PRELIMINARY DESIGN OF A MINI-HEADQUARTERS TRAILER FOR A CONSTRUCTION COMPANY

by

Linda Garcia Cubero

Project Report submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE
in
Systems Engineering

APPROVED:

Benjamin S. Blanchard, Chairman

Wolter J. Fabrycky

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August 1992

Blacksburg, Virginia

Statements by Professor W. J. Fabrycky in partial explanation of why he voted "fail" regarding Linda Garcia Cubero's final examination, and why his signature is not affixed to the approval page of her Project Report entitled PRELIMINARY DESIGN OF A MINI-HEADQUARTERS TRAILER FOR A CONSTRUCTION COMPANY.

1. Although entitled "preliminary design," this Project Report is excessively detailed in its consideration of system elements to the exclusion of important systems engineering process concerns. As promised in the Abstract ... "design proposed ... is the result of trade-off between the operating requirements and standard human factor practices, and is evaluated based on operational performance and life-cycle costs." These promises are not adequately met.

2. Regarding life-cycle cost, the only explicit evaluation of alternatives occurs in Chapter 4 and this is incorrectly done. The following defects were noted:

    a. The alternatives presented in Chapter 4 do not derive from the systems engineering process of earlier chapters.

    b. The money flow diagrams in Figure 23 do not follow from costs within a 5% inflationary environment as shown in Table 6 and discussed in Section 4.2.

    c. The PE evaluations in Section 4.3.1 do not follow correctly from the money flow diagrams in Figure 23.

    d. The PW-Cost analysis in Section 4.3.3 and Table 9 is incorrect.

    e. The sensitivity analysis based on PW-Cost in Table 10 is incorrect.

3. Continuing with life-cycle cost evaluation, the candidate exhibits a lack of understanding as indicated by the following:

    a. Selection of the best alternative (based on the money flow diagrams of Figure 23) should be evident from dominance, making all of the (incorrect) analysis of Chapter 4 unnecessary.

    b. PE evaluation and PW-Cost analysis are presented as though they are two different methods for choosing the best alternative.

    c. Total budgetary cost of $242,405 cited in the Abstract and detailed in Table 6 is not the life-cycle cost upon which selection from among alternatives should be based.

The points raised in this statement are limited to those made in the memorandum from Fabrycky to Dean B. S. Blanchard on April 20, 1992. There are others of concern.

Professor Fabrycky's refusal to support this candidate for the Master of Science degree in Systems Engineering is based on the conviction that she is not qualified to receive said degree.

Respectfully submitted on September 14, 1992,

W. J. Fabrycky

W. J. Fabrycky, Ph.D., P.E.
Lawrence Professor of ISE

PRELIMINARY DESIGN OF A MINI-HEADQUARTERS TRAILER FOR A CONSTRUCTION COMPANY

By

Linda G. Cubero

Committee Chairman: Dean Blanchard (Systems Engineering)

(ABSTRACT)

The systems engineering life-cycle approach is used to develop the preliminary system design of a mini-headquarters trailer for the XYZ Construction Company. The design proposed by a design company is the result of trade-offs between the operating requirements and standard human factor practices, and is evaluated based on operational performance and life-cycle costs. These costs include research and development, procurement and construction, and operations and maintenance costs. Recommendations are based on criteria provided by the XYZ Construction Company.

The previous trailer headquarters, recently gutted by fire, had poor lighting and ventilation systems and did not meet fire code and safety standards. The XYZ Construction Company requires a new mini-headquarters as soon as possible for upcoming contracts. The trailer will contain a working area for up to six engineers, a conference room for eight, a private office area and a restroom. The trailer will have its own power and water supplies, sewage disposal and phone connectivity, as well as hookups for external electrical power and water. The trailer's life expectancy is ten years from design to disposal, with a cost over the entire life-cycle of approximately $242,405 for the assumed situation and example.

ACKNOWLEDGEMENTS

I would like to acknowledge Dean Benjamin S. Blanchard for his patience and understanding during the preparation of this report, as well as the General Electric Company for its support of higher education. I also acknowledge the help of my sister-in-law, Frances Cubero, for setting up the tour of the mobile trailers; Joseph Ratajczak for his time, advice and personal tours of mobile trailers; Robert McFadden for his professional sketches of my designs; and my good friend, David Streeter, for formatting my final report, tables and figures. Special thanks go to my dear friends Tanya and Jim Regan and Allan Kuczka, whose friendship and encouragement have helped me through some rough periods.

I wish to also acknowledge my husband, Frank, whose love and support through these trying years have helped to make this degree possible. Finally, I humbly acknowledge the wonderful support of my loving parents, Juan and Sally Garcia, and my sisters and brothers, Amanda, Mara, Luis and Juan, Jr. They have shared this agonizing experience with me and have kept my drive alive.

This is for you, my darling Jennifer Ashley!!

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1.0 INTRODUCTION

The purpose of this report is to provide the results of a preliminary analysis to design a mobile construction site mini-headquarters. This includes identifying the needs and requirements of the company requiring the trailer (the XYZ Construction Company), selecting the trailer size, performing a cost comparison between two trailer manufacturer's products, determining the trailer layout, and specifying the equipment used in the trailer.

The XYZ Construction Company, which is based in Rockville, Maryland, requires a mini-headquarters trailer as soon as possible for upcoming building contracts in Northern Virginia. The distance between the Maryland headquarters and the actual construction sites in Virginia (a 1.5 hour drive in non-rush hour traffic) requires a mobile mini-headquarters to be set up at remote construction sites. Appendix A describes the computerized layout planning approach used to determine the most efficient internal layout and the appropriate trailer size. Appendix A, together with a Feasibility Study (section 2.2), and the Definition of Need (section 2.1), determined the ideal trailer size, and resulted in the selection of a "single-wide" trailer size for the mini-headquarters. Therefore, the XYZ Construction Company decided to buy a factory-delivered "single-wide" trailer shell. Following a cost comparison between two trailer manufacturers for a "single-wide" trailer shell, the XYZ Construction Company hired a design company to help design the interior and exterior of the mobile mini-headquarters in order to accommodate utility requirements. The XYZ Construction Company notified the design company that the mobile mini-headquarters must meet established fire code and safety standards, as well as human engineering specifications requested by the Construction Company's lead engineers. The XYZ Construction Company's last mini-headquarters trailer, recently gutted by fire, had poor lighting and ventilation systems, and did not meet fire code and safety standards.

1.1 Approach/Overview

The ideal mini-headquarters workstation design must be compatible with both the expected users and the system performance requirements. The interior design must consider operating requirements, human factors requirements, including user capabilities and limitations, as well as functional considerations. Ultimately, requirements and costs drive the design of the trailer.

The general design approach first defines the need, then performs a feasibility analysis which helps to establish an explicit set of operating requirements based on performance functions, physical constraints, user population and specifications. The design is kept flexible and tentative until all requirements have been defined (Operating Requirements are listed in Section 2.3). The logical and sequential order in which the requirements must be accomplished needs to be fully understood and agreed upon by all parties concerned.

Initially, the mobile mini-headquarters is designed with input data limited to certain generalities, specifications, interviews, and initial task analyses based on a feasibility analysis. As the design phase progresses, more detailed information becomes available; however, the design company will have less flexibility and freedom for trailer modifications. Therefore, early consideration of system requirements becomes imperative. The design company must attempt to obtain as many facts and inputs regarding operational mission, maintenance and human factors requirements, and functional analysis before starting layout conceptualization.

Basically, an iterative analysis design technique is used to consider and possibly reconsider various design options. [1] The various phases of the design analysis, which occur prior to development, are not rigidly structured. The design can move from one phase to another, as required, without waiting to complete the preceding phase. Figure 1 shows a graphic presentation of this design analysis method, and illustrates the cyclic nature of design. [1] The freedom to interact between stages is characteristic of a creative designing process, and should serve to expedite and simplify the designing process as a result of the critical feedback information and interaction.

1.2 Organization of Report

This report incorporates a System Requirements Section, a System Design Section, a Life-Cycle Cost Analysis Section and a Conclusion and Recommendations Section.

The System Requirements Section provides the overall guidelines for the system design. This section includes the definition of need, feasibility analysis, operating requirements and assumptions, effectiveness factors, system maintenance concept and functional analysis, which together determine the appropriate trailer size and focus on human factors and functional considerations. The engineering staff of the XYZ Construction Company has provided functional and environmental requirements, as well as requirements for maintainability and safety. The System Design Section details the actual trailer dimensions, preliminary layout and the utilities designs. A Life-Cycle

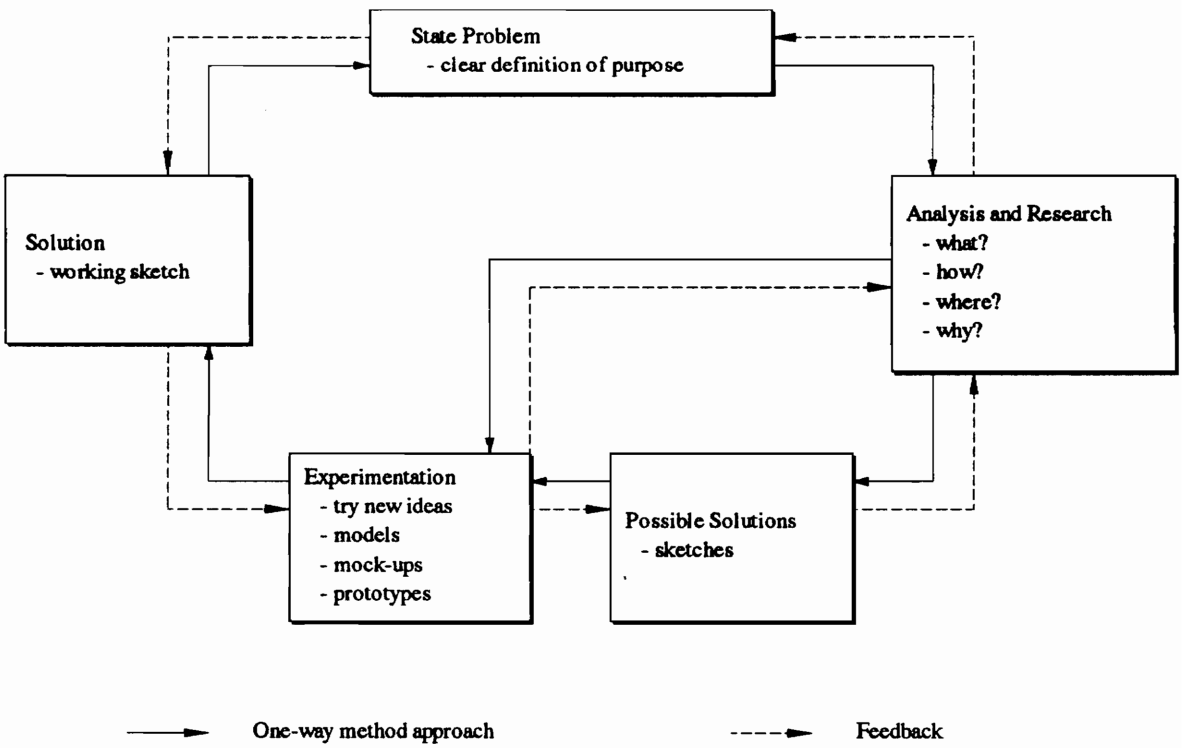


Figure 1: Graphic Illustration of the Design Analysis Method [1]

Cost Analysis that includes a cost evaluation of two alternative purchases and a system retirement plan follows. Finally, recommendations are made to XYZ Construction Company management in the last section.

