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THESIS

**A DESIGN FRAMEWORK FOR COORDINATION SUPPORT
SYSTEMS**

by

LT Eric Scott Ringwall

March, 1992

Thesis Advisor:

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A Design Framework for Coordination Support Systems

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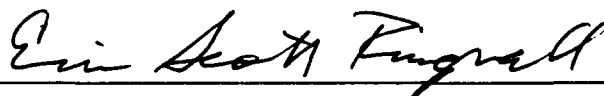
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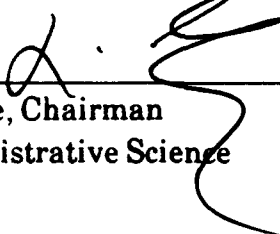
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ABSTRACT

The aim of this thesis is to develop a model for a coordination support system (CSS) based on a newly synthesized coordination theory and the group decision support system (GDSS) model proposed by Bui and Jarke (1986). Current coordination theory is reviewed and drawn upon to develop a new approach to coordination which is then applied to reach a generic CSS design by establishing modifications to the GDSS model module by module.

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TABLE OF CONTENTS

I.	INTRODUCTION	1
A.	RESEARCH OBJECTIVES	1
B.	BACKGROUND	1
C.	METHODOLOGY	3
D.	ORGANIZATION	3
II.	COORDINATION AND ITS ELEMENTS	5
A.	COORDINATION	5
B.	COORDINATION SYSTEMS	6
	1. Man-Machine Coordination	6
	2. Man-Machine-Man Coordination	7
C.	COORDINATION THEORY	8
D.	ELEMENTS OF COORDINATION	10
E.	THE ROLE OF COMMUNICATION IN GROUP COORDINATION EFFORTS	14
	1. Communication Dimensions	14
	2. Time-Space Taxonomy	16
III.	INHERENT COMPLEXITY IN COORDINATION: THE CASE OF COORDINATING ANTI-AIRCRAFT WARFARE	18
A.	BACKGROUND	18
	1. A Brief Description of Anti-Aircraft Warfare	18

2. Anti-Aircraft Warfare and the Elements of Coordination	21
B. HUMAN FACTORS	24
C. EXPECTED BENEFITS OF COORDINATION SUPPORT SYSTEMS	25
IV. THE FOUNDATION	27
A. THE GDSS MODEL	27
1. The Dialogue Manager	27
2. The Data Manager	28
3. The Model Manager	28
4. The Communication Manager	29
a. The Group Norm Constructor	29
b. The Group Norm Filter	29
c. The Invocation Mechanism	30
d. The IDSS-GDSS Formatter	30
B. A COMPARISON	30
C. SUMMARY	31
V. MODIFICATIONS TO THE MODEL	32
A. THE NATURE OF A COORDINATION SUPPORT SYSTEM . .	32
1. Selection Phase	32
2. Resource Allocation Phase	32
3. Schedule Generation Phase	33
4. Output Generation Phase	34
5. Monitoring Phase	34

B. OVERVIEW	34
C. THE GDSS MODEL REVISITED	35
1. The Revised Dialogue Manager	36
2. The Revised Data Manager	37
3. The Revised Model Manager	38
4. The Revised Communication Manager	39
a. The Group Norm Constructor	39
b. The Group Norm Filter	39
c. Information Formatter	39
(1) Environmental Input Data Conversion	39
(2) Resource Monitor Data Conversion .	40
d. Invocation Mechanism	40
VI. SUMMARY AND REVIEW	41
A. SUMMARY	41
B. JUSTIFICATION	43
C. ASSUMPTIONS	44
D. FURTHER RESEARCH QUESTIONS	45
LIST OF REFERENCES	46
INITIAL DISTRIBUTION LIST	49

I. INTRODUCTION

A. RESEARCH OBJECTIVES

The aim of this thesis is to develop a model for a coordination support system (CSS) based on a newly synthesized coordination theory and the group decision support system (GDSS) model proposed by Bui and Jarke (Bui and Jarke, 1986). Current coordination theory is reviewed and drawn upon to develop a new approach to coordination which is then applied to reach a generic CSS design by establishing modifications to the GDSS model module by module.

Additionally, the purpose of CSS, the expected benefits from their use, a sample rationale for developing such a system and the assumptions on which they are based are provided.

B. BACKGROUND

For many years computer hardware and software engineers have worked on achieving the smoothest and most efficient means of allocating scarce resources such as main memory, CPU time and peripherals. For this purpose, using various techniques such as process calls, hardware interrupts and input/output controllers have been exploited. Ideally, the machine coordinates all of its resources via an operating

system such that the user is presented with a tool that carries out all of the instructions provided.

Even in large distributed computer systems the user has traditionally been provided with a "virtual" machine that is his alone despite the fact that there may be literally hundreds of other people using the system simultaneously. The operating system coordinates the machine resources so well that the user does not even realize other users exist.

All of this has been accomplished in the absence of a coherent body of coordination theory (Malone and Crowston, 1990). Recent research in the fields of computer-supported collaborative work (Lim and Benbasat, 1990), distributed artificial intelligence (Shaw, et al., 1990) and organizational coordination methods (Crowston, 1991) indicates that machines will not only be used to coordinate their own activities, but the activities of users as well.

Only recently have users seen the potential to coordinate their own activities using a machine as a tool. This is evidenced by the recent popularity of office automation tools such as electronic calendars, notebooks, spreadsheets and the like. Several activities seem to lend themselves well to machine coordination. Some examples are decision support, office automation, meeting support and battle management systems. Coordination theory will most certainly prove vital to the further refinement of existing coordination systems and to the development of new ones (Malone, 1990).

C. METHODOLOGY

In order to develop a new approach to the design of a CSS, a review of current work in the areas of coordination theory, coordination methods, command and control organizations, crew decision making and distributed artificial intelligence (DAI) is conducted. From this review, a new coordination theory is developed reflecting a systems design perspective.

The utility of a CSS is discussed with respect to the expected benefits of such a system, particularly in the coordination of complex activities. One activity, the management of Anti-Aircraft Warfare (AAW) assets in a hypothetical carrier battlegroup (CVBG) serves as an example of a complex coordination activity throughout the paper.

Once the need for a CSS is justified, the foundation for building such a system, the GDSS model proposed by Bui and Jarke, is reviewed to provide the reader with a reference for the more detailed discussion to follow.

Finally, modifications to the GDSS model are proposed in order to form a generic CSS design.

