# NAVAL POSTGRADUATE SCHOOL
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# THESIS

**EVALUATION OF POTENTIAL DSS TOOL FOR BDF_HQ MANPOWER AND OPERATIONAL EQUIPMENT RESOURCE PLANNING**

by

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June 2003

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This thesis explores the Bahrain Defense Force (BDF) needs for a decision support system in the area of analyzing, establishing and maintaining the organizational structures of BDF units. It also identifies the BDF measures that must be taken to qualify a certain unit structure.

Subsequently, the thesis designs and develops a specific DSS prototype that can aid BDF decision makers and planners perspectives in this area. Creating this prototype has involved three different layers to be investigated: the data, the models and the user interfaces. The data layer consists of a Microsoft Access™ database application that houses BDF Units, Manpower, Vehicles, Weapons, Salaries, and Jobs information. The model layer consists of two Microsoft Excel™ spreadsheets that contain Infantry Battalion and enhanced Armor Battalion HR optimization models. The UI layer consists of user controls, input/output forms, queries, reports, and visualization aids (i.e. charts and pivot tables). These interfaces were developed using MS Access capabilities. Consequently, the BDF_DSS is an integration of database and optimization technology using widely available desktop tools.

The general benefits of this DSS are reduced costs for data gathering, computation, and data presentation, and added value resulting from investigating more alternatives, doing more sophisticated analyses of alternatives, using better methods of comparing alternatives, and making quicker and better decisions.

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# EVALUATION OF POTENTIAL DSS TOOL FOR BDF_HQ MANPOWER AND OPERATIONAL EQUIPMENT RESOURCE PLANNING

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# I. INTRODUCTION

## A. BACKGROUND

Given the complexity of military organizational structures and the need to establish modernized military forces, BDF decision makers or planners require database technology to support the processes of analyzing, establishing and maintaining different kinds of BDF organizational structures. For instance, during the study phase, and before approving a proposed BDF unit organizational structure, BDF-HQ needs to know the estimated fixed cost and the running cost in establishing and maintaining such a unit. Also, BDF-HQ needs to compare all cost drivers of a proposed unit to other existing units which would generate more choices for BDF-HQ decision-makers.

Currently, the BDF current system of doing such processes is done manually and indeed there are many associated anomalies to that system which sometimes impair the growth of BDF in different aspects. Consequently, and as an illustration of the required decision support tool, this research involves building and prototyping a database and associated decision model to support the following BDF requirements:

1. To build an organizational structure and establishment satisfying manpower and operational equipment requirements (vehicles and weapons) of an organization.
2. To track and highlight the vacancies and requirements of the new and existing organization.
3. To compute the estimated operational cost of establishing and maintaining a unit.
4. To compare the cost of maintaining two or more units in an organization.
5. To illustrate a current BDF unit situation with respect to actual cost vs. budgeted cost.
6. To illustrate the BDF overall situation with respect to actual cost vs. budgeted cost.
7. To support decision makers and planners in BDF-HQ for effective and efficient resource planning with respect to manpower and operational equipment.

## B. OBJECTIVE AND RESEARCH QUESTIONS

The objective of this research is to define, design and implement a prototype version of a decision support system (DSS) that addresses the Bahrain Defense Force (BDF) requirements for analyzing, establishing and maintaining the organizational structures of BDF units. The DSS will combine database technology and optimization models.

The primary research question with respect to this objective is to determine the appropriate design heuristics in terms of data, models, and user interfaces for a system to support decisions about the creation and maintenance of organizational structures in the BDF. There are also several subsidiary research questions:

1. What are relevant performance metrics for maintaining BDF organizational structures of manpower and equipment?
2. What database architecture is required to support such a DSS tool?
3. What analytical models are appropriate for developing robust cost models? How can software systems supporting such models be integrated with the database architecture?
4. What visualization tools and user interfaces are appropriate for supporting decision makers using this DSS?

## C. SCOPE

The scope of the thesis will include:

1. Identification of the current processes of analyzing, approving and maintaining a BDF unit organizational structure.
2. Identification and prototyping a suggested database model and DSS interface that would satisfy a critical mass of BDF requirements and objectives.
3. Identification of alternative solutions to such a DSS tool.
4. Only a prototype will be developed, which can be used to generate requirements for a full operational system. It is beyond the scope of this thesis to develop an operational system.

## D. METHODOLOGY

The methodology used to fulfill the requirements for this thesis will consist of the following steps:

1. Conduct a literature review of books, professional journals, magazines articles, web-based materials, and other library information sources. The reviews will address topics on decision support systems, database technologies, operations research, human resources, costing models, cost-benefit analysis, and military organizational structures.

2. Gather sample data from Planning and Organization Directorate on several existing and proposed organizational structures of BDF units to examine the functions needed in the proposed system.

3. Identify user interface requirements by interviewing key users in POD (the intended DSS users). The GUI requirements will be in terms of input controls as well as output displays such as reports, queries, "what if" capabilities, and other visual displays.

4. Design underlying database schema that has a complete logical view of the database using a software application called Visible Analysis. Once the database schema is created and analyzed (normalized), it can then be converted to the desired database application such as Microsoft Access.

5. Identify and build associated cost models using simulation, what-if analysis, and/or optimization (linear programming) models.

6. Build a standalone database prototype in Microsoft Access in which can be easily migrated to a client-server database in the future.

7. Design and implement user interfaces.

8. Test prototype system.

## E. PRIMARY BENEFIT OF THE STUDY

This thesis will develop a prototype DSS tool for manpower and operational equipment resource planning in support of BDF_HQ decision makers and planners.

Specifically, this thesis will propose a DSS application which can provide the BDF better vision in planning for its current and future organizational structures. The prototype can serve as a preliminary requirements specification for a fully operational system in the BDF.

## F. THESIS ROADMAP

The coming chapters will address the following subjects:

1. Chapter II will provide an overview of the current BDF system of maintaining its organizational structures of manpower and equipment that identifies processes of analyzing, approving and maintaining those organizational structures. This chapter will also address relevant performance metrics used to evaluate BDF organizational structures of manpower and equipment, and finally will discuss the current system and factors that have led to its suboptimal performance.

2. Chapter III will discuss a database design that satisfies the critical mass of BDF requirements and objectives described in the first chapter.

3. Chapter IV will develop and illustrate examples of optimization models that can be linked to the database model to provide the requisite decision support.

4. Chapter V will discuss the prototype that has been developed with emphasis upon the user interfaces such as input/output forms, queries, reports, and model "what if" analyses.

5. Finally, Chapter VI will conclude the research and include recommendations for future research. Furthermore, the core benefits of applying such a tool will also be discussed.

# II. OVERVIEW OF THE CURRENT BDF SYSTEM OF MAINTAINING ORGANIZATIONAL STRUCTURES FOR MANPOWER AND EQUIPMENT

## A. INTRODUCTION

The BDF builds organizational structures to include all manpower and operational equipment resources that will be allocated to a unit. The resources of operational equipment in a unit are weapons, vehicles, and communication instruments. However, the request to study major changes in the organizational structure of an existing unit or establishing new ones gets initiated by the BDF top-level positions (i.e. Commander in Chief (CINC), Minister of Defense (MOD), Chief of Staff (COS)…etc) for many reasons:

1. BDF needs to develop the organizational structure of its forces according to a potential external threat that has arisen to the homeland.
2. BDF needs to reorganize its forces to be compatible with its friendly forces structures.
3. When BDF plans to receive recent operational equipment (i.e. tanks, ships, weapons, radars…etc).
4. Or when the original mission assigned to a unit has changed and/or expanded in such a way that the current organizational structure of that unit does not match with the new mission.

In addition, all proposed structures must be presented to the HQ officials before approval. Thus, it is important that the process of creating organizational structures have computer-based tools that provide accuracy, efficiency and predictability in presenting information which in turn eventually lead to effective decisions. However, at this time the current BDF system for maintaining organizational structures of manpower and equipments is done manually, and the number of staff assigned in this area is not sufficient to handle multiple, complex tasks simultaneously.

Therefore, the purpose of this chapter is to describe the present process of maintaining the BDF organizational structures and the expected performance associated with it. The description of the processes will help to justify the BDF baselines for acquiring a decision support system as well as provide specifications for that system.

## B. CURRENT PROCESSES

The current processes of maintaining the BDF organizational structures are illustrated in Figure 1 below. They are somewhat dependent upon each other and involve four main steps as follows:

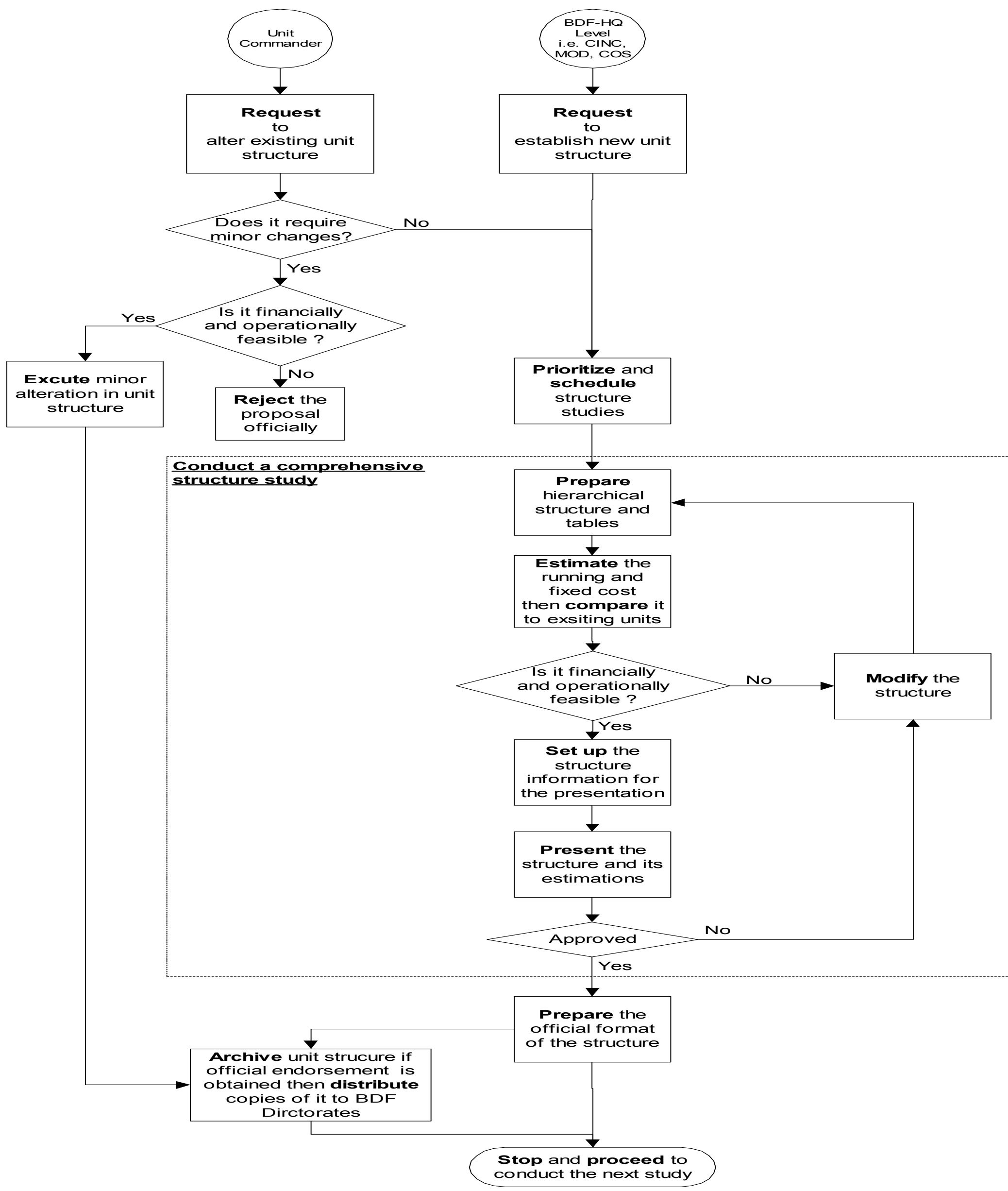


Figure 1. Current Process for Maintaining BDF Organizational Structures

### 1. Receiving Requests to Study Future Establishment of a New Unit or to Reorganize the Structure of an Existing Unit

A request to alter an existing structure of a unit or to make slight adjustments to that structure is usually initiated by the unit commander. Those requests are received on a daily basis, whereas orders to study future units come from the HQ top level officers on a monthly basis or sometimes weekly basis.

### 2. Prioritizing and Scheduling those Studies

Upon Planning and Organization Directorate (POD) director instructions, only studies that require a comprehensive analysis are prioritized and timetabled. Requests that need only small modifications to the structure are directly put into the execution cycle of the structure alteration process, once they get the first approval to do so. Moreover, the first approval test is part of this process and is applied to quickly determine whether the minor changes in a structure are economically and operationally feasible or not. Since the focus of this research is to define major current processes for maintaining the organizational structures of BDF, the descriptions of minor structure alteration processes will be neglected because they are easy to maintain and do not require huge efforts.

### 3. Building and Analyzing an Inclusive Structure Study

To conduct such a study the POD planners must be freed to do one study at a time since this process needs a huge amount of time and effort to be achieved. Therefore, this step requires decomposing an overall process into sub-processes because it accounts for about 80% of the POD planner workload. These sub-processes are as follow:

#### *a. Preparing the Proposed Hierarchical Structure and Tables of the Intended Unit*

The size of the unit determines the time and effort needed to accomplish this stage. Normally, the POD staff uses the MS-Office applications to build the proposed unit tables along with other applications (i.e. FileMaker-Claries) to fabricate the final product of hierarchical structures.

### *b. Estimating the Running and Fixed Costs of the Structure and Comparing it to Similar Existing Units*

The next step is to insert the computed number of resources that has been allocated to the structure in spreadsheets to generate estimations of the most important cost drivers in the structure. The costs resulting from manpower resources have the top priority in this sub-process because it accounts for 60% to 70% of the total budget needed to run this structure. The manpower cost is determined based upon basic rank salary, allowances associated with rank (i.e. transportation, social…etc), and allowances associated with job (i.e. position, job type…etc). Additionally, POD planners must gather data regarding the initial cost of operational resources such as weapons, vehicles and wire/wireless communication devices every time they do this process. Once all estimations are calculated, the matching sub-process is started; this is currently done manually. When comparing similar existing units to the proposed unit, overstaffed structures might appear to the POD staff that require chopping if no justification has accompanied it. Thus, when putting the intended structure under a mini-scope that is still done by hand might not illuminate tiny and might be major anomalies to that structure. Then, a careful feasibility check is done before proceeding to the next step. If this test is not passed, then the structure must be modified and fed back to the preparing sub-process again. Moreover, unique proposals need experts to decide on the maximum ceiling of the organizational structure for this kind of unit. Customarily, a committee headed by the POD director is responsible to conduct such studies that recommend more than one option for the unit structure.

### *c. Setting up the Structure Information for the Briefing, and then Presenting it to HQ*

After editing the proposed hierarchical structure and finalizing it, the POD staff translates those structures into multi-format tables that hold numbers of manpower and operational equipments and the costs related to them in order to brief the BDF-HQ officials. To generate those tables that hold estimations of fixed and running cost of the intended structure, a substantial computing job must be done to give a clear picture to the decision-makers group. Obviously, this stage is critical and the presentation contents need to be well-organized with all cost drivers tailored to reasonable figures within the BDF budget in order to persuade the necessary decision makers. Usually before presenting the final product of a proposed unit, a POD director directs his planners to work within boundaries and constraints of how a proposed structure might look and what parts of the structure need to be focused upon. Finally, either an approval feedback is returned to the POD director, or further studying is needed. In the first case, the POD planners are still responsible to complete the work they have started and submit the final official draft of the proposed unit to be signed by the BDF CINC. In the second case, the POD planners need to rework the whole study and repeat the preparation and analysis process to include modifications that have been approved during the presentation and/or additional suggestions for the proposed unit.

#### *d. Archiving All Studies and Distributing Copies Among BDF Directorates*

This process is essential to keep performing all future structure studies that require information about previous endorsed structures and rejected ones as well for comparison purpose. Currently, a hardcopy of any approved structure and its related tables are kept in the POD cabinet whereas softcopy is saved in a dedicated hard disk with floppy disks as a backup. However, a unit organizational structure could have several files of different types. For instance, MS Word files contain unit mission, unit roles, and unit job description for the jobs it currently has, MS PowerPoint or FileMaker files contain all hierarchical structures of that unit, and finally, MS Excel files contain all information about unit tables such as different formats of manpower list, weapon list, etc. All BDF-HQ directorates and the commander of that unit must receive a hard copy through the regular BDF mail system.

## C. PERFORMANCE METRICS

During the study stage of establishing new unit structure, there are two primary performance metrics of effectiveness that decision makers use to decide which organizational structures are better (or worse) than others. These measures are taken into account by POD planners to verify how feasible and reliable is the unit structure before supporting the idea of endorsing this structure. The measures are as follows:

### 1. Unit Structure Outlay Costs

Theses can be either fixed costs or running costs resulting from creating a unit structure that requires resource allocations in order to operate according to the unit's assigned missions. The fixed costs involve expenditures that are paid once during the unit lifecycle, and which are also considered as the unit's assets. For instance, building unit facilities, purchasing unit weapons and vehicles are examples of the fixed costs associated with establishing a BDF unit. The running costs concern expenditures that are paid periodically (weekly, monthly or annually) during the whole unit lifecycle to make the unit fully operational. Examples of unit running costs are manpower costs (such as salaries, allowances, promotions and family health care expenses), training costs, ammunition costs, and maintenance costs of the equipments.. Therefore, the POD planners try to achieve a cost-effective unit structure which will stay within the BDF budget constraints, and will not exceed it under the assumption that no new operational equipment is intended to be purchased in the near future.

### 2. Unit Structure Quality

This measure means operationally how feasible or practical is the unit structure before implementation. Does it serve the assumed unit roles and tasks? Different tests conducted by POD planners to verify this measure are as follows:

#### *a. Combat Doctrine Test*

The unit structure must initially comply with the BDF combat doctrine. For example, an infantry battalion must be comprised exactly of three infantry companies, one supporting company, and one administrative company. Each infantry company encompasses three infantry platoons.

#### *b. Category Test*

The unit manpower is divided into three major categories: operations, administrative, and technical manpower. The unit type can only determine the minimum and the maximum manpower percentages that will be assigned to each category (i.e. field artillery battalion can have 70-80% for operation vacancies, 15-25% for administrative vacancies, and 5-10% for technical vacancies). Thus, POD planners try to define those interval constraints for each model and adhere to them as much as possible to obtain a robust unit structure.

#### *c. Military Standard Test*

The unit structure must obey the military standards in filling the jobs required to operate and maintain a certain weapon or vehicle. Also, POD planners use friendly forces structures, if available, as a reference when creating such unit structures.

#### *d. Rank Distribution Test*

Finally, the unit structure ranks must be shaped as a pyramid for both officers and enlisted ranks as shown in Figure 2 below. In the enlisted case for instance, the number of corporal ranks (third lowest rank) must always be greater than (best scenario) or at least equal to (worst scenario) the number of sergeant ranks (fourth lowest rank). Again, the unit type can only determine a rank’s intervals.

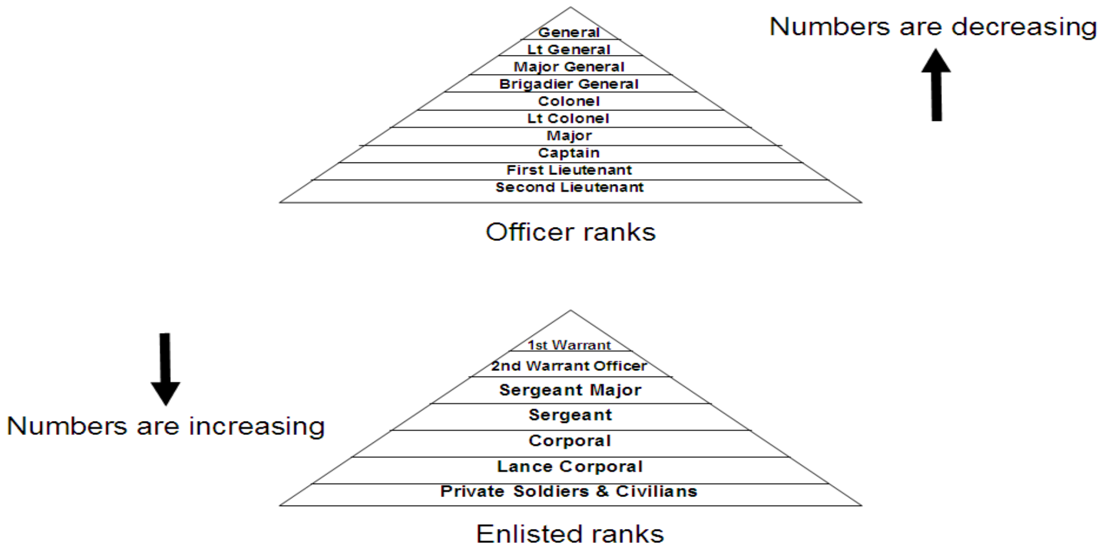


Figure 2. Ordering the BDF Ranks Distribution

As a result, the typical unit structures are those which best satisfy both performance measures mentioned above, and POD planners use those measures when comparing two or more of BDF unit structures to determine which is better.

## D. CURRENT SYSTEM PERFORMANCE

BDF-HQ is always willing to update or establish new organizational structures of its forces, reengineer its business processes, and adopt technologies whenever that is deemed best for BDF. In general, the overall performance of the current BDF system of maintaining its organizational structures is not efficient and effective enough to support concurrently the BDF development process and its ambitious perspectives. There are many reasons or factors that have led to such weak outcome of this system:

### 1. Shortfall of POD Planners

As mentioned before, the number of POD planners and staff is not sufficient to handle the nonstop, increasing workload. This degrades the overall performance of that system. Subsequently, the current POD staff can conduct only one comprehensive study at a time, and the related outcome is often not sufficient to achieve any but the minimum requirement. The recommended solution to solve this problem will be discussed in chapter 4.

**2. No Embedded Computer-Based System in the Current Processes**

BDF-HQ has owned personal computers, servers and mainframe computers since the late 1980's and started networking them shortly thereafter. However, the POD system of maintaining the BDF organizational structures does not fully utilize computer capabilities to achieve maximum, or even moderate benefits. For example, a computer-based system can be built to hold customized business rules that control and validate actions taken by the system users. Consequently, the lack of using an automated tool such as a decision support system has prevented the current POD system from considering more potentially useful decision alternatives. The benefits of a DSS include the following:

1. Discourage premature decision-making and alternative selection.
2. Generate multiple and higher quality alternatives for consideration.
3. Improve response time of decision maker.
4. Explore and test multiple problem-solving strategies.
5. Increase the decision maker's ability to tackle large scale and complex problems.
6. Explore multiple analysis scenarios for a given decision context.
7. Improve the reliability of a decision process outcome.

**3. Several Data Files are Used to Maintain One Unit Structure**

This is a big dilemma in the current system which needs additional file processing efforts to retrieve data, create reports and so forth. By splitting and isolating the data in many files, the following drawbacks may occur in the system performance:

#### *a. Data Integrity Degradation*

For instance, if a change is made in one file of a unit structure, then POD planners must manually feed all subsequent updates in the remaining files that contain the same information about that unit. Actually, entering data more than once will increase the data error probability, and much of the data is duplicated.

#### *b. Integration and Speed Problems*

Since there is no real or virtual link between data files that contain information about all BDF structures, POD planners have to do extra work to integrate those files to extract common reports needed to enhance the decision-making process in maintaining the BDF organizational structure.

#### *c. The Difficulty of Presenting Data in the POD User's Perspective*

It is difficult to present separate file data in a form that seems natural to POD planners and decision makers. This complexity arises because with manual file processing, data relationships must be maintained which is not an easy task to do. Also, making queries based on certain or set of criteria is time-consuming in the current situation.

### 4. Lack of Using Analysis Techniques in the Current System

Presently, POD does not implement any kind of analysis strategies (i.e. simulation, forecasting, linear programming and what-if analysis tools) in order to obtain optimum numbers of resources allocated to a unit. In fact, if these capabilities were used in the current system, POD could effectively reduce cost and achieve better quality output in establishing and maintaining a unit organizational structure. Thus, without having such techniques in the POD system, a quantum performance will never be reached.

In a nutshell, the aforementioned factors highlight some of the system shortcomings in maintaining BDF organizational structures. The current situation is almost completely manual, and does not automate any part of the system processes in a way that could lower BDF cost and enhance the speed and the quality of building and updating BDF structures.

The first step in designing a DSS to support the requirements outlined above is to identify the data requirements and an associated database structure for housing the data. In the next chapter, we will analyze and design a database model that meets the BDF data requirements and objectives. The database design will flow from the performance metrics described above.

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# III. THE DATABASE MODEL

## A. INTRODUCTION

The objective of this research is to propose a decision support system (DSS) solution that addresses the Bahrain Defense Force (BDF) needs for analyzing, establishing and maintaining the organizational structures of BDF units in order to facilitate more effective decision-making processes in that area . The DSS solution will be built on top of an automated database application that contains all information required for establishing the costs of building and maintaining an operational military unit. This in turn will allow BDF decision-makers and planners to track and monitor the manpower, staffing, and operational support requirements, and to propose or approve a cost-effective, quality organization structure.

The components of a DSS can generally be classified into three distinct parts: data, models, and user interface. [Ref. 1] The data component of a DSS is where the various activities associated with retrieval, storage, and organization of the relevant data for the particular decision context are managed. Additionally, the data management system provides for the various security functions, data integrity procedures, and general administration duties associated with using the DSS. The model component is similar to the data component in performing the retrieval, storage, and organizational activities associated with the various quantitative models that provide the analytical capabilities for the DSS. Finally, the user interface is a key element in DSS functionality. It provides the vehicle through which the user navigates through the DSS, views output displays and performs what-if analyses.

This chapter will focus mainly on the DSS data design phase, which emphasizes development of a conceptual data model that fulfills the requirements. However, in order to clarify the system design, this chapter will start with a brief discussion about the system or prototype analysis to outline the investigation of the problem and requirements (functional and interface requirements).

## B. ANALYSIS PHASE

The BDF_DSS system must embrace a database application along with an embedded DSS interface. Therefore, the database tool must be designed to meet the BDF functional requirements and support the DSS user interface requirements as follows:

1. Establish an organizational structure that satisfies manpower and operational equipment requirements (vehicles and weapons) of an organization. The database structure must segregate the unit entity from the resources entities and create relationships among each in order to facilitate the appropriate database management.

2. Track and highlight the staffing requirements of the new and/or existing organizations. The database shall allow the computation of manpower shortfalls or surpluses in a selected unit or an organization as a whole. This database application feature will enable the decision-makers to execute informed and responsive changes to manpower recruitment and retention policies when needed.

3. Compute the estimated operational cost of establishing and maintaining a unit based on resources allocated to that unit. The database shall automatically calculate all cost drivers for an existing unit structure or a proposed one. Additionally, the calculated cost drivers for a unit structure must accompany any changes made to the unit resources. In other words, the DSS user can see the instant cost impact whenever he/she makes modifications in the unit resources.

4. Compare the cost of maintaining two or more units in an organization. The model must allow the DSS user to visualize and present cost information in different ways, e.g. numerical or graphical presentations.
5. Illustrate a current BDF unit situation with respect to actual cost vs. budgeted cost. The database must allow the DSS user to see the difference between the unit actual cost and the unit planned cost.
6. Illustrate the overall BDF situation with respect to actual cost vs. budgeted cost. The database must differentiate the approved unit structures from the proposed ones in order to estimate the BDF overall cost situation (current or actual cost vs. planned cost).

7. Support decision makers and planners in BDF-HQ for effective and efficient resource planning with respect to manpower and operational equipment. This requirement symbolizes the ultimate BDF goal in designing the database model which should provide its users with the following capabilities:
    a. Analytical models that can be built-in or linked to the database application. These models are:
        1) Optimization models that help to find the best solutions for cost and manpower based on user-defined constraints. The next chapter will discuss this point in more detail.
        2) Simulation of an existing or proposed unit structure in the database by providing a tool to duplicate the unit information and related resources but with a different unit identity. This process will widen the unit structure alternatives and help to obtain the desired cost and quality in the unit structure under study.
        3) What-if models that help to meet the desired specification of the suggested unit structure in a short time. The what-if technique can be described as sensitivity analysis that allows generation of different unit structure scenarios that trigger automatic computations whenever a change is made to the unit resources.
    b. Visualization tools and graphical representations such as pivot tables and charts can be utilized when comparing two or more of unit structures.
    c. Defining and creating queries and reports in formats that are in accordance with the users' needs. This will support the demonstration process of the proposed unit structure.

## C. DATABASE DESIGN PHASE

The process for building the BDF_DSS data component is Analysis (Logical Design), Physical Design, and Process Design.

### 1. Logical Design of BDF_DSS

The conceptual data model can be created accordingly from the previously defined database requirements. As shown in Figure 3 below, the main entities for this model are Unit, Manpower, Weapons, Vehicles, Jobs and Salaries. Their associated primary keys, attributes, and relationships are defined in the Entity-Relationship (ER) diagrams shown in **Appendix A**. The standard forms (normalization), entity integrity and referential integrity rules were considered when building this data model to achieve data consistency and at the same time to avoid update, insertion, and deletion anomalies.

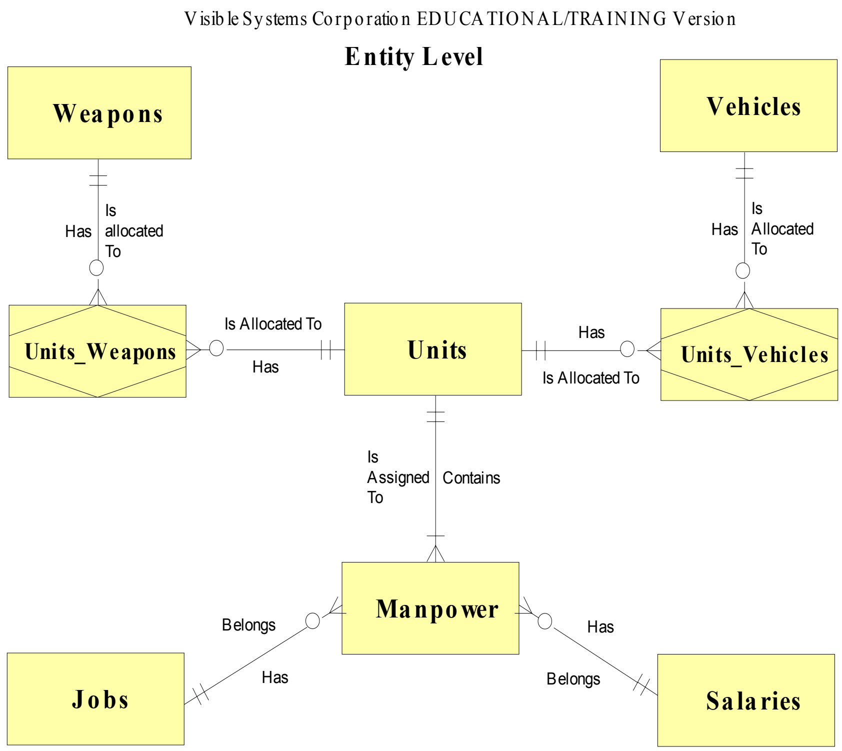


Figure 3. Entity Relationship Diagram of the Database Model (BDF_DSS)

There is a vast amount of information and literature available in the area of relational database design. Therefore, the following definitions are provided for clarity:

**Relation** is a table, or flat file, with columns and rows

**Relation attribu**te is a column in a relation.

**Primary key** is one or more attributes, the value(s) of which uniquely identify each row in a relation.

**Composite Key** is a primary key consisting of more than one attribute.

**Foreign key** is a set of attributes in one relation that constitute a key in some other (or possibly the same) relation; used to indicate logical links between relations.

**Entity integrity rule** states that no key attribute of any row in a relation may have a null value.

**Normal forms** are rules for structuring relations that eliminate anomalies.

**Referential integrity rule** states that the value of a non-null foreign key must be a primary key value in some relation.

**Update anomaly** refers to the data inconsistency resulting from data redundancy and partial updates.

**Deletion anomaly** refers to the unintended loss of data due to deletion of other data.

**Insertion anomaly** refers to the inability to add data to the database due to the absence of other data.

**Integrity constraints** are rules that restrict the values that may be present in the database. Codd's relational data model includes several constraints that are used to verify the validity of data in a database as well as to add meaningful structure to the data. [Ref. 2]

The entities and relationships in this model are developed via the Visible Analyst™ application that allows a subsequent examination of each relation to assure it follows desirable normalization criteria. Visible Analyst can also generate easily the database schema shown in **Appendix B** that defines the database structure, its tables, relationships, domains, and business rules. [Ref. 3] The main entities are described as follows:

***a. Unit Entity***

The most important entity (central entity) in this model is the unit since the total cost of establishing a unit or organization is derived from the other secondary entities such as manpower, vehicles, etc. In other words, the unit entity acts as the unit repository that holds information about all BDF unit resources which a BDF unit needs. The primary key of this entity is the unit identification number (Unit ID).

***b. Manpower Entity***

This entity represents the model human resource planning part which in fact is the most costly resource that a BDF must consider when establishing new units. Hence, it is the second most important entity, which holds all job information and their related costs for a BDF unit. This entity has three relationships with Unit, Jobs and Salaries entities. First, many Unit manpower instances (rows) in the Manpower entity will be linked to one instance from Unit entity. On the other hand, many Jobs and Ranks instances can be shared by many Units assuming the unit ID, rank and the job type are not repeated in Unit manpower. This means that the key of manpower entity is the combination of unit ID, rank and the job type. Accordingly, the unit manpower data can be constructed based on both Salary and Job entities that have information about current BDF jobs and their estimated costs, which includes basic salaries and allowances. Therefore, linking those entities to the manpower entity is essential in order to share one source of current BDF jobs and one source of salary-based ranks data. In addition, the Manpower entity must hold two essential properties (attributes) that specify the available and occupied number of jobs in a unit. The first will correspond to the budgeted number of jobs; whereas the second will represent the actual number of jobs (current manpower situation of a unit), and finally the difference between them will correspond to the shortfall or surplus.

***c. Vehicles and Weapons Entities***

Both entities have similar attributes and primary keys. They symbolize the resource catalogs of BDF operational equipment which a BDF unit needs. In addition, the costs established for those entities include not only the fixed costs for a type of vehicle or weapon but also the running cost to maintain it. All existing and proposed BDF units will share those entities as needed but in different quantities via the indirect many-to-many relationships depicted in Appendix A. As a result, two associative entities are required between Vehicle/Weapon and Unit entities to create a many-to-many relationship. Those entities are called Unit_Vehicles and Unit_Weapons. The primary key of Unit_Weapons for example, is the weapon type plus unit ID.

In summary, the resources entities are structured in a way that all proposed and approved BDF units will share the BDF job dictionary, BDF salary and allowance tables, and BDF vehicle and weapon catalogs. As a result, this will minimize redundancy of information and make the database run more efficiently during execution of the DSS.

### 2. Physical Design of BDF_DSS

The database schema can be transformed to the relational database design in a desired target DBMS which in our case will be MS Access™. MS Access™ provides the underlying database management functions and features needed for designing the BDF_DSS. The relational structure diagram of the BDF_DSS and the properties of the relationships are depicted **in Appendix C**. In the relational structure diagram, each entity (relation) in the ER diagram is translated to a table which has a primary key or composite key that uniquely identifies each row (record) in that table. The second part of **Appendix C** depicts all the relationships and the related properties established between the tables.