2.0 SYSTEM REQUIREMENTS

The initial phases of the Systems Engineering Life-Cycle are applied to the trailer's design. These steps include [2]:

1. Definition of Need
2. Performance of a Feasibility Analysis
3. Development of Operating Requirements
4. Development of a System Maintenance Concept
5. Performance of a Functional Analysis
6. Evaluation of Alternatives
7. Allocation of Resources
8. A Preliminary System Design

This paper deals directly with the initial steps up to and including a Preliminary System Design for the XYZ Construction Company. In addition, several sections touch on the Detailed Design Analysis Phase outlined by Blanchard and Fabrycky. [2]

2.1 Definition of Need

The XYZ Construction Company's previous mini-headquarters trailer was recently gutted by fire. While the Company will initially have to rent a trailer for the temporary use as a mini-headquarters at construction sites, the firm's lead engineers insist that a new mobile construction workstation be designed and built to their specifications as soon as possible, with human factors engineering a primary concern. Although the rented trailer will temporarily serve some needs of the construction engineers at the site, it does not meet all the requirements (shortcomings are discussed in the Feasibility Analysis in Section 2.2). In addition, the cost of obtaining a new mini-headquarters trailer eventually is more economical that continued rental. This is due to inflation, which increases the cost of rental over time, and convenience. In order to accommodate the construction company's engineering staff in a rented trailer, the construction company must rent additional equipment and furniture to ensure the rented trailer serves its purpose. This results in additional costs that also increase over time. A newly designed mobile mini-headquarters that alleviates the shortcomings of the previous trailer and meets the needs of users in the 5th to 95th percentile range of the population is necessary for XYZ's on-site engineering staff to function properly and meet all their project requirements. The new trailer will be used by engineers and staff of the XYZ Construction Company for up to 16 hours per day for at least 267 days per year, with very little down time. The 16 hours per day is based on the XYZ Construction Company's policy that no more than two shifts of eight hours per day will be worked. The 267 days per year factors in holidays and most weekends off. The trailer must be usable at different sites throughout the Northern Virginia, Washington, D.C. and Maryland area.

The XYZ Construction Company requires the trailer to have three areas, which include a meeting room, a workspace area with a restroom, and a private office space. The trailer is required to accommodate up to 16 individuals at one time, eight in the conference room, six in the workbench area, and two in the private office. A meeting table for up to eight construction engineers is necessary in the mini-headquarters trailer for conferences. A horizontal workspace area that can accommodate up to six engineers is essential for the daily activities. Furthermore, a private office for the site's lead engineer, combined with an administrative station, is also required in the mini-headquarters by The XYZ Construction Company. Specific layouts of the trailer are detailed in Section 3.0.

Fire and building safety codes require a minimum of two exit doors on the trailer, one at each end, which is acceptable for the XYZ Construction Company. An additional door was deemed unnecessary and impractical. Additionally, the engineers requested steel "I" beams in the roofing and flooring metal trusses for additional stability in order to eliminate the need for columns in the trailer's interior. Although the XYZ Construction Company must pay extra up front for the steel "I" beams, the lack of columns creates more open space in the interior of the trailer and is ultimately well worth the cost.

Other needs that must be fulfilled by the trailer include bathroom facilities (sink and toilet; no shower); three windows (24-inches wide by 48-inches long) in each area; three to five electric wall outlets spaced in each area to fill utility requirements; and two-tube (48-inches long) fluorescent ceiling lights generally spaced every four feet. In addition to overhead fluorescent lighting, the interior of the trailer requires task lighting in each of the three areas. The XYZ Construction Company also requested the standard requirement of 3.5 inches of fiberglass insulation within the exterior walls to help absorb noise and maintain internal temperatures. Another requirement in order to design sound attenuation into the walls is the request for vinyl gypsum board walls along all the interior walls in each area. This vinyl gypsum material is better than wood panelling or fabric panels because it better insulates the interior, resulting in less sound coming into the trailer. This is because sound bounces off wood-panelled walls quicker than off vinyl-clad walls. This vinyl gypsum material will also cover the interiors of each exit door, as well as both sides of the doors dividing the three main trailer areas.

The exterior of the trailer consists of mostly treated wood, which is deemed more fire resistant than untreated wood. Engineers who use trailers frequently insist the wooden-type trailers generally hold up better than other exterior materials because they repair quicker and are sturdier in the long run over the aluminum exteriors, which dent easily. The entire trailer sits on three sets of tires and has telescopic fold-down jacks in each corner for stability and a faster mobility time. These jacks are attached to frame rails that run the length of the trailer's underside. The trailer shell also contains collapsible stairs outside each of the two exit doors.

The XYZ Construction Company has defined the utility requirements for the design company in its statement of need. Although some project sites have access to external water, electric power, sewage disposal and telephone lines, other sites do not have access to outside sources. Therefore, the trailer must be designed to be a self-contained mini-headquarters, with its own power and water supplies, sewage disposal system and phone connectivity. In addition, a specially built cabinet below the bathroom sink is required to house a water heater. To accommodate the utility requirements, the trailer's main dividing walls have been specially built with venting systems and plastic PVC piping. Plastic PVC piping is not only cheaper than copper piping, it is also very reliable because it is temperature resistant. PVC piping is recognized for its ability to withstand temperatures well beyond any experienced in this geographic area. For added protection against freezing or bursting pipes, the XYZ Construction Company requires the PVC piping to be wrapped with thick, black rubber piping insulation. The specific utility system designs are described in Section 3.7.

One final need the XYZ Construction Company has spelled out to the design company is the requirement for the trailer to have a four-to-eight hour "pick up and go" time. In other words, the trailer must be towable with only four to eight hours of notice.

2.2 Feasibility Analysis

Normally, feasibility analysis includes conducting marketing analysis, performing feasibility studies and carrying out advanced planning. [2] The marketing function for this project does not require a large amount of effort. Based on an outstanding reputation for quality work at reasonable cost, the XYZ Construction Company has already selected a design company to design the mobile mini-headquarters. Therefore, the potential market for the designed mobile mini-headquarters, the XYZ Construction Company, has already been identified.

Meanwhile, a Feasibility Study has already been conducted by the design company to analyze the requirements, identify existing deficiencies in the gutted mobile workstation, and make a determination if there are feasible ways to improve the new design, within any budgetary and technical limitations, as well as any physical constraints of the mobile trailer. This study also helped determine the appropriate size of the trailer.

In order to determine required technical parameters and particular human factors desires, the following questions were asked during the Feasibility Study and interviews/consultations. The questions, designed to find out preliminary design phase information in order to establish a set of operating requirements, were directed towards XYZ Construction Company employees, with emphasis on the engineering staff.

- What mission is the trailer system expected to accomplish in terms of operations and functional performance characteristics?
- What are the operating requirements (functional, safety, maintainability, environmental)?
- How will the trailer system be utilized?
- How will the trailer system be maintained and where?
- When is the trailer system needed?
- Who will be using the trailer system and for what period of time in terms of hours of operation per day for how many days?
- How many individuals will use the trailer system at one time and for what purposes?
- What is the operating budget?

- How will the trailer system be deployed to sites?

- What did you like/dislike about the gutted mini-headquarters that you would like to keep/change?

- What new features would you like to be incorporated into the design of the new mini-headquarters?

- What is the expected operational life of the trailer system?

- When the trailer system becomes obsolete, what are the requirements for disposal?

The following list of deficiencies of the gutted trailer was identified in the Feasibility Study. It is these shortcomings that the new design will strive to improve upon using human factors design engineering. All of the shortcomings listed below, with the exception of the first bullet, are not fire/building code requirements; however, the XYZ Construction Company engineers prefer that they be corrected or improved.

- Did not meet fire and building codes for safety
    - only one fire extinguisher available for use (fire code requires one fire extinguisher at each exit door)
    - No smoke alarms
    - No non-flammable materials used
- Poor ventilation system
- No central air conditioning/heating system

- Poor lighting system
- Cramped working conditions due to the addition of new features, such as cellular phones, typewriter, computers, printer, facsimile machine, software, file cabinets and storage cubicles
- Inadequately sized office area for two occupants
- No meeting room available due to cramped conditions
- No bathroom facilities available
- Inadequate number of power outlets available in each area
- Poor sound attenuation features

2.2.1 Determination of Trailer Size

Appendix A details the computerized layout planning approach to determine the most efficient internal layout and trailer size required by the engineering staff. Appendix A, together with the Feasibility Study, and the Definition of Need, resulted in the trailer system selection, that is, the type of trailer shell best suited for the XYZ Construction Company. After evaluating different alternative trailer shell sizes and shapes, comparing them to the needs and specifications of the XYZ Construction Company, and determining the most efficient internal layout (see Appendix A), the XYZ Construction Company selected a factory-delivered "single-wide" trailer shell. This trailer, shown in Figure 2 and measuring 12-feet wide by 60-feet long by 9-feet high, is the only standard factory-delivered trailer size that meets both the size and