D. ORGANIZATION

Chapter II provides a definition of coordination and a literature review covering coordination theory and other topics relevant to the development of coordination support systems. A new coordination theory is proposed for use in the design of CSS.

Chapter III discusses issues related to complexity in coordination and the strengths and weaknesses of human versus machine coordination of complex activities.

Chapter IV reviews the GDSS model proposed by Bui and Jarke (Bui and Jarke, 1986) and describes the functions of each module. This chapter provides the reader with a reference for the discussion in the following chapter.

Chapter V proposes modifications to the GDSS model that yield a model for a generic CSS.

Chapter VI provides a summary and review of the material covered, discusses assumptions made in generating the generic CSS model and poses questions for further research.

II. COORDINATION AND ITS ELEMENTS

A. COORDINATION

Before entering a detailed discussion of what coordination is and what it is not, it is best to give the word meaning in common terms. Coordination, as defined by Mooney (1947), is nothing more than "the orderly arrangement of group effort, to provide unity of action in pursuit of a common purpose." Or, more simply, the act of coordination involves the harmonious sequencing of events in order to achieve a specific goal (Random House, 1987). Coordination can be achieved by an individual, as in a well-coordinated athlete, or by groups, teams, crews and organizations. A less formal definition is given by Malone and Crowston (1990):

We all have an intuitive sense of what the word 'coordination' means. When we attend a well run conference, when we watch a winning basketball team, or when we see a smoothly functioning assembly line we may notice how well coordinated the actions of a group of people seem to be. Often, however, good coordination is nearly invisible, and we sometimes notice coordination most clearly when it is lacking. When we spend hours waiting on an airport runway because the airline can't find a gate for our plane, when the hotel room we thought had been reserved for us is sold out, or when a company fails repeatedly to capitalize on innovative ideas its researchers develop we may become very aware of the effects of poor coordination.

B. COORDINATION SYSTEMS

There are several types of computer systems that assist users in coordinating their activities. Some are designed to be used by a single user, while others are designed for multiple users. Some examples follow.

1. Man-Machine Coordination

Perhaps the most obvious instance of man-machine coordination is that observed on modern assembly lines. In the case of automobile manufacturing, humans work side by side with robotic welders and other machines in order to produce a steady stream of vehicles to meet production schedules.

On an individual level, many managers now make use of a decision support system (DSS) to coordinate their decision making processes. This computer-based system is typically constructed of a database, a model base and a user interface or dialogue. Via the dialogue a user stores and retrieves data; enters, updates, and modifies models; and manipulates data using the available models. The DSS provides a pattern or structure within which decisions are made.

The DSS coordinates the decision-making process by providing the user with the means to define a problem or decision situation, describe the environment by choosing and tailoring a suitable model, access the pertinent data as a resource and solve the problem. Using an iterative process, the user can further refine the models and data to increase

the accuracy of the solution or solve "what if" queries. The common "spreadsheet" program is a simple example of this type of system.

2. Man-Machine-Man Coordination

More often, however, it is necessary to coordinate the activities of a group of individuals. This capability falls in the arena of Group Decision Support Systems (GDSS) which allow groups to make decisions through the use of various decision techniques such as multiple-criteria decision methods (MCDM's) and consensus seeking algorithms. In addition to the forementioned components of a DSS, the GDSS has a communication component which facilitates the involvement of more than one member in the decision-making process. These systems are very complex and often have complex electronic messaging schemes and sophisticated graphical displays. For these reasons they are usually managed by trained facilitators. Trained facilitators play a crucial coordination role in group decision making. The GDSS Co-op, designed to aid groups in cooperative multiple-criteria decision making, is an example of such a system (Bui, 1987) as is the Interactive Management system (Biddle, 1991).

Office automation systems are also a common example of coordination systems. They are designed to aid in coordinating the activities of group members through various communication and scheduling tools such as e-mail and

electronic calendars. Wordperfect Office is an example of such a system (Coleman, 1991). Unlike GDSS, current office automation systems tend to serve as media for solely text-based information exchange.

Electronic Meeting Systems, such as that implemented at the University of Arizona (Nunamaker et al., 1991), aid groups in structuring meetings and information exchange.

Finally, battle management systems, which aid military commanders in tactical decision-making, are perhaps the ultimate coordination systems. Examples of existing systems are the Naval Tactical Data System (NTDS), which chiefly acts as a display of tactical information about radar and sonar contacts; and the Joint Operational Tactical System (JOTS), which is a PC-based information system that displays and manipulates information about contacts worldwide and provides software for the manipulation of various other data.

C. COORDINATION THEORY

There are a variety of coordination theories in the literature and it appears that an easily distinguishable body of knowledge about coordination has not yet been established (Malone and Crowston, 1990). Following are some of the more prevalent theories in the literature.

Shaw et al. (1990) in their work on Distributed Artificial Intelligence (DAI) suggest that coordination is vital to multiple-agent problem solving. Since each participant in the

problem-solving process has only a local view of the effort put forth on the project, coordination with other agents is necessary to reach solutions efficiently. Furthermore, Shaw et al. review several mechanisms used to coordinate multiple-agents in the problem solving process including:

- Coordination by Revising Actions - provides a plan of group actions such that all conflicts among group members are avoided.
- Coordination by Synchronization - regulates and controls the timing of interactions among group members to achieve solutions.
- Coordination by Negotiation - involves two-way communication to reach a mutually agreed upon course of action.
- Coordination by Structured Group Mediation - involves the use of structured group processes like the nominal group technique and the brainstorming process to arrive at a set of group actions.
- Coordination by Opportunistic Goal Satisfaction - employs the blackboard model for problem solving (Nii et al., 1989) wherein group members opportunistically contribute to the group solution process.
- Coordination by Exchanging Preferences - applies game theory to determine how groups should interact to achieve globally satisfactory solutions.

Each of these mechanisms is described in detail in his work.

Orasanu (1990), concluded in her research on aircrew decision-making that the use of certain types of communication aided the development of shared mental models (cognitive frameworks), and thereby enhanced decision-making performance and coordination.

Research by Stout et al. (1990) and Franz et al. (1990) revealed that certain behaviors including leadership, decision making, cooperation, communication and adaptability all led to superior crew coordination and performance.

In their work on command and control nodes Monguillet (1991) and Levis (1991) model decision-makers using the Petri Net Formalism and describe coordination as the interaction between decision making nodes.