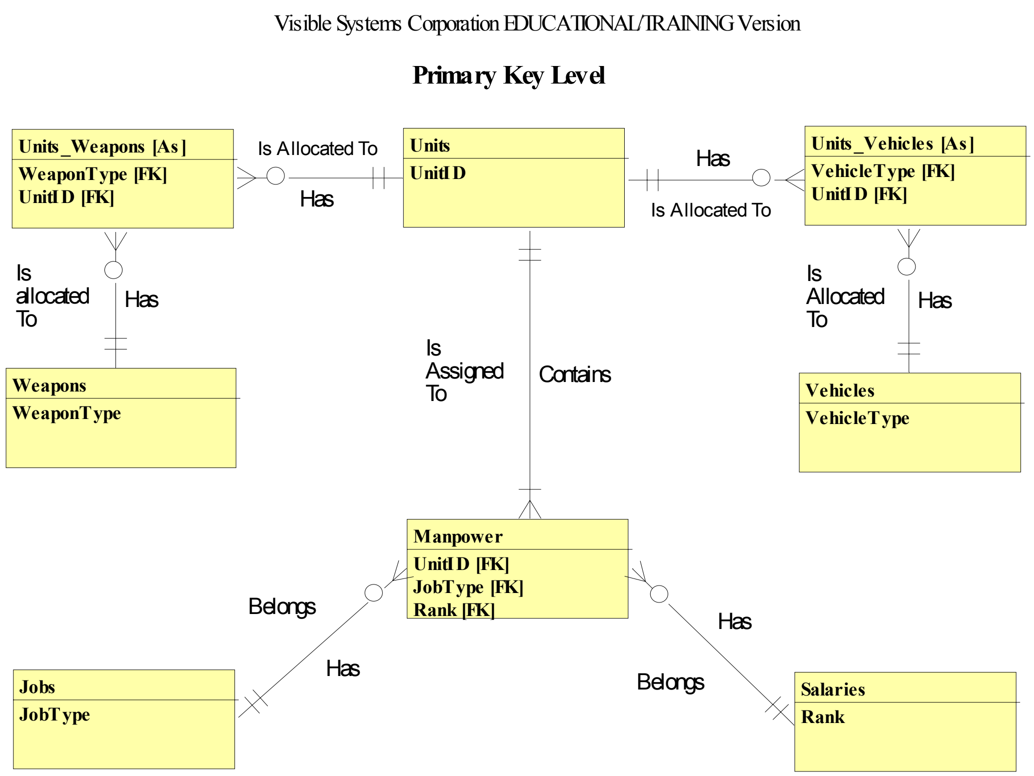


Figure 4. Entity Relationship Diagram of the Database Model – Primary Key Level

### 3. Process Design of BDF_DSS

Initially, the process will commence when POD planners want to compute the fixed and recurring cost of setting up a BDF unit and compare it with other existing units. The database structure enforces the referential integrity constraints in all relationships to assure data reliability. Consequently, the data model requires that data entry sequentially follow the steps outlined below; otherwise, the user will encounter error messages from the related built-in business rule if a precondition of data entry is not satisfied:

a. The database user must first specify the unit identification number, unit type, unit size, and whether it is an existing BDF unit or a proposed BDF unit (i.e. 101 approved artillery battery, 104 approved armor battalion, 114 proposed infantry brigade…etc).

b. Before building the unit manpower, all jobs that are required in the new BDF unit must first be in the BDF job dictionary. In other words, a JobType in Jobs table must exist first in order to add the same JopType in Manpower table.

c. Before building the unit manpower, all ranks that are required in the new BDF unit must be in the BDF salary table. Similarly, a Rank in Salaries table must exist first in order to add the same Rank in Manpower table.

d. Before building the unit vehicles and weapons, all vehicle and weapon types that are required in the new BDF unit must be in the BDF vehicle and weapon catalogs. For example, a VehicleType in Vehicle table must exist first in order to add the same VehicleType in Vehicle_Units table.

e. Finally, the physical design enforces two important relationship properties that a BDF_DSS user must be aware of while maintaining the data. These are the cascade update related fields and the cascade delete related records. Cascade update related fields allow the BDF_DSS users to update primary key fields in a parent table and automatically update all related fields in associated child tables. Cascade delete related records will delete all child records once their parent record has been deleted.

In addition, the database has many capabilities that fulfill the BDF_DSS requirements which are stated in the system analysis phase. For instance, the database can instantly compute the unit statistics based on hidden equations built-in via database macros once a modification to the unit resources occurs. When the application user modifies a unit_weapon record for example, subsequent changes will occur in the unit record for both Weapon Total Cost and Weapon Maintenance Cost fields. However, this process will only be allowed through the BDF_DSS analysis menu that manipulate proposed unit structures to generate more scenarios and at the same time avoid alterations on existing unit structures.

The second component in designing a DSS is to develop the analytical models that will be utilized in the BDF_DSS. In the next chapter, we will introduce two examples of applications of optimization models which comply with the performance metrics described in earlier chapter. The chapter will cover the construction cycle of each model and explain it step by step.

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# IV. THE OPTIMIZATION MODELS

## A. INTRODUCTION

> Our world is filled with limited resources. The amount of oil we can pump out of the earth is limited. The amount of land available for garbage dumps and hazardous waste is limited and, in many areas, diminishing rapidly….Deciding how best to use the limited resources available to an individual or a business is a universal problem. In today's competitive business environment, it is increasingly important to make sure that a company's limited resources are used in the most efficient manner possible. Typically, this involves determining how to allocate the resources in such a way as to maximize profits or minimize costs. [Ref. 4. Sect. 2.0-16]

Mathematical programming (MP) is part of a larger field of management science called operations research that finds the optimal, or most efficient, way of using limited resources to achieve the objectives of an individual or a business. For this reason, mathematical programming is often referred to as optimization. [Ref. 5]

Optimization covers a broad range of problems that share a common goal, namely determining values for decision variables in a problem that will maximize (or minimize) some objective functions while satisfying various constraints. Constraints impose restrictions on the values that can be assumed by the decision variables and define the set of feasible options (or the feasible region) for the problem. Accordingly, the linear programming (LP) problem represents a special category of MP problems in which the objective function and all the constraints can be expressed as linear combinations of the decision variables. [Ref. 6]

This chapter will present two optimization models which will be part of the BDF_DSS. These models are essential for the required DSS in order to satisfy the cost and quality performance metrics described in chapter 2. This chapter also explains in detail how to create and maintain optimization models that support BDF decision-makers.

## B. INFANTRY BATTALION MODEL

Before describing this model, we will first implement a general form of the problem-solving process in order to best understand and visualize how modeling fits into the entire BDF_DSS problem. [Ref. 7] As shown in Figure 4 below, the problem-solving process consists of five major steps. For each step below, we will describe the BDF-specific circumstances which are relevant and the appropriate sub-processes which comprise it if any.

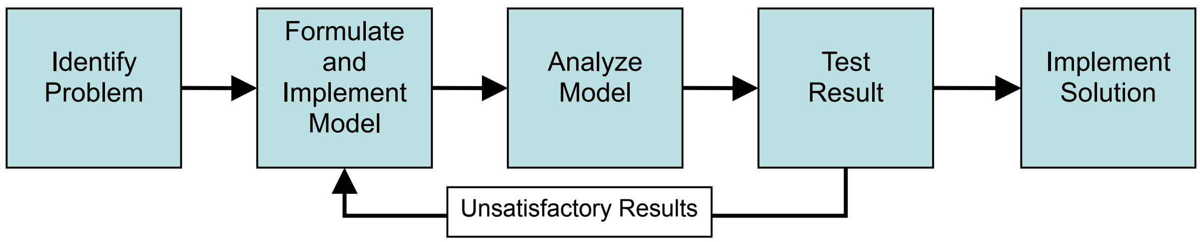


Figure 5. Visual Model of the Problem-solving Process (From Ref 4)

### 1. Identify Problem

The BDF wants to optimize its budget when establishing or maintaining a unit structure that has associated resources and costs. At the same time, BDF also wants to make that unit structure as effective as possible so that it will produce at maximum throughput. The first BDF demand emphasizes the cost performance metric of the unit structure, whereas the second one focuses on the quality performance metric of the unit structure (see chapter 2). As a result, we can precisely define the BDF problem as follows: "BDF wants to achieve simultaneously a cost-effective and high quality unit structure which respectively captures efficiency and effectiveness measures of the unit structure."

### 2. Formulate and Implement the Optimization Model

The formulation process is better described as "brainstorming the model". We will create the manpower optimization model of the infantry battalion step by step as follows:

#### *a. Defining the Decision Variable*

The decision variables that we wish to compute are the numbers of all ranks required in an infantry battalion structure. Therefore, we can refer to the ranks with the equivalent military standard symbols as the following:

O1 refers to # of 2nd Lieutenant Officer
O2 refers to # of 1st Lieutenant Officer
O3 refers to # of Captain Officer
O4 refers to # of Major Officer
O5 refers to # of Lt Colonel Officer
O6 refers to # of Colonel Officer
E7 refers to # of Warrant officer (Enlisted rank)
E6 refers to # of 2nd Warrant
E5 refers to # of Sergeant Major
E4 refers to # of Sergeant
E3 refers to # of Corporal
E2 refers to # of Lance Corporal
E1 refers to # of Private Soldier
CIV refers to # of Civilians

***b. Defining the Objective Function***

The objective function is to maximize the total number of ranks (optimized ranks) subject to the maximum budget that the BDF can afford. The budget ceiling will be the first restriction included in the constraints part. Therefore, the objective function is:

Maximize: O1+O2+O3+O4+O5+O6+E1+E2+E3+E4+E5+E6+E7+CIV

***c. Defining the Constraints***

Several types of constraints affect this model.

Budget Constraint: BDF will estimate the maximum budget that it can afford to establish an infantry battalion when it determines the average spending on existing similar unit structures. We will name the estimated maximum budget as T which is an input field (user-defined). We obtain the optimized total annual salary for the infantry battalion by multiplying the number of each rank (optimized rank) and the correspondent monthly basic salary by 12, and then summing these values. As shown in the formula below, the constraint is that the optimized total annual salary should be less or equal to the estimated maximum budget (T).

[(O6*4500) + (O5*4000) + (O4*3500) + (O3*3000) + (O2*2500) + (O1*2000) + (E7*1500) + (E6*1300) + (E5*1100) + (E4*900) + (E3*700) + (E2*500) + (E1*400) + (CIV*300)] * 12 <= T

Default Constraints: Certain ranks in the BDF must be allocated exactly, either by default according to BDF regulations. Additionally, the user can define those values dynamically to override the BDF defaults. Those are as follows:

O6 = 1 (# of COL=1)
O5 = 6 (# of LTC=6)
O4 = 14 (# of MAJ=14)
E7 = 7 (# of WAR=7)

Budget Allocation Constraints: This type of constraint will divide the optimized total annual salary into officer (OS or officers salaries), enlisted (ES or enlisted salaries), and civilian (CS or civilian salaries) groups to be matched with user-defined percentages. The percentages will be automatically multiplied by the estimated maximum budget (T) which will then correspond to the maximum budget allocation to each group. As stated in the formula below, for each group, the constraint is that the group optimized total annual salary should not be greater than the corresponding maximum allocation of the budget.

OS<= 20% of T
ES<= 78% of T
CS<= 02% of T

Manpower Allocation Constraints: Similar to the budget allocation constraints, this constraint separates the optimized total ranks into officer (OM or officers manpower) and enlisted plus civilian (ECM) groups to be matched with user-defined percentages. In the first case, a percentage of 4% will be automatically multiplied by the optimized total ranks which should be less than, or equal to, the optimum number of officer ranks. In the second case, a percentage of 96% will be automatically multiplied by the optimized total ranks which should be greater or equal than the optimum number of enlisted plus civilian ranks. These two percentages will be user-specified to allow flexibility in the model.

OM >= 04% of Manpower (4% of the total optimized manpower)
ECM <= 96% of Manpower (96% of the total optimized manpower)

Upper and Lower Boundary Constraints: This set of constraints will force the rank numbers to be shaped as a pyramid in which they obey one of the performance measures stated in chapter 2. For the enlisted infantry battalion ranks, we wish to separate adjacent ranks from each other. For example, the number of the E6 rank must be at least two times that of the number of the E7 rank which is a user-specified parameter and not more than four times that of the E7. However, we can set the upper bound only for the last rank, E1, to be not more than four times that of E2 because we do not know how much will be left from the budget to cover the last rank. Additionally, to meet the BDF default in distributing the lowest officer's ranks, we presumed that the number of O1 is less or equal than the number of O2 and the number of O2 is less or equal than the number of O3. Thus, for an infantry battalion, we set the upper bound factor to be 4 and the lower bound factor to be 2 as seen in the equations below.

2*E7 <= E6 <= 4*E7 (i.e. for E7=7 then 14<=E6<=28)
2*E6 <= E5 <= 4*E6
2*E5 <= E4 <= 4*E5
2*E4 <= E3 <= 4*E4
2*E3 <= E2 <= 4*E3
E1 <= 4*E2
O1 <= O2
O2 <= O3

Integrality conditions: We must embed this constraint to ensure integer values and avoid fractions in all of the optimized ranks. Besides, all ranks must be greater than zero to obtain nonnegative solutions. Clearly, this is an integer programming model strictly speaking, rather than a linear programming model, although one can do away with the integer constraints and just round (up or down) the resultant values to the nearest whole number in order to utilize as much as possible of the allocated budget (T). The constraint is as follow:

All ranks are Integer and >=0

***d. Implement the Model***

Having identified the problem and formulated the model, we turn our attention to implementing the model. We have selected MS Excel to present our model since it is the most popular spreadsheet application and it is widely available. **Appendix**

**D** shows the model and the generated reports related to the model. To get a reliable, auditable and modifiable spreadsheet design, we followed the guidelines stated in the *Spreadsheet Modeling and Decision Analysis* textbook. [Ref. 4] Briefly, these guidelines are as follows:

1) Organize the data, then build the model around the data.
2) Do not embed numeric constants in formula.
3) Things which are logically related (e.g., left-hand sides and right-hand sides of constraints) should be arranged in close physical proximity to one another and in the same columnar or row orientation.
4) A design that results in formulas that can be copied is probably better than one that does not.
5) Column or row totals should be in close proximity to the columns or rows being totaled.
6) The English-reading human eye scans left to right, top to bottom.
7) Use color, shading, borders and protection to distinguish changeable parameters from other elements of the model.
8) Use text boxes and cell comments to document various elements of the model.

### 3. Analyze the Model

After verifying that the spreadsheet model has been implemented accurately as illustrated in **Appendix D**, the next step in the problem-solving process is to check that the model is doing exactly what it was designed to do (i.e. the optimized values are always within the constraints that have been specified). The main focus of this step is to generate and evaluate alternatives that might lead to the best solution of the problem. This involves playing out a number of scenarios or asking several "What if" questions. Spreadsheets are particularly helpful in analyzing mathematical models in this manner. Generally, "What if" questions imply loosening or tightening the constraints, adding more constraints, or deleting previous constraints as needed. However, in this model, it should be fairly simple to change some of the assumptions in the model to see what might happen in different situations.

### 4. Test Results

The process of analyzing a model does not always provide a solution to the actual problem being studied as in our case. As we analyze a model by asking various "What if" questions, it is important that a BDF_DSS user be able to test the feasibility and quality of each potential solution. We know that an optimal solution derived from the model can exhibit known LP problem anomalies (i.e. more than one solution can be obtained, and degeneracy, the condition which gives different interpretations of the values on the sensitivity report that cannot be relied upon); therefore, the BDF_DSS user must know how to read the sensitivity report generated by Excel in order to see how sensitive the solution is and if is it applicable or not. [Ref. 8]

Fortunately, MS Excel provides a help tool to assist the user in reading the sensitivity report in an appropriate way. This tool is called the Sensitivity Assistant Add-in and can be installed by copying the Sensitivity.xla file from the MS Office CD-ROM to the folder on the hard drive that contains the Solver.xla (In most cases, this will be the folder C:\Program Files\Microsoft Office\Office\Library\Solver). [Ref. 4] Then by following the steps below, the user can utilize the mentioned tool when needed:

a. In Excel, click *Tools*, *Add-Ins*

b. Click the *Browse* button.

c. Locate the Sensitivity.xla file and click *OK*.

Therefore, to check the model validity, users must always conduct a sensitivity analysis about the model assumptions whether they reflect reality by either negotiating those assumptions with the domain experts and decision makers of BDF or comparing them with the assumptions of similar unit structure of friendly forces.

### 5. Implement the Solution

The last step of the problem-solving process, implementation or presentation, is often the most difficult. In other words, the BDF_DSS users still have to convince the BDF top level decision-makers that the solutions they found when constructing the proposed unit organizational structure are worthy of implementation in the real world. The BDF_DSS users can always use the visualization tools provided in the BDF_DSS application (i.e. charts and pivot tables) in concert with the optimization models when presenting their arguments. Therefore, a well-organized and clear presentation to the BDF top level decision-makers may help to obtain the initial approval in implementing a sound proposal for a unit structure.

## C. ARMOR BATTALION

When building this model, we followed the same sequence of the problem-solving process used in the previous one. However to avoid redundancy, we will address only the differences that occur in this model. The steps in creating the Armor battalion optimization model were the same as the Infantry battalion except for the following:

### 1. Identify Problem

The BDF goal which was described in the first model was to achieve a cost-effective and a high quality BDF unit structure. However, we have assumed that the BDF representatives have looked at the first model and their feedback question has been: "Can we achieve more quality than this?". Thus, this model will focus upon higher quality in the unit structure which is one of the major performance measures that impact the structure score in addition to the structure cost.

### 2. Formulate and Implement the Optimization Model

To achieve the goal of obtaining a higher quality in the unit structure, we have included another feature in this model to attain the quality needed. As explained in chapter 2, this feature is to include the BDF unit's manpower categories in the BDF_DSS. Earlier, we said that those manpower categories are operation, administrative, and technical positions and each type of unit has certain ranges that should not be exceeded. Therefore, this model will be a second version of the first which handles the dilemma of how to optimize the number of categories necessary in the unit structure along with other constraints demonstrated previously.

### *a. Defining the Decision Variable*

This model requires more decision variables since we set apart the manpower into three groups. Consequently, we will multiply the 14 different ranks as defined in the infantry battalion structure by three to get a total of 42 decision variables as shown bellow:

| | | |
|---|---|---|
| O6 ranks for operation | O6 ranks for administration | O6 ranks for technical |
| O5 ranks for operation | O5 ranks for administration | O5 ranks for technical |
| O4 ranks for operation | O4 ranks for administration | O4 ranks for technical |
| O3 ranks for operation | O3 ranks for administration | O3 ranks for technical |
| O2 ranks for operation | O2 ranks for administration | O2 ranks for technical |
| O1 ranks for operation | O1 ranks for administration | O1 ranks for technical |
| E7 ranks for operation | E7 ranks for administration | E7 ranks for technical |
| E6 ranks for operation | E6 ranks for administration | E6 ranks for technical |
| E5 ranks for operation | E5 ranks for administration | E5 ranks for technical |
| E4 ranks for operation | E4 ranks for administration | E4 ranks for technical |
| E3 ranks for operation | E3 ranks for administration | E3 ranks for technical |
| E2 ranks for operation | E2 ranks for administration | E2 ranks for technical |
| E1 ranks for operation | E1 ranks for administration | E1 ranks for technical |
| Civ ranks for operation | Civ ranks for administration | Civ ranks for technical |

### *b. Defining the Objective Function*

The Objective function is to maximize the total number of ranks including all categories (optimized ranks) to as the extent the estimated budget (T) allows. In other words, this objective will embrace the same concept of the infantry battalion model in trying to use as much of the allocated budget as possible. Therefore, the objective function is:

Maximize:

$$[O1+O2+O3+O4+O5+O6+E1+E2+E3+E4+E5+E6+E7+CIV]_{Ops} +$$
$$[O1+O2+O3+O4+O5+O6+E1+E2+E3+E4+E5+E6+E7+CIV]_{Admin} +$$
$$[O1+O2+O3+O4+O5+O6+E1+E2+E3+E4+E5+E6+E7+CIV]_{Tech}$$

### *c. Defining the Constraints*

The only added constraints in this model are two types and the rest were modified accordingly. Those are as follow:

Category Constraint: The model will give the user the ability to assign a range of certain percentages (user-specified values) of the total manpower to each manpower category in the Armor battalion. This means that each category of the required manpower will have upper and lower bounds to fit in. The conditions are:

$[O1+O2+O3+O4+O5+O6+E1+E2+E3+E4+E5+E6+E7+CIV]_{Ops} > 70\%$ of total manpower
$[O1+O2+O3+O4+O5+O6+E1+E2+E3+E4+E5+E6+E7+CIV]_{Ops} < 80\%$ of total manpower
$[O1+O2+O3+O4+O5+O6+E1+E2+E3+E4+E5+E6+E7+CIV]_{Admin} > 3\%$ of total manpower
$[O1+O2+O3+O4+O5+O6+E1+E2+E3+E4+E5+E6+E7+CIV]_{Admin} < 10\%$ of total manpower
$[O1+O2+O3+O4+O5+O6+E1+E2+E3+E4+E5+E6+E7+CIV]_{Tech} > 5\%$ of total manpower
$[O1+O2+O3+O4+O5+O6+E1+E2+E3+E4+E5+E6+E7+CIV]_{Tech} < 16\%$ of total manpower

Default Constraints: As a subsequent constraint to the category restriction, this condition must be included in the model to ensure that the BDF standards in the number of officer ranks in each category will not be violated. Those ranks must be exactly defined and cannot be optimized in an Armor battalion structure. Those defaults are as follow:

O6= 1 (as operation Colonel)
O5= 6 (5 as operation LTC, and 1 as Admin LTC)
O4=10 (8 as operation MAJ, 1 as Admin MAJ, and 1 as Tech MAJ)
O3 are neither Admin nor Tech CAPT's
O2 are neither Admin nor Tech 1st LT's
O1 are neither Admin nor Tech 2nd LT's
E7 = 7 (will remain the same as in the first model)

Upper and Lower Boundary Constraints: This set of constraints follows the same notion of the infantry battalion, except that the upper bound factor has changed to 2.75 instead of 4, and the lower bound factor has changed to 1.25 instead of 2 as seen in the equations below. This was done because the Armor battalion requires relatively less manpower than the infantry battalion.

$1.25 * E7 <= E6 <= 2.75*E7$
$1.25 * E6 <= E5 <= 2.75*E6$
$1.25 * E5 <= E4 <= 2.75*E5$
$1.25 * E4 <= E3 <= 2.75*E4$
$1.25 * E3 <= E2 <= 2.75*E3$
$E1 <= 2.75*E2$
$O1 <= O2$
$O2 <= O3$

In conclusion, these two models demonstrate the computer-based tools that will be linked to the BDF_DSS in order to enhance the decision-making process when creating and maintaining the BDF organizational structures. The purpose of the Armor battalion is to illustrate that the model could be more complicated if additional decision variables were added to meet the modified objective function (see **Appendix D**).

Furthermore in the last chapter, we will suggest a few points regarding modeling that will help to improve this capability in the BDF_DSS.

Meanwhile, the last part in designing a DSS is the DSS user interface that allows the user to access the internal components of the DSS in a relatively easy fashion and without having to know specifically how everything is put together or how it works together. The last set of appendixes in this research will briefly describe each part of the user interface prototypes which are supported with figures. The appendixes will illustrate the following:

1. Appendix E: Program control diagrams
2. Appendix F: Prototype of input/output forms
3. Appendix G: Prototype of queries
4. Appendix H: Prototype of reports
5. Appendix I: Prototype of analysis forms
6. Appendix J: Brief Users' Manual

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# V. THE USER INTERFACES

## A. INTRODUCTION

The user interface, the last component in designing a DSS, is one of the most important parts of any program because it determines how easily you can make the program do what you want. A powerful program with a poorly designed user interface has little value. Also, graphical user interfaces (GUIs) that use windows, icons, and pop-up menus have become standard on today's computer systems. [Ref. 9]

Therefore and as proof of concept, we will demonstrate in this chapter a specific use case scenario, namely, building a new unit and how the DSS user would evaluate it through the BDF_DSS user interface capabilities. In this case study, we will presume that the BDF wants to establish a new infantry battalion besides the two existing ones they have right now (101 and 103). Additionally, this new unit has an initial structure depicted on paper and has not been entered in the BDF_DSS yet. Basically, we will tackle the BDF_DSS user interface functionalities into two stages:

1. Data entry and editing stage
2. Analysis and rebuilding proposals stage.

## B. DATA ENTRY AND EDITING STAGE

The user would first enter the preliminary structure of the new unit in the BDF_DSS and give it a unique id number to be referred to later, as shown in Figure 6 below.

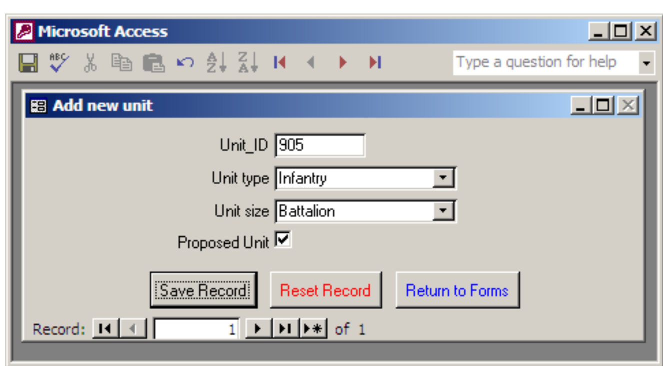



Figure 6. "Add new unit" Form

By clicking on the “Save Record” button, the user has entered a new proposed infantry battalion in the system. Then, to attach the manpower resources to that unit, the user needs to return to the “Forms” menu and click on the “Add new jobs to a unit” button that will popup the manpower data entry form as shown in Figure 7 below. As long as the manpower required for this unit are in the BDF job dictionary (job table), the user will insert the unit manpower records using this form; otherwise the user needs to insert those jobs first into the job table. Similarly, to attach the vehicles and weapons resources to that unit, the user needs to select “Add new vehicles to a unit” or “Add new weapons to a unit” in the “Forms” main menu, and follow the same procedure as for attaching unit manpower.

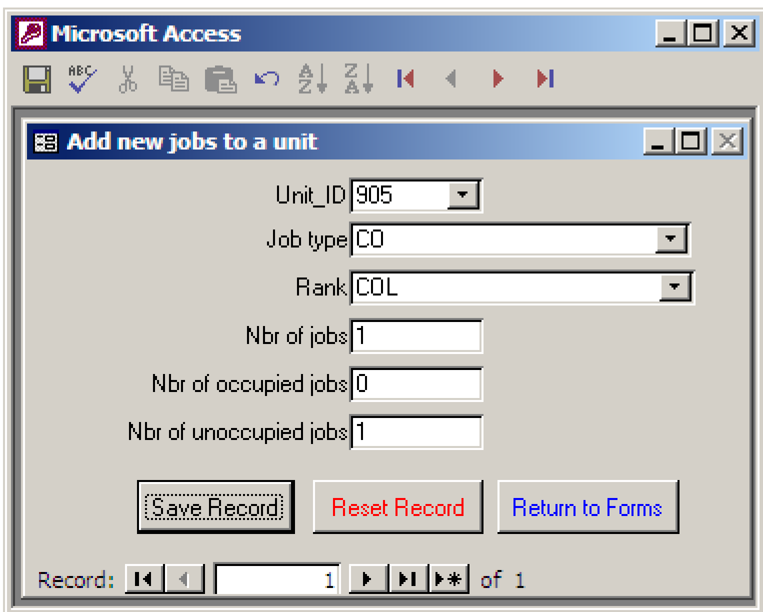



Figure 7. “Add new jobs to a unit” Form

Having entered the new unit structure in the BDF_DSS, the user now can edit all records related to that unit via the “Modify” part of “Forms” main menu. For instance, the user can make necessary corrections in unit 905 vehicles by clicking on the “Modify vehicles on a unit” button as shown on Figure 8 below. To speed up this process, the user must filter unit 905 vehicles from other unit vehicles by using the “Filter by form” icon which is the third one in the tool bar list.

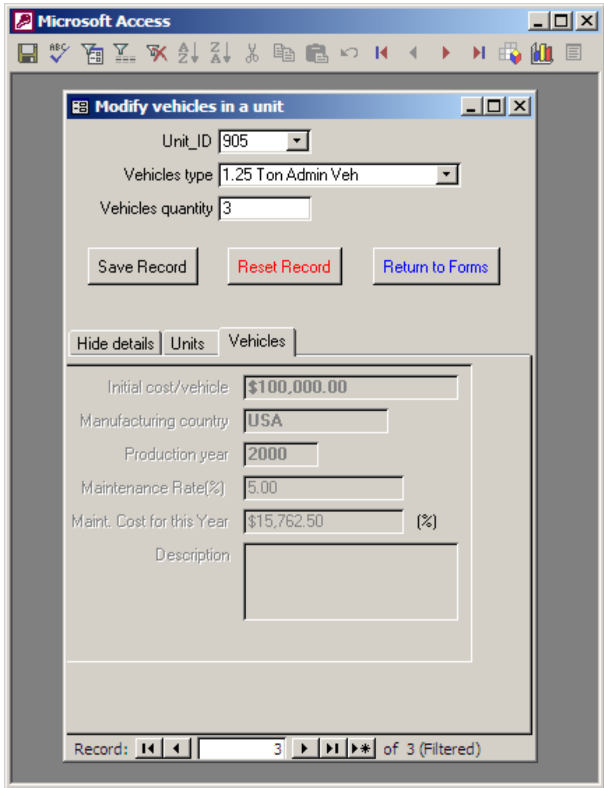



Figure 8. “Modify vehicles in a unit” Form

Alternatively, if the BDF_DSS already has a similar unit type, the user can utilize the built-in system tool called “Copy any unit as a proposed unit” to rapidly enter the new unit 905 and its resources in the BDF_DSS. This capability as shown in Figure 9 below is found in the Analysis main menu which will be widely used in analyzing proposals that requires generating unit scenarios function. After this step, the user can make small modifications to unit 905 resources to match the initial structure.

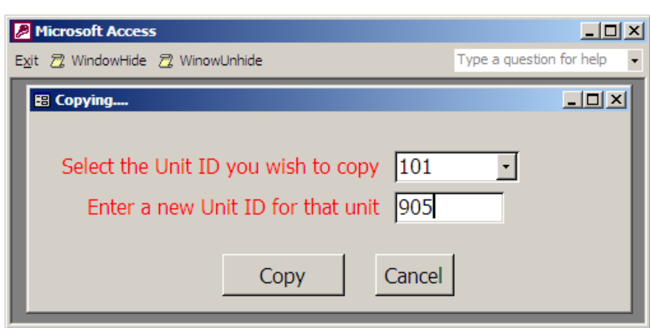
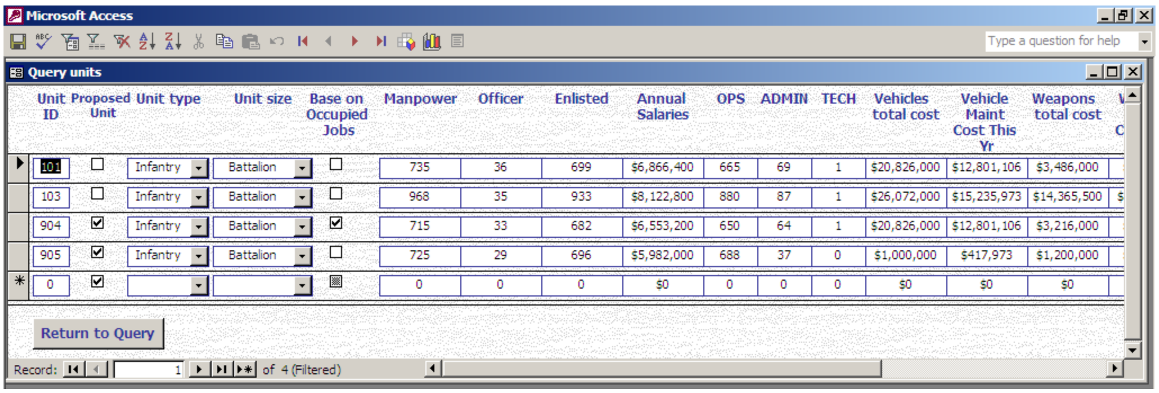



Figure 9. “Copy any unit as a proposed unit” Form

## C. ANALYSIS AND REBUILDING PROPOSALS STAGE

At this stage, the user can compare the 905 unit structure to similar existing ones by viewing a query available in the "Queries" main menu as shown in Figure 10 below. However, this figure depicts unit statistics only and does not give explanations about differences among similar unit type structures. Therefore, other queries can be used to view unit resource differences as shown in Figure 11 below.


Microsoft Access

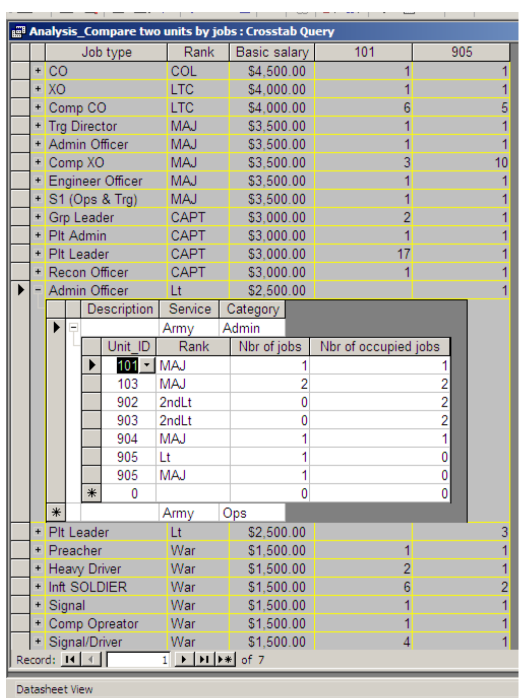
Query units

| Unit ID | Proposed Unit | Unit type | Unit size | Base on Occupied Jobs | Manpower | Officer | Enlisted | Annual Salaries | OPS | ADMIN | TECH | Vehicles total cost | Vehicle Maint Cost This Yr | Weapons total cost |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | ☐ | Infantry | Battalion | ☐ | 735 | 36 | 699 | $6,866,400 | 665 | 69 | 1 | $20,826,000 | $12,801,106 | $3,486,000 |
| 103 | ☐ | Infantry | Battalion | ☐ | 968 | 35 | 933 | $8,122,800 | 880 | 87 | 1 | $26,072,000 | $15,235,973 | $14,365,500 |
| 904 | ☑ | Infantry | Battalion | ☑ | 715 | 33 | 682 | $6,553,200 | 650 | 64 | 1 | $20,826,000 | $12,801,106 | $3,216,000 |
| 905 | ☑ | Infantry | Battalion | ☐ | 725 | 29 | 696 | $5,982,000 | 688 | 37 | 0 | $1,000,000 | $417,973 | $1,200,000 |
| 0 | ☑ | | | | 0 | 0 | 0 | $0 | 0 | 0 | 0 | $0 | $0 | $0 |

Return to Query

Record: 1 of 4 (Filtered)

Figure 10. "Query units" Form


Analysis_Compare two units by jobs : Crosstab Query

| Job type | Rank | Basic salary | 101 | 905 |
|---|---|---|---|---|
| CO | COL | $4,500.00 | 1 | 1 |
| XO | LTC | $4,000.00 | 1 | 1 |
| Comp CO | LTC | $4,000.00 | 6 | 5 |
| Trg Director | MAJ | $3,500.00 | 1 | 1 |
| Admin Officer | MAJ | $3,500.00 | 1 | 1 |
| Comp XO | MAJ | $3,500.00 | 3 | 10 |
| Engineer Officer | MAJ | $3,500.00 | 1 | 1 |
| S1 (Ops & Trg) | MAJ | $3,500.00 | 1 | 1 |
| Grp Leader | CAPT | $3,000.00 | 2 | 1 |
| Plt Admin | CAPT | $3,000.00 | 1 | 1 |
| Plt Leader | CAPT | $3,000.00 | 17 | 1 |
| Recon Officer | CAPT | $3,000.00 | 1 | 1 |
| Admin Officer | Lt | $2,500.00 | | 1 |

| Description | Service | Category |
|---|---|---|
| | Army | Admin |
| | Army | Ops |

| Unit_ID | Rank | Nbr of jobs | Nbr of occupied jobs |
|---|---|---|---|
| 101 | MAJ | 1 | 1 |
| 103 | MAJ | 2 | 2 |
| 902 | 2ndLt | 0 | 2 |
| 903 | 2ndLt | 0 | 2 |
| 904 | MAJ | 1 | 1 |
| 905 | Lt | 1 | 0 |
| 905 | MAJ | 1 | 0 |
| 0 | | 0 | 0 |

| Job type | Rank | Basic salary | 101 | 905 |
|---|---|---|---|---|
| Plt Leader | Lt | $2,500.00 | | 3 |
| Preacher | War | $1,500.00 | 1 | 1 |
| Heavy Driver | War | $1,500.00 | 2 | 1 |
| Inft SOLDIER | War | $1,500.00 | 6 | 2 |
| Signal | War | $1,500.00 | 1 | 1 |
| Comp Opreator | War | $1,500.00 | 1 | 1 |
| Signal/Driver | War | $1,500.00 | 4 | 1 |

Record: 1 of 7

Datasheet View

Figure 11. "Compare two units by jobs" Crosstab Query

Moreover, the user can see the impact of unit 905 on the overall BDF existing units (101, 102, and 103 in this case) as illustrated in Figure 12 below. This screen utilizes the chart capability in the BDF_DSS application that shows only the unit cost drivers such as unit annual salary, vehicle maintenance cost for this year, and vehicle total cost for each unit. However, the user can use other visualization tool like pivot tables to see numbers and grand totals among those units as shown in Figure 13 below. The chart and pivot tables' tools are available in the application forms and queries which allow the user to drill, slice and dice, and change displays in the desired measures and dimensions.

