, 8.5, 11.5);

   korean view - disp_set_view_home(37.0, 37.5, 127.2, 127.6);

*/

db_view_home( area );
```

```
    /* Turn on the troops                                          */

    ub_on();


    /* Realize the windowing system and start event processing

       - this routine MUST be called                               */

    mw_start();

} /* end main */
```

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