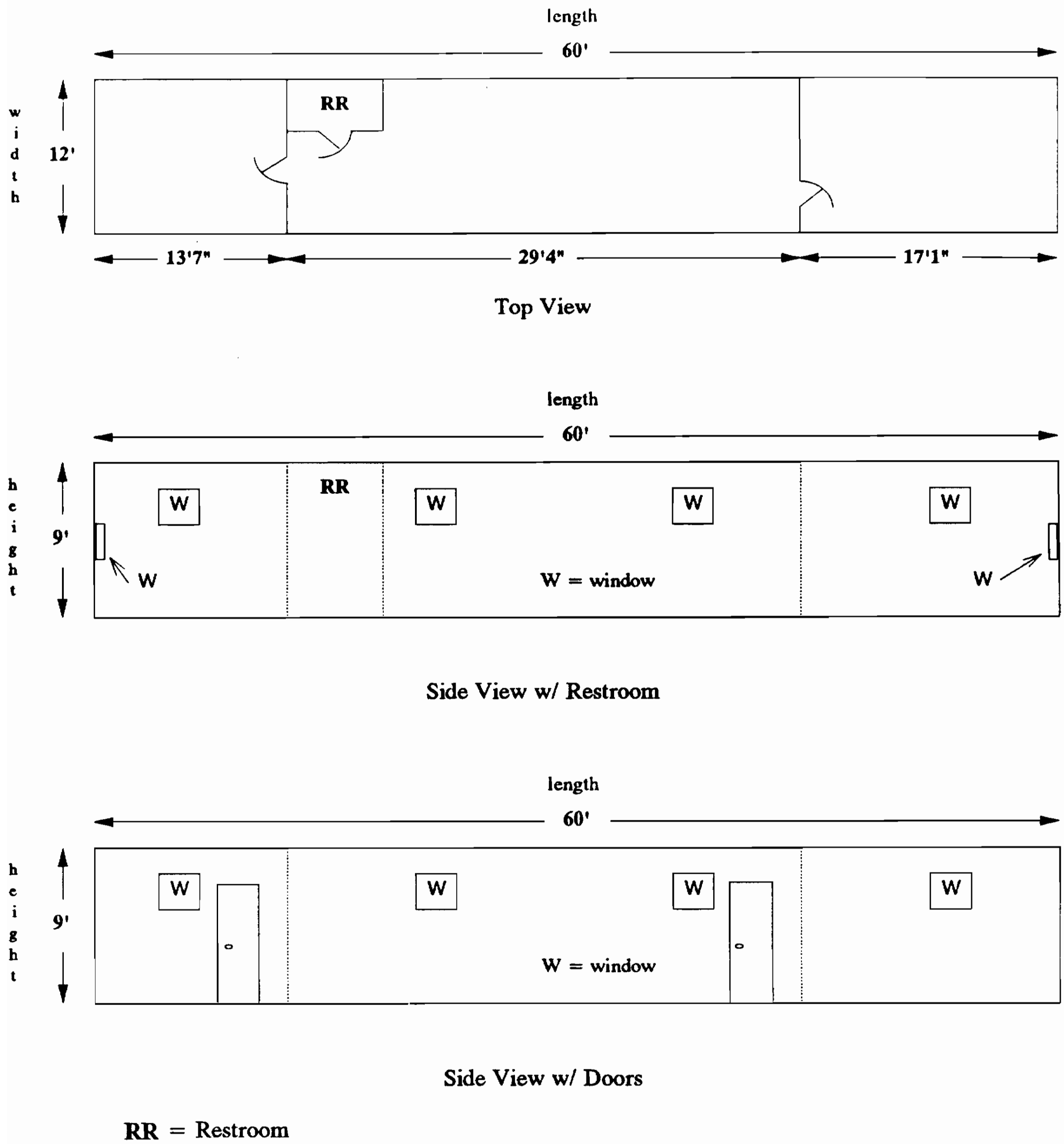


Figure 2: Standard Factory-Delivered "Single-Wide" Trailer Shell

(Top and Side Views)

shape requirements, as well as the budget allocations. The next trailer shell larger in size is too expensive and too large for the Construction Company's needs, and would result in cost overruns and wasted space. The next smaller-sized trailer, while meeting budget constraints, does not have enough space to accommodate the three functional areas required by the XYZ Construction Company. A cost comparison between two trailer manufacturers for a standard factory-delivered "single-wide" trailer shell is presented in Section 4.

2.2.2 Trailer Life-Cycle Approach

Besides conducting marketing analysis and a feasibility study, the feasibility analysis also involves advanced planning, which is already underway. The design company hopes their advanced planning will help establish schedules and prepare preliminary plans associated with product design and production. [2] The system life-cycle approach to systems engineering, detailed by Blanchard and Fabrycky, is employed in the design of the mobile mini-headquarters. [2] The life-cycle approach serves as a comprehensive method of designing a mobile mini-headquarters best suited for the XYZ Construction Company's needs while minimizing costs. The life-cycle approach begins with the initial identification of a need and extends through planning, research, design, development, evaluation, consumer use, and ultimately, product phase out. Figure 3 represents the overall trailer life-cycle with the operational life beginning at 8 months and continuing through year 10. Figure 4 further defines the preliminary and detailed system design phases of the trailer. [2] This project covers the first two stages in Figure 4, the Conceptual Design Phase and the Preliminary System Design Phase (Advanced Development). In addition, several sections touch on the

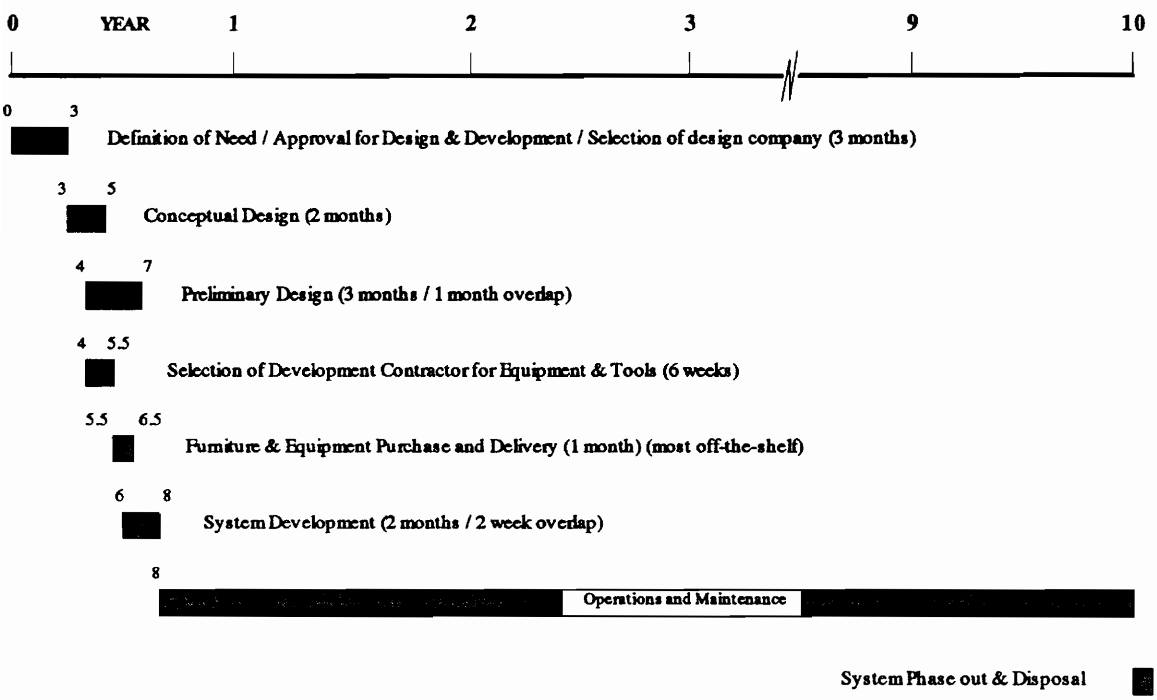


Figure 3: Trailer Life-Cycle

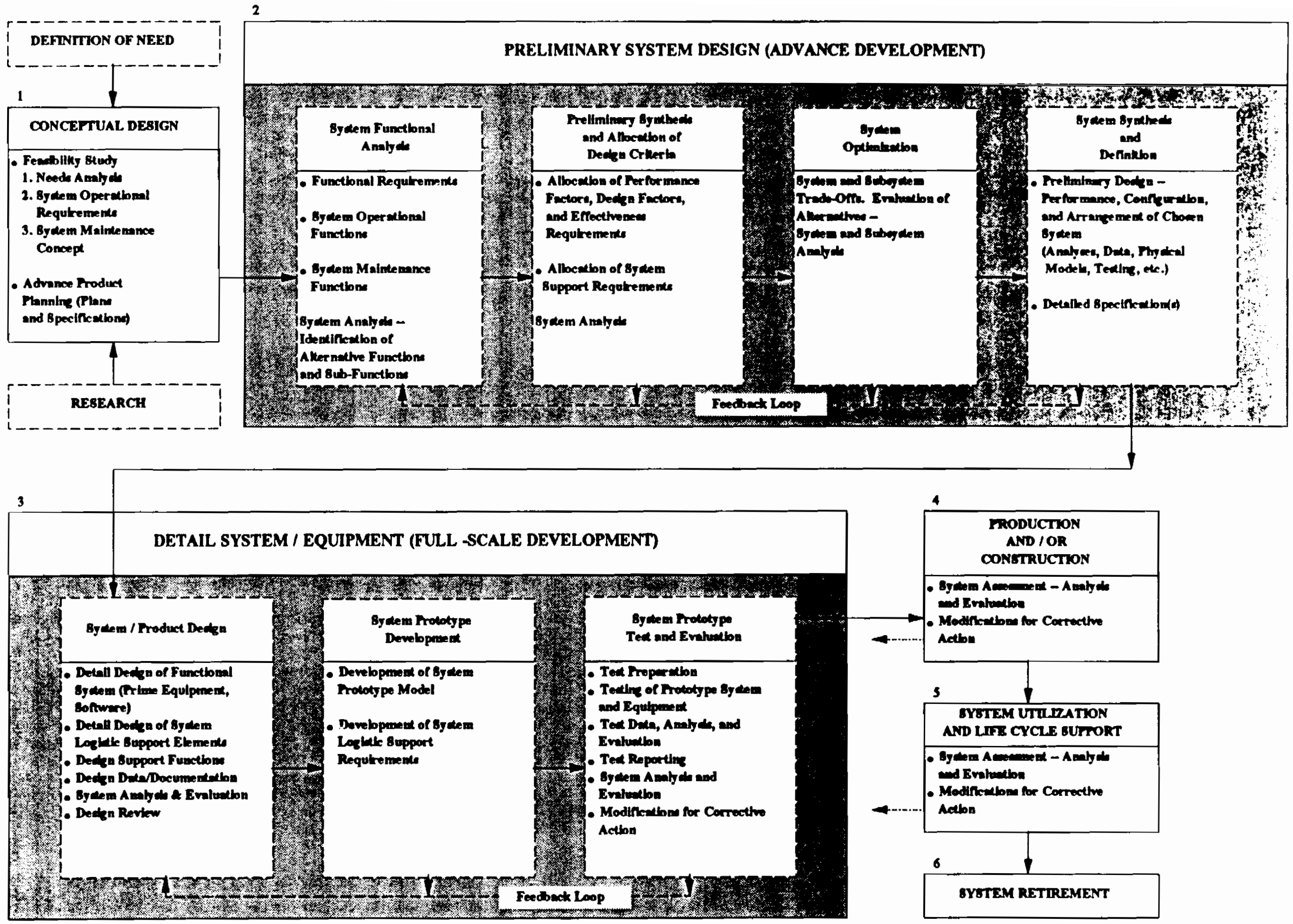


Figure 4: System Design Evolution [2]

Detailed Design Analysis Phase. The definition of need, combined with the feasibility analysis, translate easily into operating requirements for the XYZ Construction Company.

2.3 Operating Requirements

The conceptual design, the first step in the evolution of system design, is accomplished through a definition of system operating requirements. These system operating requirements have been acquired through the definition of need, feasibility study, extensive interviews with XYZ Construction Company management and engineering staff, as well as from established legal fire and building codes and safety standards. In addition, other personnel in the construction business were consulted to gain an appreciation of both worthy and inefficient existing designs.