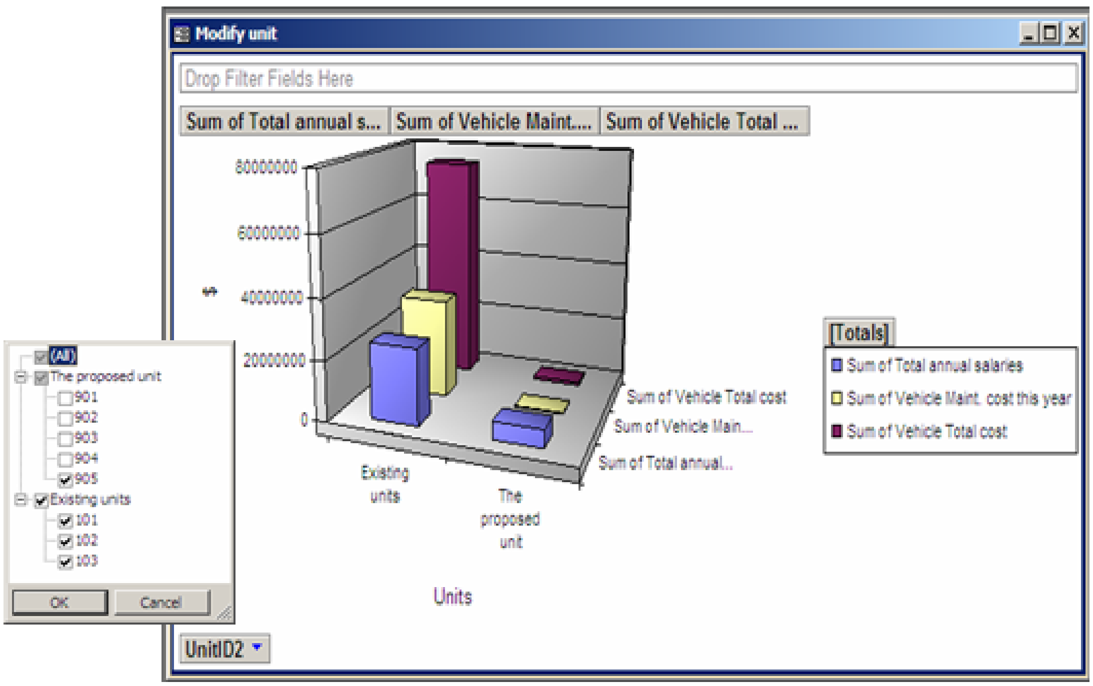



Figure 12. 3-D Chart of Unit 905 and All Other Existing BDF Units

Drop Filter Fields Here

| UnitID2 | Unit_ID | Sum of Total annual salaries | Sum of Vehicle Maint. cost this year | Sum of Vehicle Total cost |
|---|---|---|---|---|
| ⊟ Existing units | 101 | 21.76% | 38.09% | 27.22% |
| | 102 | 33.54% | 15.34% | 37.39% |
| | 103 | 25.74% | 45.33% | 34.08% |
| | Total | 81.04% | 98.76% | 98.69% |
| ⊟ The proposed unit | 905 | 18.96% | 1.24% | 1.31% |
| | Total | 18.96% | 1.24% | 1.31% |
| Grand Total | | 100.00% | 100.00% | 100.00% |

Figure 13. Pivot Table of Unit 905 and All Other Existing BDF Units in Percentages

Most of the time, the user gets feedback from BDF officials about the manpower budget constraint. Hypothetically, we will presume that the HR budget constraint of building unit 905 is $6,000,000 (at least 20% less than the annual salary of unit 101 and 103 infantry battalions). Thus, the user can use the built-in HR optimization models to figure out the best rank distribution within this constraint and others as described in earlier chapter. Thus, as shown in Figure 14 below, the user can select the Optimization model submenu from the "Analysis" main menu and then click on the "Infantry Battalion" icon that matches the unit 905 type and start to play different scenarios. As shown on Figure 15 below, we assume that the user has run different scenarios and "what-if" questions and found that solution as the most reasonable option to the problem at hand.

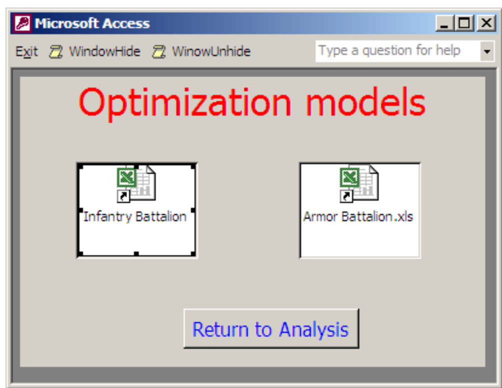



Figure 14. Optimization Models Submenu

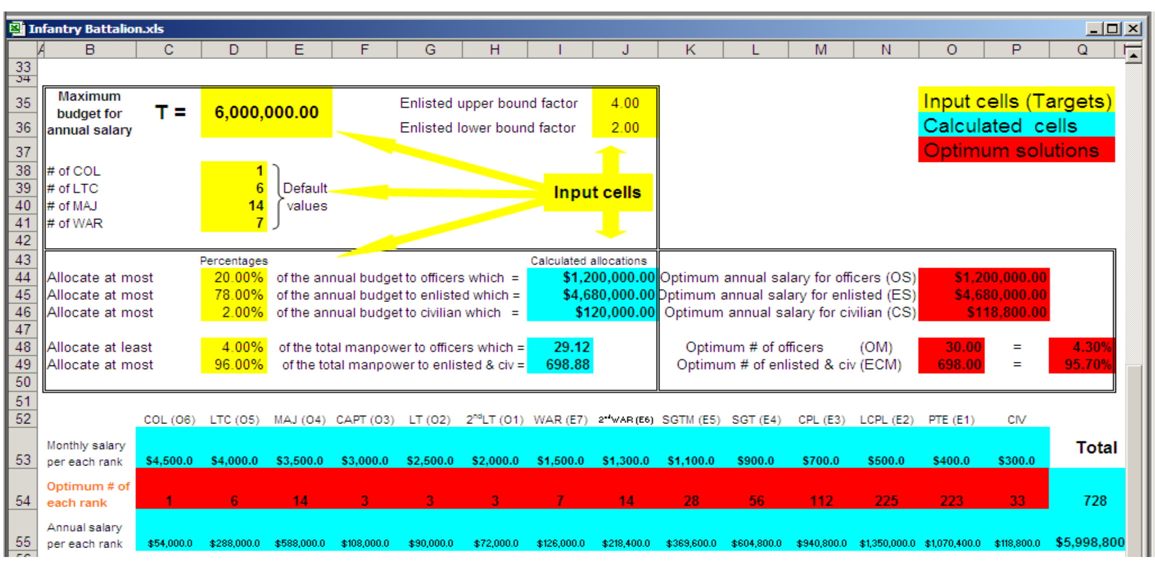



Figure 15. MS Excel spreadsheet of the Infantry Battalion HR Model

After assuring that this is the best solution and the decision variables reflect reality for the required structure, the user can rebuild the unit 905 based on the values that will represent unit 905 manpower requirements. Ultimately, the user will see that all constraints set in the previous model are verified automatically by the system as depicted in Figure 16 below. Additionally, the user can view more details on unit 905 as seen in Figure 17 below.

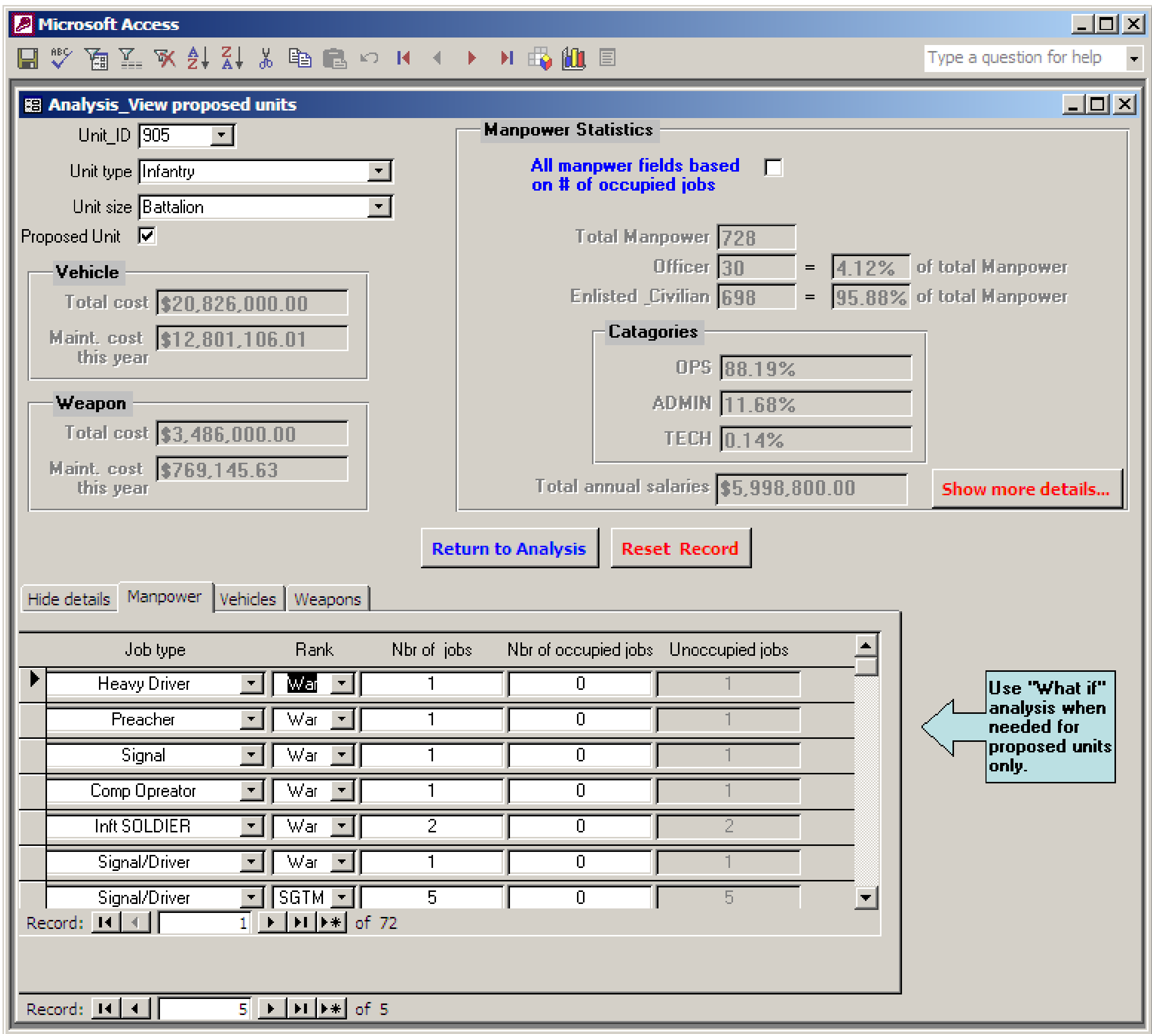
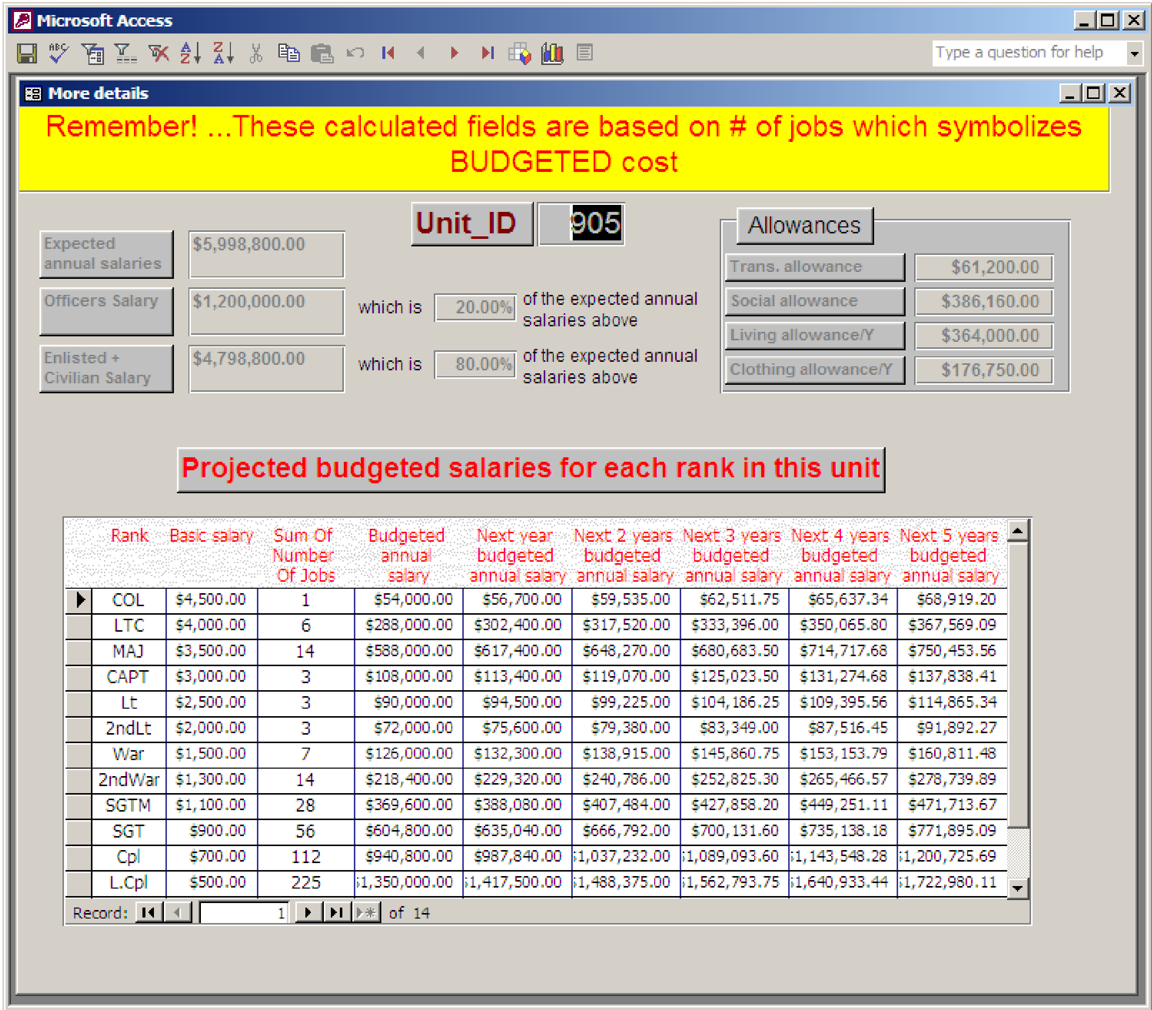



Figure 16. “View proposed units” Form




| Rank | Basic salary | Sum Of Number Of Jobs | Budgeted annual salary | Next year budgeted annual salary | Next 2 years budgeted annual salary | Next 3 years budgeted annual salary | Next 4 years budgeted annual salary | Next 5 years budgeted annual salary |
|---|---|---|---|---|---|---|---|---|
| COL | $4,500.00 | 1 | $54,000.00 | $56,700.00 | $59,535.00 | $62,511.75 | $65,637.34 | $68,919.20 |
| LTC | $4,000.00 | 6 | $288,000.00 | $302,400.00 | $317,520.00 | $333,396.00 | $350,065.80 | $367,569.09 |
| MAJ | $3,500.00 | 14 | $588,000.00 | $617,400.00 | $648,270.00 | $680,683.50 | $714,717.68 | $750,453.56 |
| CAPT | $3,000.00 | 3 | $108,000.00 | $113,400.00 | $119,070.00 | $125,023.50 | $131,274.68 | $137,838.41 |
| Lt | $2,500.00 | 3 | $90,000.00 | $94,500.00 | $99,225.00 | $104,186.25 | $109,395.56 | $114,865.34 |
| 2ndLt | $2,000.00 | 3 | $72,000.00 | $75,600.00 | $79,380.00 | $83,349.00 | $87,516.45 | $91,892.27 |
| War | $1,500.00 | 7 | $126,000.00 | $132,300.00 | $138,915.00 | $145,860.75 | $153,153.79 | $160,811.48 |
| 2ndWar | $1,300.00 | 14 | $218,400.00 | $229,320.00 | $240,786.00 | $252,825.30 | $265,466.57 | $278,739.89 |
| SGTM | $1,100.00 | 28 | $369,600.00 | $388,080.00 | $407,484.00 | $427,858.20 | $449,251.11 | $471,713.67 |
| SGT | $900.00 | 56 | $604,800.00 | $635,040.00 | $666,792.00 | $700,131.60 | $735,138.18 | $771,895.09 |
| Cpl | $700.00 | 112 | $940,800.00 | $987,840.00 | $1,037,232.00 | $1,089,093.60 | $1,143,548.28 | $1,200,725.69 |
| L.Cpl | $500.00 | 225 | $1,350,000.00 | $1,417,500.00 | $1,488,375.00 | $1,562,793.75 | $1,640,933.44 | $1,722,980.11 |

Figure 17. “More details” Form

In conclusion, this chapter has briefly illustrated the BDF_DSS user interfaces through a case study that requires building a new infantry battalion (905). However, the last group of the appendixes show more examples of user interfaces as well as provide a brief users’ manual.

# VI. CONCLUSIONS AND RECOMMENDATIONS

## A. SUMMARY

This thesis designed and developed a DSS prototype that integrated relational database with optimization models to analyze organizational problems arising in the BDF. Initially, we described the current processes for maintaining the BDF organizational structures in order to justify the BDF needs for a computer-based system in this area. In addition, the significant parameters that must be taken into consideration while processing the BDF structures were identified in order to measure a structure's validity and feasibility.

The thesis then presented the DSS design phase; which involved the development of a database application. The data element of the DSS was discussed in three stages: the conceptual data model, the physical design, and the process design. The required system capabilities were incorporated in the system design phase: the visualization tools and analytical models.

Next, the research introduced two examples of optimization models that are linked to the BDF_DSS database. The performance metrics discussed in an earlier chapter were embedded in the models' design to reflect the supportability of the system. Generally, the two examples were an attempt to satisfy the BDF requirements in articulating resource-planning problems to find the best options among the many scenarios.

Finally, to complete the creation of the required BDF_DSS, the last part of the thesis was dedicated to the user interfaces which are shown in the related appendixes. Furthermore, a brief user's manual was provided at the end of the research to help real decision-makers use the system.

## B. BDF_DSS BENEFITS

As a result of this work, BDF can obtain several benefits when implementing the DSS tool prototyped in this research:

1. DSS users can easily analyze the effectiveness of BDF organizational structures with less effort and in a shorter time. With this DSS tool, users can approximately achieve 50% time savings required to manipulate the BDF organizational structures.
2. The DSS can help users to produce evidence in support of a decision confirmation for a proposed BDF organizational structure. In other words, these decisions are based upon data and analysis instead of intuition or heuristic.
3. The DSS users can produce a wider range of unit structure options and then select the most appealing ones to be presented.
4. As they gain experience with the DSS, DSS users can develop new approaches when thinking about a problem area or decision context. In other words, the DSS users can improve their ability to tackle complex unit structures as time passes.
5. Last but not least, the suggested decision system allows for careful, analytical financial planning. This means that the DSS users can easily obtain the projected costs of the BDF structures, which gives the users, and the BDF, a robust resource-planning tool.

## C. RECOMMENDATIONS

A future study of this topic is germane to the BDF. The proposed BDF_DSS is sufficient as a first step but it is not fully operational as was discussed earlier. The recommendations for a future research in this field are summarized as follows:

- The development cycle of this DSS must never stop whenever a system update is needed to meet the added objectives.
- Beside the manpower, vehicles, and weapons resources, the DSS must include all of the tangible and non-tangible resources needed to run a unit structure in order to give the decision-maker a complete picture of the unit total estimated cost. For instance, tangible resources could be other operational equipment that is not included in the system (i.e. communication equipment and weapon ammunitions). Also, non-tangible resources could be manpower-related costs such as training costs, health care costs, etc; or costs related to the unit itself such as a unit's

military exercise costs and unit service costs such as electricity, water and so forth.

- The optimization models developed in this system can be further remodeled with more valid assumptions to accurately reflect reality.
- In addition, the optimization models in this research were exclusively considering the HR basic salary costs. Thus, other HR cost drivers such as allowances can be embedded in the model to achieve HR cost precision.
- A more robust database engine must be considered when building such a system to speed up the application processing time and to accommodate further data expansion and features. For example, Microsoft SQL Server or Oracle databases can house and process larger data than MS Access™ does.
- With regard to information security issue, this system can easily be transformed to a Web-based system using the Microsoft Data Access Page tool (DAP) in order to allow decision-makers to remotely present their models and data from anywhere.
- Finally, the optimization model in this system can be extended to include other model types such as forecasting model. Using time series or regression methods, for instance, users can predict BDF manpower end strength requirements over the next 3, 5, 10 years. This type of model could then feed the related optimization model.

This thesis has shown a useful integration of database and optimization technology that can potentially help solve real problems in the BDF. By combining optimization models in a transparent way with standard database management tools, a simple yet effective decision support system has been developed to evaluate and compare BDF organizational unit structures. The benefits of this system underscore the value of good decision support, namely more decision alternatives can be evaluated in a shorter amount of time.

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# APPENDIX A: ENTITY RELATIONSHIP DIAGRAMS OF BDF_DSS

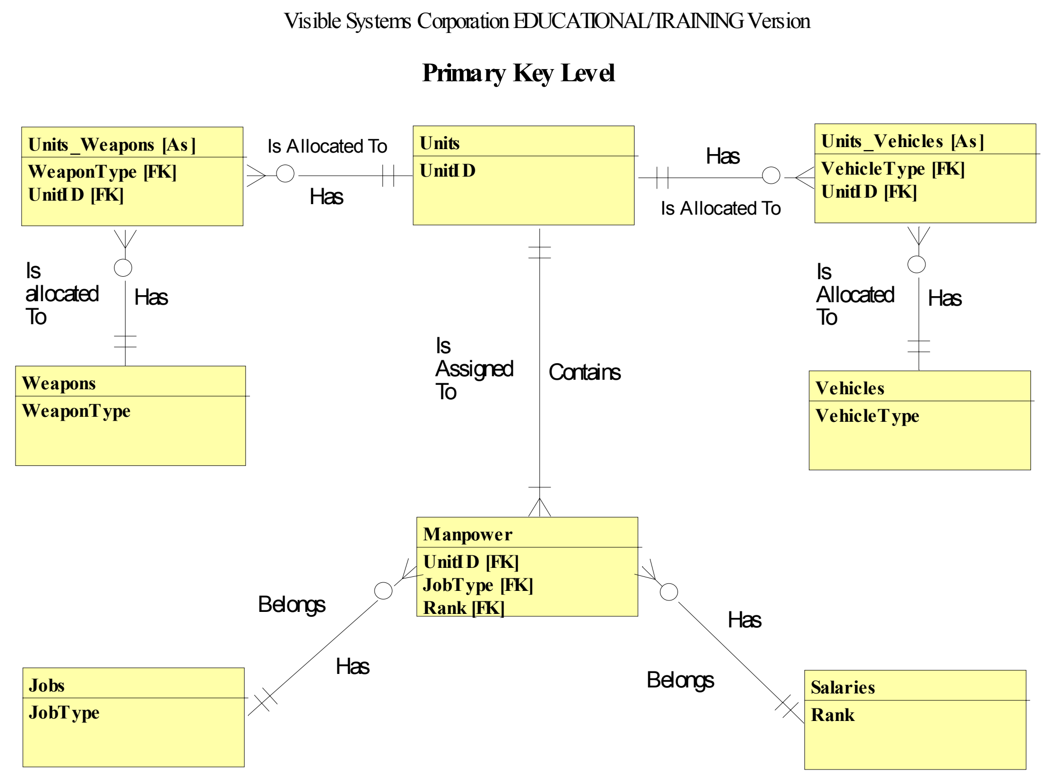


Figure 18. Entity Relationship Diagram of the Database Model – Primary Key Level

**Attribute Level**

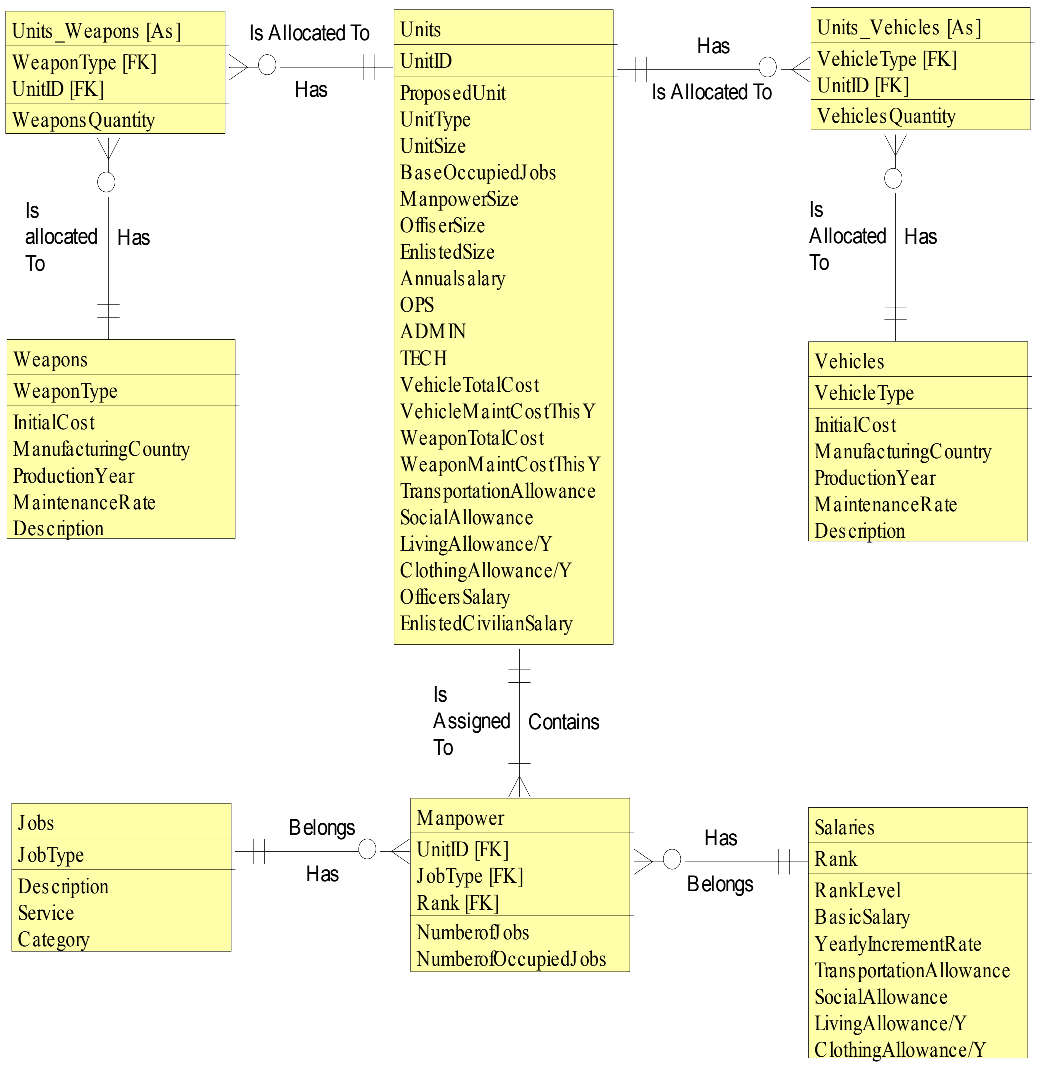


Figure 19. Entity Relationship Diagram of the Database Model – Attribute Level

# APPENDIX B: DATABASE SCHEMA OF BDF_DSS

## 1. RELATIONAL MODEL

**Jobs** (JobType, Description, Service, Category)

**Manpower** (UnitID_FK, JobType_FK, Rank_FK, NumberofJobs, NumberofOccupiedJobs)

**Salaries** (Rank, RankLevel, BasicSalary, YearlyIncrementRate, TransportationAllowance, SocialAllowance, LivingAllowance/Y, ClothingAllowance/Y)

**Units** (UnitID, ProposedUnit, UnitType, UnitSize, BaseOccupiedJobs, ManpowerSize, OffiserSize, EnlistedSize, Annualsalary, OPS, ADMIN, TECH, VehicleTotalCost, VehicleMaintCostThisY, WeaponTotalCost, WeaponMaintCostThisY, TransportationAllowance, SocialAllowance, LivingAllowance/Y, ClothingAllowance/Y, OfficersSalary, EnlistedCivilianSalary)

**Units_Vehicles** (VehicleType_FK, UnitID_FK, VehiclesQuantity)

**Units_Weapons** (WeaponType_FK, UnitID_FK, WeaponsQuantity)

**Vehicles** (VehicleType, InitialCost, ManufacturingCountry, ProductionYear, MaintenanceRate, Description)

**Weapons** (WeaponType, InitialCost, ManufacturingCountry, ProductionYear, MaintenanceRate, Description)

## 2. GENERATED DATABASE SCHEMA

```
CREATE TABLE Jobs
(
  JobType                    CHAR(20) NOT NULL,
  Description                CHAR(400),
  Service                    CHAR(20),
  Category                   CHAR(20) NOT NULL
);

CREATE TABLE Manpower
(
  UnitID                     INTEGER NOT NULL,
  JobType                    CHAR(20) NOT NULL,
  Rank                       CHAR(20) NOT NULL,
  NumberofJobs               CHAR(20),
  NumberofOccupiedJobs       INTEGER,
);

CREATE TABLE Salaries
(
  Rank                       CHAR(20) NOT NULL,
  RankLevel                  CHAR(10) NOT NULL,
  BasicSalary                CHAR(20) NOT NULL,
  YearlyIncrementRate        NUMBER NOT NULL,
  TransportationAllowance    MONEY,
  SocialAllowance            MONEY,
  LivingAllowance/Y          MONEY,
  ClothingAllowance/Y        MONEY
);

CREATE TABLE Units
(
  UnitID                     INTEGER NOT NULL,
  ProposedUnit               BIT,
  UnitType                   INTEGER NOT NULL,
  UnitSize                   CHAR(50) NOT NULL,
  BaseOccupiedJobs           BIT,
  ManpowerSize               INTEGER,
  OffiserSize                INTEGER,
  EnlistedSize               INTEGER,
  Annualsalary               CHAR(20),
  OPS                        INTEGER,
  ADMIN                      INTEGER,
  TECH                       INTEGER,
  VehicleTotalCost           MONEY,
```

```
  VehicleMaintCostThisY          MONEY,
  WeaponTotalCost                MONEY,
  WeaponMaintCostThisY           MONEY,
  TransportationAllowance        MONEY,
  SocialAllowance                MONEY,
  LivingAllowance/Y              MONEY,
  ClothingAllowance/Y            MONEY,
  OfficersSalary                 MONEY,
  EnlistedCivilianSalary         MONEY
);

CREATE TABLE Units_Vehicles
(
  VehicleType                    CHAR(50) NOT NULL,
  UnitID                         INTEGER NOT NULL,
  VehiclesQuantity               INTEGER
);

CREATE TABLE Units_Weapons
(
  WeaponType                     CHAR(50) NOT NULL,
  UnitID                         INTEGER NOT NULL,
  WeaponsQuantity                INTEGER
);

CREATE TABLE Vehicles
(
  VehicleType                    CHAR(50) NOT NULL,
  InitialCost                    CHAR(20) NOT NULL,
  ManufacturingCountry           CHAR(20) NOT NULL,
  ProductionYear                 INTEGER NOT NULL,
  MaintenanceRate                NUMBER NOT NULL,
  Description                    CHAR(400)
);

CREATE TABLE Weapons
(
  WeaponType                     CHAR(50) NOT NULL,
  InitialCost                    CHAR(20) NOT NULL,
  ManufacturingCountry           CHAR(20) NOT NULL,
  ProductionYear                 INTEGER NOT NULL,
  MaintenanceRate                NUMBER NOT NULL,
  Description                    CHAR(400)
);
```

```
CREATE UNIQUE  INDEX PKJobs ON Jobs ( JobType ASC );
CREATE UNIQUE  INDEX PKManpower ON Manpower (UnitID ASC, JobType ASC, Rank ASC );
CREATE UNIQUE  INDEX PKSalaries ON Salaries ( Rank ASC );
CREATE UNIQUE  INDEX PKUnits ON Units ( UnitID ASC );
CREATE UNIQUE  INDEX PKUnits_Vehicles ON Units_Vehicles ( VehicleType ASC, UnitID ASC );
CREATE UNIQUE  INDEX PKUnits_Weapons ON Units_Weapons ( WeaponType ASC, UnitID ASC );
CREATE UNIQUE  INDEX PKVehicles ON Vehicles ( VehicleType ASC );
CREATE UNIQUE  INDEX PKWeapons ON Weapons ( WeaponType ASC );
ALTER TABLE Jobs ADD
  CONSTRAINT PKC_Jobs0000 PRIMARY KEY ( JobType );
ALTER TABLE Manpower ADD
  CONSTRAINT PKC_Manpower0004 PRIMARY KEY (UnitID, JobType, Rank);
ALTER TABLE Salaries ADD
  CONSTRAINT PKC_Salaries0005 PRIMARY KEY ( Rank );
ALTER TABLE Units ADD
  CONSTRAINT PKC_Units0006 PRIMARY KEY ( UnitID );
ALTER TABLE Units_Vehicles ADD
  CONSTRAINT PKC_Units_Vehicles0009 PRIMARY KEY ( VehicleType, UnitID );
ALTER TABLE Units_Weapons ADD
  CONSTRAINT PKC_Units_Weapons000C PRIMARY KEY ( WeaponType, UnitID );
ALTER TABLE Vehicles ADD
  CONSTRAINT PKC_Vehicles000D PRIMARY KEY ( VehicleType );
ALTER TABLE Weapons ADD
  CONSTRAINT PKC_Weapons000E PRIMARY KEY ( WeaponType );
ALTER TABLE Manpower ADD
  CONSTRAINT FKC_Belongs0001 FOREIGN KEY ( Rank ) REFERENCES Salaries;
ALTER TABLE Manpower ADD
  CONSTRAINT FKC_Belongs0002 FOREIGN KEY ( JobType ) REFERENCES Jobs;
ALTER TABLE Manpower ADD
  CONSTRAINT FKC_Contains0003 FOREIGN KEY ( UnitID ) REFERENCES Units;
ALTER TABLE Units_Vehicles ADD
```

```
  CONSTRAINT FKC_Is_Allocated_To0007 FOREIGN KEY ( VehicleType ) REFERENCES
    Vehicles;

ALTER TABLE Units_Vehicles ADD

  CONSTRAINT FKC_Has0008 FOREIGN KEY ( UnitID ) REFERENCES Units;

ALTER TABLE Units_Weapons ADD

  CONSTRAINT FKC_Is_allocated_To000A FOREIGN KEY ( WeaponType ) REFERENCES Weapons;

ALTER TABLE Units_Weapons ADD

  CONSTRAINT FKC_Has000B FOREIGN KEY ( UnitID ) REFERENCES Units;
```