Finally, Malone and Crowston (1990) propose a framework for analyzing coordination that decomposes the act of coordination into four component parts and their associated processes, see Table I. "Goals" correspond to the desired result of the coordinated effort. "Activities" are the individual actions that must be completed in order to achieve the desired "goal." "Actors" are the persons conducting the "activities." "Interdependencies" are the relationships between activities which govern their sequence.

All of these theories contribute to the field of coordination theory but none suggest methods of designing CSS.

D. ELEMENTS OF COORDINATION

In this thesis, coordination is decomposed in order to yield elements that are easier for the system designer to understand and use in the design of a CSS. To this end, six elements of coordination are proposed and described below. They are (i) outcome, (ii) environment, (iii) resources, (iv)

Table I: COMPONENTS OF COORDINATION

Components of Coordination	Associated Coordination Process
Goals	Identifying Goals
Activities	Mapping Goals to Activities
Actors	Selecting Actors/Assigning Activities to Actors
Interdependencies	Managing Interdependencies

time, (v) schedule and (vi) communication. Some of these elements have been written about previously by other authors but this set of six elements provides the CSS designer with a more designer-friendly framework.

An *outcome*, or goal, is the desired result of the coordinated event, its key objective. For an outfielder, it may be catching a fly ball; for an F/A-18 crew, it may be a successful bombing mission or for a construction crew, it may be the completion of a new building on schedule. Whatever the outcome, it must be identified before it can be coordinated. On a computer the outcome would have to be selected from perhaps several outcomes listed on a menu before the machine could proceed with the coordinating process. Malone and Crowsten (1990) use the term "goal" in place of outcome.

The *environment* must then be evaluated for conditions that may effect the coordination process. These conditions include, but are not limited to weather conditions, economic conditions, political conditions, even traffic conditions. It is important to note that the environment can not be controlled or directed by the coordination process but, in contrast, it can impact the coordination process in many ways. Environmental conditions include any externality that could effect the coordination process. Environmental sensors can be linked to a computer providing continuous information on elements of the environment important to the coordination process. Cheng (1983) supports the importance of the environment in the coordination process.

Resources are those elements which play an active role in achieving the selected outcome. In the previous examples they may be the number of outfielders, the number of bombs or the number of bulldozers and cranes. There are often many resources that must be considered in complex coordination processes, e.g. in landing a plane. Before landing, a myriad of resources must be checked such as the electro-hydraulic system, landing gear, flaps, rudders, tire rotation, availability of a runway etc. Without any one of these the successful achievement of the desired outcome may be severely impaired. Resources can also be linked to, or make use of, a computer to receive information and provide feedback.

Resources correspond to "actors" in the Malone and Crowsten (1990) framework.

Time is the fourth key element in the coordination process. The selected outcome must be assigned a time for completion or maximum duration, i.e. the outcome must have a due date or deadline. It may be determined that there is not enough time to achieve a particular outcome without sacrificing some intermediate steps, perhaps safety checks, or overriding default limits. If this is the case, a decision must be made to either cease or continue the coordination process. In some cases the deadline will be "as soon as possible" but this must be known for the coordination process to continue to the next step. Computers monitor the passage of time using internal clocks and can be programmed to generate alerts when certain time constraints are not met.

Once the outcome is determined, the environment and resources checked and a deadline assigned, a *schedule* can be generated that will guide the individual or group members toward the completion of the coordination process. In the case of a group or crew coordinated event, the schedule will have role specific task assignments for each person (resource) and make provisions for assignments to be carried out in parallel where possible or necessary. Schedule generation involves managing the "interdependencies" of Malone and Crowston (1990).

Finally, *communication* of the schedule, and feedback on the progress of the participants through the schedule, is required to effectively implement the coordination process. Aircrews commonly use checklists to help them through the coordination process. One member reads the checklist while the others verify that certain conditions exist then respond with verbal confirmations of compliance. Computers can communicate via network linkages with other computers and data sources (Fitzgerald, 1990). Without communication, the coordination process could not take place, in fact, some consider communication to be the key to coordination (Stoner and Freeman, 1989).

All of these six elements must be considered and built into the design of a coordination support system to make it effective.

E. THE ROLE OF COMMUNICATION IN GROUP COORDINATION EFFORTS

The importance of smooth communication in the coordination process cannot be overstated, it is fundamental to group work (Lim and Benbasat, 1990). Often environmental conditions and resources can be overlooked and time and schedule requirements can be adjusted but, without communication, the entire process will become ineffective.

1. Communication Dimensions

Group communication situations can be classified according to four different dimensions (Jarke, 1986): (i)

spatial distance, (ii) temporal distance, (iii) centralization of control and (iv) degree of cooperation.

Spatial distance refers to the actual distance between group members. Are they meeting in the same room or are they widely distributed and communicating via telephone, radio, computer, or videoconference?

Temporal distance refers to the time between inputs to the communication process. Are group members communicating one immediately after the other or are their inputs separated by days, weeks or months?

Centralization of control refers to the level of equality of the group members. Does one member have more power than the others or are all of their communications considered of equal importance?

Degree of cooperation refers to the communication style of the group. Are they striving to achieve a common goal or are they negotiating or debating a point?

These four dimensions must be considered by a CSS designer if his system is to be successful. For example, a CSS in which the resources are widely separated (spatial distance) must provide a means of communicating between the various remote locations. Also, if the CSS is to support asynchronous input by resources (temporal distance), the designer must implement the additional communication capabilities.