The management of the XYZ Construction Company wants a system that serves as a mini-headquarters away from the Company's main headquarters, located in Rockville, Maryland. The engineering staff of the XYZ Company wants a trailer system that contains a working area for up to six engineers, serves as a meeting place on site for groups of up to eight individuals, contains a private office for the lead engineer and an administrative clerk, promotes brainstorming and open communications, and meets all building and fire codes, as well as safety regulations. The trailer system should incorporate the following operating requirements:

- The trailer shell must not exceed a purchase cost from the factory of $15,000.

- The trailer system must be a self-contained mobile construction workstation, to include its own power and water supplies, sewage disposal and phone connectivity for up to 10 days.
- The trailer must contain hookups to accommodate external supplies of electric power, water, sewage disposal and phone connectivity, when outside sources are available.
- The trailer must be capable of being towed.
- The trailer must be able to travel on normal, improved roadways, urban streets and unpaved dirt roads in a safe and reliable manner.
- The trailer shell must be built with non-flammable materials.
- The trailer shell must contain steel "I" beams in the roofing and flooring metal trusses, with no columns in the trailer's interior.
- The trailer shell must consist of treated wood on the trailer's exterior vice aluminum or metal siding.
- The trailer shell must contain vinyl gypsum board walls along the interior walls.
- The trailer shell must contain at least 3.5 inches of fiberglass insulation within all of the exterior walls.
- The trailer must have three compartmented areas to accommodate a workspace area with a restroom, a meeting room, and a private office.

- The workspace area must be capable of accommodating a crew of up to six working engineers.
- The meeting room must be able to accommodate a sit-down meeting for up to eight individuals.
- The private office space must contain an office for the construction site's lead engineer and secretary.
- The trailer must contain at least two exit doors, each at opposite ends of the trailer.
- The trailer must contain a fire extinguisher near each exit door in accordance with fire and building safety codes.
- The trailer system must meet all current federal Department of Transportation motor vehicle safety standards that are applicable to trailers.
- The trailer must contain a proper ventilation system, including an adequate air conditioning system in the summer and adequate heating facilities in the winter season.
- The trailer must be capable of retaining stored items in storage areas during travel.
- The trailer must contain at least three windows in each of the three separate areas and at least one window in the restroom.
- The trailer must contain ideal workspace lighting for varying tasks, including two-tube (48-inch long) fluorescent ceiling lights, generally spaced every four

feet, and task lighting for everything from small detailed drafting to reading technical materials.

- The trailer must have three to five total wall and floor electrical outlets in convenient locations in each of the three separate areas to accommodate the utility requirements.

- The trailer system must incorporate the following technological features in a non-obtrusive, non-interfering basis:

  - computers linked to the HQ's mainframe via modems (up to three in the trailer);

  - a printer;

  - a copier;

  - a facsimile machine; and

  - up to three phones (cellular).

- The trailer must contain bathroom facilities, to include a toilet and wash sink (no shower facility is required).

- The trailer must contain an adequate drinking water supply.

- The trailer's phone system must have an effective operating range of 150 miles (limited by the paging system or modem).

- The trailer system must be capable of operating under all weather conditions.

- The trailer must have a truly mobile capability, that is, it must be able to "pick up" and be towed within four-to-eight hours notice for emergency redeployments.
- The trailer system must have a life expectancy of 10 years.

2.4 Assumptions

Some assumptions are made in order to simplify the life-cycle analysis and facilitate the design process. The assumptions are:

1. The new trailer "shell" meets accepted industry standards for size, fire and building code requirements, and safety regulations. The interior as well as exterior modifications must be designed to meet these same standards.
2. The trailer provides maximum safety in terms of vehicle systems performance, structural integrity, cargo restraint and nonflammability.
3. The number of failures, that is, when the trailer is totally unusable, does not exceed two per year.
4. The trailer can operate up to 16 hours per day for at least 267 days per year.
5. The Mean Maintenance Down Time for the new trailer averages 3.5 hours.
6. The new trailer contains a minimum of two exits, one at each end.
7. Every attempt is made to design a cost-efficient mini-headquarters while ensuring all operational requirements are met.

8. All of the materials used in the construction of the mini-headquarters are available for purchase over-the-counter, reducing the amount of time required to construct the mobile workstation.

9. The mobile workstation makes the most of available space in order to ensure a functional and efficient design.

10. The mini-headquarters being designed is strictly a field office with toilet facilities. It contains a working area for six engineers, a conference room that accommodates eight individuals, and a private office for two occupants. The XYZ Construction Company already owns the other required temporary construction site buildings, such as tool sheds, store sheds and some types of workshops.

11. Access to an external water source, power source, sewage disposal source and phone lines is not always available at sites.

12. The average trailer life expectancy is 10 years, and depends on how the trailer is handled, the individuals using it, where it is set up, and how often it is moved.

2.5 System Maintenance Concept

The maintenance concept defines the level of support the trailer system will receive throughout its life-cycle. It describes the maintenance levels and areas, to include the location of the maintenance performed, who will perform it and the type of work accomplished. The maintenance concept must also be consistent with the established maintenance procedures and facilities of the XYZ Construction Company.

For this project, the maintenance concept addresses three distinct maintenance levels: organizational, intermediate and depot. These levels of maintenance are differentiated by the extent of maintenance performed and the remoteness from the maintenance headquarters of the XYZ Construction Company, collocated with the Company Headquarters in Rockville, Maryland. The responsibilities and skills of the maintenance personnel involved, as well as the complexity and amount of maintenance required, increase from the organizational to the depot level. Table 1 shows the three levels of maintenance. [2] Explicit responsibilities are identified in order to prevent overlap and duplication of effort, as well as to prevent neglect in other areas.

2.5.1 Organizational Maintenance

Organizational level maintenance is performed at the project site locations, where the equipment is actually located. It is performed by XYZ Construction Company field technicians deployed to the site and normally consists of minimal preventive maintenance actions performed at scheduled intervals. Basically, organizational maintenance is limited to visual inspections, performance checks and periodic cleaning/changing of the utility system filters and ducts. Only basic "system level" repairs are accomplished at this level.

2.5.2 Intermediate Maintenance

Intermediate level maintenance is performed by full-time maintenance employees located at the XYZ Construction Maintenance Headquarters in Rockville, Maryland, which is collocated with the XYZ Company Headquarters. These

Table 1: System Maintenance Levels [2]

Criteria	Organizational Maintenance	Intermediate Maintenance	Depot Maintenance
Location	Off-Site Project Locations	XYZ Construction Co. HQ's, Rockville, MD	At a remote facility owned by the manufacturer of the equipment
Personnel Involved	XYZ Construction Co. technicians deployed to the site	XYZ Construction Co Maintenance Employees	Manufacturers Technicians (Different skill levels)
Type of Work Accomplished	•Site Maintainability •Visual Inspection •Component Replacement •Equipment Cleaning •Operational Checkouts •Minor Adjustments •Minor Troubleshooting	•Major Servicing •Detailed Inspection and System Checkout •Component Replacement •Equipment Repair •Major Adjustments and Calibrations •Major Troubleshooting	•Detailed Equipment Repairs •Complicated Factory Adjustments •Overhaul of Components •Supply Support •Detailed Calibrations •Rebuilds •Special Diagnostic Testing

individuals are trained and equipped to analyze and repair most components in the trailer system inventory, including the computer-related hardware and software. Therefore, most of the maintenance for the trailer system is expected to be performed at the intermediate level. Services provided at this level include routine preventive maintenance, equipment calibration, equipment repair, detailed inspections and system checkouts, as well as component replacement. These XYZ maintenance personnel are available for direct technical and engineering support to the organizational level maintenance technicians, as required. Organizational support to remote locations is critical, since it is unrealistic to expect construction activities at the site to possibly be delayed because the trailer needs to return to the headquarters in order to fix a problem with the toilet, for example, that the organizational technicians are unable to fix.

2.5.3 Depot Maintenance

Depot level maintenance involves the most complex type of maintenance work required. Technicians hired by the manufacturers of the equipment perform this level maintenance, including both highly skilled and lower skilled workers. The highly skilled individuals diagnose problems and perform special testing, while the lower skilled workers usually fix the problems after identification. Extensive component overhauls, detailed diagnostics and analysis, complicated repairs and calibrations, and maintenance not resolved at the intermediate maintenance level are all handled at this maintenance level. Occasionally, a skilled employee of the manufacturer may be sent out to the XYZ Construction Company Headquarters to work at the intermediate level; however, this is rare due to the high labor and travel costs involved. Normally, faulty components are either shipped to the manufacturer's location by the organizational or intermediate level maintenance personnel, or they are delivered by the intermediate level maintenance personnel. There are numerous depot level facilities since there are many different types of system components, including hardware and software, in the mobile trailer. Each depot level facility houses all the equipment, tools, personnel and documentation necessary to repair or replace their respective components in the trailer system. An inventory of replacement parts and a list of their manufacturer are kept on hand at the XYZ HQ's to limit system down time. The depot level also serves as an information source, primarily to the intermediate maintenance level personnel, but also to the organizational level. Of note, each manufacturer is encouraged to incorporate built-in self-test provisions, and the utility designers are required to build easily accessible and readily removable functional filter packages into the designed air, heat, electrical and water systems, as much as possible. The same encouragement is given to manufacturers of the trailer's phone, facsimile, computers, copier, printer and other hardware, to enable easier and quicker maintenance at the organizational and intermediate levels.

2.6 Functional Analysis

In the design of the trailer system, optimum design of the trailer hardware does not guarantee successful results. The human-machine relationship must also be considered early in the system life-cycle in order to create an effective design. [2] One critical objective of functional analysis in design is to strive for an optimum human-machine interface environment. This is accomplished by ensuring the compatibility between the system's physical design features and the human element in the operation, maintenance and support of that system. This section looks at this human-machine relationship in the context of the trailer's three basic functions, administrative (private office), engineering (workbench area), and conferencing (meeting room). Normally, a functional analysis is performed on each of these three main areas; however, for the purposes of this report, a functional flow diagram is developed on only one of the main functional areas, the workbench area used for engineering work, in order to demonstrate knowledge of the functional analysis process. The workbench area function must be examined to identify the system/subsystem functions required, how to accomplish them, the resources required to accomplish them, and the constraints that may affect how each function is most effectively accomplished.

2.6.1 Functional Flow Diagrams

Functional flow diagrams are concerned with what is to be accomplished rather than how and with what means to do it. According to Blanchard and Fabrycky, "The top level diagram shows gross operational functions. The first-level and second-level diagrams represent progressive expansions of the individual functions of the preceding level." [2] These diagrams are expanded down to the level necessary to establish the needs, in terms of hardware, software, facilities and personnel, of the trailer system. Figure 5 shows functional flow diagrams applied to the trailer system. Three levels of operational flows and two levels of maintenance flows are illustrated. Although these block diagrams do not cover all of the trailer system's functions, the flow diagrams presented provide enough detail to demonstrate knowledge and proficiency in the development of functional block diagrams.