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# APPENDIX C: RELATIONAL DATABASE DESIGN OF BDF_DSS FROM MS ACCESS™

## 1. RELATIONAL STRUCTURE DIAGRAM

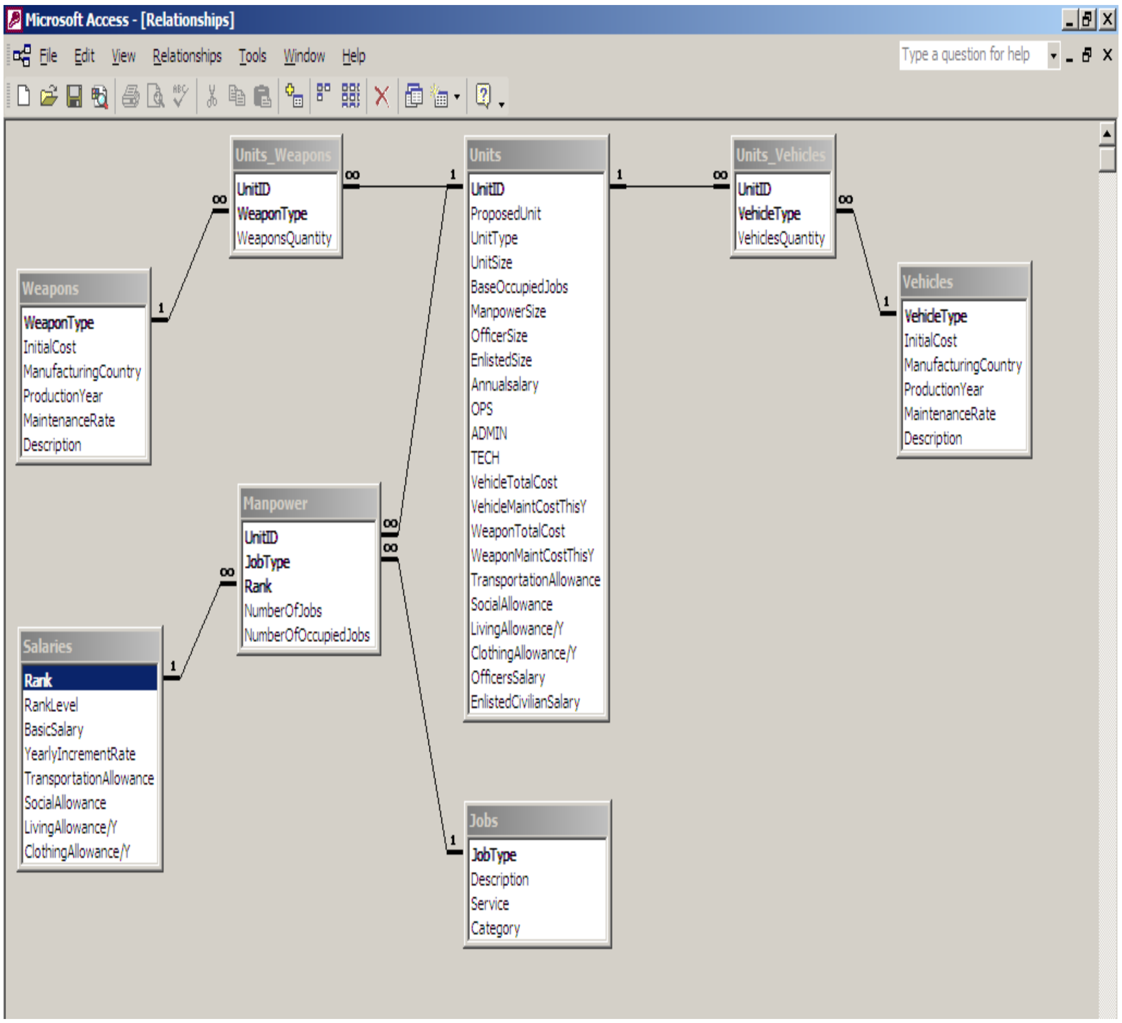
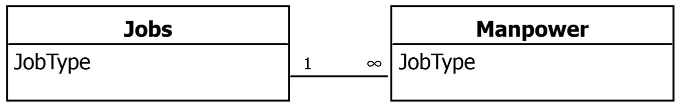



Figure 20. MS Access™ Relational Structure Diagram of BDF_DSS

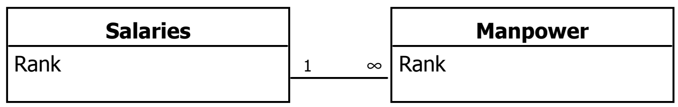
## 2. RELATIONSHIPS PROPERTIES

**JobsManpower**



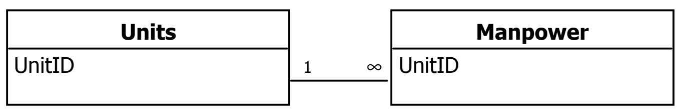

Attributes: Enforced, Cascade Updates, Cascade Deletes
RelationshipType: One-To-Many

**SalariesManpower**



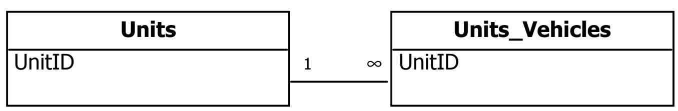

Attributes: Enforced, Cascade Updates, Cascade Deletes
RelationshipType: One-To-Many

**UnitsManpower**



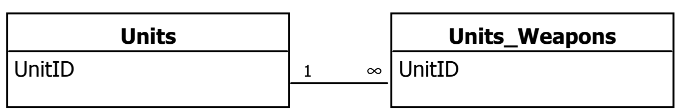

Attributes: Enforced, Cascade Updates, Cascade Deletes
RelationshipType: One-To-Many

**UnitsUnits_Vehicles**



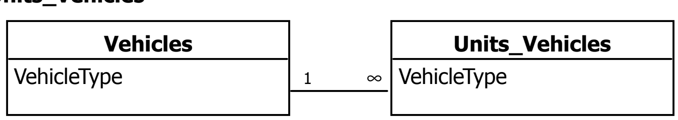

Attributes: Enforced, Cascade Updates, Cascade Deletes
RelationshipType: One-To-Many

**UnitsUnits_Weapons**



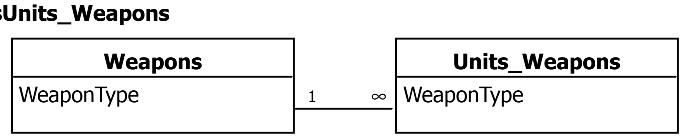

Attributes: Enforced, Cascade Updates, Cascade Deletes
RelationshipType: One-To-Many

**VehiclesUnits_Vehicles**




Attributes: Enforced, Cascade Updates, Cascade Deletes
RelationshipType: One-To-Many

**WeaponsUnits_Weapons**




Attributes: Enforced, Cascade Updates, Cascade Deletes
RelationshipType: One-To-Many

# APPENDIX D: OPTIMIZATION MODELS

## 1. INFANTRY BATTALION

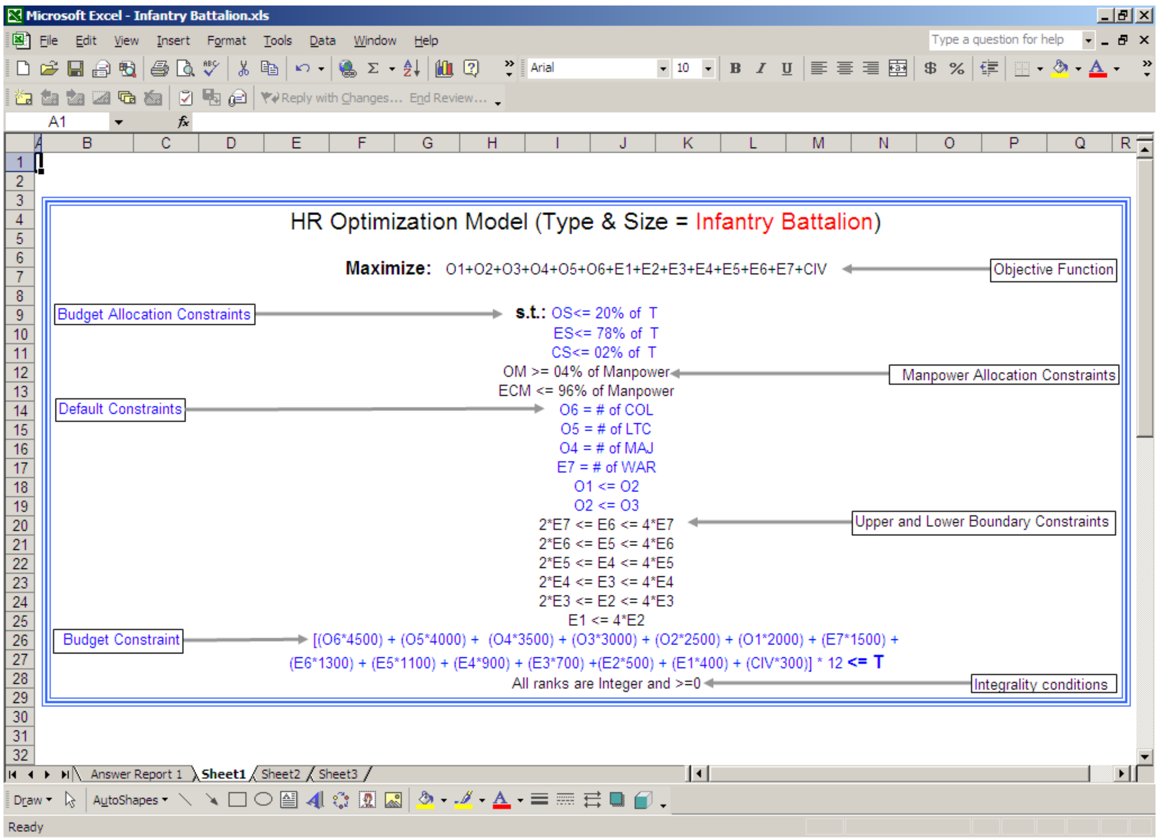



Figure 21. Mathematical Model of the Infantry Battalion

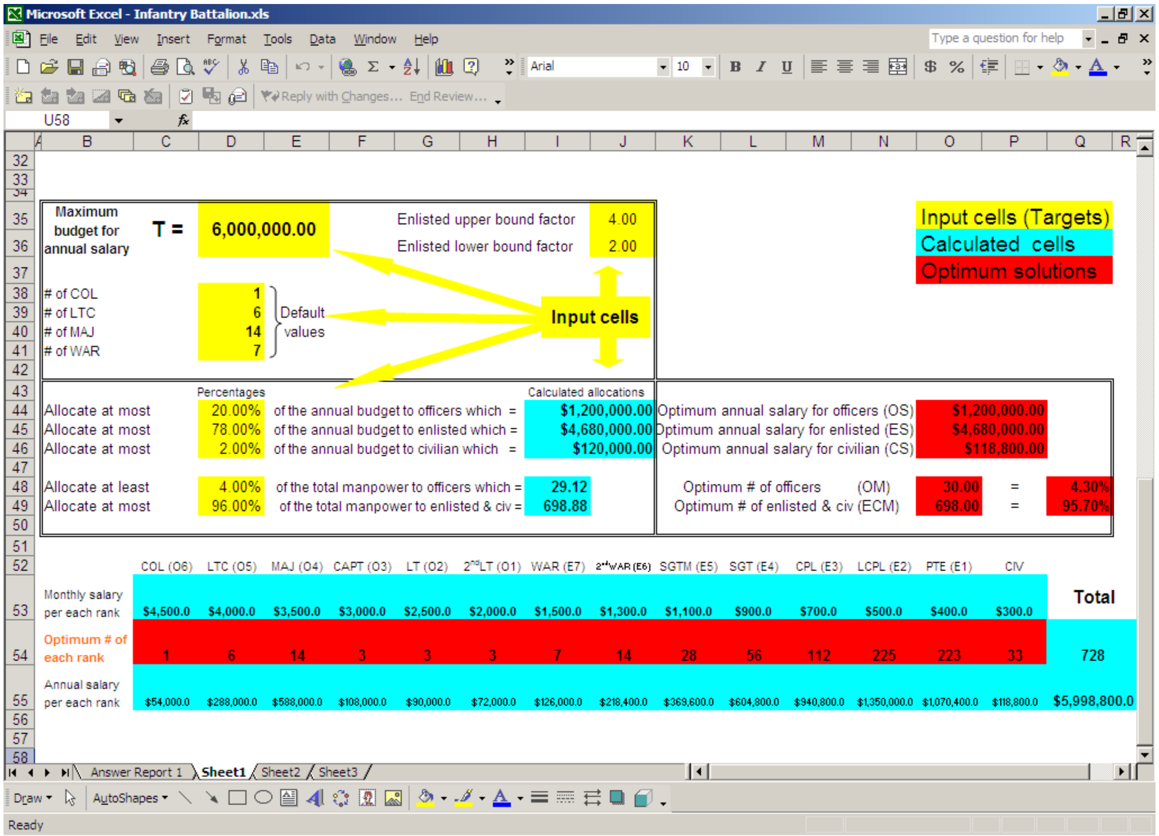



Figure 22. Implemented Model of the Infantry Battalion

**Microsoft Excel 10.0 Answer Report**
**Worksheet: [Infantry Battalion.xls]Sheet1**
**Report Created: 4/19/2003 10:43:46 PM**

Target Cell (Max)

| Cell | Name | Original Value | Final Value |
|---|---|---|---|
| $Q$54 | Optimum # of each rank Total | 0 | 728 |

Adjustable Cells

| Cell | Name | Original Value | Final Value |
|---|---|---|---|
| $C$54 | Optimum # of each rank COL (O6) | 0 | 1 |
| $D$54 | Optimum # of each rank LTC (O5) | 0 | 6 |
| $E$54 | Optimum # of each rank MAJ (O4) | 0 | 14 |
| $F$54 | Optimum # of each rank CAPT (O3) | 0 | 3 |
| $G$54 | Optimum # of each rank LT (O2) | 0 | 3 |
| $H$54 | Optimum # of each rank 2ndLT (O1) | 0 | 3 |
| $I$54 | Optimum # of each rank WAR (E7) | 0 | 7 |
| $J$54 | Optimum # of each rank 2ndWAR (E6) | 0 | 14 |
| $K$54 | Optimum # of each rank SGTM (E5) | 0 | 28 |
| $L$54 | Optimum # of each rank SGT (E4) | 0 | 56 |
| $M$54 | Optimum # of each rank CPL (E3) | 0 | 112 |
| $N$54 | Optimum # of each rank LCPL (E2) | 0 | 225 |
| $O$54 | Optimum # of each rank PTE (E1) | 0 | 223 |
| $P$54 | Optimum # of each rank CIV | 0 | 33 |

Constraints

| Cell | Name | Cell Value | Formula | Status | Slack |
|---|---|---|---|---|---|
| $O$44 | Optimum annual salary for officers (OS) Optimum solutions | $1,200,000.00 | $O$44<=$I$44 | Binding | 0 |
| $O$45 | Optimum annual salary for enlisted (ES) Optimum solutions | $4,680,000.00 | $O$45<=$I$45 | Binding | 0 |
| $O$46 | Optimum annual salary for civilian (CS) Optimum solutions | $118,800.00 | $O$46<=$I$46 | Not Binding | 1200 |
| $K$54 | Optimum # of each rank SGTM (E5) | 28 | $K$54<=$J$35*$J$54 | Not Binding | 28 |
| $O$54 | Optimum # of each rank PTE (E1) | 223 | $O$54<=$J$35*$N$54 | Not Binding | 677 |
| $M$54 | Optimum # of each rank CPL (E3) | 112 | $M$54<=$J$35*$L$54 | Not Binding | 112 |
| $L$54 | Optimum # of each rank SGT (E4) | 56 | $L$54>=$J$36*$K$54 | Binding | 0 |
| $J$54 | Optimum # of each rank 2ndWAR (E6) | 14 | $J$54>=$J$36*$I$54 | Binding | 0 |
| $N$54 | Optimum # of each rank LCPL (E2) | 225 | $N$54<=$J$35*$M$54 | Not Binding | 223 |
| $M$54 | Optimum # of each rank CPL (E3) | 112 | $M$54>=$J$36*$L$54 | Binding | 0 |
| $L$54 | Optimum # of each rank SGT (E4) | 56 | $L$54<=$J$35*$K$54 | Not Binding | 56 |
| $O$49 | Optimum # of enlisted & civ (ECM) Optimum solutions | 698.00 | $O$49<=$I$49 | Not Binding | 0.88 |
| $J$54 | Optimum # of each rank 2ndWAR (E6) | 14 | $J$54<=$J$35*$I$54 | Not Binding | 14 |
| $K$54 | Optimum # of each rank SGTM (E5) | 28 | $K$54>=$J$36*$J$54 | Binding | 0 |
| $Q$55 | Annual salary per each rank Total | $5,998,800.0 | $Q$55<=$D$35 | Not Binding | 1200 |
| $O$48 | Optimum # of officers (OM) Optimum solutions | 30.00 | $O$48>=$I$48 | Not Binding | 0.88 |
| $H$54 | Optimum # of each rank 2ndLT (O1) | 3 | $H$54<=$G$54 | Binding | 0 |
| $N$54 | Optimum # of each rank LCPL (E2) | 225 | $N$54>=$J$36*$M$54 | Not Binding | 1 |
| $G$54 | Optimum # of each rank LT (O2) | 3 | $G$54<=$F$54 | Binding | 0 |
| $C$54 | Optimum # of each rank COL (O6) | 1 | $C$54=$D$38 | Not Binding | 0 |
| $E$54 | Optimum # of each rank MAJ (O4) | 14 | $E$54=$D$40 | Not Binding | 0 |
| $D$54 | Optimum # of each rank LTC (O5) | 6 | $D$54=$D$39 | Not Binding | 0 |
| $C$54 | Optimum # of each rank COL (O6) | 1 | $C$54>=0 | Not Binding | 1 |
| $D$54 | Optimum # of each rank LTC (O5) | 6 | $D$54>=0 | Not Binding | 6 |
| $E$54 | Optimum # of each rank MAJ (O4) | 14 | $E$54>=0 | Not Binding | 14 |
| $F$54 | Optimum # of each rank CAPT (O3) | 3 | $F$54>=0 | Not Binding | 3 |
| $G$54 | Optimum # of each rank LT (O2) | 3 | $G$54>=0 | Not Binding | 3 |
| $H$54 | Optimum # of each rank 2ndLT (O1) | 3 | $H$54>=0 | Not Binding | 3 |
| $I$54 | Optimum # of each rank WAR (E7) | 7 | $I$54>=0 | Not Binding | 7 |
| $J$54 | Optimum # of each rank 2ndWAR (E6) | 14 | $J$54>=0 | Not Binding | 14 |
| $K$54 | Optimum # of each rank SGTM (E5) | 28 | $K$54>=0 | Not Binding | 28 |
| $L$54 | Optimum # of each rank SGT (E4) | 56 | $L$54>=0 | Not Binding | 56 |
| $M$54 | Optimum # of each rank CPL (E3) | 112 | $M$54>=0 | Not Binding | 112 |
| $N$54 | Optimum # of each rank LCPL (E2) | 225 | $N$54>=0 | Not Binding | 225 |
| $O$54 | Optimum # of each rank PTE (E1) | 223 | $O$54>=0 | Not Binding | 223 |
| $P$54 | Optimum # of each rank CIV | 33 | $P$54>=0 | Not Binding | 33 |
| $I$54 | Optimum # of each rank WAR (E7) | 7 | $I$54=$D$41 | Binding | 0 |
| $C$54 | Optimum # of each rank COL (O6) | 1 | $C$54=integer | Binding | 0 |
| $D$54 | Optimum # of each rank LTC (O5) | 6 | $D$54=integer | Binding | 0 |
| $E$54 | Optimum # of each rank MAJ (O4) | 14 | $E$54=integer | Binding | 0 |
| $F$54 | Optimum # of each rank CAPT (O3) | 3 | $F$54=integer | Binding | 0 |
| $G$54 | Optimum # of each rank LT (O2) | 3 | $G$54=integer | Binding | 0 |
| $H$54 | Optimum # of each rank 2ndLT (O1) | 3 | $H$54=integer | Binding | 0 |
| $I$54 | Optimum # of each rank WAR (E7) | 7 | $I$54=integer | Binding | 0 |
| $J$54 | Optimum # of each rank 2ndWAR (E6) | 14 | $J$54=integer | Binding | 0 |
| $K$54 | Optimum # of each rank SGTM (E5) | 28 | $K$54=integer | Binding | 0 |
| $L$54 | Optimum # of each rank SGT (E4) | 56 | $L$54=integer | Binding | 0 |
| $M$54 | Optimum # of each rank CPL (E3) | 112 | $M$54=integer | Binding | 0 |
| $N$54 | Optimum # of each rank LCPL (E2) | 225 | $N$54=integer | Binding | 0 |
| $O$54 | Optimum # of each rank PTE (E1) | 223 | $O$54=integer | Binding | 0 |
| $P$54 | Optimum # of each rank CIV | 33 | $P$54=integer | Binding | 0 |

Table 1. Infantry Battalion Answer Report

## 2. ARMOR BATTALION

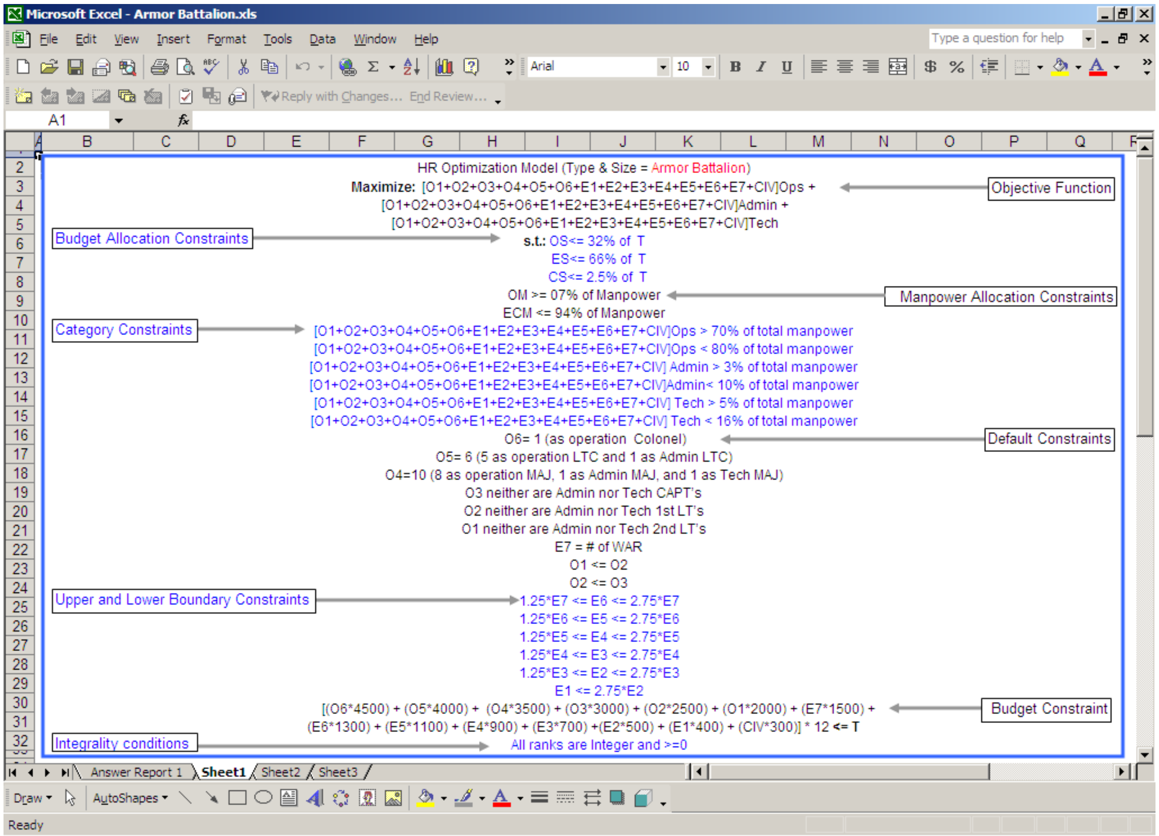



Figure 23. Mathematical Model of the Armor Battalion

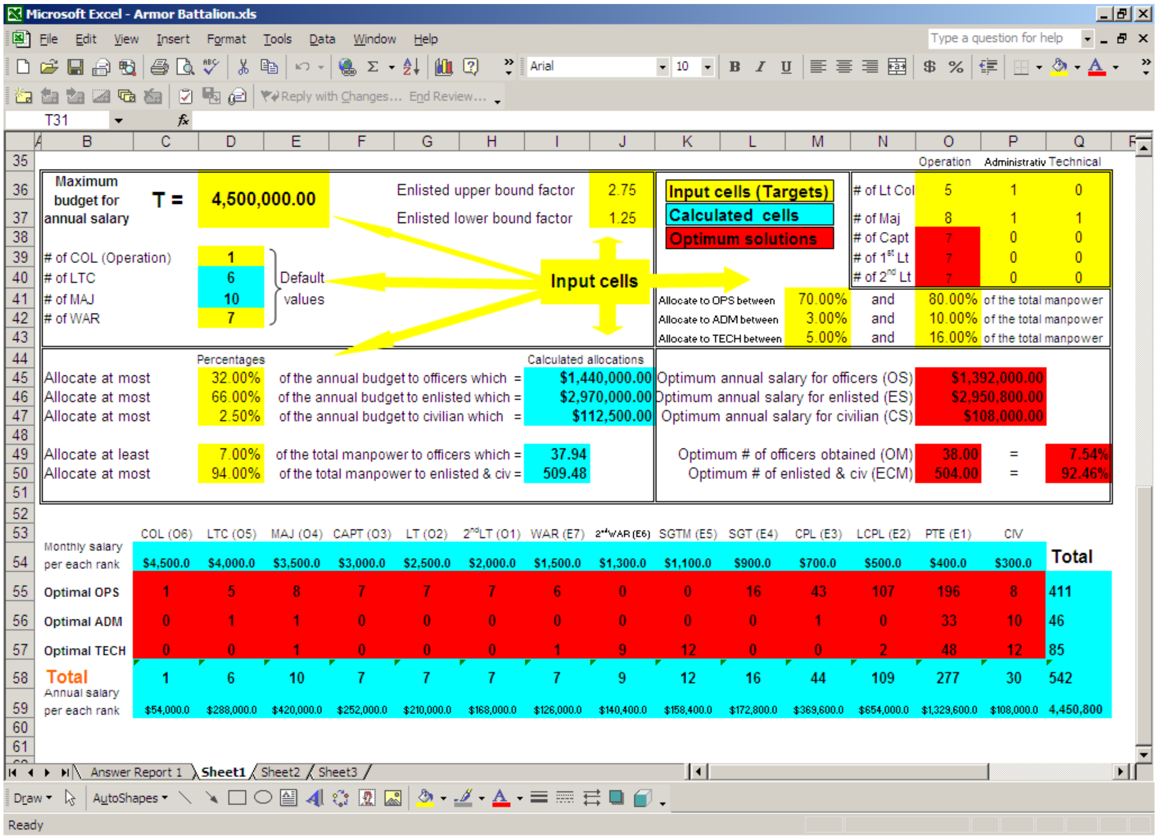



Figure 24. Implemented Model of the Armor Battalion

**Microsoft Excel 10.0 Answer Report**
**Worksheet: [Armor Battalion.xls]Sheet1**
**Report Created: 4/20/2003 1:47:42 AM**

Target Cell (Max)

| Cell | Name | Original Value | Final Value |
|---|---|---|---|
| $Q$58 | Total Total | 0 | 542 |

Adjustable Cells

| Cell | Name | Original Value | Final Value |
|---|---|---|---|
| $C$55 | Optimal OPS COL (O6) | 0 | 1 |
| $D$55 | Optimal OPS LTC (O5) | 0 | 5 |
| $E$55 | Optimal OPS MAJ (O4) | 0 | 8 |
| $F$55 | Optimal OPS CAPT (O3) | 0 | 7 |
| $G$55 | Optimal OPS LT (O2) | 0 | 7 |
| $H$55 | Optimal OPS 2ndLT (O1) | 0 | 7 |
| $I$55 | Optimal OPS WAR (E7) | 0 | 6 |
| $J$55 | Optimal OPS 2ndWAR (E6) | 0 | 0 |
| $K$55 | Optimal OPS SGTM (E5) | 0 | 0 |
| $L$55 | Optimal OPS SGT (E4) | 0 | 16 |
| $M$55 | Optimal OPS CPL (E3) | 0 | 43 |
| $N$55 | Optimal OPS LCPL (E2) | 0 | 107 |
| $O$55 | Optimal OPS PTE (E1) | 0 | 196 |
| $P$55 | Optimal OPS CIV | 0 | 8 |
| $C$56 | Optimal ADM COL (O6) | 0 | 0 |
| $D$56 | Optimal ADM LTC (O5) | 0 | 1 |
| $E$56 | Optimal ADM MAJ (O4) | 0 | 1 |
| $F$56 | Optimal ADM CAPT (O3) | 0 | 0 |
| $G$56 | Optimal ADM LT (O2) | 0 | 0 |
| $H$56 | Optimal ADM 2ndLT (O1) | 0 | 0 |
| $I$56 | Optimal ADM WAR (E7) | 0 | 0 |
| $J$56 | Optimal ADM 2ndWAR (E6) | 0 | 0 |
| $K$56 | Optimal ADM SGTM (E5) | 0 | 0 |
| $L$56 | Optimal ADM SGT (E4) | 0 | 0 |
| $M$56 | Optimal ADM CPL (E3) | 0 | 1 |
| $N$56 | Optimal ADM LCPL (E2) | 0 | 0 |
| $O$56 | Optimal ADM PTE (E1) | 0 | 33 |
| $P$56 | Optimal ADM CIV | 0 | 10 |
| $C$57 | Optimal TECH COL (O6) | 0 | 0 |
| $D$57 | Optimal TECH LTC (O5) | 0 | 0 |
| $E$57 | Optimal TECH MAJ (O4) | 0 | 1 |
| $F$57 | Optimal TECH CAPT (O3) | 0 | 0 |
| $G$57 | Optimal TECH LT (O2) | 0 | 0 |
| $H$57 | Optimal TECH 2ndLT (O1) | 0 | 0 |
| $I$57 | Optimal TECH WAR (E7) | 0 | 1 |
| $J$57 | Optimal TECH 2ndWAR (E6) | 0 | 9 |
| $K$57 | Optimal TECH SGTM (E5) | 0 | 12 |
| $L$57 | Optimal TECH SGT (E4) | 0 | 0 |
| $M$57 | Optimal TECH CPL (E3) | 0 | 0 |
| $N$57 | Optimal TECH LCPL (E2) | 0 | 2 |
| $O$57 | Optimal TECH PTE (E1) | 0 | 48 |
| $P$57 | Optimal TECH CIV | 0 | 12 |

Constraints

| Cell | Name | Cell Value | Formula | Status | Slack |
|---|---|---|---|---|---|
| $Q$56 | Optimal ADM Total | 46 | $Q$56<=$O$42*$Q$58 | Not Binding | 8.2 |
| $O$50 | Optimum # of enlisted & civ (ECM) Operation | 504.00 | $O$50<=$I$50 | Not Binding | 5.48 |
| $Q$57 | Optimal TECH Total | 85 | $Q$57<=$O$43*$Q$58 | Not Binding | 1.72 |
| $O$45 | Optimum annual salary for officers (OS) Operation | $1,392,000.00 | $O$45<=$I$45 | Not Binding | 47999.99998 |
| $O$46 | Optimum annual salary for enlisted (ES) Operation | $2,950,800.00 | $O$46<=$I$46 | Not Binding | 19200 |
| $O$47 | Optimum annual salary for civilian (CS) Operation | $108,000.00 | $O$47<=$I$47 | Not Binding | 4500 |
| $J$58 | Total 2ndWAR (E6) | 9 | $J$58>=$J$37*$I$58 | Not Binding | 0 |
| $N$58 | Total LCPL (E2) | 109 | $N$58<=$J$36*$M$58 | Not Binding | 12 |
| $L$58 | Total SGT (E4) | 16 | $L$58>=$J$37*$K$58 | Not Binding | 1 |
| $L$58 | Total SGT (E4) | 16 | $L$58<=$J$36*$K$58 | Not Binding | 17 |
| $J$58 | Total 2ndWAR (E6) | 9 | $J$58<=$J$36*$I$58 | Not Binding | 10.25 |
| $N$58 | Total LCPL (E2) | 109 | $N$58>=$J$37*$M$58 | Not Binding | 54 |
| $M$58 | Total CPL (E3) | 44 | $M$58<=$J$36*$L$58 | Binding | 0 |
| $K$58 | Total SGTM (E5) | 12 | $K$58>=$J$37*$J$58 | Not Binding | 1 |
| $O$49 | Optimum # of officers obtained (OM) Operation | 38.00 | $O$49>=$I$49 | Not Binding | 0.06 |
| $I$58 | Total WAR (E7) | 7 | $I$58=$D$42 | Not Binding | 0 |
| $K$58 | Total SGTM (E5) | 12 | $K$58<=$J$36*$J$58 | Not Binding | 12.75 |
| $Q$59 | Annual salary per each rank Total | 4,450,800 | $Q$59<=$D$36 | Not Binding | 49199.99998 |
| $H$58 | Total 2ndLT (O1) | 7 | $H$58<=$G$58 | Binding | 0 |
| $G$58 | Total LT (O2) | 7 | $G$58<=$F$58 | Binding | 0 |
| $M$58 | Total CPL (E3) | 44 | $M$58>=$J$37*$L$58 | Not Binding | 24 |
| $O$58 | Total PTE (E1) | 277 | $O$58<=$J$36*$N$58 | Not Binding | 22.75 |
| $Q$55 | Optimal OPS Total | 411 | $Q$55>=$M$41*$Q$58 | Not Binding | 32 |

Table 2. Armor Battalion Answer Report

Constraints (Cont.)