2. Time-Space Taxonomy

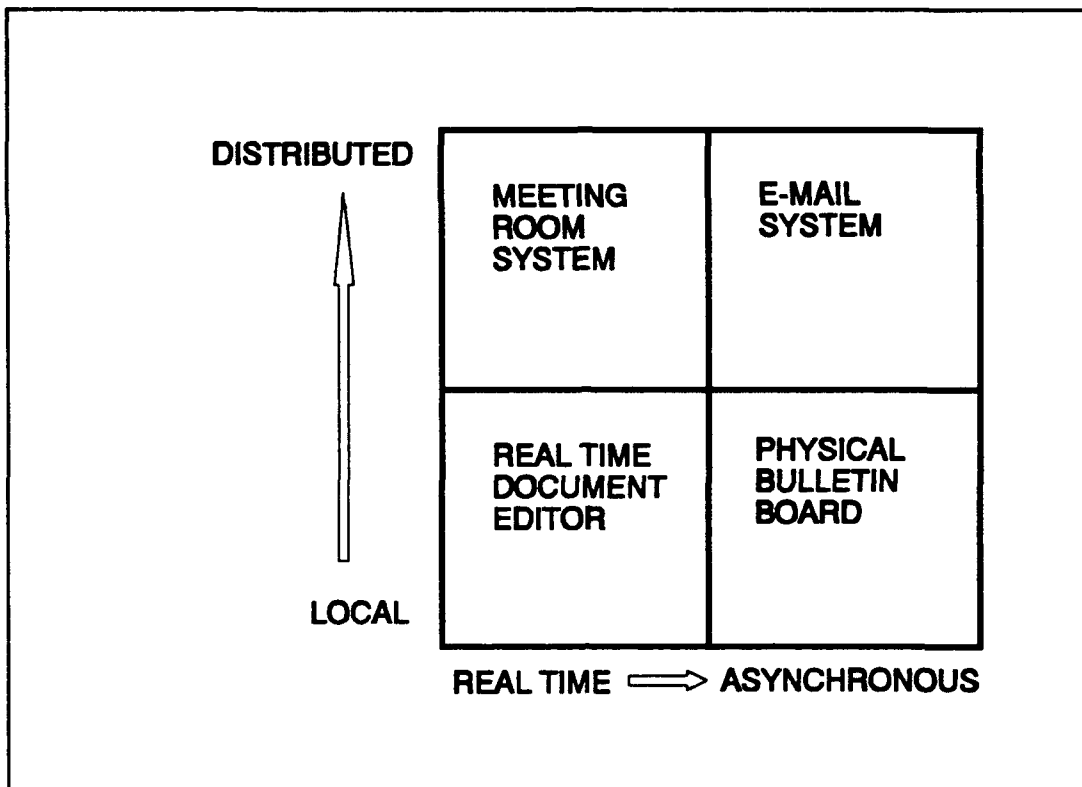


Figure 1 A Taxonomy of Groupware (Ellis et al., 1991)

Ellis et al. (1991) provide a diagrammatic taxonomy (Figure 1) expressing the differences between various types of "groupware" (software designed for use in group systems). The simple two-by-two matrix distinguishes between distributed and local group systems on one axis and between real-time and asynchronous group systems on the other. In the upper left quadrant, one would find an Anti-Aircraft Warfare CSS, in the lower left, a nuclear power plant CSS, in the upper right, a nationwide telecommunications trouble shooting CSS and in the lower right, a project management CSS. Each type of system

has its own communication requirements and a comprehensive CSS should be capable of exploiting them all.

III. INHERENT COMPLEXITY IN COORDINATION: THE CASE OF COORDINATING ANTI-AIRCRAFT WARFARE

A. BACKGROUND

1. A Brief Description of Anti-Aircraft Warfare

Anti-Aircraft Warfare (AAW) is a highly complex activity requiring sophisticated command, control and communication systems and the precise coordination of many widely dispersed participants. A simplified AAW scenario involving only the use of fighters and other tactical air assets will serve to illustrate the level of complexity frequently encountered in similar situations.

In order to provide the carrier battle group (CVBG) with an appropriate defense against hostile aircraft and anti-ship missiles, the Anti-Aircraft Warfare Commander (AAWC) must be able to detect, intercept and destroy enemy aircraft capable of firing missiles (missile platforms). In the case of some of the most threatening air-launched anti-ship cruise missiles this translates into a requirement that the AAWC have control of fighter aircraft resources with which to create a barrier capable of destroying airborne enemy cruise missile platforms before they launch their weapons.

Though the AAWC is not normally located aboard the aircraft carrier, he has the authority to direct the launch of alert aircraft in order to fulfill his requirements. Upon

doing so, the AAWC becomes responsible for the aircraft until it is safely back on deck. This includes keeping aware of vital systems status, weapons loadout, pilot condition and fuel status. The AAWC instructs the pilot on the direction and speed to the intercept point, the point at which the fighter could conceivably launch missiles to intercept the incoming hostile missile platform, what to do when he arrives at the intercept point, how long to stay there and when to return. Should a fighter fail to reach the intercept on time, the hostile aircraft could launch its cruise missiles unmolested and the likelihood of severe damage to the CVBG would increase greatly. It is this consequence that the AAWC must strive to prevent.

Based on the perceived threat at any given time the CVBG adopts a specific readiness posture. The AAWC designates the number of aircraft of each type (fighters, tankers, airborne early warning (AEW) aircraft) to have in various alert states based on the current readiness posture.

Accurate environmental inputs are critical to success. Among these are wind speed and direction, atmospheric conditions, cloud conditions, visibility, humidity, rain, snow, proximity to land, the current Rules of Engagement (ROE), precise position of the CVBG etc. Often these factors determine the ability to launch and land aircraft, sensor performance, aircraft engine performance, the ability to engage a target etc. Ignorance of these inputs may cause the

AAWC to needlessly endanger the safety of an aircrew or even the CVBG or cause an adverse political incident.

Initially, the AAWC is concerned with detecting enemy aircraft at a distance great enough to allow time for him to respond. He has various assets (resources) at his disposal to do this including but not limited to intelligence, long range air search radar, and AEW systems. Once an enemy is detected and classified, the time to weapons release must be calculated. This time is based on the position of the enemy relative to the CVBG, the classification and probable loadout of the enemy, the enemy course and speed, and the CVBG course and speed.

Next, the AAWC must determine the appropriate aircraft to conduct the intercept. Indeed, there may already be an aircraft airborne that could do the job. Consideration must be given to pilot fatigue, fuel status, equipment status etc. If the decision is to conduct the intercept with an aircraft that was returning to the carrier, it may be necessary to launch a tanker to provide in-flight refueling services to the returning aircraft before sending it out again. If the intercept must be made quickly due to a late detection, the increased fuel burn rate of the interceptor racing to the intercept must trigger the launch of a tanker as well. Timing is critical since battlegroup survival may be at stake.

Data regarding the weapons loadouts, cruise speeds, attack speeds, dash speeds, ranges, sensors, tactics etc. of

all enemy aircraft must be easily accessible. Likewise, corroborating historical data should also be accessible. Similar data about all friendly aircraft must also be maintained including alert status, engagement status, and launch delay status.

During periods of sustained high threat the AAWC promulgates a schedule that directs the employment of aircraft toward the end of CVBG defense. The schedule provides for regular launch and recovery of aircraft, their assigned stations, fuel requirements, and action to be taken if an enemy aircraft is detected.