OPERATIONAL FUNCTIONAL FLOW - THREE LEVELS

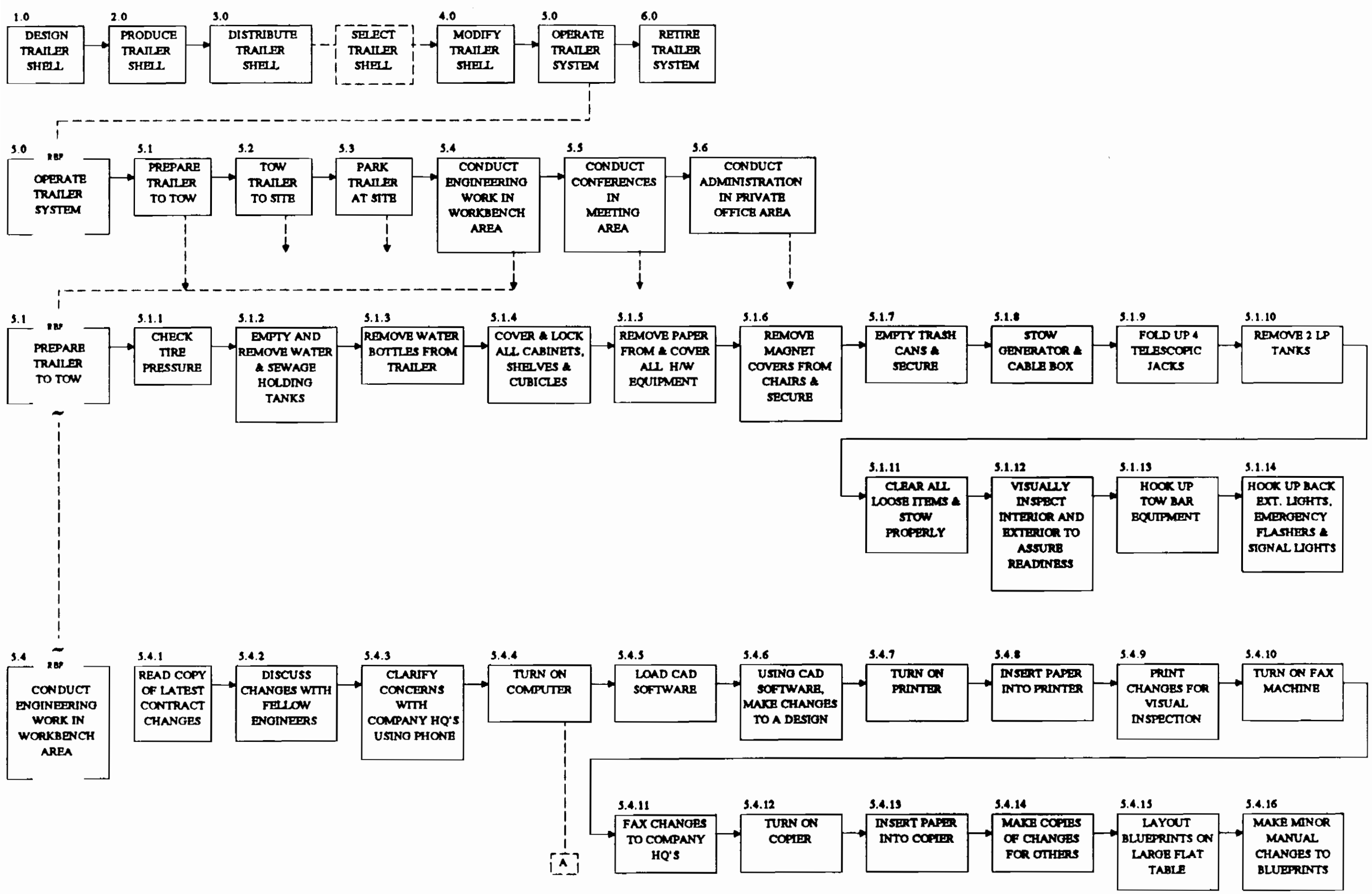


Figure 5: Trailer System Functional Flow Diagrams [2]

ORGANIZATIONAL MAINTENANCE FUNCTIONAL FLOW - TWO LEVELS

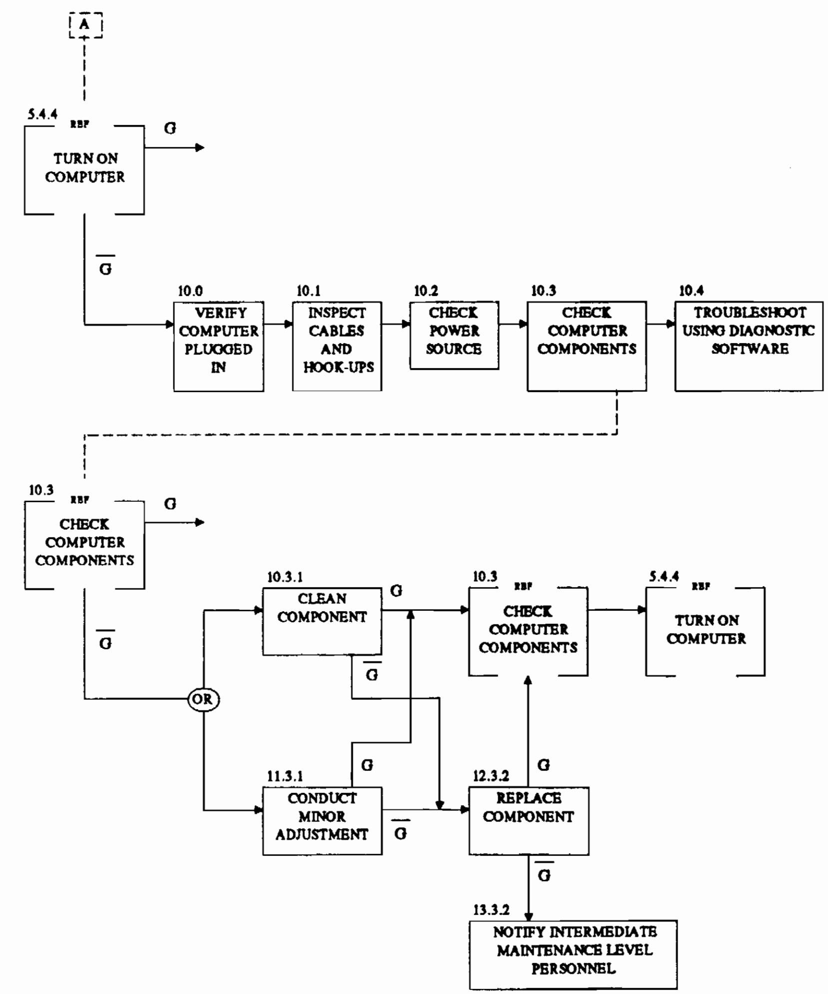


Figure 5: Trailer System Functional Flow Diagrams (continued) [2]

2.6.2 Functional Allocation Analysis

This section involves the allocation of top-level system factors to various subsystems and lower-level elements of the trailer system. According to Blanchard and Fabrycky, the purpose of allocation is to provide some guidelines to help the designer develop a product that will be compatible with system requirements. They stress that when accomplishing allocation, all appropriate qualitative and quantitative criteria that will significantly influence the design process should be considered. [2] Allocation analysis needs to consider all significant system parameter requirements, presented in the form of maximum and minimum criteria, or tolerance bands where appropriate. Dean Blanchard and Professor Fabrycky indicate that these system parameters include system effectiveness factors, such as availability, reliability, dependability and maintainability, as well as human factors requirements, which detail system performance and physical parameters. [2]

2.6.2.1 Effectiveness Factors

Effectiveness factors specify availability, reliability, dependability and maintainability for the system and its components. These parameters determine how well the system will operate, its level of efficiency and its effectiveness. These system parameters are difficult to define in advance. They are best determined through experience, data retrieval and research, obviously, after the system is operational. Therefore, for design purposes, these parameters can only be estimated based on interviews with experienced design engineers and personal experience and research.

However, requirements must be set forth and the trailer system designed to accomplish these goals.

Table 2 lists the effectiveness factors for this trailer system. Total hours of operation is based on 16 hours per day for 267 days per year. The 16 hours per day is based on the XYZ Construction Company's policy that no more than two shifts of eight hours per day will be worked. The 267 days per year accounts for holidays and most weekends off. A failure is defined as a situation where the trailer is totally unusable. The requirement is that the number of failures not exceed two per year. The failure rate, λ , is calculated using

$$\lambda = \frac{\text{number of failures}}{\text{total mission time}}.$$

The mean time between failures (MTBF) is 2,136 hours, based on the required failure rate, given by

$$\text{MTBF} \doteq \frac{1}{\lambda}.$$

The mean time between maintenance (MTBM) is the average time between all maintenance actions, both scheduled (preventive) and unscheduled (corrective). Preventive maintenance ($MTBM_p$) is required quarterly. Each preventive maintenance action takes on the average three hours and includes such tasks as hardware checkouts and servicing, visual inspections, and cleaning/changing utility system filters and ducts. Corrective maintenance actions ($MTBM_c$) are required around three times per year and take an average of four hours. MTBM is calculated using

Table 2: Effectiveness Factors

Total Hours of Operation per Year	4272
Number of Failures per Year	2
Failure Rate (λ)	0.00047
Mean Time Between Failures (MTBF)	2136
Maximum Reliability	0.99
Mean Time Between Maintenance (MTBM)	610
Mean Maintenance Down Time (MDT)	3.5
Operational Availability (Ao)	0.99

$$\text{MTBM} = \frac{1}{\left(\frac{1}{\text{MTBM}_P}\right)+\left(\frac{1}{\text{MTBM}_C}\right)}.$$

Therefore, MTBM for the entire trailer system is 610 hours. With 610 hours between maintenance actions over 4272 hours of operational life, the total number of maintenance actions is 7. Seven maintenance actions at an average of 3.5 hours each means that there will be 24.5 hours of maintenance performed during the trailer's operational life of 4272 hours. The availability of the trailer is measured using the operational availability (A_O), given by

$$A_o = \frac{(\text{MTBM})}{(\text{MTBM} + \text{MDT})}.$$

Since maintenance is a direct result of system design, and most of the site construction engineers' time will be devoted to the construction project, it is important that a high degree of maintainability be incorporated into the trailer system design requirements. Some component-level and system-level reliability improvements of the trailer system have already occurred at the manufacturing plants in recent trailer shell designs, including fewer moving parts, less bulk resulting in fewer pounds of weight, fewer feet of cables/wires, and fewer screws and bolts to work with during maintenance activities. [3]

2.6.2.2 Human Factors Requirements

In designing the interior of the mobile mini-headquarters, human engineering and analysis must be applied whereby decisions are made concerning the design of the trailer, with particular emphasis on the safety, effectiveness, role and integration of people in the trailer system. The goal of this human factors engineering, or ergonomics, is to improve or optimize the design of existing or traditional mobile mini-headquarters. Basically, the human factors engineer plays two roles, one representing the potential user(s) in regard to ease of operating the trailer system, safety and comfort. In the other role, the human factors engineer needs to evaluate man as a system component and his/her contribution to the total system. For a system that already exists (traditional system), such as the trailer mini-headquarters, knowledge gained from past developments reduces trial and error, thus, shortening the design-development cycle.