| Cell | Name | Cell Value | Formula | Status | Slack |
|---|---|---|---|---|---|
| $Q$57 | Optimal TECH Total | 85 | $Q$57>=$M$43*$Q$58 | Not Binding | 58 |
| $Q$55 | Optimal OPS Total | 411 | $Q$55<=$O$41*$Q$58 | Not Binding | 22.6 |
| $Q$56 | Optimal ADM Total | 46 | $Q$56>=$M$42*$Q$58 | Not Binding | 30 |
| $C$58 | Total COL (O6) | 1 | $C$58=$D$39 | Not Binding | 0 |
| $C$55 | Optimal OPS COL (O6) | 1 | $C$55>=0 | Not Binding | 1 |
| $D$55 | Optimal OPS LTC (O5) | 5 | $D$55>=0 | Not Binding | 5 |
| $E$55 | Optimal OPS MAJ (O4) | 8 | $E$55>=0 | Not Binding | 8 |
| $F$55 | Optimal OPS CAPT (O3) | 7 | $F$55>=0 | Not Binding | 7 |
| $G$55 | Optimal OPS LT (O2) | 7 | $G$55>=0 | Not Binding | 7 |
| $H$55 | Optimal OPS 2ndLT (O1) | 7 | $H$55>=0 | Not Binding | 7 |
| $I$55 | Optimal OPS WAR (E7) | 6 | $I$55>=0 | Not Binding | 6 |
| $J$55 | Optimal OPS 2ndWAR (E6) | 0 | $J$55>=0 | Binding | 0 |
| $K$55 | Optimal OPS SGTM (E5) | 0 | $K$55>=0 | Binding | 0 |
| $L$55 | Optimal OPS SGT (E4) | 16 | $L$55>=0 | Not Binding | 16 |
| $M$55 | Optimal OPS CPL (E3) | 43 | $M$55>=0 | Not Binding | 43 |
| $N$55 | Optimal OPS LCPL (E2) | 107 | $N$55>=0 | Not Binding | 107 |
| $O$55 | Optimal OPS PTE (E1) | 196 | $O$55>=0 | Not Binding | 196 |
| $P$55 | Optimal OPS CIV | 8 | $P$55>=0 | Not Binding | 8 |
| $C$56 | Optimal ADM COL (O6) | 0 | $C$56>=0 | Binding | 0 |
| $D$56 | Optimal ADM LTC (O5) | 1 | $D$56>=0 | Not Binding | 1 |
| $E$56 | Optimal ADM MAJ (O4) | 1 | $E$56>=0 | Not Binding | 1 |
| $F$56 | Optimal ADM CAPT (O3) | 0 | $F$56>=0 | Binding | 0 |
| $G$56 | Optimal ADM LT (O2) | 0 | $G$56>=0 | Binding | 0 |
| $H$56 | Optimal ADM 2ndLT (O1) | 0 | $H$56>=0 | Binding | 0 |
| $I$56 | Optimal ADM WAR (E7) | 0 | $I$56>=0 | Binding | 0 |
| $J$56 | Optimal ADM 2ndWAR (E6) | 0 | $J$56>=0 | Binding | 0 |
| $K$56 | Optimal ADM SGTM (E5) | 0 | $K$56>=0 | Binding | 0 |
| $L$56 | Optimal ADM SGT (E4) | 0 | $L$56>=0 | Binding | 0 |
| $M$56 | Optimal ADM CPL (E3) | 1 | $M$56>=0 | Not Binding | 1 |
| $N$56 | Optimal ADM LCPL (E2) | 0 | $N$56>=0 | Binding | 0 |
| $O$56 | Optimal ADM PTE (E1) | 33 | $O$56>=0 | Not Binding | 33 |
| $P$56 | Optimal ADM CIV | 10 | $P$56>=0 | Not Binding | 10 |
| $C$57 | Optimal TECH COL (O6) | 0 | $C$57>=0 | Binding | 0 |
| $D$57 | Optimal TECH LTC (O5) | 0 | $D$57>=0 | Binding | 0 |
| $E$57 | Optimal TECH MAJ (O4) | 1 | $E$57>=0 | Not Binding | 1 |
| $F$57 | Optimal TECH CAPT (O3) | 0 | $F$57>=0 | Binding | 0 |
| $G$57 | Optimal TECH LT (O2) | 0 | $G$57>=0 | Binding | 0 |
| $H$57 | Optimal TECH 2ndLT (O1) | 0 | $H$57>=0 | Binding | 0 |
| $I$57 | Optimal TECH WAR (E7) | 1 | $I$57>=0 | Not Binding | 1 |
| $J$57 | Optimal TECH 2ndWAR (E6) | 9 | $J$57>=0 | Not Binding | 9 |
| $K$57 | Optimal TECH SGTM (E5) | 12 | $K$57>=0 | Not Binding | 12 |
| $L$57 | Optimal TECH SGT (E4) | 0 | $L$57>=0 | Binding | 0 |
| $M$57 | Optimal TECH CPL (E3) | 0 | $M$57>=0 | Binding | 0 |
| $N$57 | Optimal TECH LCPL (E2) | 2 | $N$57>=0 | Not Binding | 2 |
| $O$57 | Optimal TECH PTE (E1) | 48 | $O$57>=0 | Not Binding | 48 |
| $P$57 | Optimal TECH CIV | 12 | $P$57>=0 | Not Binding | 12 |
| $D$55 | Optimal OPS LTC (O5) | 5 | $D$55=$O$36 | Binding | 0 |
| $D$57 | Optimal TECH LTC (O5) | 0 | $D$57=$Q$36 | Binding | 0 |
| $C$55 | Optimal OPS COL (O6) | 1 | $C$55=$D$39 | Binding | 0 |
| $D$56 | Optimal ADM LTC (O5) | 1 | $D$56=$P$36 | Binding | 0 |
| $E$55 | Optimal OPS MAJ (O4) | 8 | $E$55=$O$37 | Binding | 0 |
| $E$56 | Optimal ADM MAJ (O4) | 1 | $E$56=$P$37 | Not Binding | 0 |
| $E$57 | Optimal TECH MAJ (O4) | 1 | $E$57=$Q$37 | Binding | 0 |
| $F$56 | Optimal ADM CAPT (O3) | 0 | $F$56=$P$38 | Not Binding | 0 |
| $F$57 | Optimal TECH CAPT (O3) | 0 | $F$57=$Q$38 | Not Binding | 0 |
| $G$56 | Optimal ADM LT (O2) | 0 | $G$56=$P$39 | Binding | 0 |
| $G$57 | Optimal TECH LT (O2) | 0 | $G$57=$Q$39 | Binding | 0 |
| $H$56 | Optimal ADM 2ndLT (O1) | 0 | $H$56=$P$40 | Not Binding | 0 |
| $H$57 | Optimal TECH 2ndLT (O1) | 0 | $H$57=$Q$40 | Binding | 0 |
| $C$55 | Optimal OPS COL (O6) | 1 | $C$55=integer | Binding | 0 |
| $D$55 | Optimal OPS LTC (O5) | 5 | $D$55=integer | Binding | 0 |
| $E$55 | Optimal OPS MAJ (O4) | 8 | $E$55=integer | Binding | 0 |
| $F$55 | Optimal OPS CAPT (O3) | 7 | $F$55=integer | Binding | 0 |
| $G$55 | Optimal OPS LT (O2) | 7 | $G$55=integer | Binding | 0 |
| $H$55 | Optimal OPS 2ndLT (O1) | 7 | $H$55=integer | Binding | 0 |
| $I$55 | Optimal OPS WAR (E7) | 6 | $I$55=integer | Binding | 0 |
| $J$55 | Optimal OPS 2ndWAR (E6) | 0 | $J$55=integer | Binding | 0 |
| $K$55 | Optimal OPS SGTM (E5) | 0 | $K$55=integer | Binding | 0 |
| $L$55 | Optimal OPS SGT (E4) | 16 | $L$55=integer | Binding | 0 |
| $M$55 | Optimal OPS CPL (E3) | 43 | $M$55=integer | Binding | 0 |
| $N$55 | Optimal OPS LCPL (E2) | 107 | $N$55=integer | Binding | 0 |
| $O$55 | Optimal OPS PTE (E1) | 196 | $O$55=integer | Binding | 0 |
| $P$55 | Optimal OPS CIV | 8 | $P$55=integer | Binding | 0 |
| $C$56 | Optimal ADM COL (O6) | 0 | $C$56=integer | Binding | 0 |
| $D$56 | Optimal ADM LTC (O5) | 1 | $D$56=integer | Binding | 0 |
| $E$56 | Optimal ADM MAJ (O4) | 1 | $E$56=integer | Binding | 0 |
| $F$56 | Optimal ADM CAPT (O3) | 0 | $F$56=integer | Binding | 0 |
| $G$56 | Optimal ADM LT (O2) | 0 | $G$56=integer | Binding | 0 |
| $H$56 | Optimal ADM 2ndLT (O1) | 0 | $H$56=integer | Binding | 0 |
| $I$56 | Optimal ADM WAR (E7) | 0 | $I$56=integer | Binding | 0 |
| $J$56 | Optimal ADM 2ndWAR (E6) | 0 | $J$56=integer | Binding | 0 |
| $K$56 | Optimal ADM SGTM (E5) | 0 | $K$56=integer | Binding | 0 |
| $L$56 | Optimal ADM SGT (E4) | 0 | $L$56=integer | Binding | 0 |
| $M$56 | Optimal ADM CPL (E3) | 1 | $M$56=integer | Binding | 0 |
| $N$56 | Optimal ADM LCPL (E2) | 0 | $N$56=integer | Binding | 0 |
| $O$56 | Optimal ADM PTE (E1) | 33 | $O$56=integer | Binding | 0 |
| $P$56 | Optimal ADM CIV | 10 | $P$56=integer | Binding | 0 |
| $C$57 | Optimal TECH COL (O6) | 0 | $C$57=integer | Binding | 0 |
| $D$57 | Optimal TECH LTC (O5) | 0 | $D$57=integer | Binding | 0 |
| $E$57 | Optimal TECH MAJ (O4) | 1 | $E$57=integer | Binding | 0 |
| $F$57 | Optimal TECH CAPT (O3) | 0 | $F$57=integer | Binding | 0 |
| $G$57 | Optimal TECH LT (O2) | 0 | $G$57=integer | Binding | 0 |
| $H$57 | Optimal TECH 2ndLT (O1) | 0 | $H$57=integer | Binding | 0 |
| $I$57 | Optimal TECH WAR (E7) | 1 | $I$57=integer | Binding | 0 |
| $J$57 | Optimal TECH 2ndWAR (E6) | 9 | $J$57=integer | Binding | 0 |
| $K$57 | Optimal TECH SGTM (E5) | 12 | $K$57=integer | Binding | 0 |
| $L$57 | Optimal TECH SGT (E4) | 0 | $L$57=integer | Binding | 0 |
| $M$57 | Optimal TECH CPL (E3) | 0 | $M$57=integer | Binding | 0 |
| $N$57 | Optimal TECH LCPL (E2) | 2 | $N$57=integer | Binding | 0 |
| $O$57 | Optimal TECH PTE (E1) | 48 | $O$57=integer | Binding | 0 |
| $P$57 | Optimal TECH CIV | 12 | $P$57=integer | Binding | 0 |

Table 2. Armor Battalion Answer Report (Cont.)

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# APPENDIX E: PROGRAM CONTROL DIAGRAMS