Communication channels between the AAWC and all airborne friendly aircraft must be maintained in addition to the channel between the Battle Group Commander and the AAWC so that vital information can be shared. Often this is done using encrypted signals.

2. Anti-Aircraft Warfare and the Elements of Coordination

A rapidly changing *environment* can cause the coordination process to become complex by forcing the coordinator to reevaluate earlier choices and determine if they remain valid. It may also impede the initial decision to take action at all. For example, consider the AAWC's choice of the number of aircraft to have in a particular alert status. Should the political environment change, the corresponding threat readiness level of the entire CVBG may

change necessitating a change in the AAWC's alert requirements.

Having a large number of resources to monitor can also have a dramatic effect on the complexity of coordination. Monitoring a diversity of resources is a time consuming and confusing problem often involving parallel processing. For example, it is not uncommon for the AAWC to be monitoring three communication channels (AAWC-CVBG Commander/AAWC-Aircraft/ AAWC-AAW Capable Surface Ships), four displays (NTDS/Status Boards/Navigational Charts/Air Charts) and the status of dozens of aircraft. The volume of information flowing to one person often can not be assimilated quickly enough which results in information loss.

When events need to be coordinated on a real-time basis rather than over a long time span, the coordination process is more complex. This is due to a distinct lack of time to follow the decision processes necessary to make or modify schedules. Often the achievement of a particular outcome is desired in a relatively short time span, as in the proper handling of a surprise missile attack. There is little time during an emergency to coordinate group actions, think about what must be done and issue instructions. To improve coordination, pre-planned responses to particular situations are developed and practiced regularly so that they may be performed swiftly and safely when required.

As the interdependence of events increases, so does the complexity of the coordination process (Cheng, 1983). The communication overhead required to monitor interdependencies often slows the coordination process and the generation of *schedules*. For example, the choice of an aircraft to conduct an intercept is dependent on the type of enemy aircraft, its loadout, speed and range, the time to weapons release distance, the availability of fighters and tankers, their loadout, systems status etc. Highly interdependent events form virtual bottlenecks in the coordination process, see Figure 2. See Malone and Crowston (1990) or Crowston (1991) for a treatment of the types of interdependence.

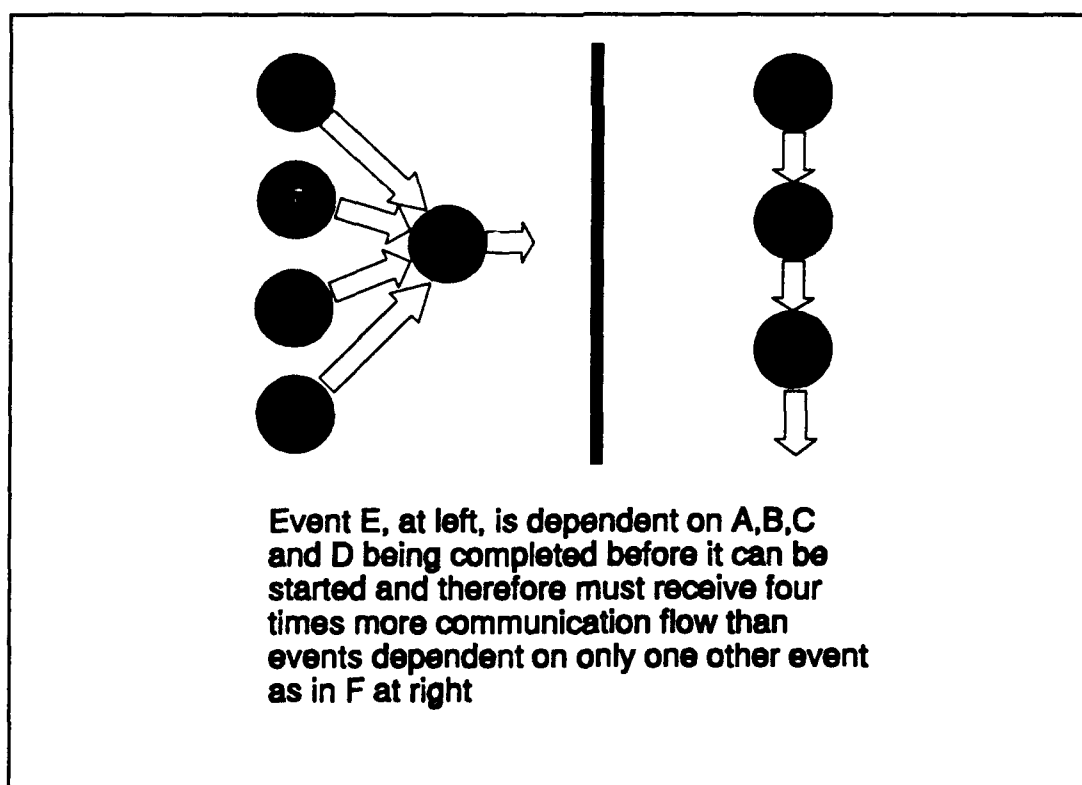


Figure 2 Interdependent Events

Difficulty in *communication* can also impede the coordination process by halting the flow of information between group or crew members. When information flow is disrupted it becomes impossible to coordinate interdependent events and to monitor resources or the environment. Without radio contact, the AAWC would find it nearly impossible to coordinate the actions of his many resources for any reasonable length of time. In practice, he is confined to the use of pre-planned responses.

B. HUMAN FACTORS

These were just a few isolated samples of causes of increased complexity in the coordination process. The reality is in fact even more complex. All of this complexity can cause a coordinator to become overwhelmed which ultimately leads to failure to achieve the desired outcome.

Typically decision-makers become overwhelmed when they are unable to assimilate information at a high enough rate or they do not know what to do with the information they have. In essence, they become input/output (I/O) bound and are unable to process the information they are receiving. When this happens, decisions are made on a primarily subjective "gut feeling" basis and therefore can be partially or wholly illogical.

Humans can also be tired, bored, anxious, impatient, angry, ill etc. and their performance is often affected by their current disposition.

Battle management in a multi-threat environment is often an overwhelming situation. A ship tasked with defending itself against hostile surface, air and submarine attacks simultaneously must collect, evaluate and make decisions based on an enormous amount of information; all on a real-time basis. The entire process is often described as "managed chaos" and requires a well-practiced team to prevent a disastrous failure in the defense.