This section addresses some of the personnel and environmental factors that, according to Blanchard and Fabrycky, can influence job performance; some of these factors are shown in Figure 6. [2] The figure shows the process of defining the overall human factors requirements for the system, and illustrates the relationship of the various elements in this process. These elements include the anthropometric, human sensory, physiological and psychological factors that can influence job performance. The environmental considerations of the trailer system, such as noise, weather, sand and dust, temperature extremes, and humidity, are also discussed throughout this section, where appropriate. The effects of glare (also an environmental consideration) is addressed in Section 3.7.1.1 (Lighting System).

2.6.2.2.1 Anthropometric Factors

According to Sanders and McCormick, anthropometry is concerned with the measurement of the dimensions and certain other physical characteristics of the

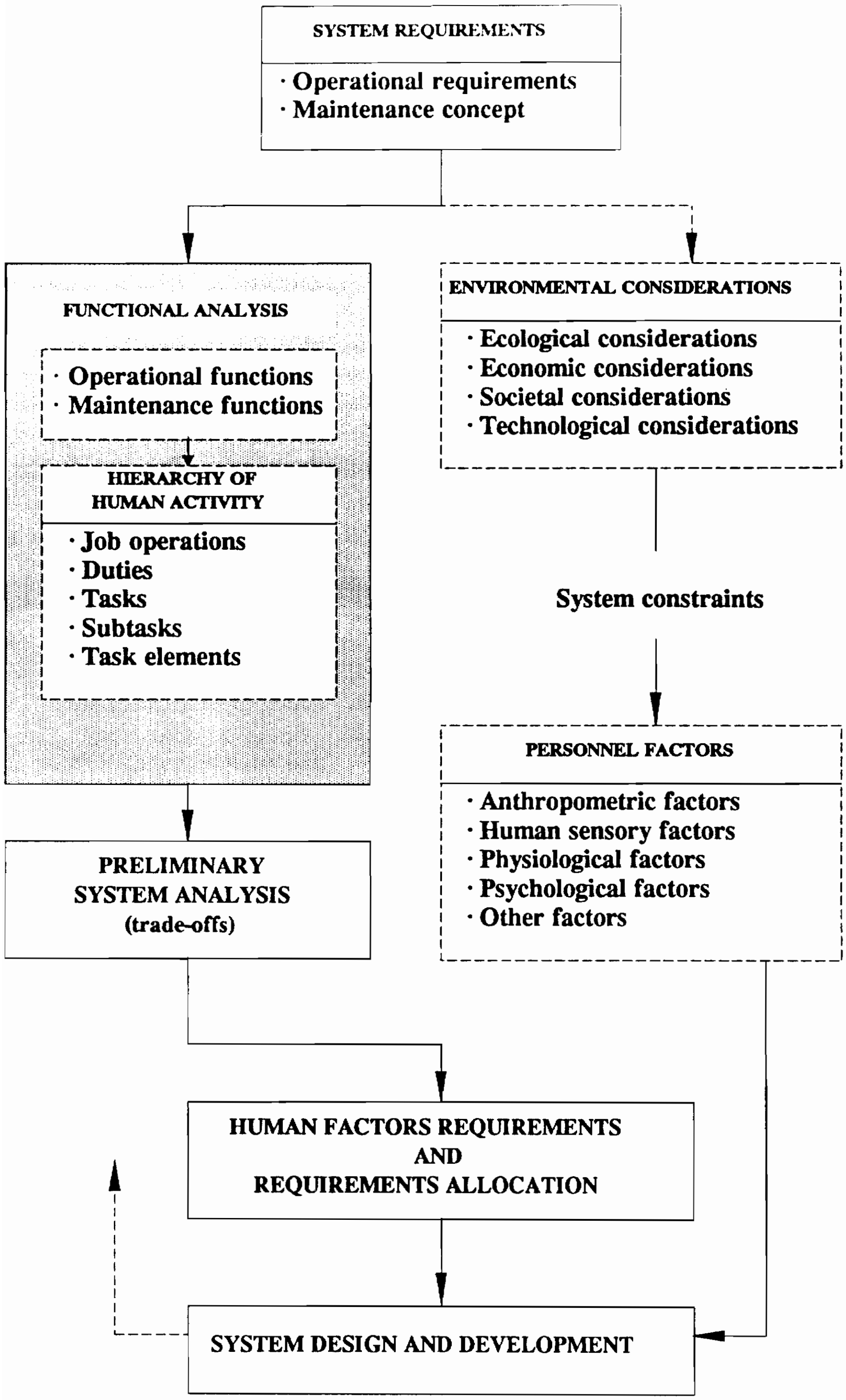


Figure 6: Human Factors Requirements [2]

body. [4] These measurements are relevant to the design of various equipment and/or workstations that individuals use. Table 3 outlines the five design principles that Sanders and McCormick feel should be followed when applying anthropometric data to any preliminary design project. [4] The five design principles and accompanying anthropometric data are discussed in detail in Appendix B. This project design will accommodate the 5th to the 95th percentiles of the relevant population.

2.6.2.2.2 Human Sensory Factors

According to Blanchard and Fabrycky, the two senses of sight and sound are the most critical when dealing with the human-machine interface in system design. [2] Although this project need not discuss the detailed process of seeing and hearing, nor the anatomical features of the eyes and ears, Appendix C discusses the two senses as they pertain to system design.

2.6.2.2.3 Physiological Factors

Physiological factors, environmental stresses (impact, vibration, oscillation, noise, temperature extremes, humidity, etc.) and design implications must all be considered in design because they naturally interact. Workstation design must maintain physiological systems within acceptable limits. The designer should be responsive to subtle physiological stresses arising from simple design incongruities. For example, improper distribution of body/limb weight, restricted cardiovascular flow, awkward reaching or sitting positions, frequent requirement to use maximum reach or force, no accommodation for anthropometric differences, poor body posture, poor internal

Table 3: Design Principles When Applying Anthropometric Data [4]

1. Determine the body dimensions important in the design, that is, sitting height, standing height, reach, etc.
2. Define the population to use the mobile workstation. This establishes the dimensional range that needs to be considered.
3. Determine what principle should be applied: design for extreme individuals, for an adjustable range, or for the average. When relevant, select the percentage of the population to be accommodated, that is, 90 percent, 95 percent, 99 percent, etc.
4. Locate anthropometric tables appropriate for the population, and extract relevant values.
5. If special clothing is to be worn (hard hat, jacket, etc.), add appropriate allowances.

temperature control mechanisms, poor ventilation system, etc., are all design incongruities that should be kept in mind by the design company when designing the mini-headquarters trailer.

At any construction site environment, the critical external stress factors the designer must understand and compensate for include noise (covered in the previous section), temperature extremes, humidity, the effects of sand and dust from outside activities, awkward reaching or sitting positions, and the anthropometric differences in the users of the trailer. One environmental requirement of the trailer is that it must be able to operate throughout the entire Washington Metropolitan Area all year round. This area experiences all types of weather conditions, with temperatures ranging from sub-zero to approximately 100 degrees, accompanied by high humidity during the summer months. Given these environmental conditions, the trailer must independently be able to sustain working temperatures between 65 to 70 degrees Fahrenheit all year round. Fluctuations of +/- 20 degrees are acceptable for time periods less than 8 to 10 hours; however, the air and heating systems must be capable of cooling/heating the trailer to proper temperatures within 20 to 30 minutes. Temperature extremes and humidity are controlled inside the trailer by the heating/air conditioning system (detailed in Section 3.7.1.2). In addition, the effects of sand and dust are eliminated inside the trailer by reconfiguring the two fans inside the heating/air conditioning unit to form a closed system to recycle air inside the trailer. The problems of awkward reaching or sitting positions and anthropometric differences are resolved by the ergonomically-designed chairs (discussed in Section 3.2) and by designing with the 5th and 95th percentiles in mind.

2.6.2.2.4 Psychological Factors

Psychological factors are just as important to accommodate during the design phase. Certainly, a primary psychological objective of workstation design should be to promote user acceptance. For any type of workplace, an operator will be motivated if his/her workstation is well organized, convenient, simple, reliable, safe and attractive. If not, the operator will be frustrated and, therefore, less productive. For example, if an operator has difficulty reaching equipment because of poor arrangement, or has difficulty seeing certain displays or information, his or her motivation and concentration will be reduced. In performing tasks in the workstation, the operator's sensory, cognitive and psychomotor attributes are influenced by the design of the workplace.

According to Blanchard and Fabrycky, "Psychological factors may be highly influenced by physiological factors." [2] Therefore, if the user's needs and realistic expectations are taken care of by a worthy trailer design, the motivation, attitude and initiative of the users should increase as a result. One component that significantly influences psychological factors but is not totally within the designer's influence is the leadership characteristics of supervisory personnel using the trailer. Beyond the designer ensuring that the lead engineer's office and work area are designed with human factors engineering as a top priority, it is up to the XYZ Construction Company to hire supportive and effective leaders to maintain morale, good communications, motivation and, therefore, job performance, at the construction sites.

Another factor that can impact the psychological (and physiological) well-being of the users is the constraining space of the trailer environment. Where space is constrained, a satisfactory solution to all arrangement relationships is possible only in simple arrangements where the number of personnel and equipment involved remain low. Hence, the requirement for the trailer to accommodate only up to 16 individuals at a time. Usually, in a constrained and limited environment, there is no solution which will not violate one or more human engineering minimum recommendations. The main goal here is to attempt to minimize the seriousness of the encroachments. The limited confines of the trailer significantly reduce the amount of space available for aisles or traffic spaces, equipment and tools, working space, utilities, etc. The space constraint may require incorporating some "off-the-shelf" assemblies into the design. Integration of some off-the-shelf components into the trailer system will also provide some standardization and ease of operator use.

Now that the trailer system's operating requirements and performance specifications/human factors requirements have been established and identified, the preliminary design can be developed. This is the next major phase in the systems engineering life-cycle approach.

3.0 PRELIMINARY SYSTEM DESIGN

This section goes through a preliminary system design phase, also known as advanced development. Basically, the preliminary design represents an operational translation of the system requirements. As the system design takes shape, the designer must keep in mind that unforeseen changes and modifications may become necessary for design optimization. In the preceding sections, the design process evolved through a conceptual design phase, where performance parameters, operational requirements and crucial dimensions were established. This section details the required hardware and software equipment, the recommended layout of the trailer's interior and exterior designs, and the preliminary design of the utility systems (power, air, heat, water and sewage disposal). Several sections in this Preliminary Design Phase also touch on the Detailed Design Analysis Phase, as outlined in Figure 4.