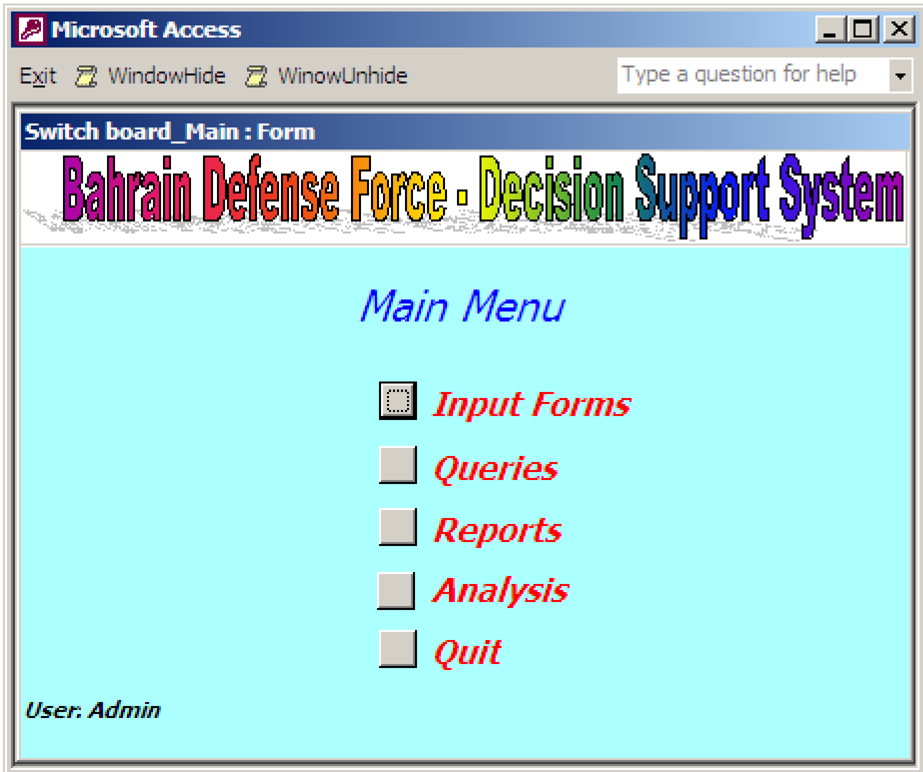


Figure 25. Main Menu Switchboard

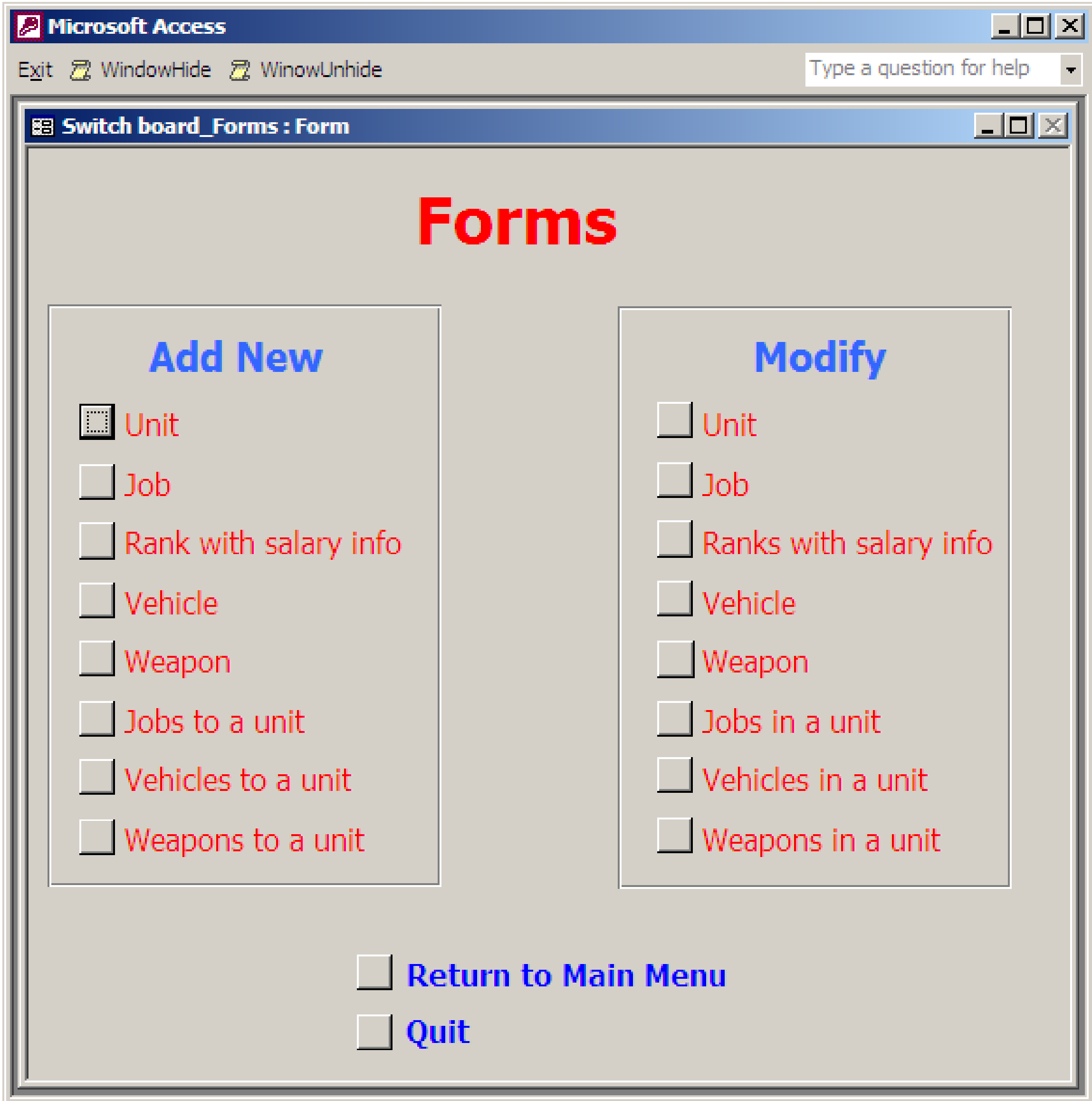


Figure 26. Forms Switchboard

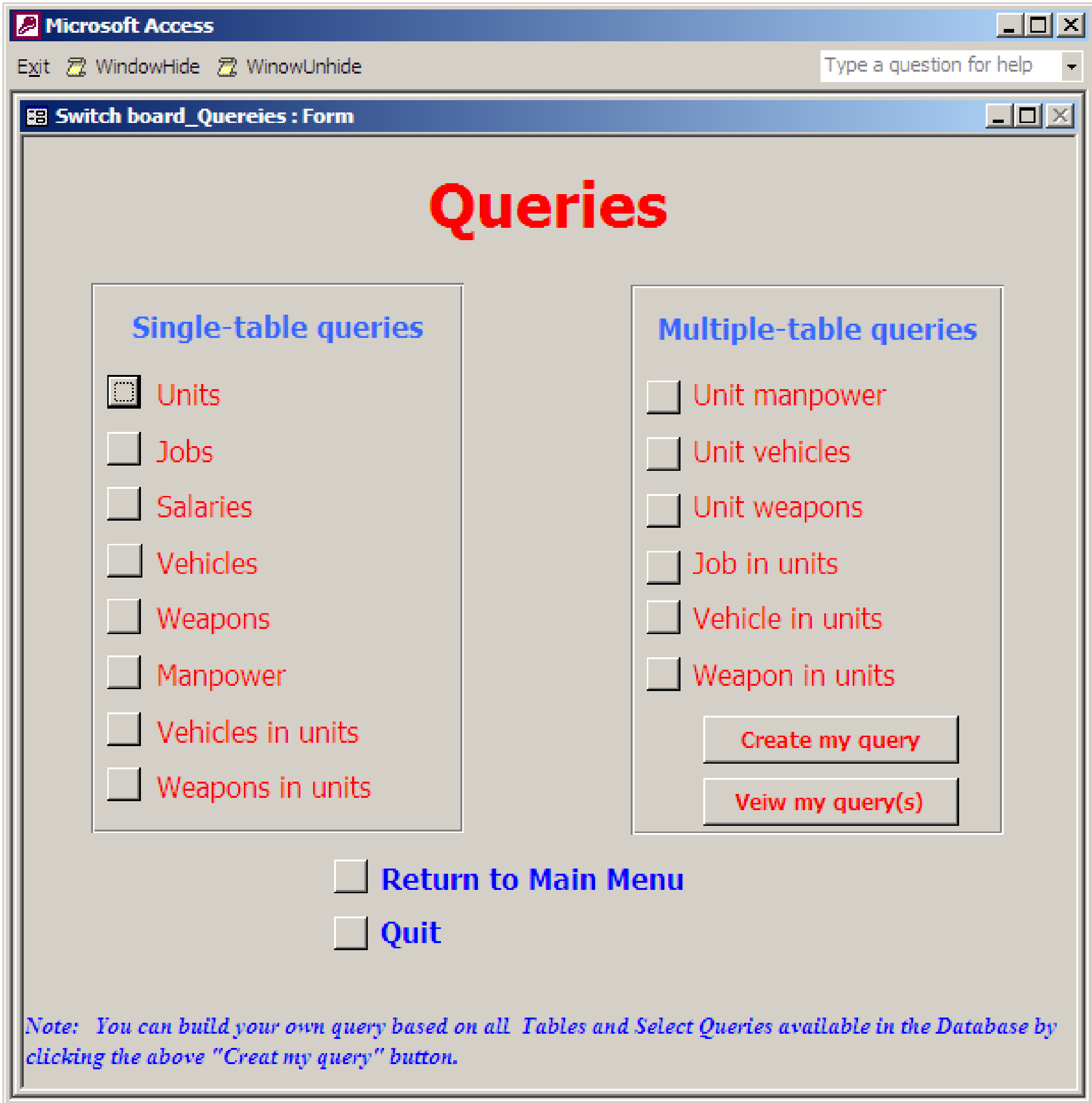


Figure 27. Queries Switchboard

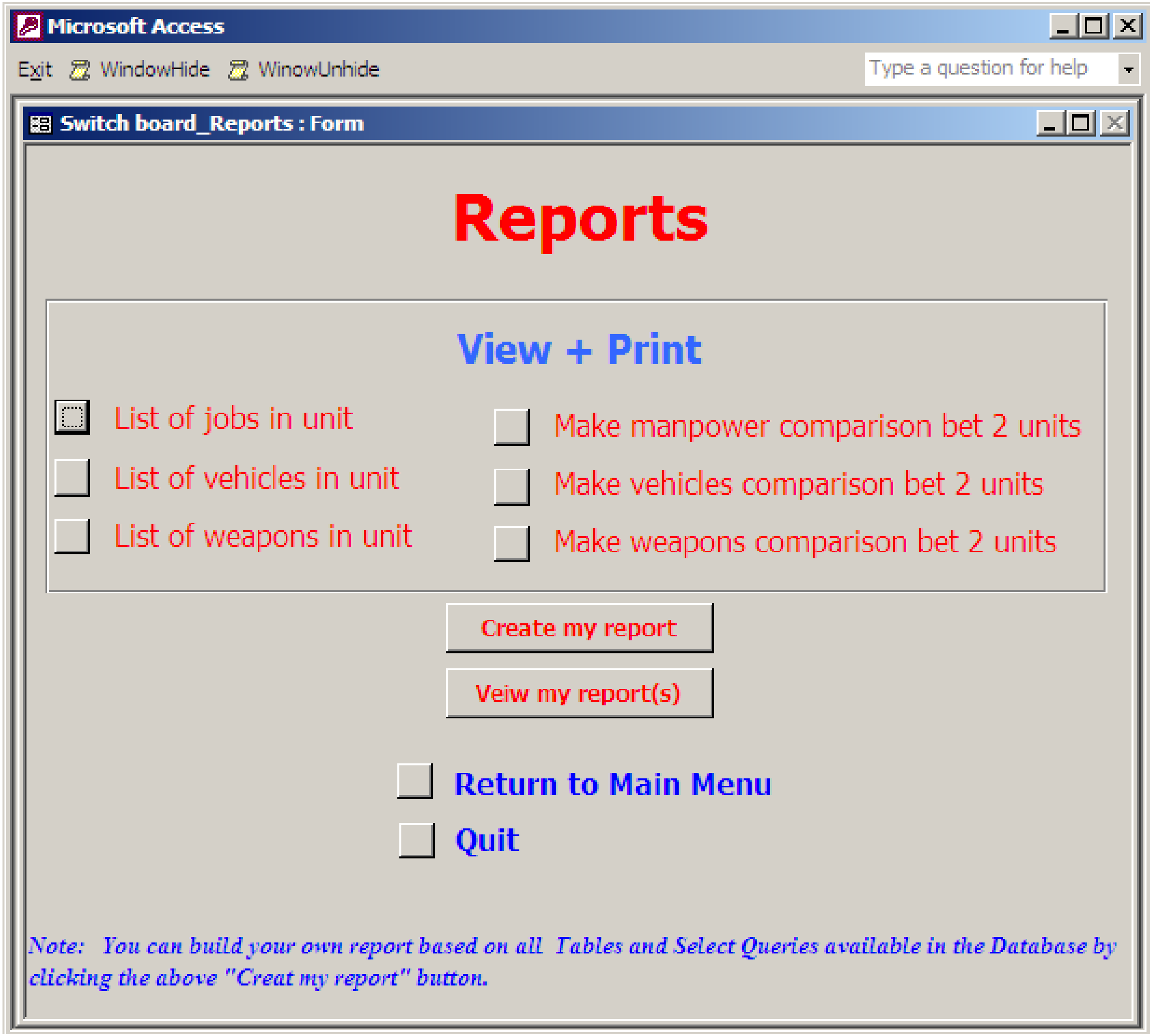


Figure 28. Reports Switchboard

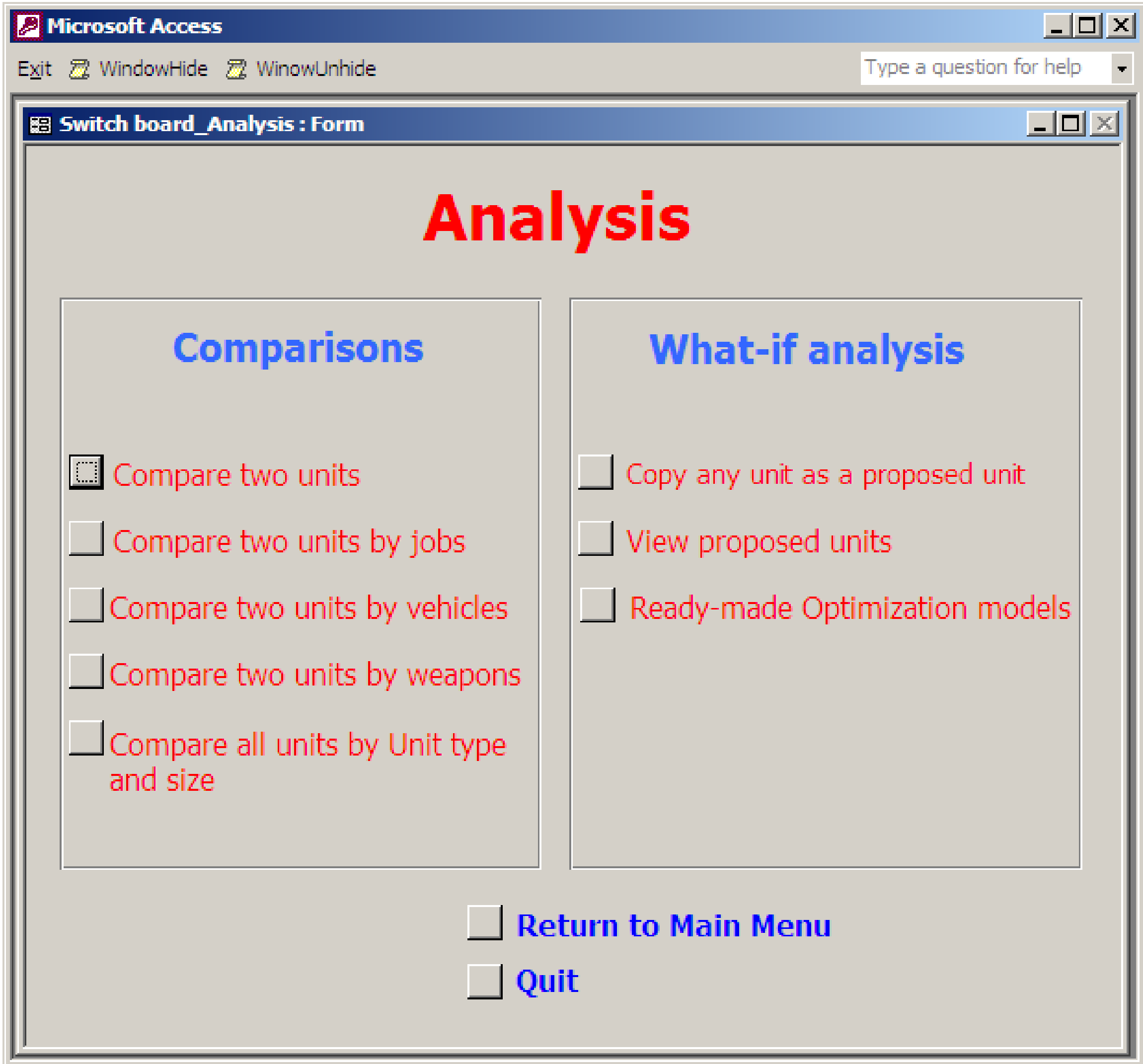


Figure 29. Analysis Switchboard

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## APPENDIX F: PROTOTYPE OF INPUT/OUTPUT FORMS

### 1. INPUT FORMS

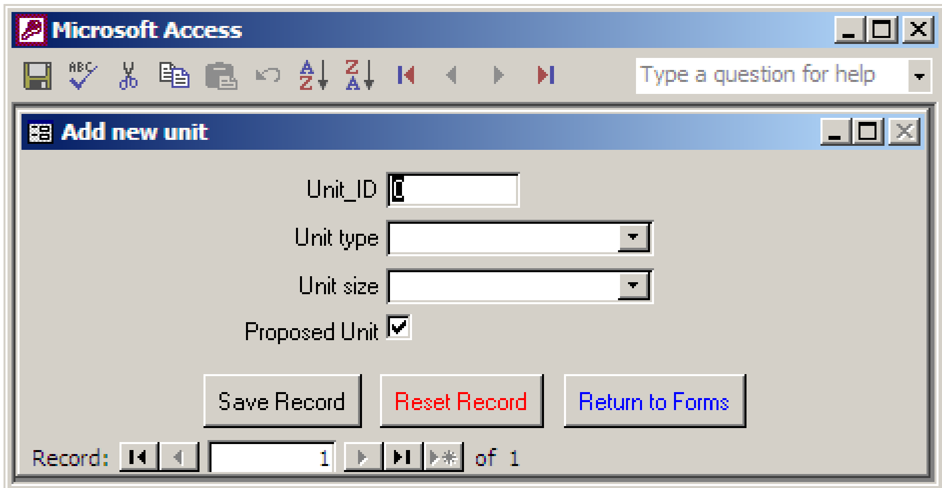



Figure 30. "Add new unit" Form

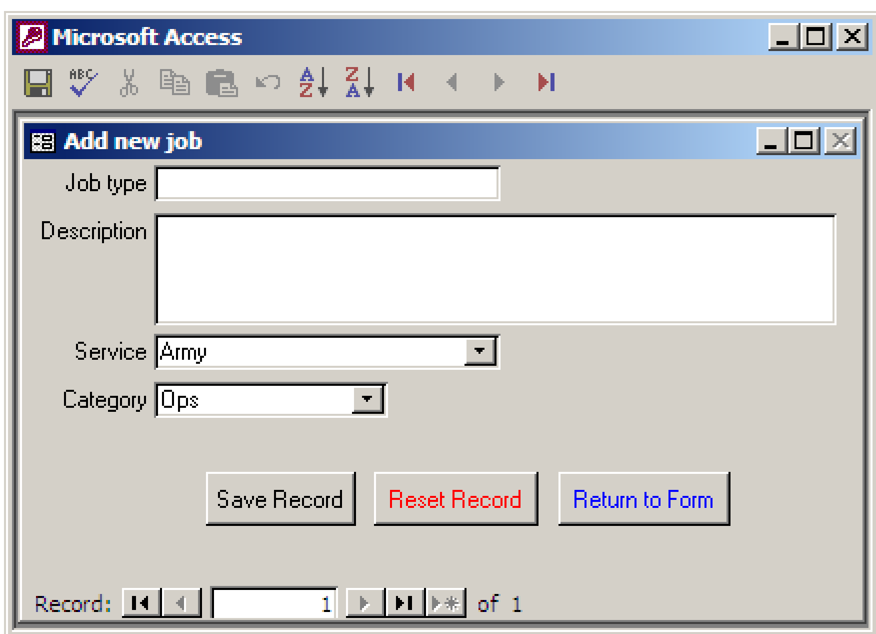



Figure 31. "Add new job" Form

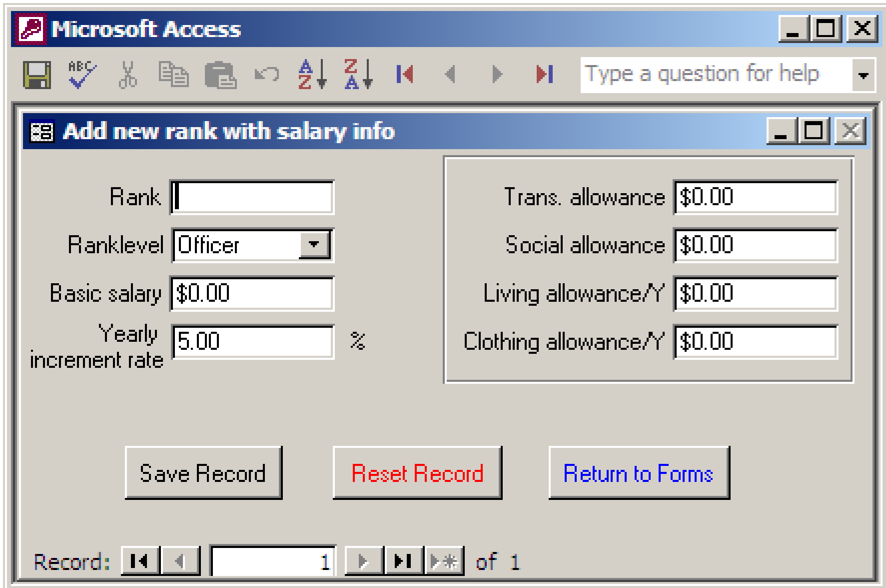



Figure 32. “Add new rank with salary info” Form

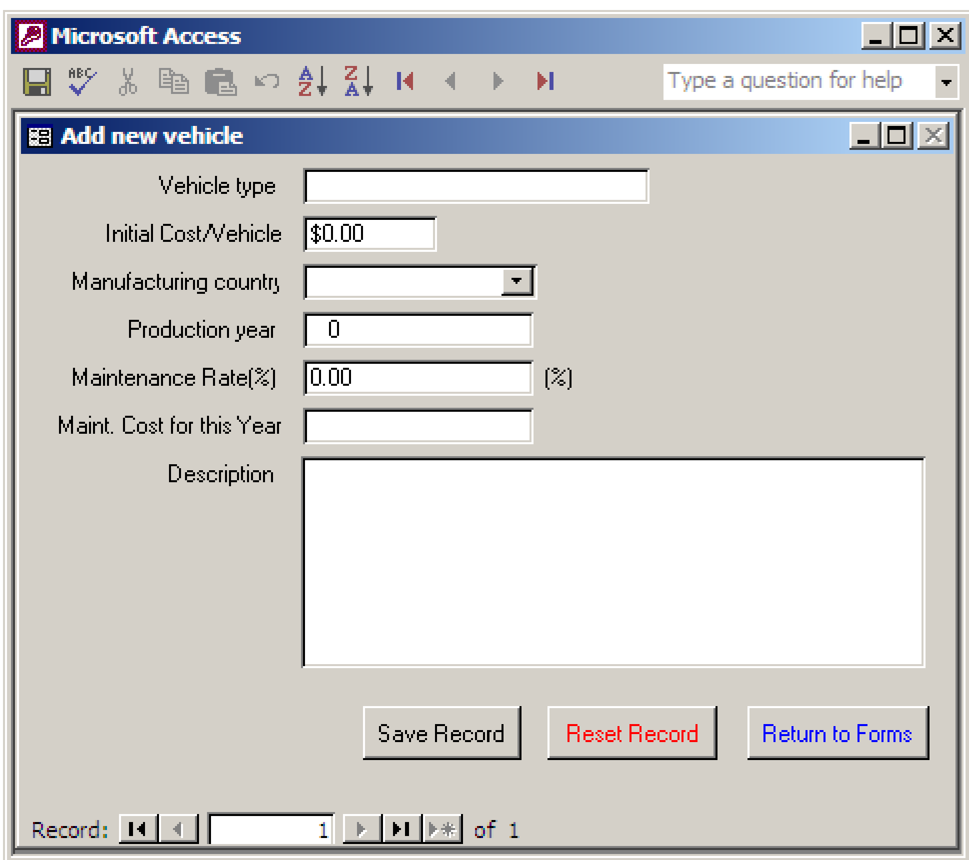



Figure 33. “Add new vehicle” Form

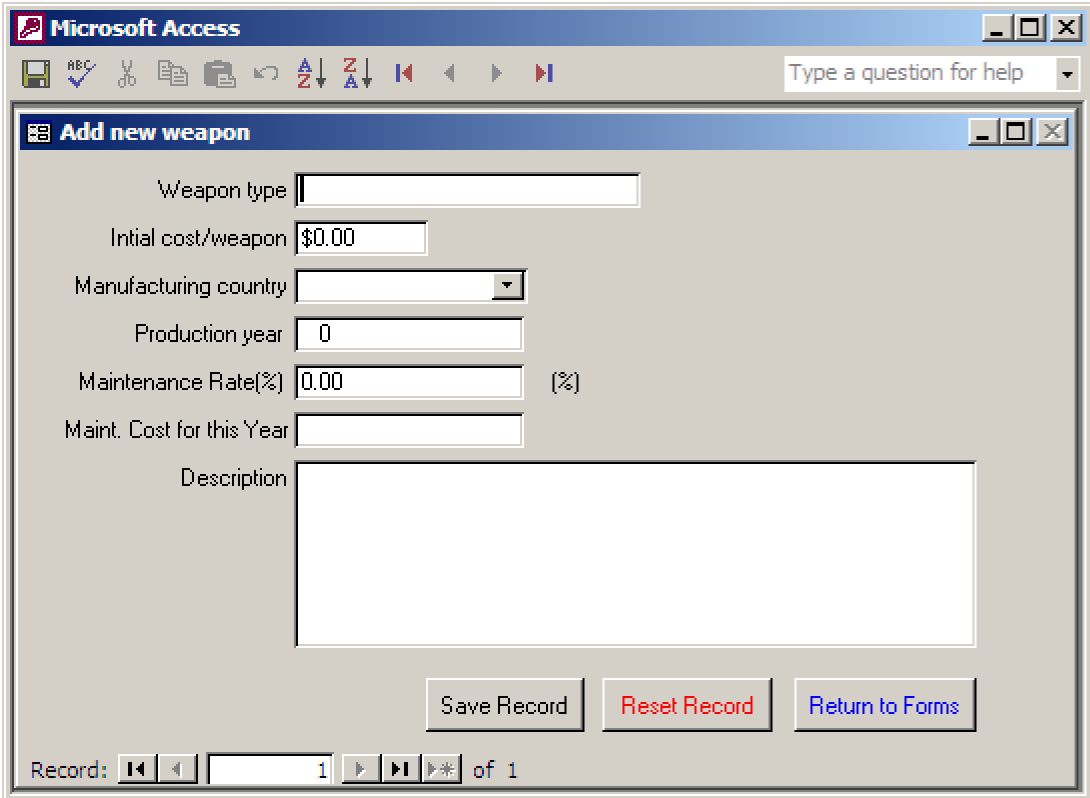



Figure 34. “Add new weapon” Form

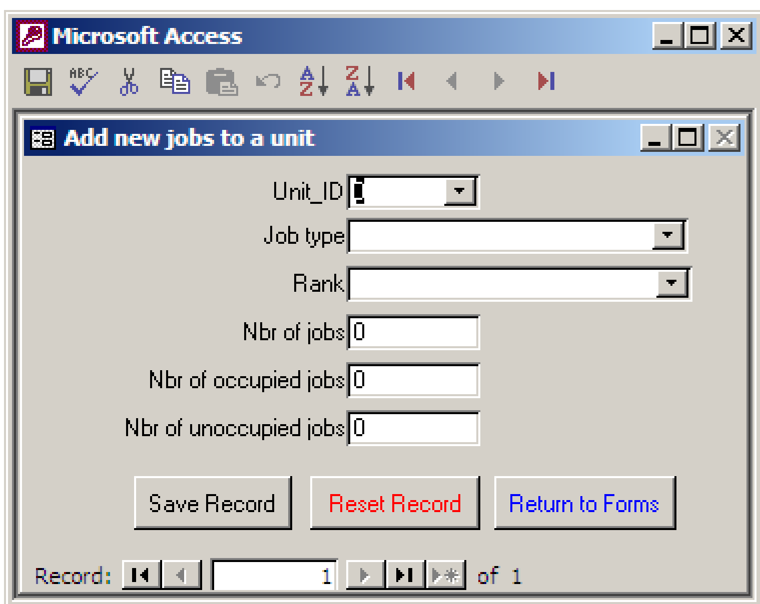



Figure 35. “Add new jobs to a unit” Form

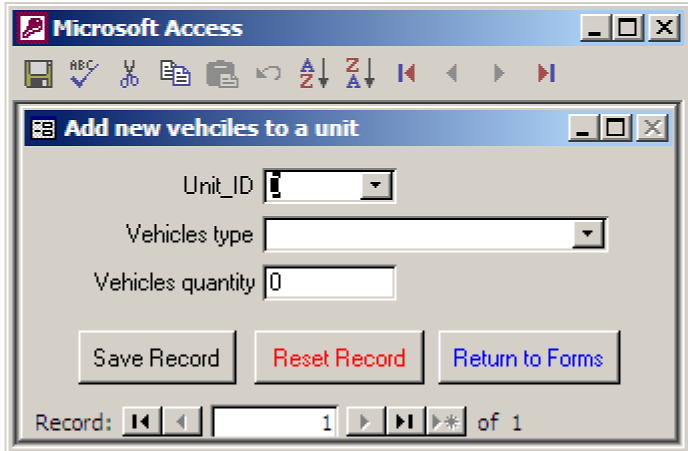



Figure 36. “Add new vehicles to a unit” Form

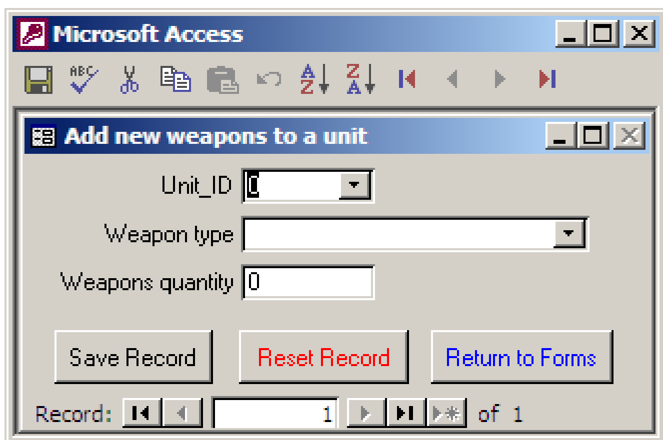



Figure 37. “Add new weapons to a unit” Form

## 2. OUTPUT FORMS

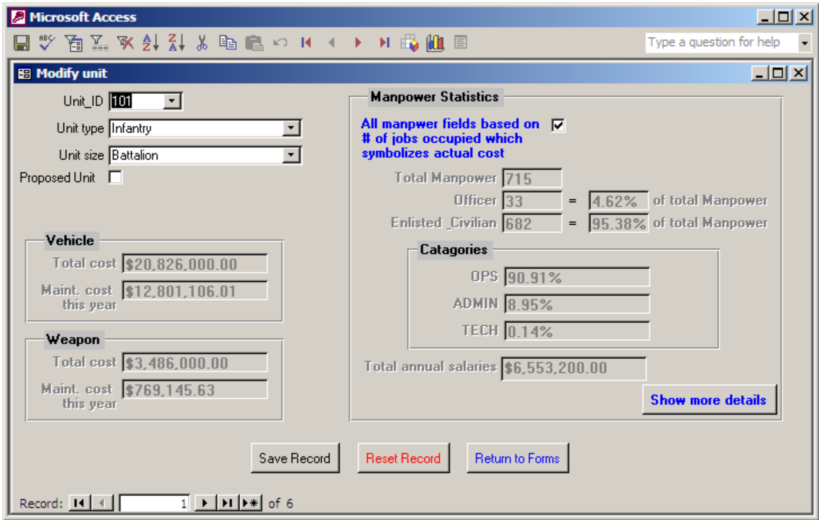
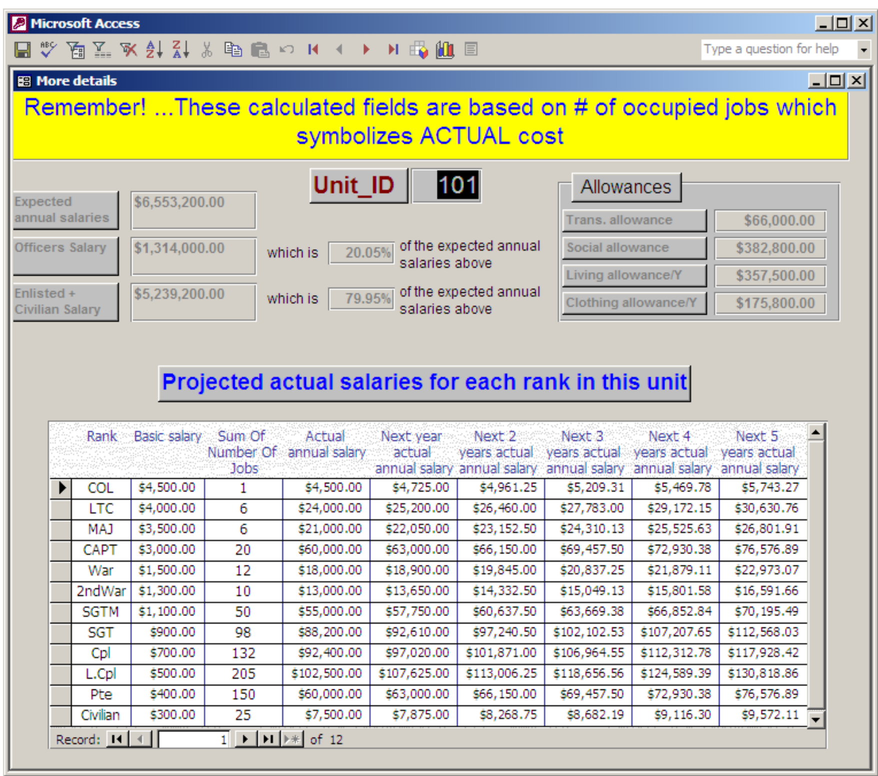



Figure 38. “Modify unit” Form




| Rank | Basic salary | Sum Of Number Of Jobs | Actual annual salary | Next year actual annual salary | Next 2 years actual annual salary | Next 3 years actual annual salary | Next 4 years actual annual salary | Next 5 years actual annual salary |
|---|---|---|---|---|---|---|---|---|
| COL | $4,500.00 | 1 | $4,500.00 | $4,725.00 | $4,961.25 | $5,209.31 | $5,469.78 | $5,743.27 |
| LTC | $4,000.00 | 6 | $24,000.00 | $25,200.00 | $26,460.00 | $27,783.00 | $29,172.15 | $30,630.76 |
| MAJ | $3,500.00 | 6 | $21,000.00 | $22,050.00 | $23,152.50 | $24,310.13 | $25,525.63 | $26,801.91 |
| CAPT | $3,000.00 | 20 | $60,000.00 | $63,000.00 | $66,150.00 | $69,457.50 | $72,930.38 | $76,576.89 |
| War | $1,500.00 | 12 | $18,000.00 | $18,900.00 | $19,845.00 | $20,837.25 | $21,879.11 | $22,973.07 |
| 2ndWar | $1,300.00 | 10 | $13,000.00 | $13,650.00 | $14,332.50 | $15,049.13 | $15,801.58 | $16,591.66 |
| SGTM | $1,100.00 | 50 | $55,000.00 | $57,750.00 | $60,637.50 | $63,669.38 | $66,852.84 | $70,195.49 |
| SGT | $900.00 | 98 | $88,200.00 | $92,610.00 | $97,240.50 | $102,102.53 | $107,207.65 | $112,568.03 |
| Cpl | $700.00 | 132 | $92,400.00 | $97,020.00 | $101,871.00 | $106,964.55 | $112,312.78 | $117,928.42 |
| L.Cpl | $500.00 | 205 | $102,500.00 | $107,625.00 | $113,006.25 | $118,656.56 | $124,589.39 | $130,818.86 |
| Pte | $400.00 | 150 | $60,000.00 | $63,000.00 | $66,150.00 | $69,457.50 | $72,930.38 | $76,576.89 |
| Civilian | $300.00 | 25 | $7,500.00 | $7,875.00 | $8,268.75 | $8,682.19 | $9,116.30 | $9,572.11 |

Record: 1 of 12

Figure 39. “More details” Form Based on # of Occupied Jobs (Actual Manpower Cost)

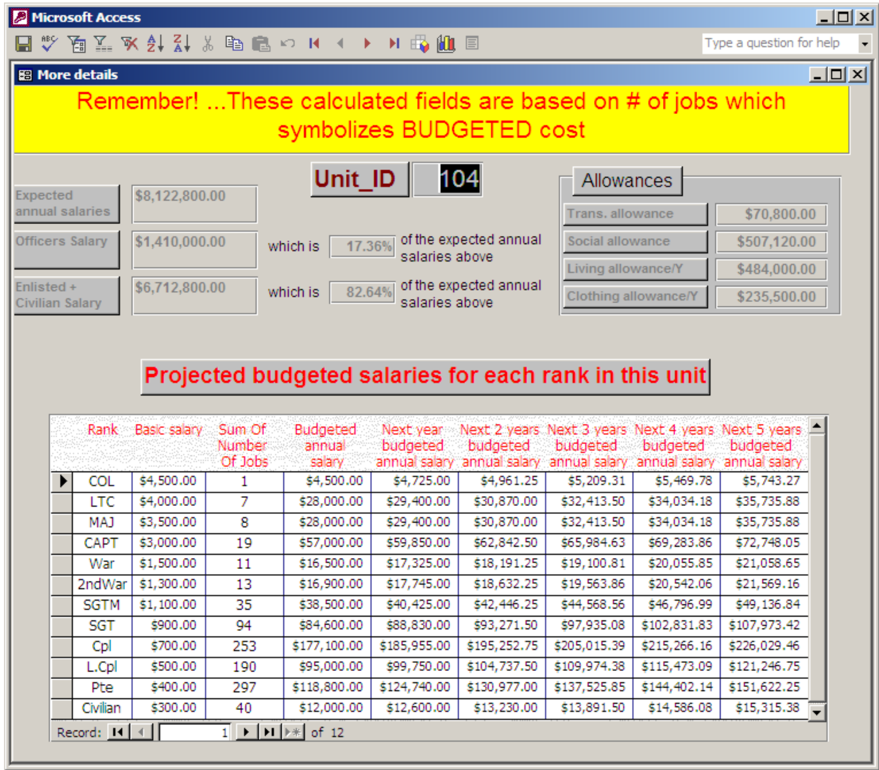



Figure 40. “More details” Form Based on # of Jobs (Budgeted Manpower Cost)

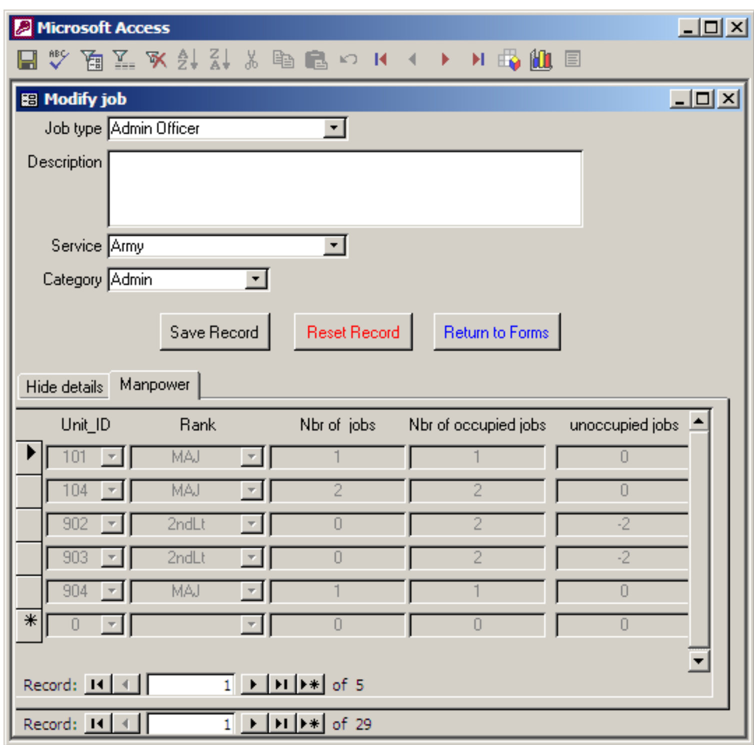



Figure 41. “Modify job” Form

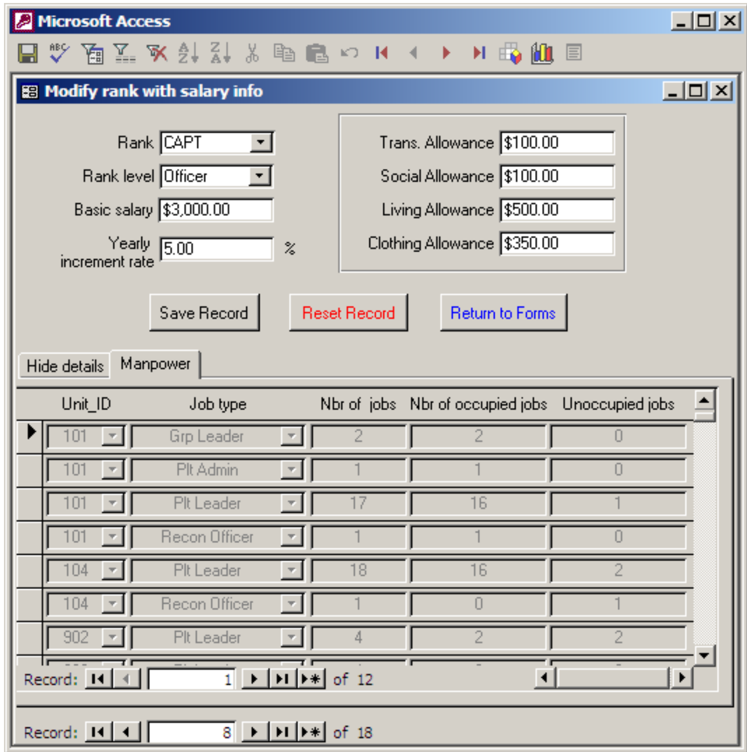



Figure 42. “Modify rank with salary” Form

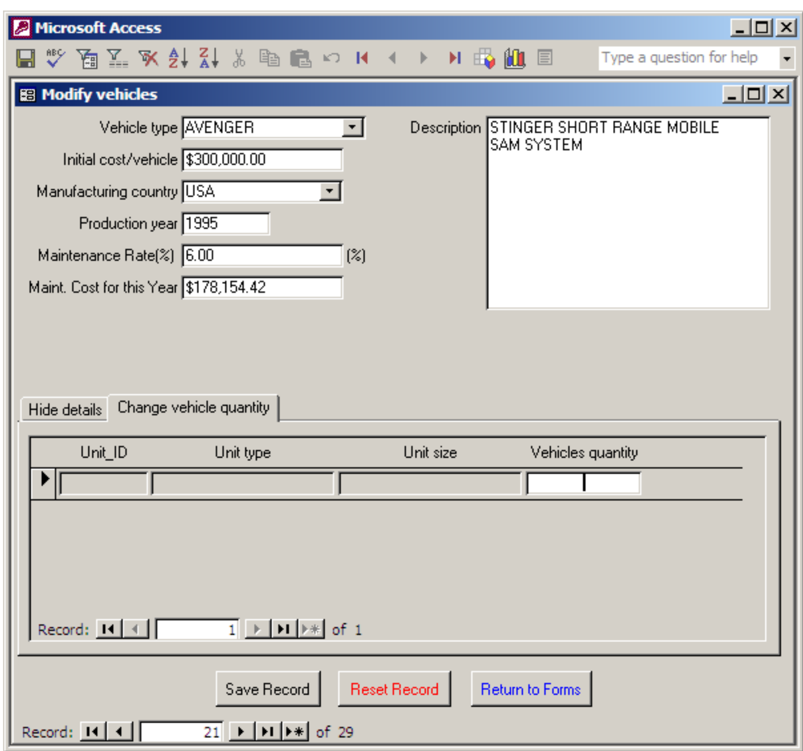



Figure 43. “Modify vehicles” Form

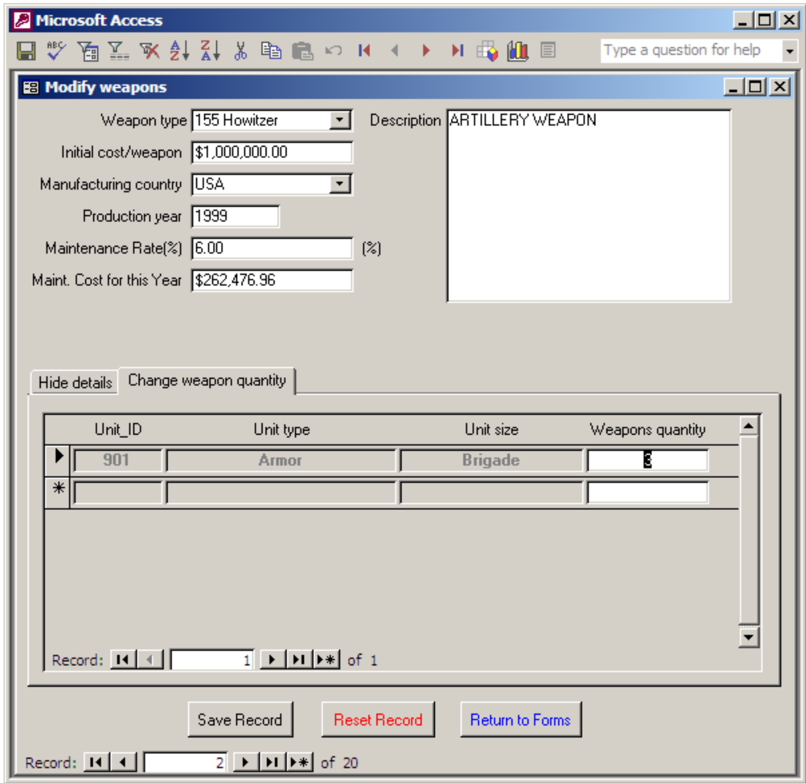



Figure 44. “Modify weapon” Form

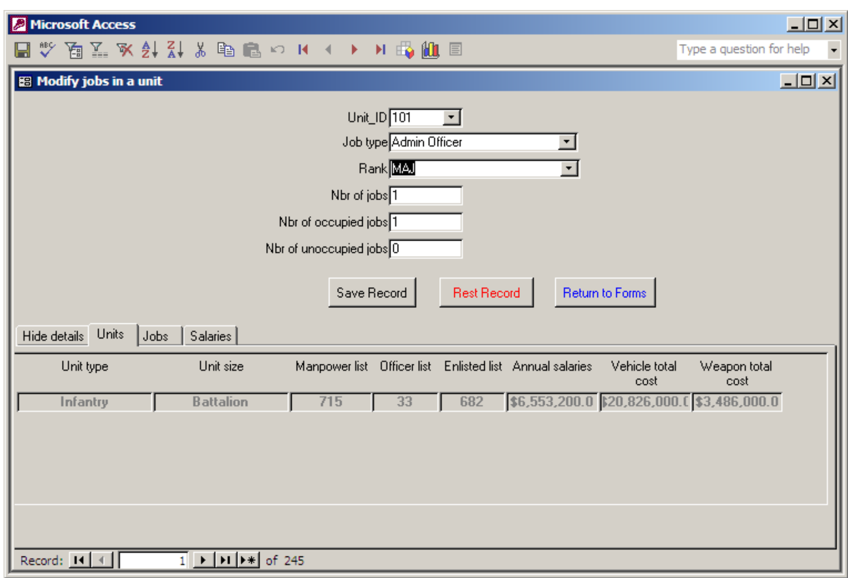



Figure 45. “Modify jobs in a unit” Form

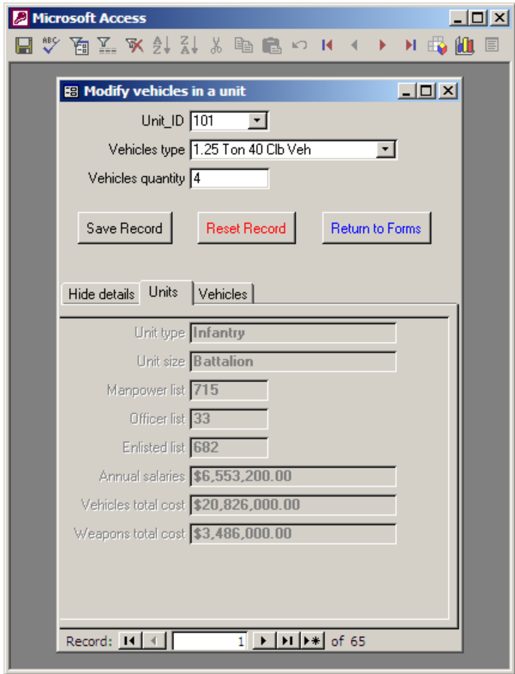



Figure 46. “Modify vehicles in a unit” Form

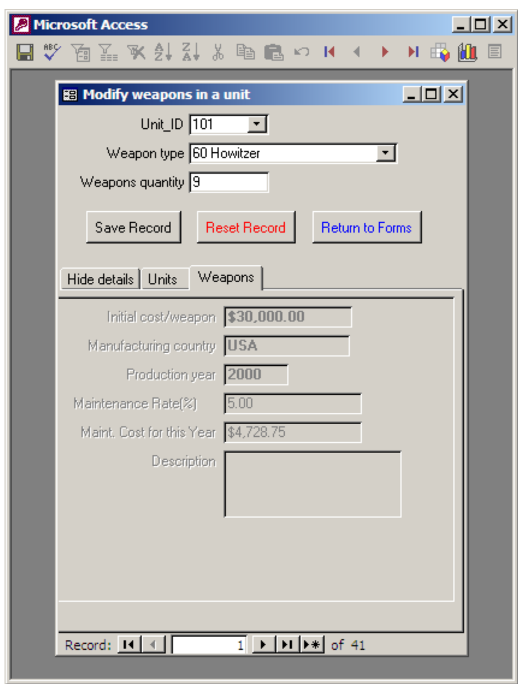



Figure 47. “Modify weapons in a unit” Form

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# APPENDIX G: PROTOTYPE OF QUERIES

## 1. SINGLE-TABLE QUERIES

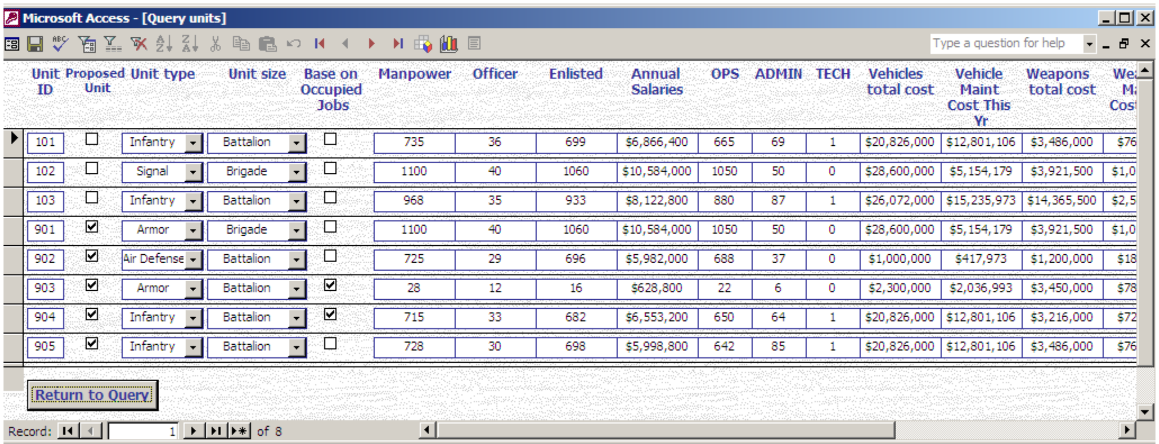



Figure 48. “Units” Query

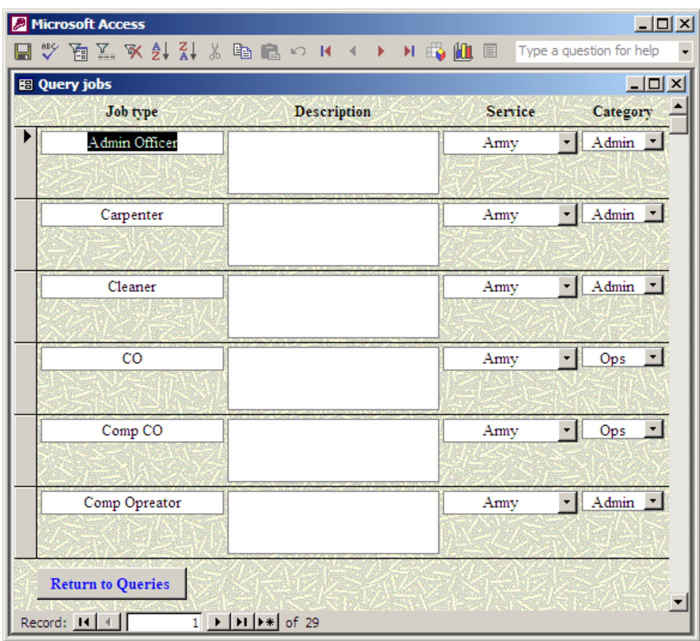
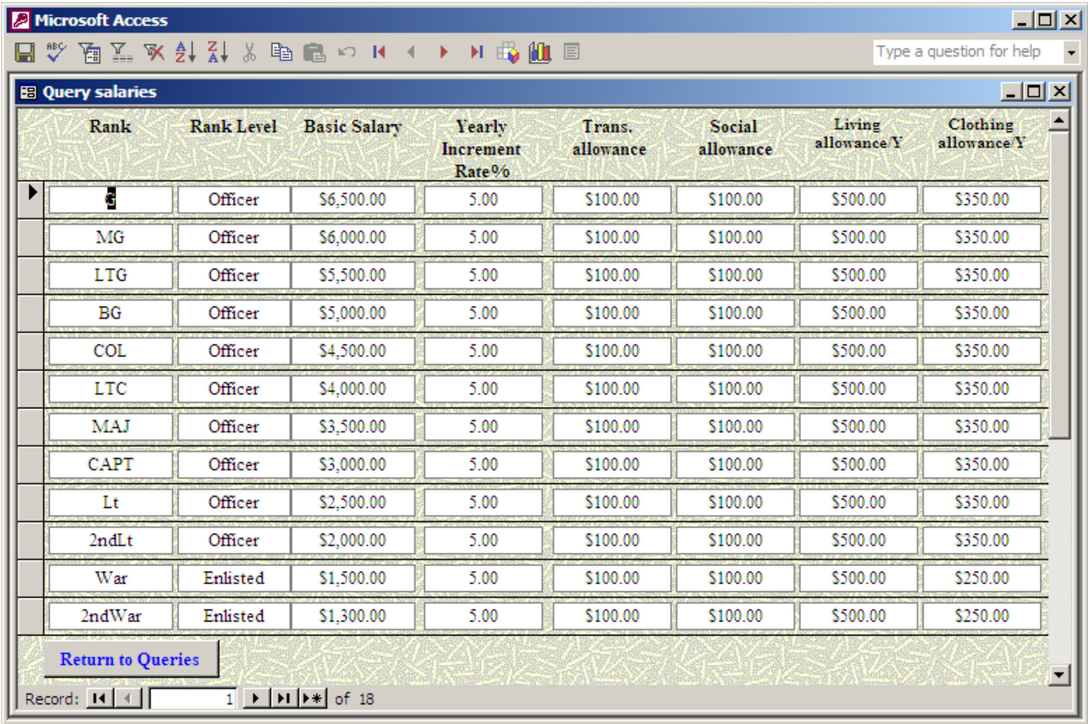



Figure 49. “Jobs” Query



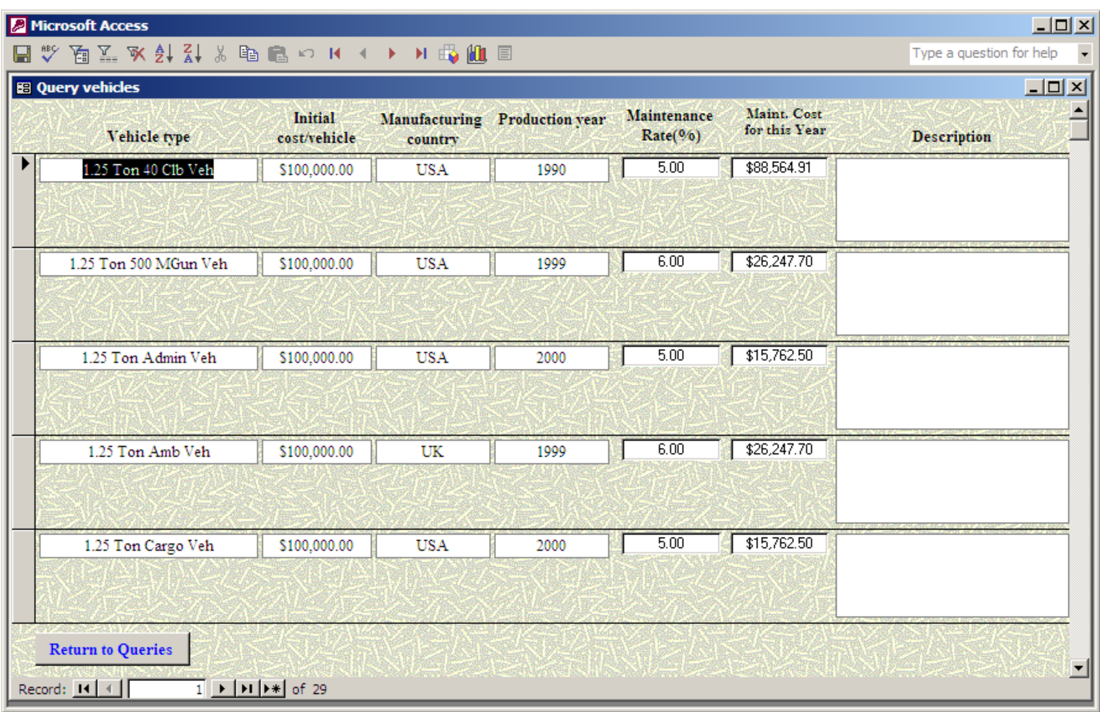
Microsoft Access — Query salaries

| Rank | Rank Level | Basic Salary | Yearly Increment Rate% | Trans. allowance | Social allowance | Living allowance/Y | Clothing allowance/Y |
|---|---|---|---|---|---|---|---|
| [illegible] | Officer | $6,500.00 | 5.00 | $100.00 | $100.00 | $500.00 | $350.00 |
| MG | Officer | $6,000.00 | 5.00 | $100.00 | $100.00 | $500.00 | $350.00 |
| LTG | Officer | $5,500.00 | 5.00 | $100.00 | $100.00 | $500.00 | $350.00 |
| BG | Officer | $5,000.00 | 5.00 | $100.00 | $100.00 | $500.00 | $350.00 |
| COL | Officer | $4,500.00 | 5.00 | $100.00 | $100.00 | $500.00 | $350.00 |
| LTC | Officer | $4,000.00 | 5.00 | $100.00 | $100.00 | $500.00 | $350.00 |
| MAJ | Officer | $3,500.00 | 5.00 | $100.00 | $100.00 | $500.00 | $350.00 |
| CAPT | Officer | $3,000.00 | 5.00 | $100.00 | $100.00 | $500.00 | $350.00 |
| Lt | Officer | $2,500.00 | 5.00 | $100.00 | $100.00 | $500.00 | $350.00 |
| 2ndLt | Officer | $2,000.00 | 5.00 | $100.00 | $100.00 | $500.00 | $350.00 |
| War | Enlisted | $1,500.00 | 5.00 | $100.00 | $100.00 | $500.00 | $250.00 |
| 2ndWar | Enlisted | $1,300.00 | 5.00 | $100.00 | $100.00 | $500.00 | $250.00 |

Return to Queries

Record: 1 of 18

Figure 50. “Salaries” Query



Microsoft Access — Query vehicles

| Vehicle type | Initial cost/vehicle | Manufacturing country | Production year | Maintenance Rate(%) | Maint. Cost for this Year | Description |
|---|---|---|---|---|---|---|
| 1.25 Ton 40 Clb Veh | $100,000.00 | USA | 1990 | 5.00 | $88,564.91 | |
| 1.25 Ton 500 MGun Veh | $100,000.00 | USA | 1999 | 6.00 | $26,247.70 | |
| 1.25 Ton Admin Veh | $100,000.00 | USA | 2000 | 5.00 | $15,762.50 | |
| 1.25 Ton Amb Veh | $100,000.00 | UK | 1999 | 6.00 | $26,247.70 | |
| 1.25 Ton Cargo Veh | $100,000.00 | USA | 2000 | 5.00 | $15,762.50 | |