C. EXPECTED BENEFITS OF COORDINATION SUPPORT SYSTEMS

Given that events can become extremely difficult to coordinate and the fact that they often must be coordinated despite their complexity, avenues of alleviating some or all of the difficulty must be sought. Since machines have capabilities to complement or augment those of humans, they are a logical choice.

First, they are capable of being programmed with the routines to handle a large number of desired outcomes. This relieves the human coordinator of the responsibility for maintaining checklists and memorizing procedures. The routines will be executed smoothly and efficiently without skipping steps. Additionally, these routines are infused with the knowledge of experts in the specific field and would

therefore prescribe actions that the novice may overlook or deem unimportant.

Second, machines are capable of continuously monitoring vast amounts of incoming data from environmental sensors. The machine can be programmed to take specific actions when certain limits are triggered by the incoming data flow. Machines are rarely "overwhelmed" by excessive data flow and therefore are not as prone to information losses.

Third, machines can monitor resources continuously and tirelessly. A machine will not become tired, bored, angry or ill.

Fourth, a machine can process data on a real time basis without becoming confused by data flow. Program execution rates far outpace the rate of human cognition in routine information processing.

Last, machines can manage and provide for communications between members of a group or crew, even on a decentralized, asynchronous basis. NTDS is an existing example of this technology.

Given these capabilities, it appears that a coordination support system could indeed simplify the coordination process by off-loading many responsibilities of the human coordinator thus allowing him to concentrate on the more important parts of the process. The remainder of this thesis proposes a model on which to base the design of a generic CSS.

IV. THE FOUNDATION

A. THE GDSS MODEL

Because the design of the GDSS is so flexible and it already provides many of the functions necessary to implement a coordination support system, the current GDSS model will form the foundation for our further study. Sprague and Carlson (1982) proposed a fundamental DSS architecture composed of three main components: (i) the dialogue manager, (ii) the data manager and (iii) the model manager. Each was discussed briefly earlier. Bui and Jarke proposed an additional fourth component fundamental to a distributed GDSS, the communication manager. Each component will be examined in detail below.

1. The Dialogue Manager

The dialogue manager provides the user interface function for the GDSS. As an interface feature, there are several possible styles. Among them are: (i) command language, (ii) menu, (iii) formatted form and (iv) prompt (Awad, 1988). The dialogue of any given system may use one or more of these styles to interface with the user and allow him to make use of the database, model management and communication functions of the GDSS.

2. The Data Manager

The data manager provides the functions of a database and a database management system (DBMS) for the GDSS. According to Kroenke and Dolan (1988), a generic DBMS performs the following functions: (i) store, retrieve and update user data, (ii) store, retrieve and update meta-data, (iii) enforce data integrity rules and constraints, (iv) enforce security constraints, (v) provide coordination and control facilities for multi-user processing and (vi) provide facilities for system backup and recovery. In addition, the DBMS must be capable of handling both internal and external data. All of these functions are required by the GDSS and the user can invoke, setup or make use of them through the dialogue.

3. The Model Manager

The model manager gives the user the ability to explore a problem completely by developing and comparing alternative solutions (Sprague and Carlson, 1982). There is a model base, which is composed of a set of analytical models, equations and algorithms and a modelbase management system (MBMS) which provides DBMS-like functions for the model base. Four basic functions of the MBMS include: (i) generation of models, (ii) restructure of models, (iii) update of models and (iv) report generation and inquiry (Sprague and Carlson, 1982). The models have access to data in the database via the

DBMS and can generate solutions to inquiries posed on a regular or ad hoc basis.

4. The Communication Manager

Finally, the communication manager proposed by Bui and Jarke is composed of four main parts: (i) the group norm constructor, (ii) the group norm filter, (iii) the invocation mechanism and (iv) the IDSS-GDSS information formatter.

a. The Group Norm Constructor

The group norm constructor is used to define group members, communication channels and group decision rules. This is achieved through a group leader or facilitator collecting information according to a checklist. User identification, communication methods and decision models are specified explicitly so that all users and the system have a common reference.

b. The Group Norm Filter

Once this information is entered into the group norm constructor, it is compiled into a set of instructions called the group norm filter. The purpose of the group norm filter is to enforce the protocol defined using the constructor. Specifically the group norm filter performs three functions: (i) grants access to users based on identification and password and warns users of upcoming decision deadlines, (ii) monitors all user data transfers, ensuring they are in accordance with the established protocol

and (iii) monitors the computation of the group decision results by the model manager. Via these functions, the group norm filter ensures the decision process proceeds as defined.

c. The Invocation Mechanism

In order to provide a degree of flexibility to the functions of the communication manager, the invocation mechanism was designed to enable the group to request and make modifications to the protocol defined using the group norm constructor. In this manner the protocol can be partially redefined during the decision process; to add another group member for instance. Since members must approve changes before they are made, the invocation mechanism also provides a means of notifying and convening members to make such a decision.

d. The IDSS-GDSS Formatter

Finally, the IDSS-GDSS formatter enables the GDSS to communicate with other IDSS in a distributed system by supplying the appropriate data conversion protocols. Without this ability, a distributed GDSS would not be possible.

B. A COMPARISON

To alleviate some of the confusion caused by the varied terminology used in discussing coordination theory and systems, Table II provides a simple comparison.

Table II COMPARISON OF TERMS

MALONE/CROWSTON	CSS	GDSS
GOALS	OUTCOMES	GROUP NORM CONSTRUCTOR
	ENVIRONMENT	
ACTORS	RESOURCES	GROUP NORM CONSTRUCTOR
	TIME	GROUP NORM CONSTRUCTOR
ACTIVITIES/ INTERDEPENDENCIES	SCHEDULE	GROUP NORM FILTER/ INVOCATION MECHANISM
	COMMUNICATION	GROUP NORM CONSTRUCTOR/ INFORMATION FORMATTER

C. SUMMARY

Having outlined the component structure of a generic GDSS and discussed the functions of each part, it is easy to see how the generic GDSS will provide a suitable foundation for a coordination support system. In order to construct a generic CSS, however, some modifications must be made to each of the components . These are the subject of the next chapter.

V. MODIFICATIONS TO THE MODEL

A. THE NATURE OF A COORDINATION SUPPORT SYSTEM

Before delving into the design specifics of a CSS, a discussion of how a CSS would be used might greatly assist the reader in understanding the design rationale proposed in later sections of this chapter.