3.1 Hardware/Software Equipment

HARDWARE: The XYZ Construction Company has provided a list, shown in Table 4, of hardware equipment required to be purchased for the mini-headquarters. The XYZ Construction Company performed numerous studies and surveys to determine the final list of equipment listed in Table 4. Although the specific items required have been identified (brand names are not considered critical to this report), their exact locations and placement in the mini-headquarters were not detailed in order to allow more flexibility in the design.

Table 4: List of Required Hardware Equipment

1. Computers (monitor, keyboard, processor)
2. Printer
3. Modems
4. Facsimile Machine
5. Cellular Phones
6. Copier
7. Multiple Power Supply System (Outlets)

A cellular phone system has been selected for the trailer for those sites with no telephone connectivity. There is no doubt that telecommunications personnel prefer hardwired telephone lines over mobile cellular phone systems. This is because hardwired phone lines provide clearer sounds with less noise and fewer interruptions, and have no distance limitations.

For this mini-headquarters trailer, both communications modes are available. Hardwired phone jacks will be installed in each of the three modular areas to meet phone, modem and facsimile hardware requirements for the occasions when telephone lines are installed and available at the site location. However, when telephone lines are not available at the site, cellular phones and a paging system are used, which are hooked up to the diesel power generator. In this case, modems and paging units will be used with an operating range of less than 150 miles, well within the distance from any Maryland/Northern Virginia/Washington, D.C. construction site to the Rockville Headquarters. The cellular phone link system will be selected to enable it to handle the data rates associated with the computer modems. The modems allow the desk top computers to link into the Rockville Headquarters' mainframe computer for inter-office communications. The paging system bounces a signal off microwave emissions, while the cellular phone and modem systems use radio transmissions.

<u>SOFTWARE:</u> The software library for the mini-headquarters trailer has already been specified by the XYZ Construction Company. The software was selected with compatibility, standardization and economy in mind. The specific software programs were coordinated with those that the XYZ Construction Company already owns and those the company intends to purchase in the future. This ensures not only software compatibility between the mainframe at the Rockville Headquarters and the

computer in the trailer, but also reduces the amount of training required by the operators to learn new software. In addition, selecting compatible and standard software packages also avoids costly duplication and wasted dollars for a sophisticated but useless software program. Although specific software packages are not identified by name in this paper, the general software programs required in the mini-headquarters include: operating system and utility programs, an executive support program, a telecommunications program, a word processing program, a decision analysis program, a database management program, a spreadsheet program, and a general purpose program with specialized software for the construction business. [5] The XYZ Construction Company understands that this latter "general purpose" software program consists of a computer-aided design (CAD) package, which is a set of computer routines that can be used individually or collectively to assist in various aspects of the construction business. [6] CAD software enables the design and production of higher-quality products at lower cost and with fewer errors, and enables faster turnaround of higher-quality bid proposals by the XYZ Construction Company. Time and effort required to develop designs are reduced because the CAD software can be used to draw figures, calculate dimensions, review fine details of a drawing through a windowing facility, check interferences, and revise existing designs. Furthermore, the engineering staff has immediate recall of data/drawings stored in the CAD memory for any number of given construction buildings so that they can quickly and easily update or amend any part of a drawing. The drawing data can then be written back to memory in its updated form. [7] Basically, CAD is a means of accumulating, manipulating and displaying related graphical data electronically, and then duplicating or modifying that data. An added benefit is CAD's ability to display any design quickly and precisely, which can improve communication with other departments in the organization. As an example, inputs into the CAD program for the construction of a small office building would include the physical boundaries of the building; the dimensions of the site location; the number of floors in the building; a defined workspace for each functional area inside the building; layout dimensions for each functional area; anthropometric data on the anticipated users; shapes of the objects to be located inside the building; and scale factors. Using these detailed inputs, the CAD software can perform such functions as workplace geometric descriptions; spatial planning; performance simulation; building scaling; building tailoring; building simulation and evaluation; reach analysis; and design analysis based on changes in specifications or requirements. Some CAD packages even perform multidimensional scaling for workspace or site layouts. At this point it is noteworthy to point out that CAD software is used to design the layout of the trailer's interior, as discussed in Appendix A. Entire books have been written on CAD software packages. However, this paper simply wants to point out that the engineering staff and designer are aware of the benefits of using computer automated design aids, which can be tailored to meet the needs of different construction projects performed by the XYZ Construction Company, thereby saving valuable time and money. The allocated budget has accounted for the software programs that need to be purchased. Since the XYZ Construction Company has had CAD software in its inventory for over five years, the engineering staff has already been trained in the use of the CAD software, having acquired the required skills either through formal training courses in the past or from on-the-job training over time.

3.2 Seat Design for the Workbench Area

The sit-stand operator station designed for the trailer workbench area requires a high chair so that the operator can maintain his/her seated eye height approximately the same as his/her standing height. This high chair does not have to be an uncomfortable chair or high stool. The chair can be an ergonomically-designed seat with adjustable features, enabling the operator to sit or stand comfortably, whichever the task requires. When the operator is seated, leg and knee clearances, as well as a footrest on the chair, become important elements to consider in the design.

The chair used for the workbench area will be used for a variety of tasks, including reading, drawing, drafting and using the computer, which is located to the operator's left (if operator is facing horizontal work surface). Sanders and McCormick suggest the following tentative guidelines for choosing/designing chairs: [4]

(1) "Lower seats probably would be most suitable when people are relatively inactive and can maintain a seated posture with the back leaning against, or supported by, the seat back."

(2) "Higher seats probably would be most suitable for persons engaged in reasonably active manual work, those who have to lean over a table or desk (as when writing), and those who can alternate standing and sitting."

The seat back should provide support for the lumbar area (lower section of the spine). A curved (convex) posture, shown in Figure 7, is preferable for persons who can use a back support while performing their work. However, when the operator is not leaning back in the chair for back support, the physical arrangement can help to

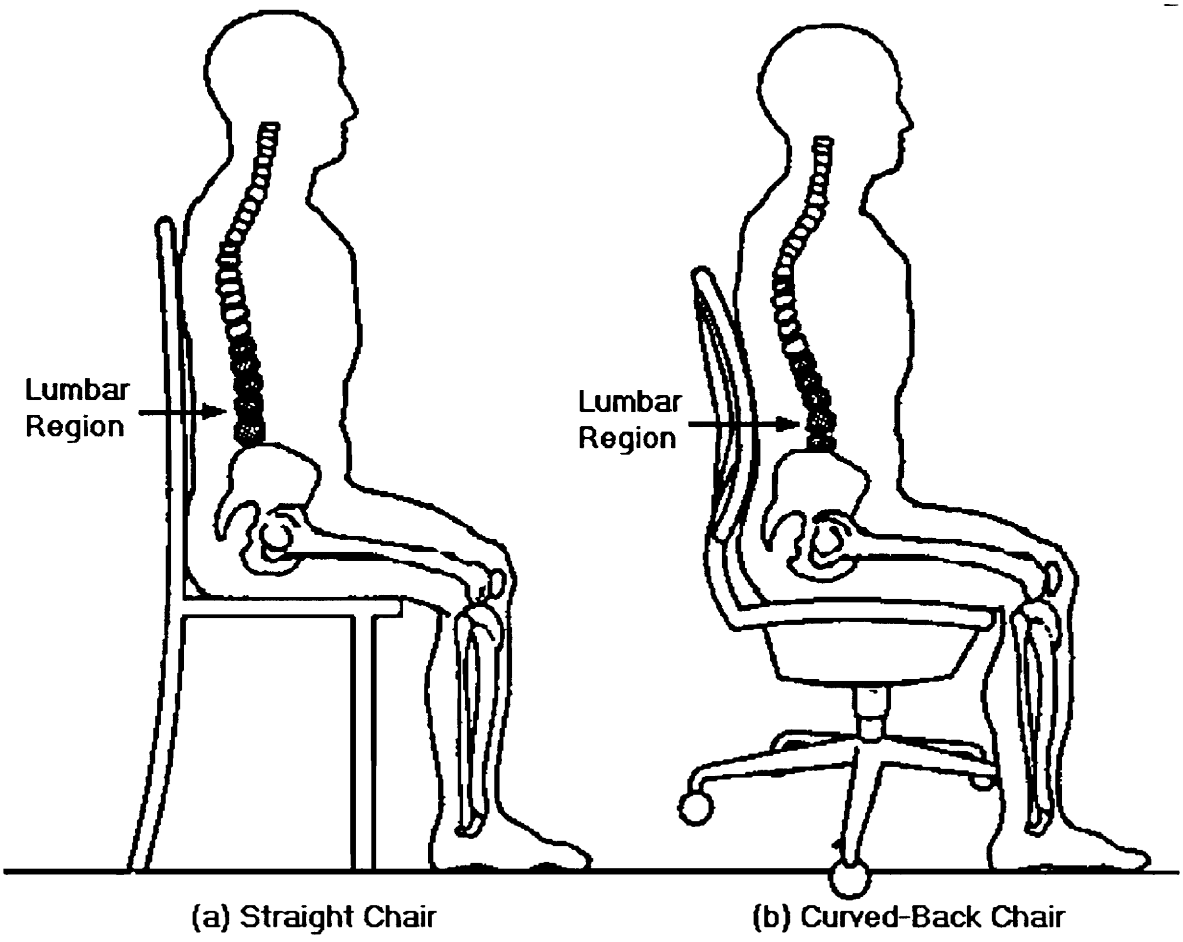


Figure 7: Seat Back Support to Lumbar Region [4]

minimize lumbar flexion (that is, the angle or amount of flexion of the spine in the lumbar area). Sanders and McCormick cite A. C. Mandal, author of the human factors book, The Correct Height of School Furniture (1982), who points out that lumbar flexion can be minimized by proper adjustment of the seat height, slope of the seat, and work surface height. [4]

The cost of designing a chair specifically for the trailer is obviously too high to seriously contemplate. There are many ergonomically designed chairs available off-the-shelf at furniture or office supply stores that can accommodate both seated and standing operators, as well as provide back support and a forward leaning posture. Therefore, the chairs required in the three areas (meeting room, working area, and office space) will be purchased by the XYZ Construction Company based on level of comfort and cost. The desk chairs (in the working area and office space) will be adjustable in seat height and slope, contain arms and an adjustable footrest, and contain rollers for ease of movement. A flexible seat with an adjustable footrest on the chair reduces lumbar flexion and at the same time minimizes under-thigh pressure. The meeting room chairs, however, will have higher backs and neck support than the desk chairs, but will also be adjustable in seat height and slope, as well as contain arms and rollers. For those readers interested in more ergonomic details on seat design for the workplace, Appendix D contains additional information.