Return to Queries

Record: 1 of 29

Figure 51. “Vehicles” Query

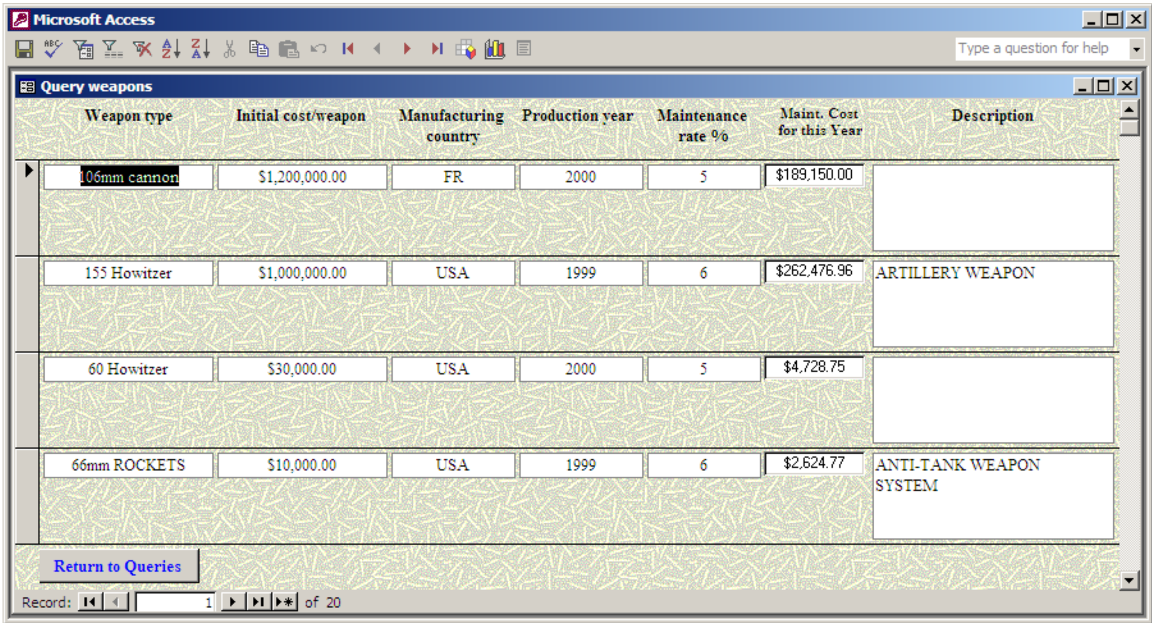



Figure 52. “Weapons” Query

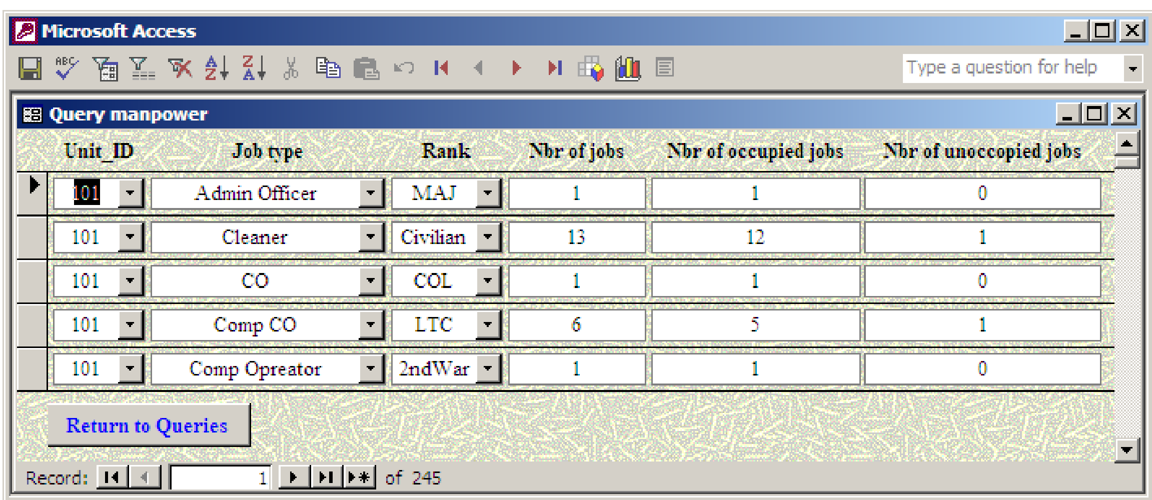



Figure 53. “Manpower” Query

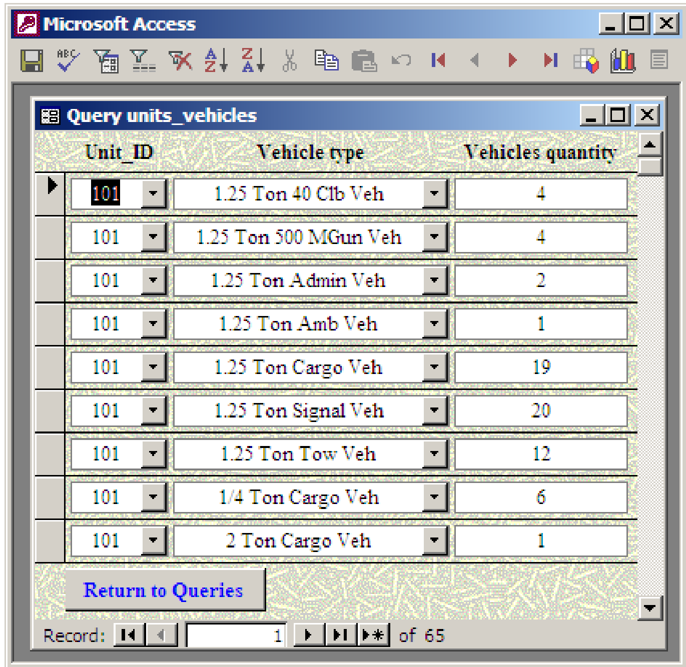



Figure 54. “Units_vehicles” Query

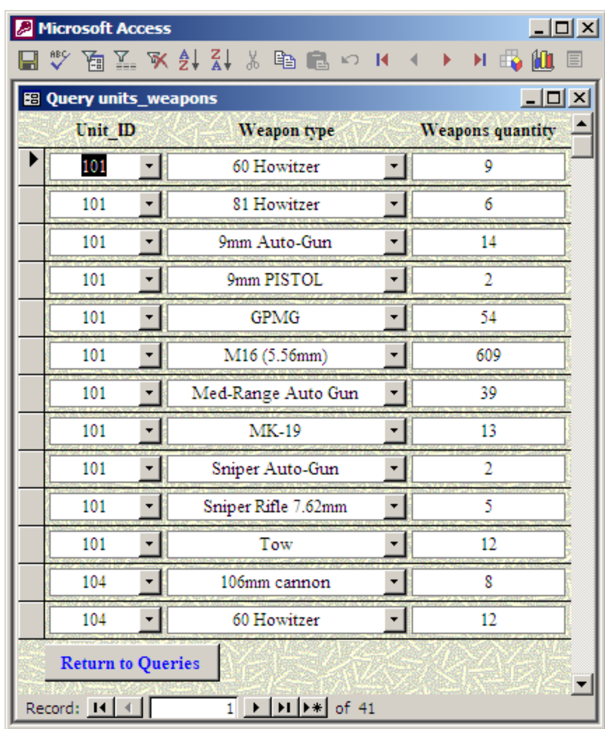



Figure 55. “Units_weapons” Query

## 2. MULTIPLE-TABLE QUERIES

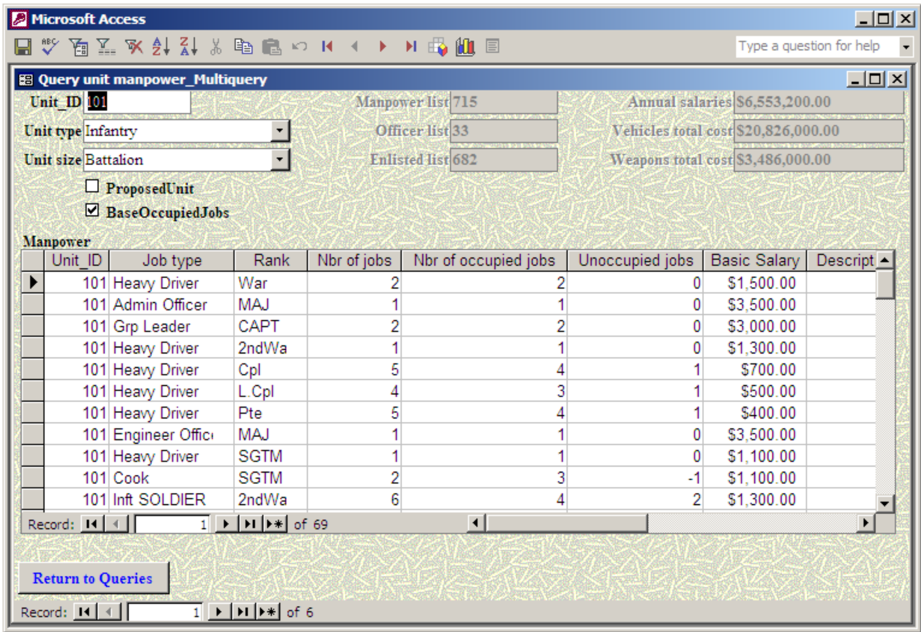



Figure 56. “Unit manpower” Query

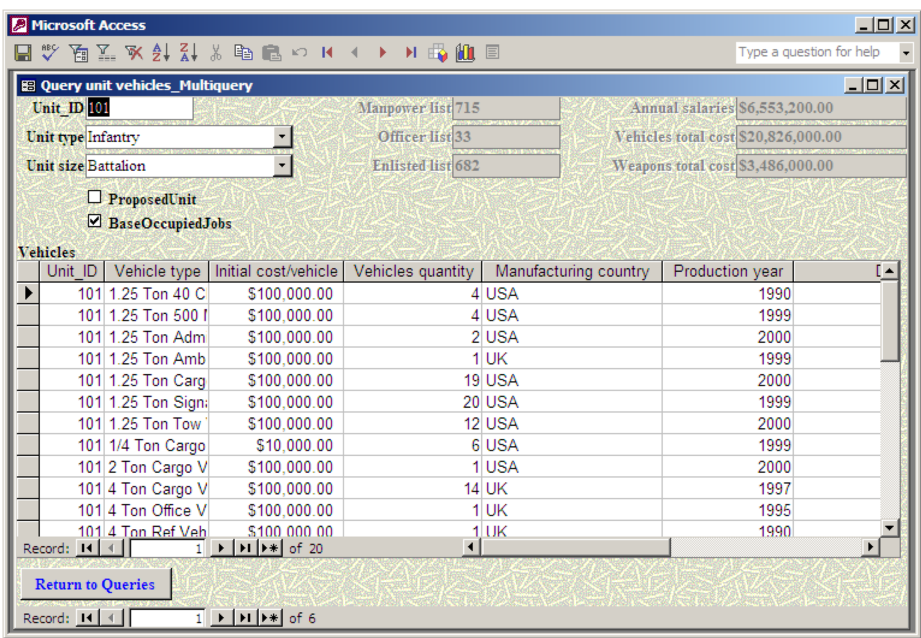



Figure 57. “Unit vehicles” Query

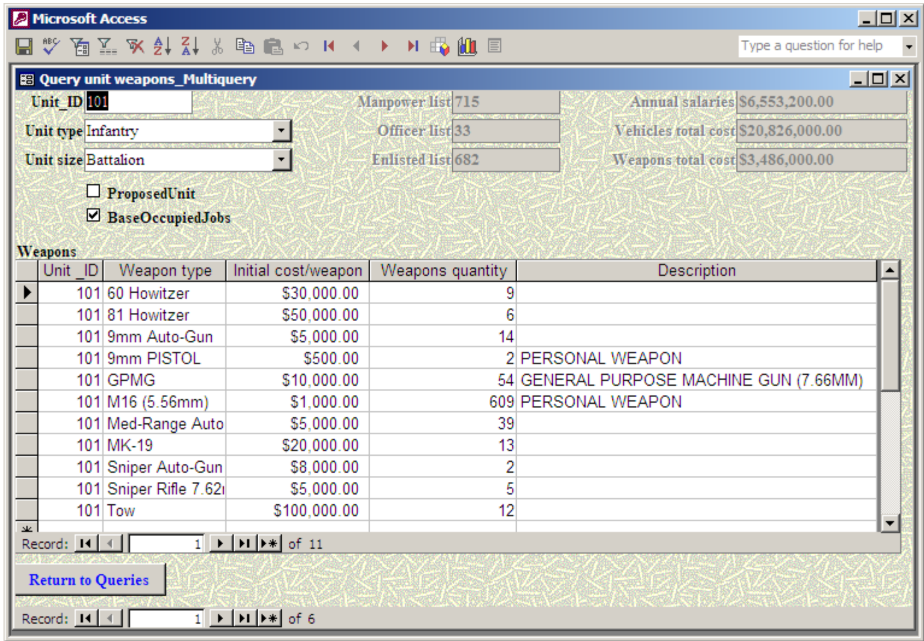



Figure 58. “Unit weapons” Query

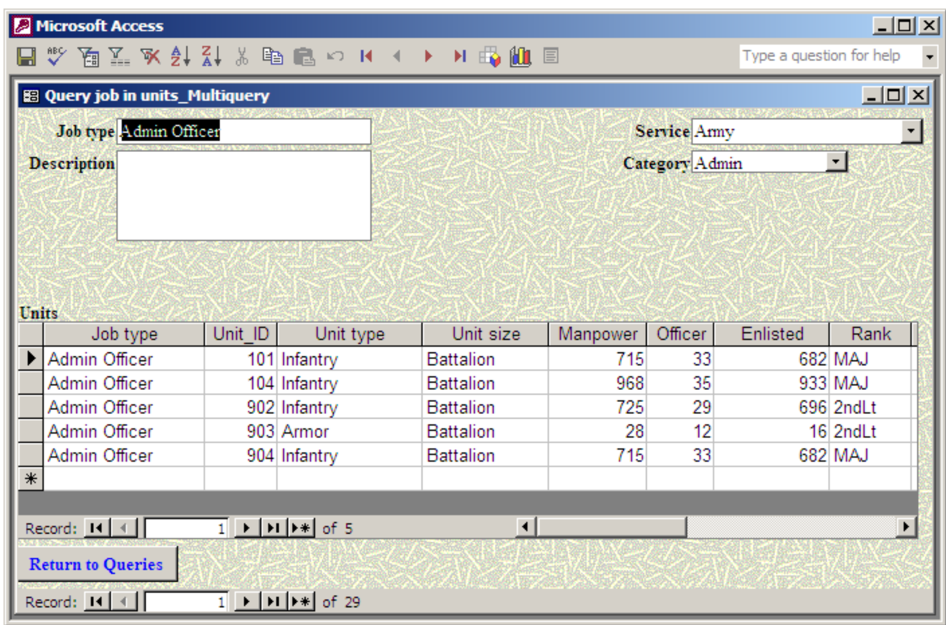



Figure 59. “Job in units” Query

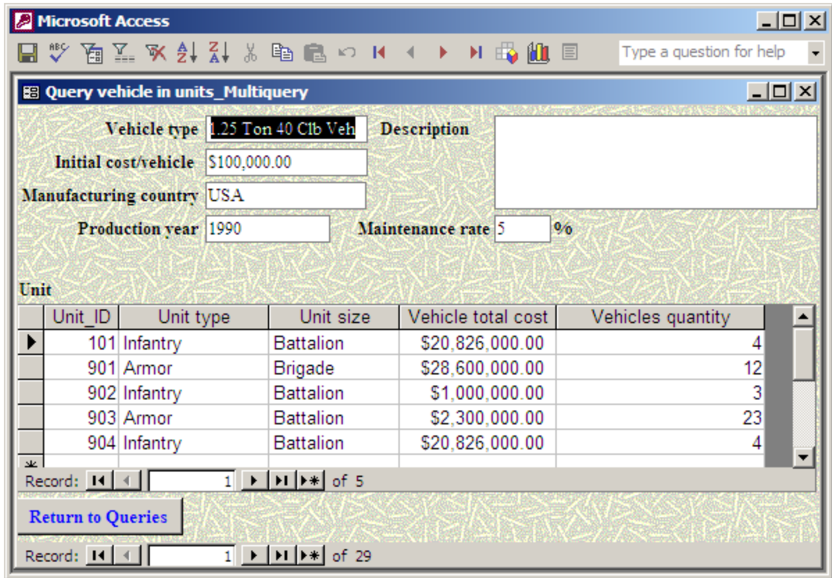



Figure 60. “Vehicles in unit” Query

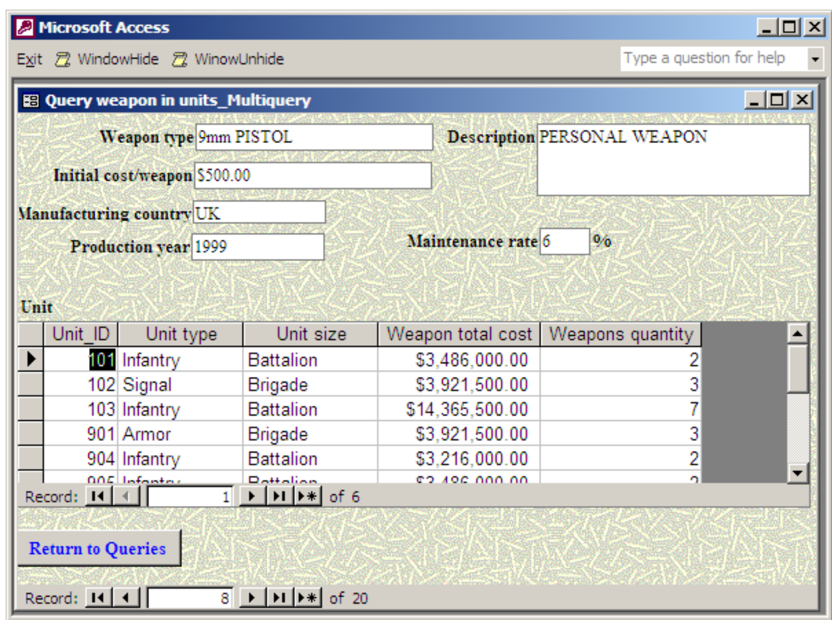



Figure 61. “Weapons in unit” Query

## 3. CREATING AND VIEWING USER'S QUERIES

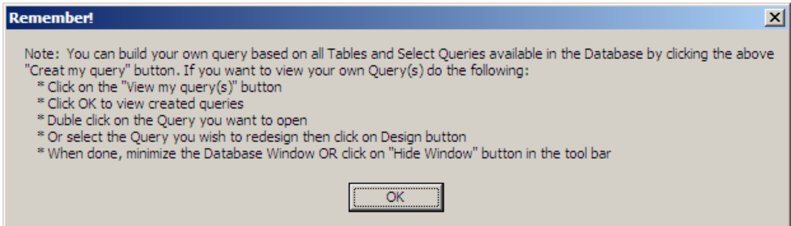



Figure 62. "Reminder instructions" Window

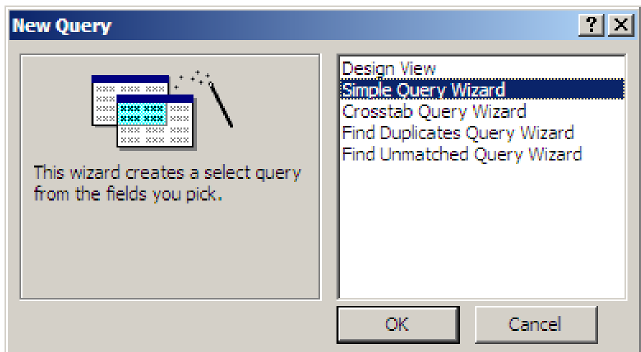



Figure 63. "New query" Window

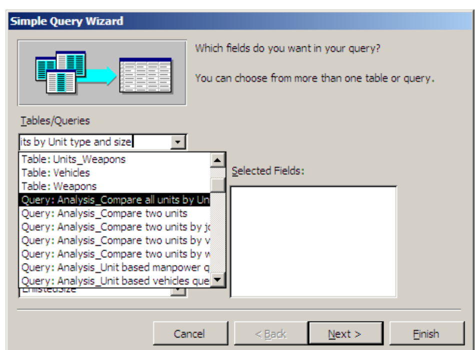



Figure 64. "Simple query wizard" Window

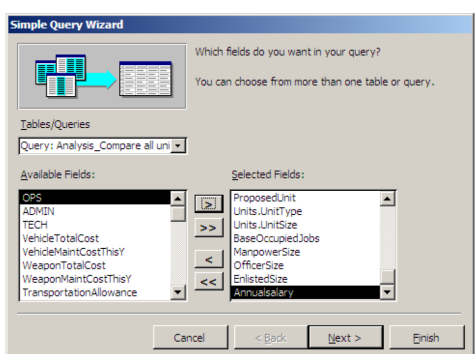



Figure 65. "Selecting the new query fields" Window

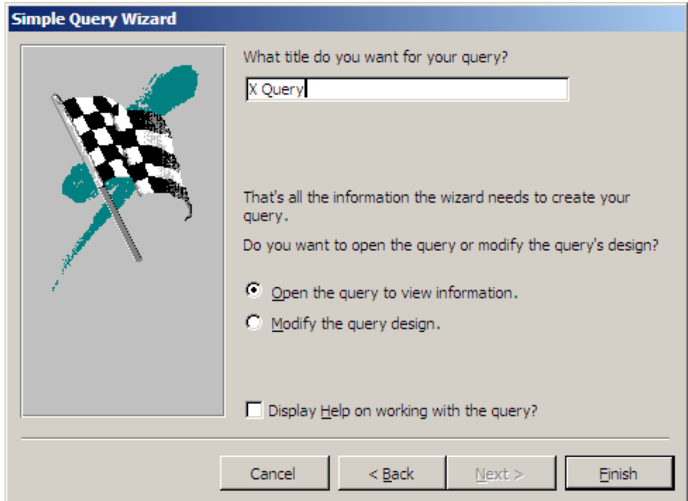



Figure 66. “Naming the new query” Window

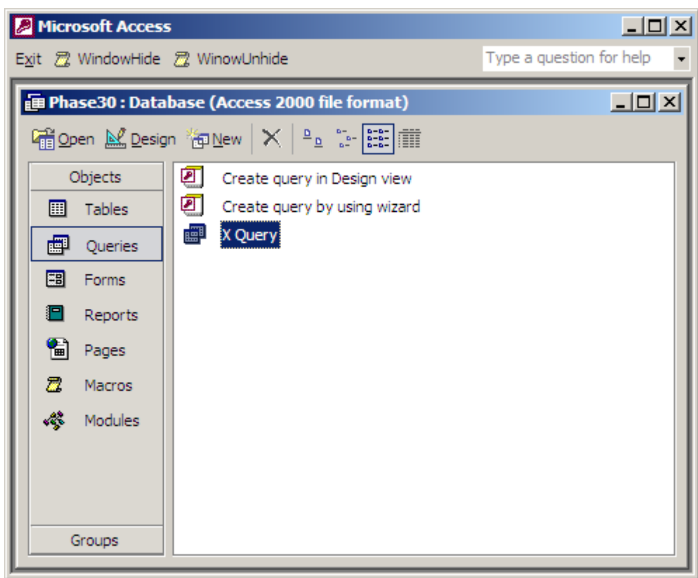



Figure 67. “Opening the new query” Window

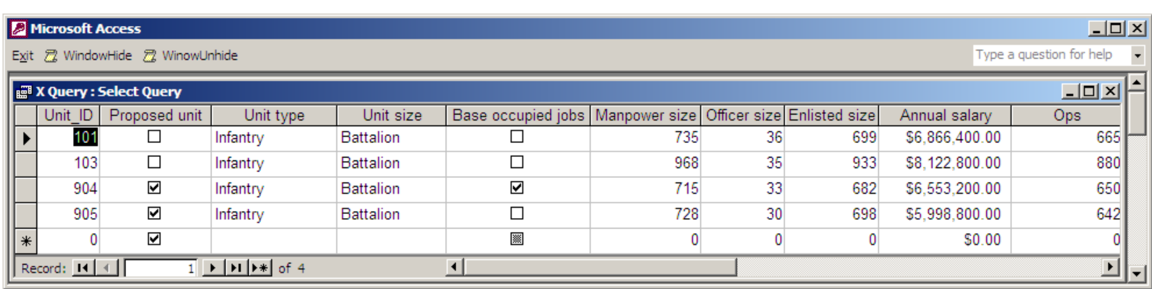



Figure 68. “Viewing the new query” Window

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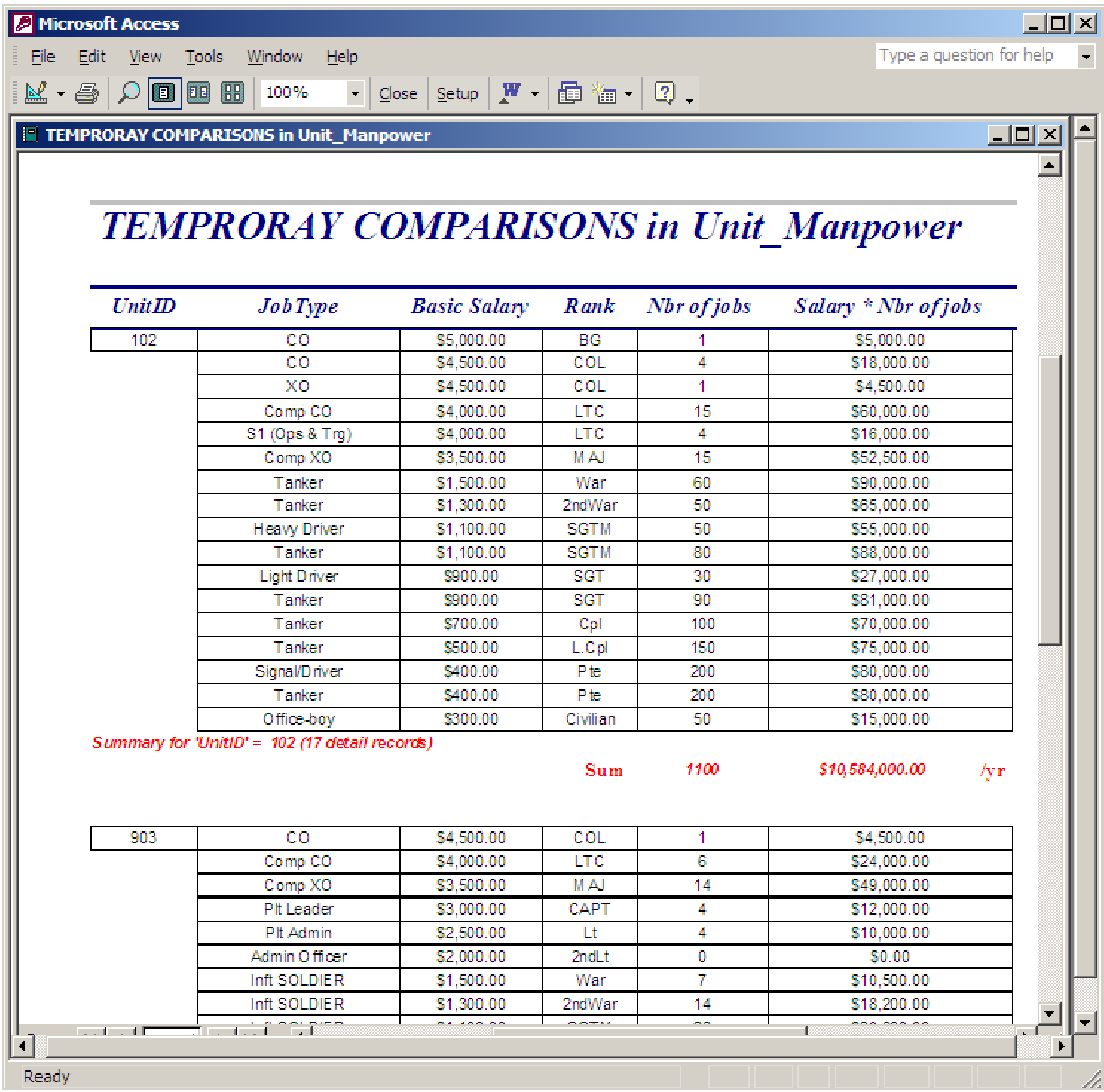
# APPENDIX H: PROTOTYPE OF REPORTS

## 1. SAMPLE REPORTS




TEMPRORAY COMPARISONS in Unit_Manpower

| UnitID | JobType | Basic Salary | Rank | Nbr of jobs | Salary * Nbr of jobs |
|---|---|---|---|---|---|
| 102 | CO | $5,000.00 | BG | 1 | $5,000.00 |
| | CO | $4,500.00 | COL | 4 | $18,000.00 |
| | XO | $4,500.00 | COL | 1 | $4,500.00 |
| | Comp CO | $4,000.00 | LTC | 15 | $60,000.00 |
| | S1 (Ops & Trg) | $4,000.00 | LTC | 4 | $16,000.00 |
| | Comp XO | $3,500.00 | MAJ | 15 | $52,500.00 |
| | Tanker | $1,500.00 | War | 60 | $90,000.00 |
| | Tanker | $1,300.00 | 2ndWar | 50 | $65,000.00 |
| | Heavy Driver | $1,100.00 | SGTM | 50 | $55,000.00 |
| | Tanker | $1,100.00 | SGTM | 80 | $88,000.00 |
| | Light Driver | $900.00 | SGT | 30 | $27,000.00 |
| | Tanker | $900.00 | SGT | 90 | $81,000.00 |
| | Tanker | $700.00 | Cpl | 100 | $70,000.00 |
| | Tanker | $500.00 | L.Cpl | 150 | $75,000.00 |
| | Signal/Driver | $400.00 | Pte | 200 | $80,000.00 |
| | Tanker | $400.00 | Pte | 200 | $80,000.00 |
| | Office-boy | $300.00 | Civilian | 50 | $15,000.00 |
| Summary for 'UnitID' = 102 (17 detail records) | | | | | |
| | | | Sum | 1100 | $10,584,000.00 /yr |
| 903 | CO | $4,500.00 | COL | 1 | $4,500.00 |
| | Comp CO | $4,000.00 | LTC | 6 | $24,000.00 |
| | Comp XO | $3,500.00 | MAJ | 14 | $49,000.00 |
| | Plt Leader | $3,000.00 | CAPT | 4 | $12,000.00 |
| | Plt Admin | $2,500.00 | Lt | 4 | $10,000.00 |
| | Admin Officer | $2,000.00 | 2ndLt | 0 | $0.00 |
| | Inft SOLDIER | $1,500.00 | War | 7 | $10,500.00 |
| | Inft SOLDIER | $1,300.00 | 2ndWar | 14 | $18,200.00 |