1. Selection Phase

Faced with the responsibility for coordinating a particular activity, the user would begin his interaction with the CSS by selecting from a menu or outcome library the particular outcome that corresponds to the activity he wishes to coordinate, e.g. intercept a hostile aircraft etc. Each CSS would have a domain similar to that found in expert systems (Sol, 1987). The domain is the description of the set of outcomes the CSS is designed to handle. This initial phase is known as the selection phase. Here the user selects an outcome which in turn invokes a specific program branch that deals with the outcome the user specifies.

2. Resource Allocation Phase

Once an outcome is selected, an activity specific program is invoked. The user will then be prompted to give the system necessary information about resources, environmental inputs, time constraints and communication

channels. The user must define such items as the number of human resources and their roles, non-human resources, environmental inputs, the deadline for completion of the outcome and the communication channels for all resources and environmental inputs. Depending on the CSS some of the resources, environmental inputs and communication channels may have default values and others may be permanently assigned. The important issue is that the CSS be able to communicate with all resources and receive pertinent environmental information. The entry of this information concludes the resource allocation phase.

3. Schedule Generation Phase

Information entered during the resource allocation phase is now passed to the schedule generator which uses optimization models, heuristic and mathematical analysis and logical algorithms to generate resource specific and contextually sensitive schedules for use in coordinating the activity requested by the user. Generic models and algorithms would be part of the CSS modelbase whereas activity specific models would be a component of the activity specific program.

Each schedule would be resource specific and composed of schedule elements, or tasks, to be completed by a specific deadline. Only those items that the machine is not capable of doing would be part of the schedule. Warnings would be

generated whenever insufficient time precluded completion of the coordination process.

4. Output Generation Phase

The CSS would now take the output from the schedule generation phase and communicate it to the resources previously defined. These outputs may take the form of electro-mechanical instructions to devices capable of digital control, messages sent via network or modem to remote human resources, printed instruction sheets, screen instructions, alerts or even synthetic voice commands. The output is the link by which the CSS directs the actions of the resources in order to coordinate the desired activity.

5. Monitoring Phase

Finally, the CSS would monitor the assigned communication channels for feedback from resources indicating completion of schedule elements. The CSS would also provide alerts to the resources as appropriate indicating impending deadlines and/or overdue schedule elements.

An additional feature of the system would be a mechanism to change elements of the resource allocation phase at any point in time so that new resources or inputs could be added or old ones deleted.

B. OVERVIEW

In summary, the user first selects a desired outcome, to intercept a hostile aircraft for instance. He then defines

the environmental inputs (wind speed, ship's navigational inputs, radar etc) and the communication path the CSS is to make use of to receive all pertinent data (COMM 1). Next he defines the various resources such as the AAWC, airborne fighters, alert fighters on deck, tankers, AEW aircraft etc and the communication channels assigned to them (e.g. video display, NTDS, voice radio). Finally a desired time of intercept, or in this case a range is sometimes more appropriate, is provided to the system. To assist the user in the resource allocation phase, the system would provide default values and the capability to save previous setups.

The CSS would subsequently generate directions in the form of schedules for each resource involved in the intercept process based on previously programmed heuristics and the input it receives on the communication channels it monitors. The system can even be programmed to request data it needs to complete its analysis. Once the schedules are communicated, the CSS would monitor resource communication channels for feedback on progress through the schedule (interceptor launched to station One Two Delta etc).

C. THE GDSS MODEL REVISITED

From the previous discussion, the reader can see that the GDSS model described in Chapter IV provides a logical foundation for modeling the proposed CSS since it already provides many of the required functions. Required

modifications to the GDSS model are the subject of the following sections.

1. The Revised Dialogue Manager

The functions of the GDSS dialogue manager would not differ much from those of the usual GDSS user interface: (i) provide the user with a representation of the system and (ii) provide the user with a means of controlling the system (Sprague and Carlson, 1982). A good dialogue is essential to the system for if it is unfriendly or obscure, the system may be rejected entirely by the user (Awad, 1988).

Specifically, the dialogue would need to enable the user to perform the following functions:

- Select an outcome from a list or library of supported outcomes. (Menu)
- Define environmental inputs, resources, time constraints and communication channels. (Formatted Form)
- Respond to alerts, error messages and acknowledgements. (Prompt)
- Issue instructions to the database, modelbase and communication managers via the invocation mechanism. (Command Language)

As noted parenthetically above, the dialogue style would be a mixture of the common forms. All of the styles are within current state-of-the-art dialogue design capabilities.

The display of data, whether textual or graphical, is another function of the dialogue manager that must be carefully implemented to ensure user acceptance of the CSS.

2. The Revised Data Manager

The data manager must be capable of fulfilling all of the requirements delineated in Chapter IV. Of paramount importance is the ability to support multiple environmental inputs and resources in a distributed CSS. This implies several capabilities including:

- Send and receive data to and from multiple resources
- Receive data from environmental inputs
- Encrypt/decrypt data for security
- Store, retrieve and update internal data
- Manage data buffers and queues
- Interface with dialogue manager for the display of data
- Store default values and communication setups
- Store transaction reports for post-action analysis

As can be seen, the data manager provides many vital functions to the CSS and the design must be correspondingly robust.

It is conceivable that several resources may desire access to data maintained in the CSS which implies that the generic CSS data manager be capable of managing a distributed database. Many issues related to data security and control are involved in designing a distributed database, see Kroenke and Dolan (1988) for a thorough discussion.

3. The Revised Model Manager

The model manager is to perform the function of the schedule generator and therefore will be designed to manage schedules, schedule elements and their related interdependencies. The four basic functions then become schedule generation, restructure, update and report generation/inquiry.

The schedules are to be coded in the same fashion as the heuristics coded in the knowledge acquisition process used in expert systems development (Hayes-Roth, 1983). Experts in the fields of interest are interviewed and their knowledge is captured as a set of heuristic rules. In the CSS case, these rules would reflect the best way to coordinate a particular event. Restructure and update of the rules must be possible to accommodate differences between the ideal "classroom" situation and the often less-than-ideal "real-world" situation.

Additionally, the model manager must provide for the interface with the dialogue, data and communication managers. Data from the environmental inputs and resources must be available to the model manager so that it may monitor the coordination process.

Schedules for AAW might include one for intercepting hostile aircraft, one for downed aircraft search and rescue (SAR), one for launching and maintaining a defensive barrier, etc.

4. The Revised Communication Manager

a. The Group Norm Constructor

The group norm constructor (GNC) provides the means for defining the coordination elements appropriate to each outcome. Once an outcome is selected, a form would appear on the screen with blanks to fill in regarding environmental inputs, resources, communication channels, and time constraints. Default values would be listed where appropriate. Once all inputs were provided the communication manager would send the data to the schedule generator for compilation.

b. The Group Norm Filter

The group norm filter grants access to the CSS, enforces the protocol defined in the GNC and monitors the schedule generation process. This means that all communications take place only between the elements specified and on the channels defined in the GNC.

c. Information Formatter

(1) *Environmental Input Data Conversion.* The variety of possible input types requires that a module be specified for the purpose of converting various input types into data streams useable by the model manager and the data manager. Examples include analog to digital conversion and data formatting. This module will vary in size and complexity with the domain of the associated CSS.

(2) *Resource Monitor Data Conversion.* Since resources also communicate directly with the CSS, data conversion similar to that explained above must also take place for both inbound and outbound data streams. Depending on the resource, the CSS may send instructions in the form of text or digital signals for example.

d. *Invocation Mechanism*

The invocation mechanism is designed to be able to modify the protocol defined in the GNC after the coordination process has begun. For instance, suppose an interceptor loses its ability to communicate or has another mission critical failure, the invocation mechanism would allow the user to interrupt the coordination process, enter information on a substitute aircraft, and re-initiate the process. In a similar fashion communication channels and environmental inputs could be changed, added or deleted.

VI. SUMMARY AND REVIEW

A. SUMMARY

In developing a fresh design for a computer system it is prudent to first survey existing systems that have common design features. This study examined the designs of DSS, GDSS, OAS and EMS technologies to determine their suitability as a foundation for developing a generic CSS. None of these designs had all of the required features but one, the GDSS, came very close.

Next, the activity of coordination was studied and decomposed into its elements of: outcome, environment, resources, time, schedule and communication. It was determined that each element must be built into the CSS at the design stage before proceeding.

The vital role played by communication in the coordination process was discussed. Noted were the key communication dimensions spatial distance, temporal distance, centralization of control and degree of cooperation. A time-space taxonomy of group systems was provided to lend perspective.

A great many factors can increase the complexity of the coordination process. Examples were provided showing it is likely that as the environment changes, the number of resources varies, the time to coordinate events decreases, the

interdependence of events increases and the difficulty of communication increases, events become much more difficult to coordinate.

Human factors such as subjectivity, inability to parallel process, slow data assimilation and irrationality can also affect the coordination process.

Some advantages of a CSS were described such as faster information processing, parallel processing, resource management capabilities, automated input from several sources, and quality of information output.

As a starting point, the GDSS architecture proposed by Bui and Jarke was used to describe the foundation for a CSS. Each component of the dialogue manager, data manager, model manager and communication manager was described in order to give the reader a common reference point when discussing the design of the proposed CSS.

Before outlining the structure of the CSS a five phase framework was developed to provide a system description. The phases were labelled selection, definition, schedule generation, output and monitor. A discussion of the five phases helped the reader understand the function and scope of a CSS.

Finally, the actual modifications to the GDSS model required to design a generic CSS were examined component by component. Each modification was proposed to better support the coordination process and the development of a CSS.

B. JUSTIFICATION

To undertake the actual design and implementation of a CSS would require an investment proportional to the size and scope of the desired system. In order to establish the utility of a CSS, and therefore to help justify the investment, it is useful to analyze system requirements with respect to the six elements of coordination. The answers to some basic questions will help to begin the analysis:

- To what extent are the outcomes of the proposed CSS recurring requirements? The more recurring the requirement, the more often the system will be used.
- To what extent can environmental inputs provide automated input to the system? The greater the number of automated inputs, the less data acquisition and assimilation required of the human coordinator.
- To what extent can resources be controlled, messaged and/or provide feedback electronically? The closer the control, the more efficient the coordination.
- What are the time constraints of the desired coordination process? The shorter the allowable time to complete the coordination process, the more effective the system.
- To what extent can the coordination process be premeditated, i.e., is there a "best" way to sequence the schedule elements? The more it can be premeditated, the greater the effectiveness of a CSS.
- To what extent can communications be established between environmental inputs, resources and the CSS? The greater the number of linkages, the greater the utility of the system.

From the answers to these questions a general feel for the utility of a proposed CSS can be sensed. If it is subsequently determined that the proposed system is worth the

estimated investment, there are several possible benefits of its implementation. Among them are:

- Faster Coordination of Events - due to the computational speed of the computer, the rapidity of electronic communications and the increased rate of data assimilation.
- More Efficient Coordination of Events - due to the reduced amount of time and effort required to prepare and coordinate an event when using a CSS.
- More Effective Coordination of Events - due to the incorporation of expert knowledge, the schedule generated for execution will be of higher quality than one generated by novices.
- Improved Analysis of the Coordination Process - due to the ability to save all system transactions for later retrieval and review.
- Improved Allocation of Slack and Scarce Resources - due to the automated monitoring of resource capabilities.

These are only a few of the more obvious benefits of implementing a CSS, others, including the more efficient use of resources and the development of competitive edge, certainly exist. Each application developed would most likely have a unique set of benefits.

C. ASSUMPTIONS

Certain assumptions were made in the process of developing a generic CSS design. Among them that there is a best way to coordinate an event and, that expert knowledge can be acquired and reduced to code for implementation in a CSS. The first assumption implies that, given a set of selection criteria, an

expert or team of experts could select from a set of possible sequences of schedule elements, the sequence that is least wasteful of time, resources, and effort. The second assumption is supported by many works in the field of expert systems and has been the guiding principle in their development (Davis, 1982).

D. FURTHER RESEARCH QUESTIONS

The theoretical design of any system is only the very beginning of its implementation. This thesis was intended to be the very beginning. There are still many questions about CSS left unanswered. Some include:

- Which types of events would benefit most from coordination using a CSS?
- What is the best way to manage interdependencies within the schedule generator?
- Could a coordination system that learns be developed?
- To what extent would a robust CSS alleviate the need for training?
- What contribution to the development of CSS will come from the study of social sciences?

While this thesis has only scratched the surface of the many issues surrounding CSS development, it has provided a useful framework within which to perform the design and analysis of coordination systems. Further research into the lower level design of the individual modules will yield great benefits.

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