Figure 69. “Unit manpower comparison” Report

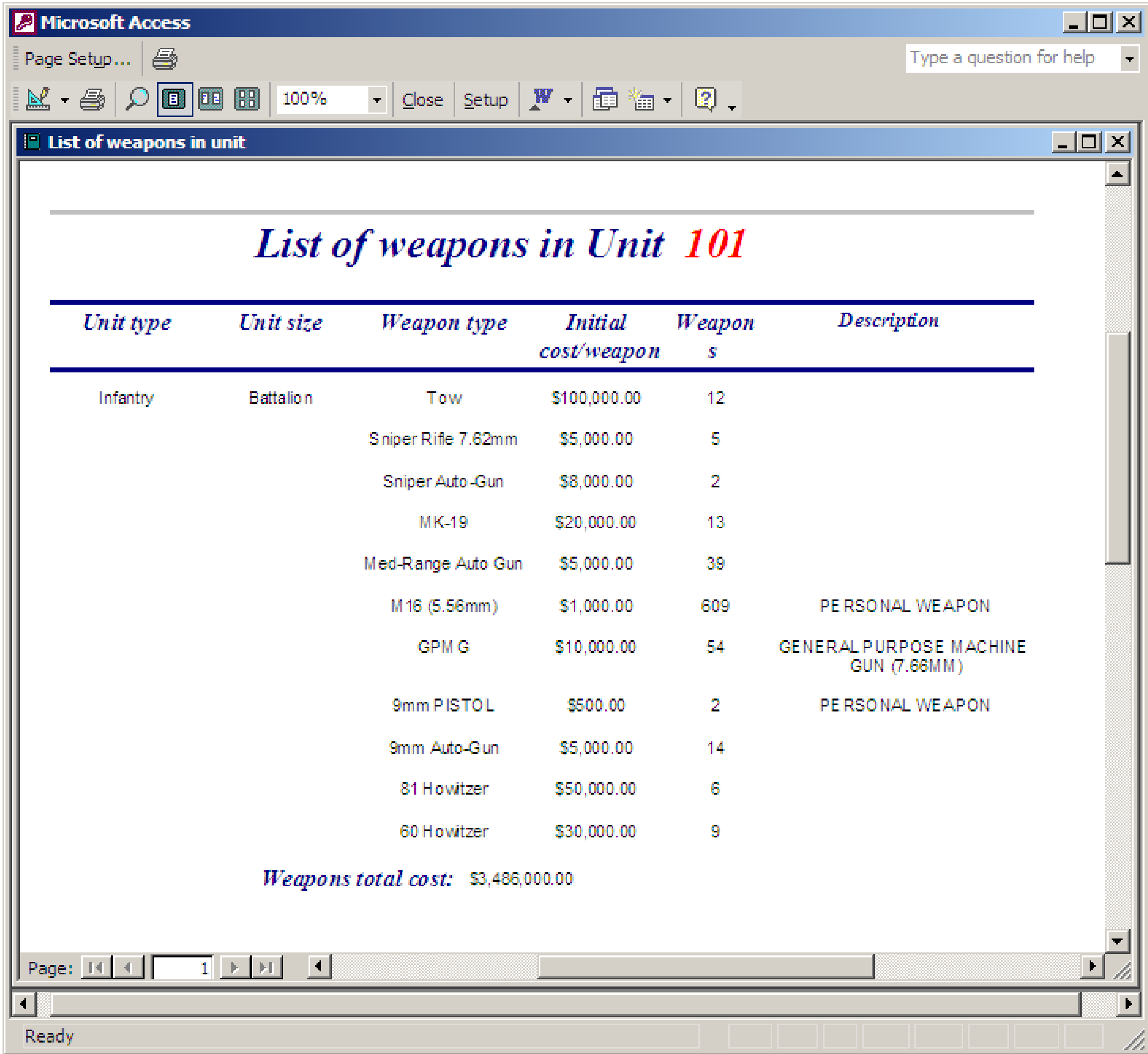



Figure 70. "List of weapons in unit" Report

## 2. CREATING AND VIEWING USER'S REPORTS

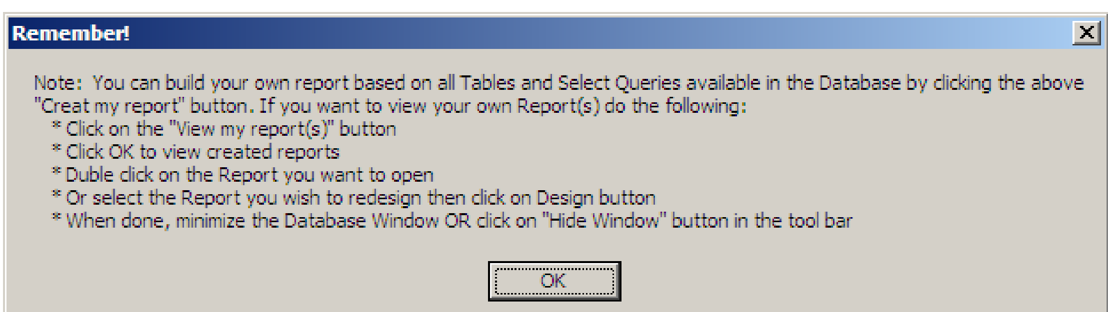



Figure 71. "Reminder instructions" Window

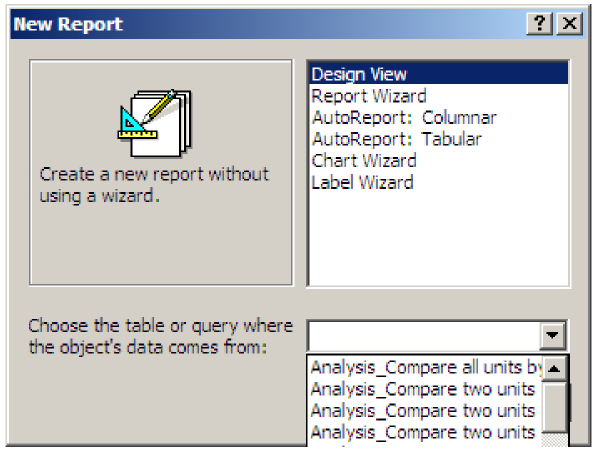



Figure 72. “New report” Window

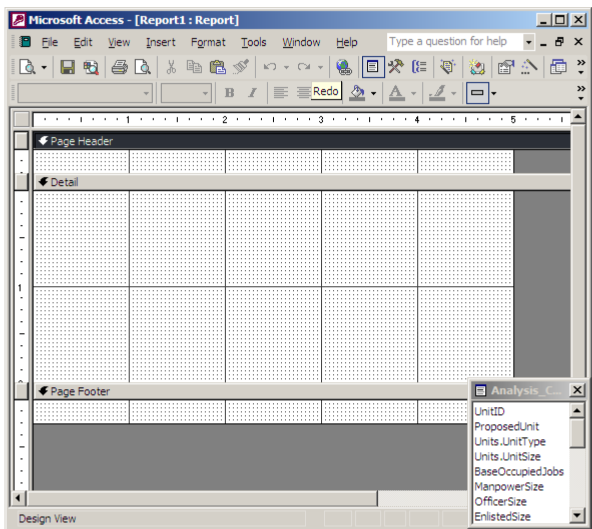



Figure 73. “Starting to design the new report” Window

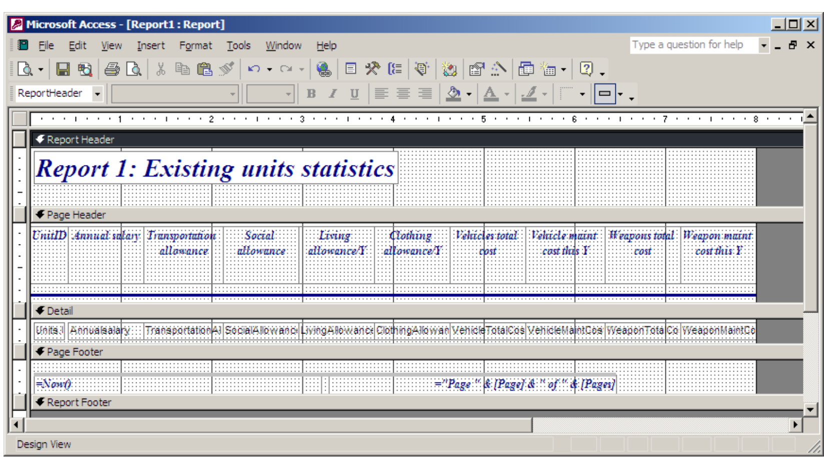



Figure 74. “New report in design phase” Window

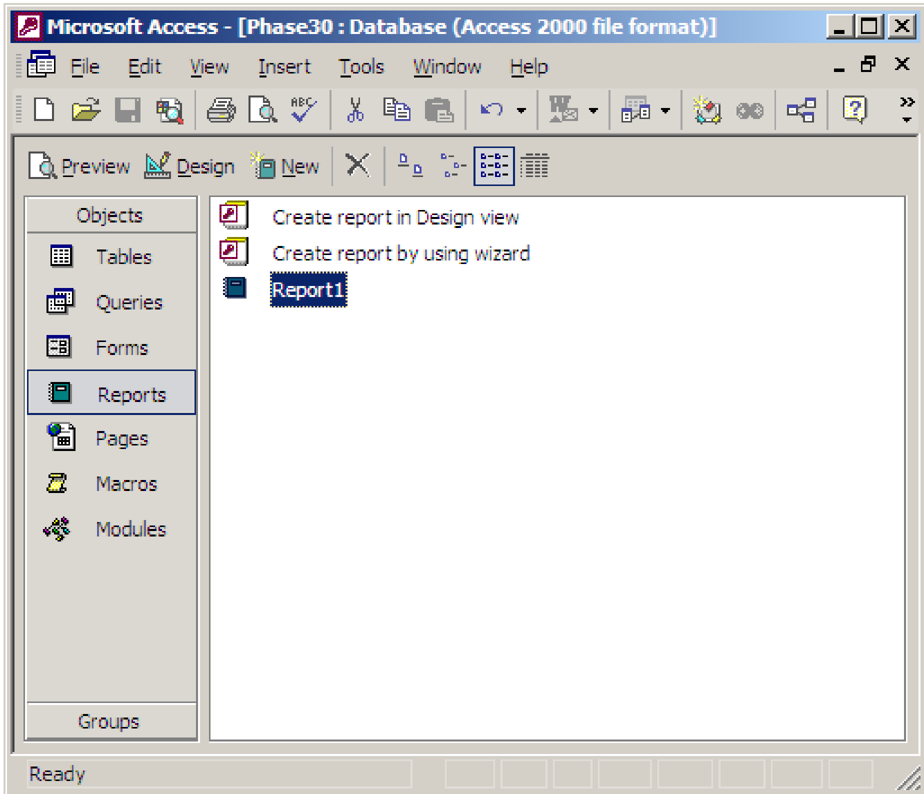



Figure 75. "Opening the new report" Window

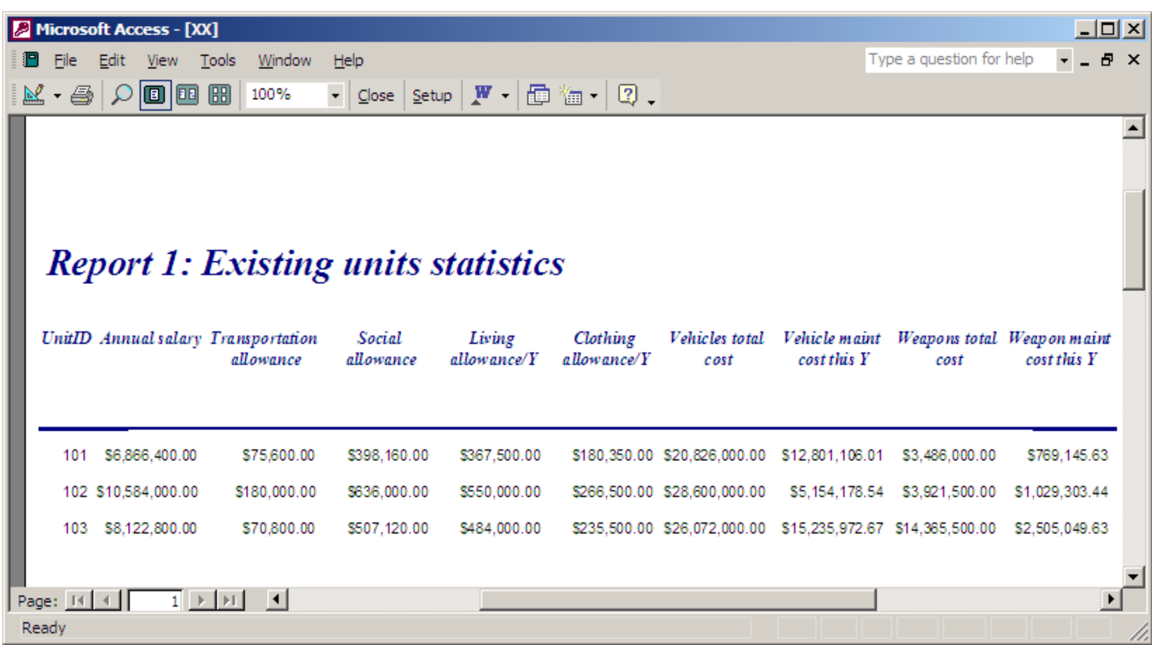



Figure 76. "Viewing the new report" Window

# APPENDIX I: PROTOTYPE OF ANALYSIS FORMS

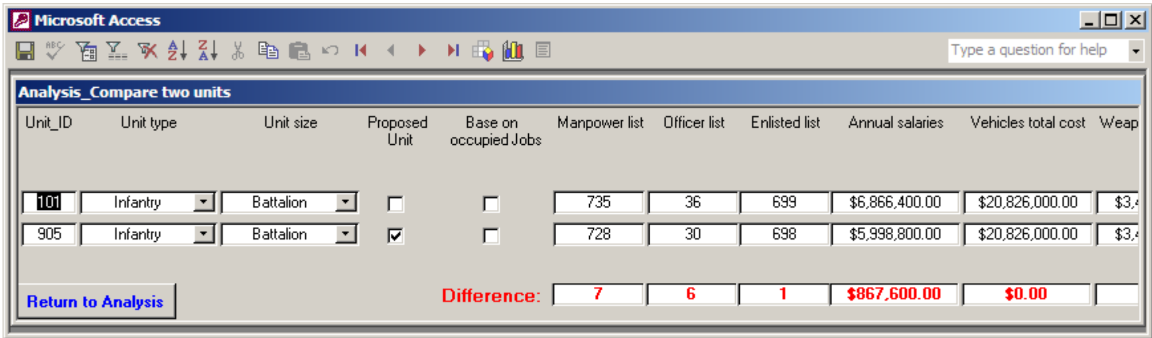
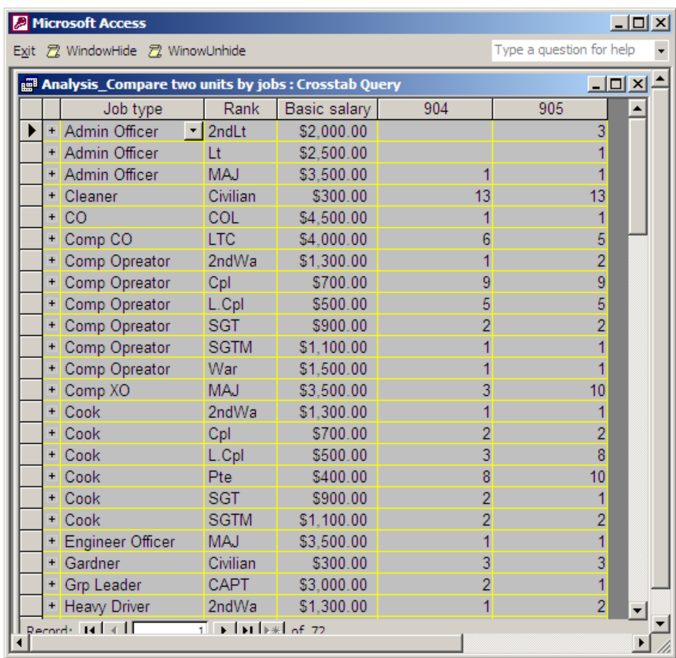
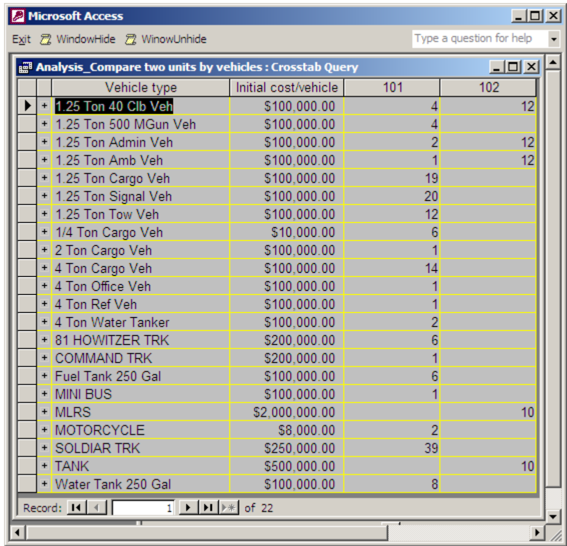



Figure 77. “Compare two units” Form



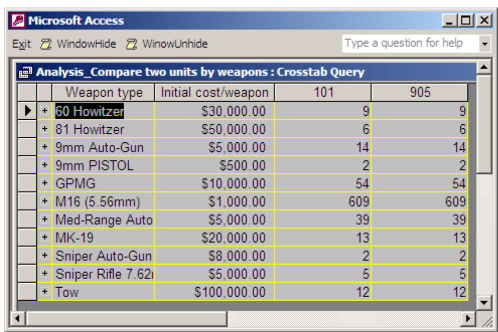

| Job type | Rank | Basic salary | 904 | 905 |
|---|---|---|---|---|
| Admin Officer | 2ndLt | $2,000.00 | | 3 |
| Admin Officer | Lt | $2,500.00 | | 1 |
| Admin Officer | MAJ | $3,500.00 | 1 | 1 |
| Cleaner | Civilian | $300.00 | 13 | 13 |
| CO | COL | $4,500.00 | 1 | 1 |
| Comp CO | LTC | $4,000.00 | 6 | 5 |
| Comp Opreator | 2ndWa | $1,300.00 | 1 | 2 |
| Comp Opreator | Cpl | $700.00 | 9 | 9 |
| Comp Opreator | L.Cpl | $500.00 | 5 | 5 |
| Comp Opreator | SGT | $900.00 | 2 | 2 |
| Comp Opreator | SGTM | $1,100.00 | 1 | 1 |
| Comp Opreator | War | $1,500.00 | 1 | 1 |
| Comp XO | MAJ | $3,500.00 | 3 | 10 |
| Cook | 2ndWa | $1,300.00 | 1 | 1 |
| Cook | Cpl | $700.00 | 2 | 2 |
| Cook | L.Cpl | $500.00 | 3 | 8 |
| Cook | Pte | $400.00 | 8 | 10 |
| Cook | SGT | $900.00 | 2 | 1 |
| Cook | SGTM | $1,100.00 | 2 | 2 |
| Engineer Officer | MAJ | $3,500.00 | 1 | 1 |
| Gardner | Civilian | $300.00 | 3 | 3 |
| Grp Leader | CAPT | $3,000.00 | 2 | 1 |
| Heavy Driver | 2ndWa | $1,300.00 | 1 | 2 |

Figure 78. “Compare two units by jobs” Form




| Vehicle type | Initial cost/vehicle | 101 | 102 |
|---|---|---|---|
| 1.25 Ton 40 Clb Veh | $100,000.00 | 4 | 12 |
| 1.25 Ton 500 MGun Veh | $100,000.00 | 4 | |
| 1.25 Ton Admin Veh | $100,000.00 | 2 | 12 |
| 1.25 Ton Amb Veh | $100,000.00 | 1 | 12 |
| 1.25 Ton Cargo Veh | $100,000.00 | 19 | |
| 1.25 Ton Signal Veh | $100,000.00 | 20 | |
| 1.25 Ton Tow Veh | $100,000.00 | 12 | |
| 1/4 Ton Cargo Veh | $10,000.00 | 6 | |
| 2 Ton Cargo Veh | $100,000.00 | 1 | |
| 4 Ton Cargo Veh | $100,000.00 | 14 | |
| 4 Ton Office Veh | $100,000.00 | 1 | |
| 4 Ton Ref Veh | $100,000.00 | 1 | |
| 4 Ton Water Tanker | $100,000.00 | 2 | |
| 81 HOWITZER TRK | $200,000.00 | 6 | |
| COMMAND TRK | $200,000.00 | 1 | |
| Fuel Tank 250 Gal | $100,000.00 | 6 | |
| MINI BUS | $100,000.00 | 1 | |
| MLRS | $2,000,000.00 | | 10 |
| MOTORCYCLE | $8,000.00 | 2 | |
| SOLDIAR TRK | $250,000.00 | 39 | |
| TANK | $500,000.00 | | 10 |
| Water Tank 250 Gal | $100,000.00 | 8 | |

Figure 79. “Compare two units by vehicles” Form




| Weapon type | Initial cost/weapon | 101 | 905 |
|---|---|---|---|
| 60 Howitzer | $30,000.00 | 9 | 9 |
| 81 Howitzer | $50,000.00 | 6 | 6 |
| 9mm Auto-Gun | $5,000.00 | 14 | 14 |
| 9mm PISTOL | $500.00 | 2 | 2 |
| GPMG | $10,000.00 | 54 | 54 |
| M16 (5.56mm) | $1,000.00 | 609 | 609 |
| Med-Range Auto | $5,000.00 | 39 | 39 |
| MK-19 | $20,000.00 | 13 | 13 |
| Sniper Auto-Gun | $8,000.00 | 2 | 2 |
| Sniper Rifle 7.62 | $5,000.00 | 5 | 5 |
| Tow | $100,000.00 | 12 | 12 |

Figure 80. “Compare two units by weapons” Form

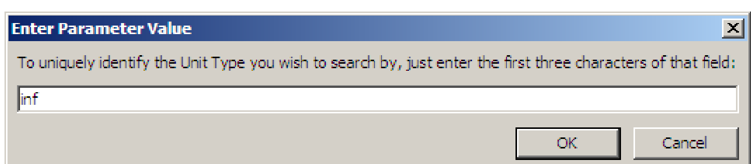



Figure 81. “Querying the unit type” Window

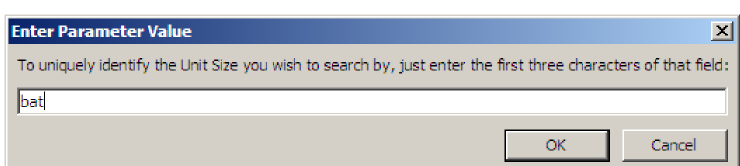



Figure 82. “Querying the unit size” Window

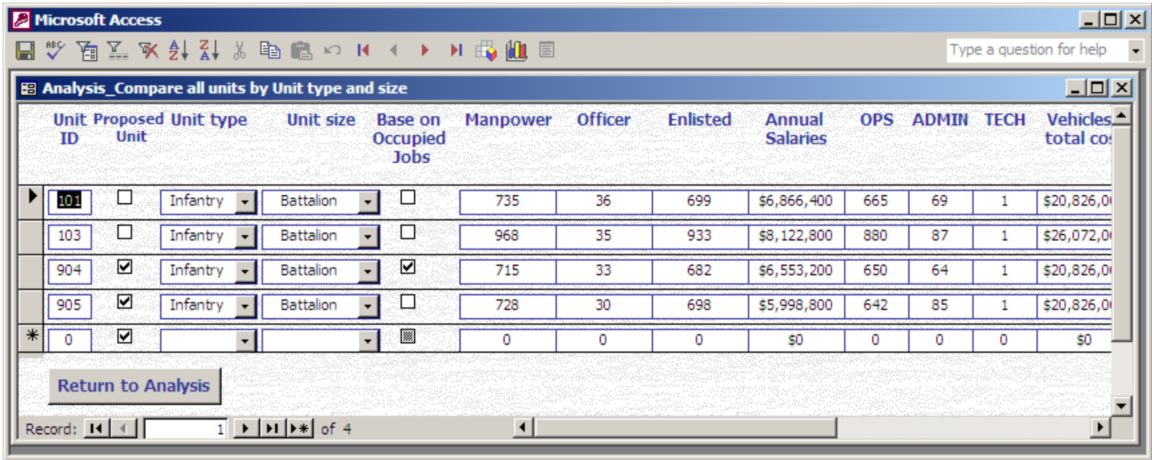



Figure 83. “Compare units by type and size” Query

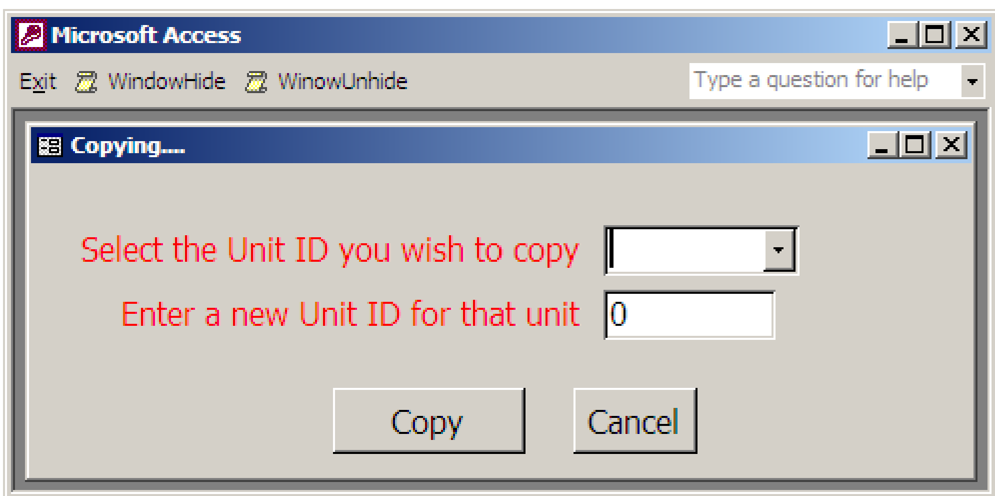



Figure 84. “Copying any unit in the database as a proposed one” Window

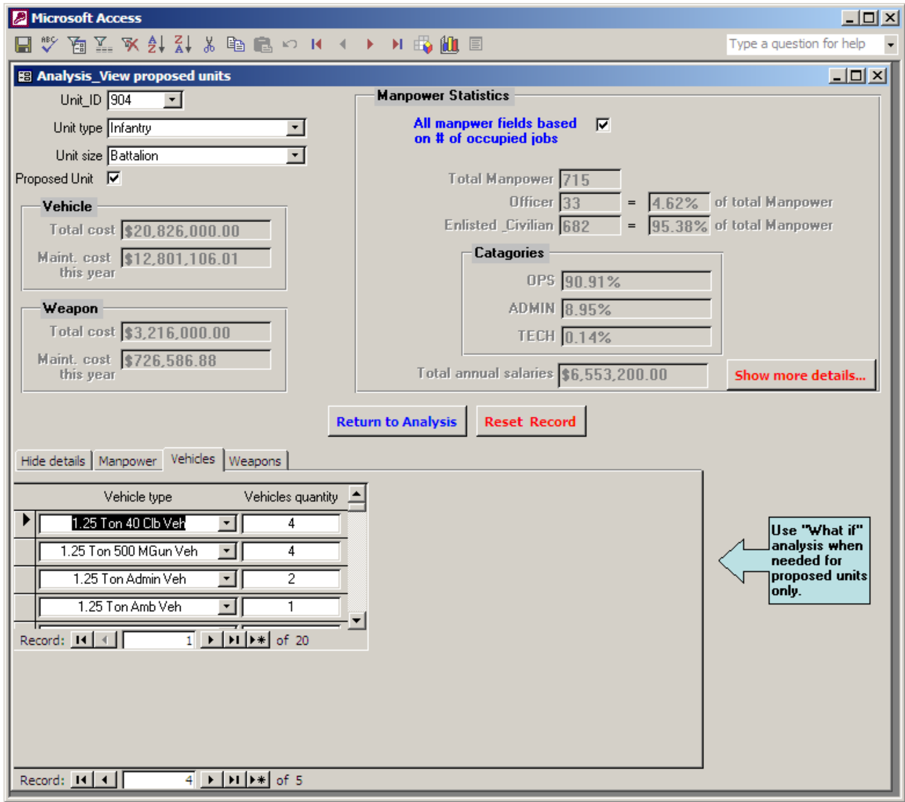



Figure 85. “Viewing and apply “What if” method on all proposed units” Form

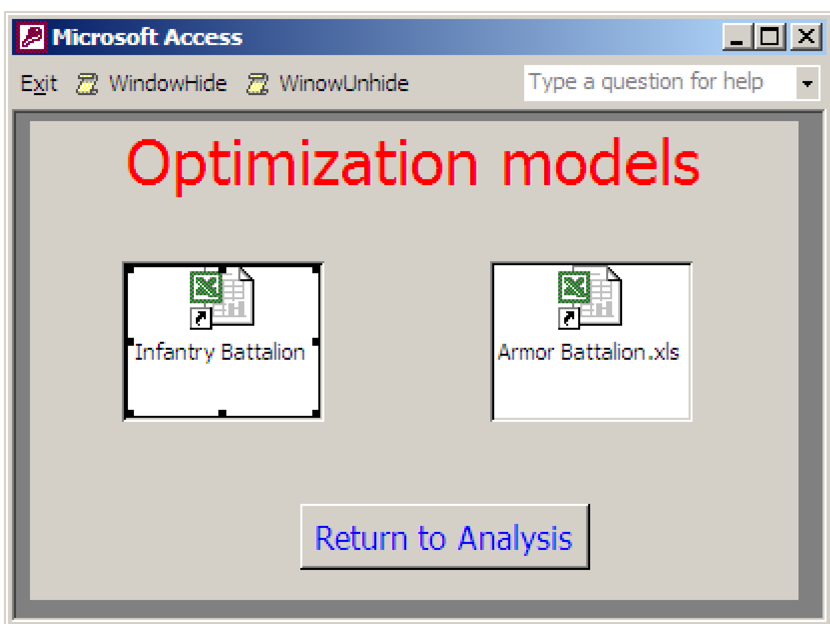



Figure 86. “Optimization models” Switchboard

# APPENDIX J: BRIEF USERS' MANUAL

## 1. PURPOSE

This DSS helps the users (mainly the force structure planners) to establish the cost of creating and maintaining an operational military unit, which in turn will aid the decision-makers or planners in tracking and monitoring the manpower and staffing requirements, operational support requirements and the proposal or approval of a cost-effective organization. The DSS tool can also be used to perform additional functions such as monitoring and highlighting job vacancies and manpower shortfalls or surpluses in an organization, as well as comparing the costs of maintaining two or more units in an organization.

## 2. GETTING STARTED

The database program is stored in a filename, entitled "BDF_DSS". Install the program by copying the file into your computer. Before you are allowed to access or use the database program, you must be an authorized user. You will need an authorized user id and password to access the program. Please see your department system administrator and request a user id and password if you do not have one and you are an authorized user. Once you enter the program with the authorized user id and password, a menu switchboard will appear and you will be ready to use the database program.

## 3. USING THE SWITCHBOARD

The switchboard shows a list of menus on which you can find the options to perform the necessary tasks as defined. There are four main menus, comprising Forms, Queries, Reports, and Analysis. Just click on the icon to access the submenu functions you need. The icon, "Return to Main menu", appears in all submenus and allows the users to return to the main menu at any time during the program execution. Figure 87 shows the main menu switchboard of the BDF_DS tool.

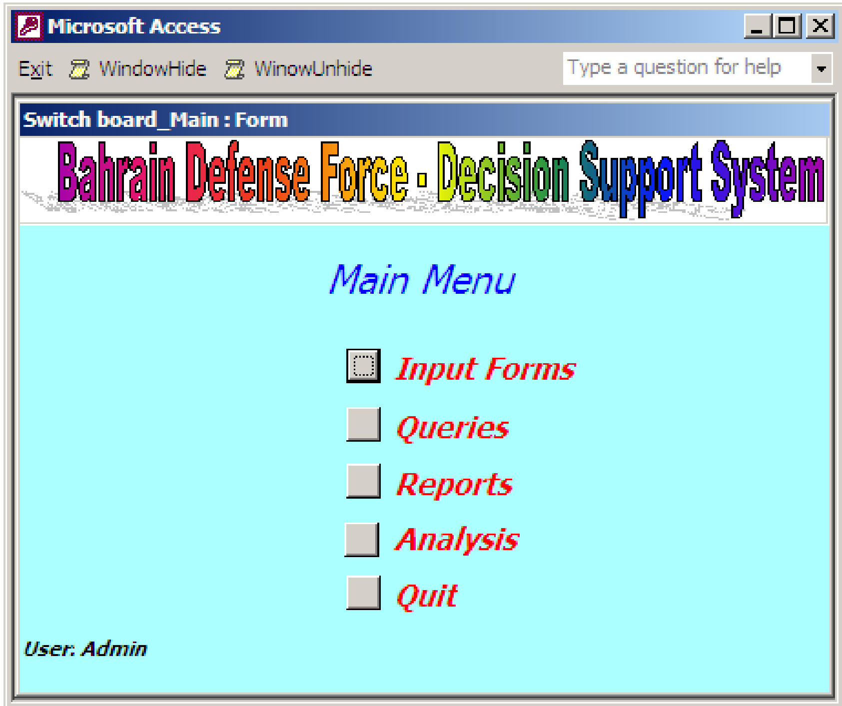



Figure 87. Main Menu Switchboard

## 4. USING FORMS

The forms are intended to allow the authorized user and system administrator to ADD new and MODIFY existing data in the database. Figure 88 depicts the "Forms" switchboard. In the ADD function, you can choose to insert new types of unit, weapons, jobs or vehicles. You can also choose to insert a particular job or weapon or vehicle into a unit. But for the latter, ***you must first create the new job, weapon or vehicle in the database before you can insert the new job or weapon or vehicle into a unit.*** Additionally, the ADD forms are supported with tool bar icons (located at the upper part of the window) for record editing, navigation, and sorting purposes.

In the MODIFY function, you can choose to update or delete existing data records or fields of each data type. Similarly, MODIFY forms are supported with tool bar icons that have two extra functions, namely, record filtration and record representation via charts or pivot tables. All ADD forms are created using the data entry form format. The lists of data which can be added and modified are given as follows:

- Unit
- Job
- Rank with Salary Info.

- Vehicle
- Weapon
- Jobs to a Unit
- Vehicles to a Unit
- Weapons to a Unit

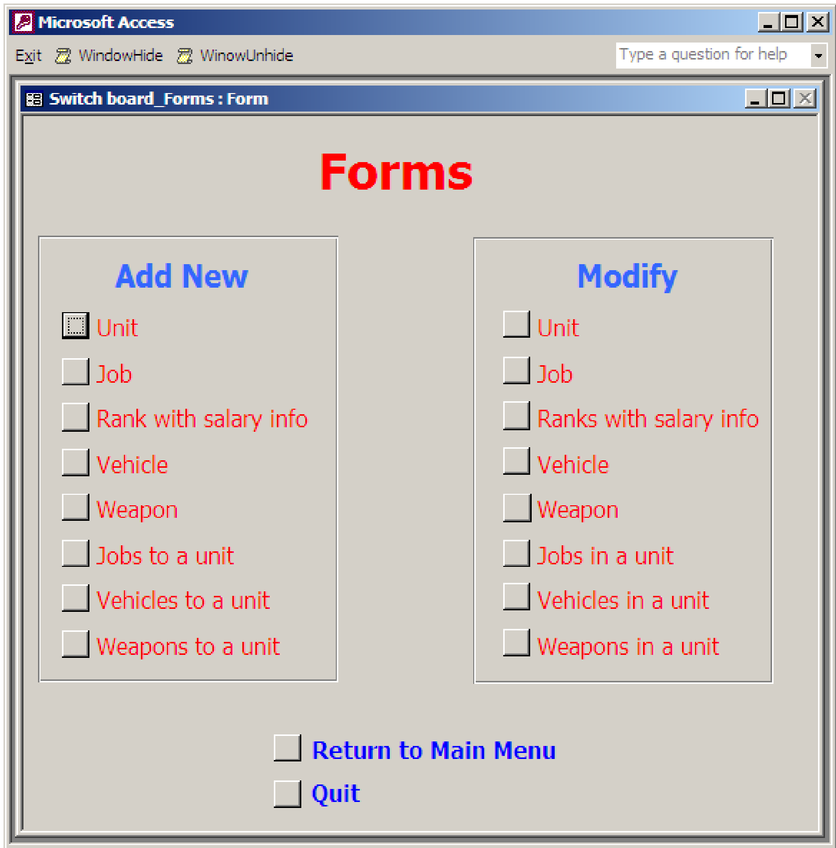



Figure 88. Forms Switchboard

## 5. USING QUERIES

From time to time, users may want to query the data to answer questions or identify problems or particular situations. Two main classes of queries were thus created in this design. The users can choose to make either single queries or multiple queries as shown in Figure 89.

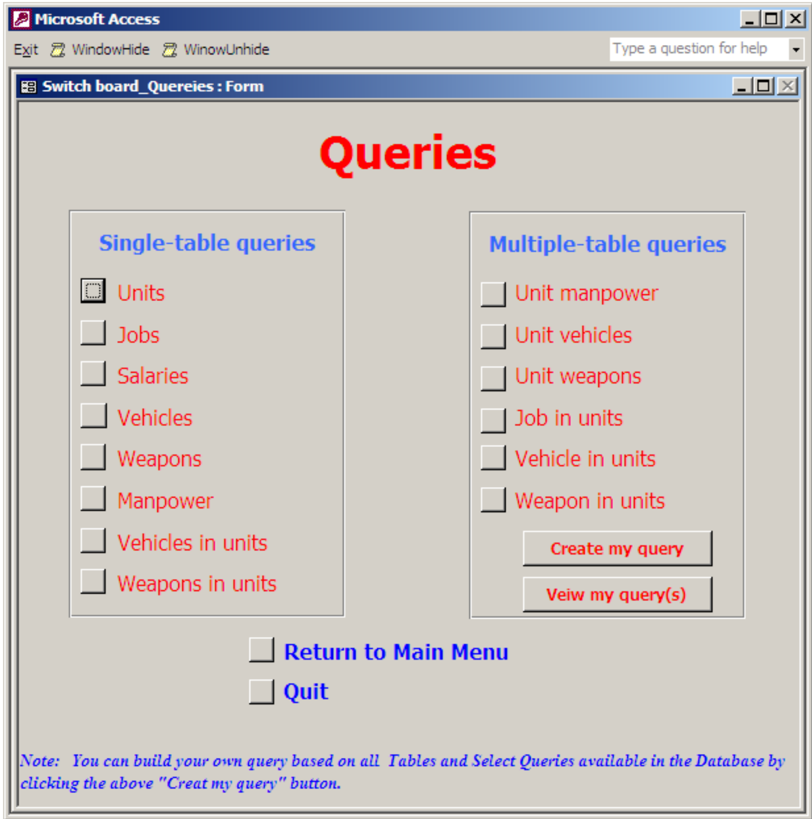



Figure 89. Queries Switchboard

**a. Single Queries**

These are mainly standard queries, which are created to provide responsive data to the users and to facilitate the users' query requirements. In a single query, the query is directed only at a single table. For example, the users can query the list of units or the list of jobs or the list of weapons, etc in the database. Queries may be directed at the following:

- Units
- Jobs
- Salaries
- Vehicles
- Weapons
- Manpower
- Vehicles in Units
- Weapons in Units

### b. Multiple Queries

For these queries, users are allowed to direct queries at two or more tables. For example, the users can make use of multiple queries to compare the operating costs of establishing two units in terms of manpower, weapons, and vehicles. The lists of such queries are given as follows:

- Unit manpower
- Unit vehicles
- Unit weapons
- Job in units
- Vehicle in units
- Weapon in units

### c. Additional feature

Moreover, the users are also allowed to conduct further searches on their own if the standard queries above do not meet their requirements. In other words, the users can create their own query based on all available tables and previously created queries in the database. The steps for executing this function are documented in the Query main menu form via the "Create my query" and "View my query(s)" command buttons.

## 6. USING REPORTS

A report is a formatted display of database data. There are in total 6 types of reports that are currently included in this database system as shown in Figure 90 below. However, it is possible for the users to define many different types of reports based on the tables and queries in the database. Users can create and view such reports by following steps similar to those described in the query section above. For the given reports, the users will need to select the data type to display. For example, when comparing the manpower between two units, the users will need to insert the unit id to compare the data. The different types of reports are as follows:

- List of jobs in Unit
- List of vehicles in Unit
- List of weapons in Unit
- Make manpower comparison between 2 units
- Make vehicles comparison between 2 units
- Make weapons comparison between 2 units

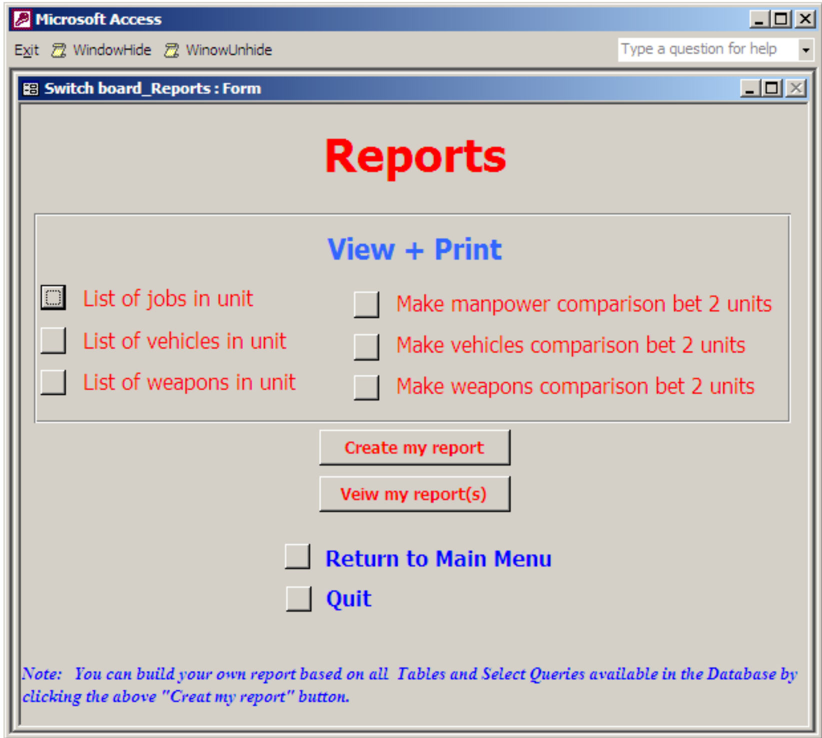



Figure 90. Reports Switchboard

### 7. USING ANALYSIS

The force structure planners will spend most of their time using the functions in the Analysis menu shown in Figure 91 below. Initially, the users can utilize the different types of comparisons available in this menu to see the units' differences. Secondly, users can simulate any unit structure in the database by copying it to a different unit id. The copied unit structure can then be manipulated and analyzed to generate other scenarios needed for the study. Thirdly, the users can utilize the human resource optimization models linked to the program to support their assumptions and solutions when proposing a unit structure. Also, users can view the proposed unit structures and apply the "what if" technique to the units' resources and match them with the best solutions found in the optimization models. Finally, the users can see the unit statistics based on either the number of jobs that refer to the unit budget cost or the number of occupied jobs that refer to the unit actual cost.

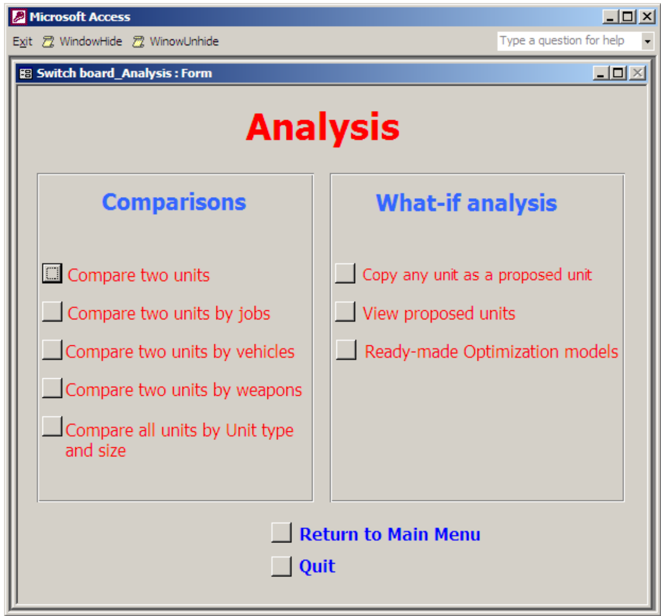



Figure 91. Analysis Switchboard

## 8. SECURITY

There are two main classes of users; namely the force structure planners and the system administrators. The main responsibility of the system administrator is to protect the data created in the database and ensure that only authorized users are allowed to access and use the data. The system administrator accomplishes the control through the granting of the appropriate access rights to the users. All authorized users will be given a user's ID and a password in order to access the database system. Additionally, all developed tables, forms, queries, reports, and macros are protected against deletion and alteration by regular users.

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