3.3 Workbench Area Design and Layout

The "workbench area" of the trailer includes the three-dimensional work envelope, the actual horizontal work surface and surrounding area in the middle trailer compartment, as well as the tools and equipment (computer, keyboard, mouse, modem, etc.) used in the workplace. The horizontal work console will be designed to have a flexible flat surface that can be raised at the back to a number of angles in order to accommodate both a reading operator (30 to 45 degree elevation of horizontal work surface) and a drafting/writing operator (0 to 10 degree elevation). Figure 8 shows the top view of the actual horizontal work surface. The dimensions (30" x 60") are larger than a typical work desk (22" x 40"), due mostly to the large blueprints and plans most construction engineers have to work with and handle. These larger dimensions meet the XYZ Construction Company's specifications for the horizontal work surface.

Rules for the arrangement of equipment in a workbench area are generally common sense. Typically, workplace layout problems are related to display surface reflections and glare (discussed in Section 3.7, Lighting System). After numerous interviews and tours of various trailer facilities, the design company designed the workbench area (including the desk, tools, hardware equipment and surrounding area) with flexibility and task performance in mind. Figure 9 shows the location of the workbench and equipment area in the trailer, which is situated in the middle section of the mini-headquarters. Figure 9 (top view) mentions additional shelf space above the horizontal work area for tools and manuals. There is 2.5-feet of clearance between the top of the horizontal work surface and the bottom of these shelves to allow the horizontal surface to be raised to various angles required for different tasks without hitting the shelves.

Figures 10 and 11 are conceptualized layout sketches of the workbench area, top and side views, respectively. Figure 10 (top view) shows the horizontal work surface with a T-Square, engineer's ruler, template, compass and an eraser brush on top. It also shows a ledge with a tray in front of the operator for pens, pencils, and other

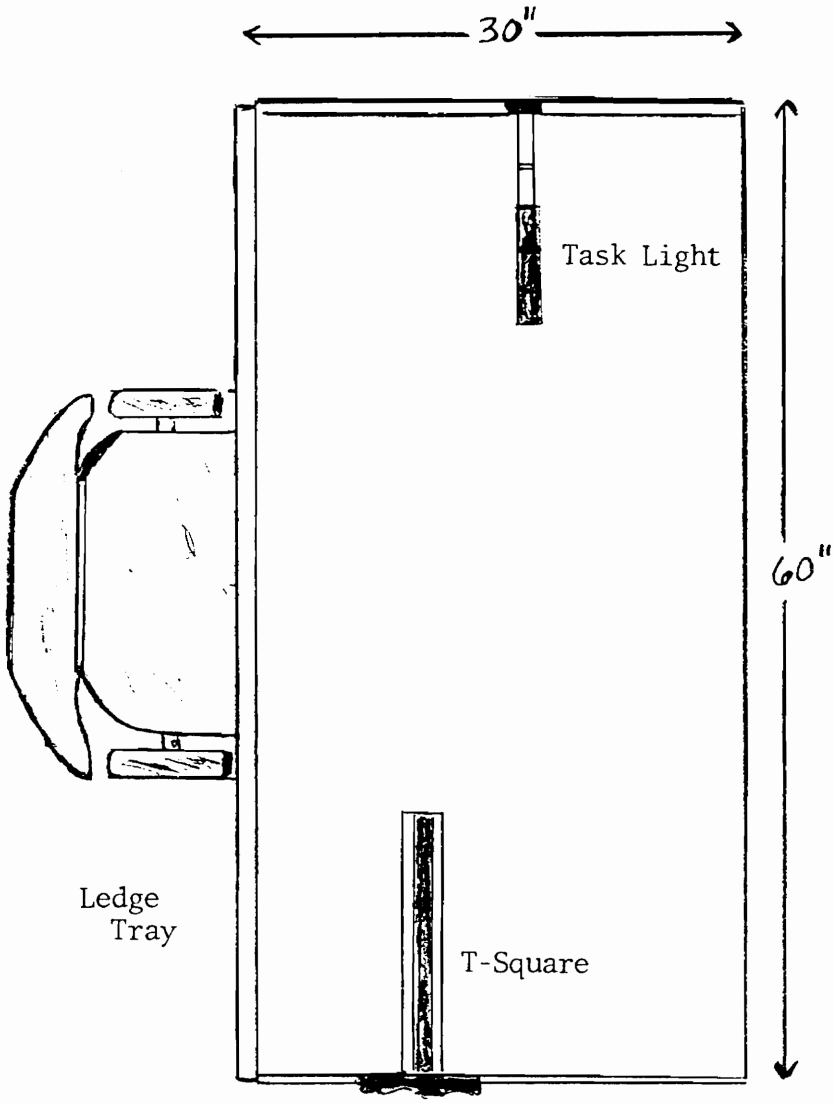
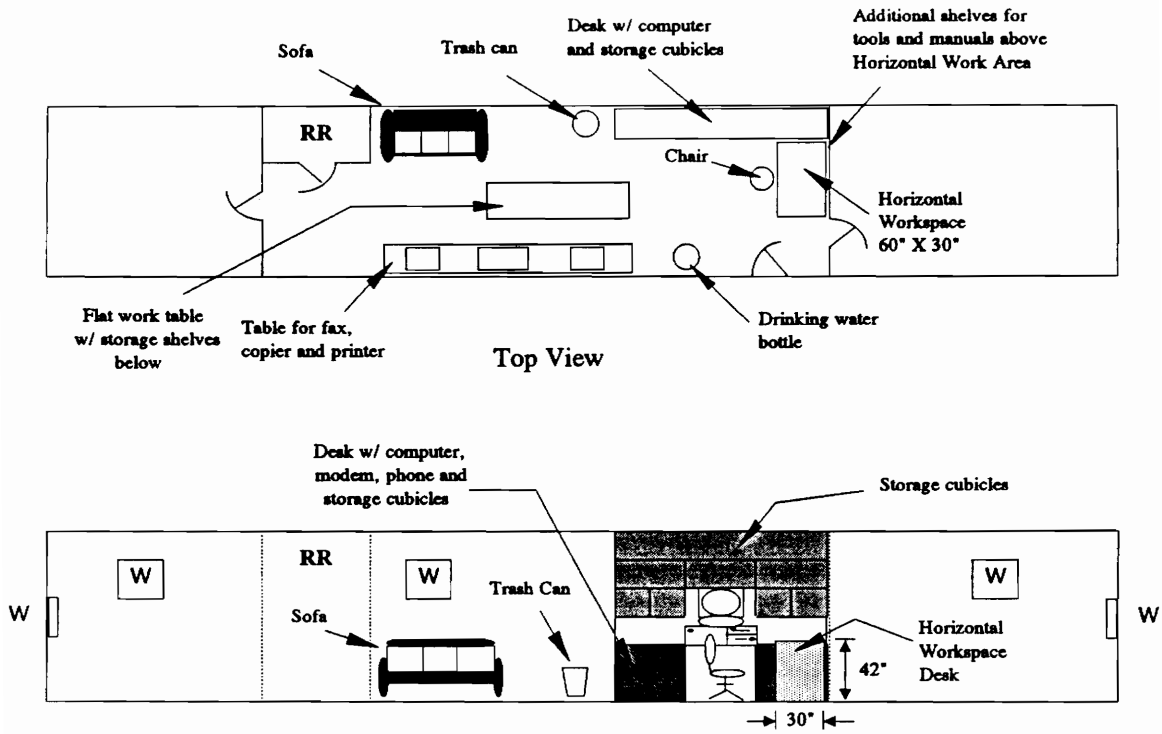


Figure 8: Horizontal Work Surface (Top View)



Side View w/ Restroom

W = window

RR = Restroom

Figure 9: Location of Workbench/Equipment Area

(Top and Side Views)

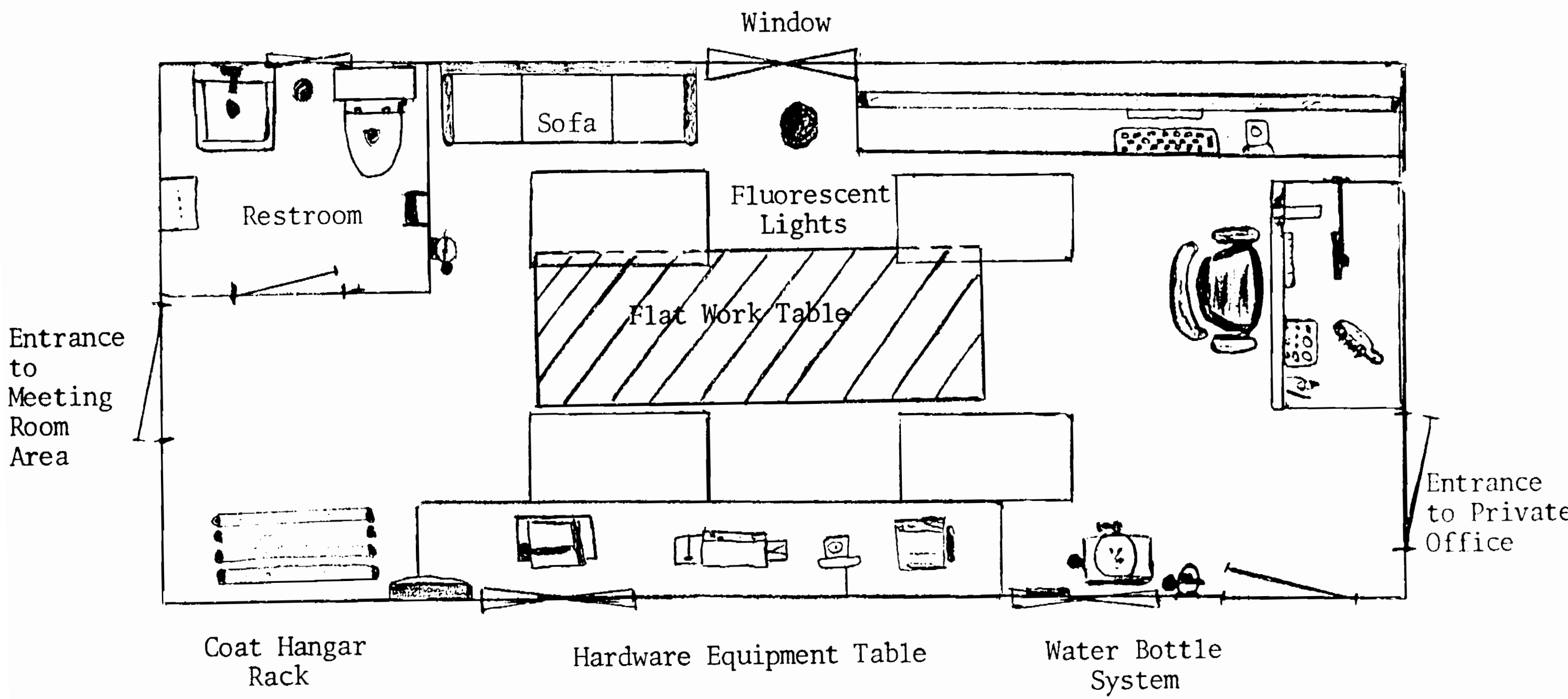


Figure 10: Conceptualized Layout Sketch of Workbench Area (Top View)

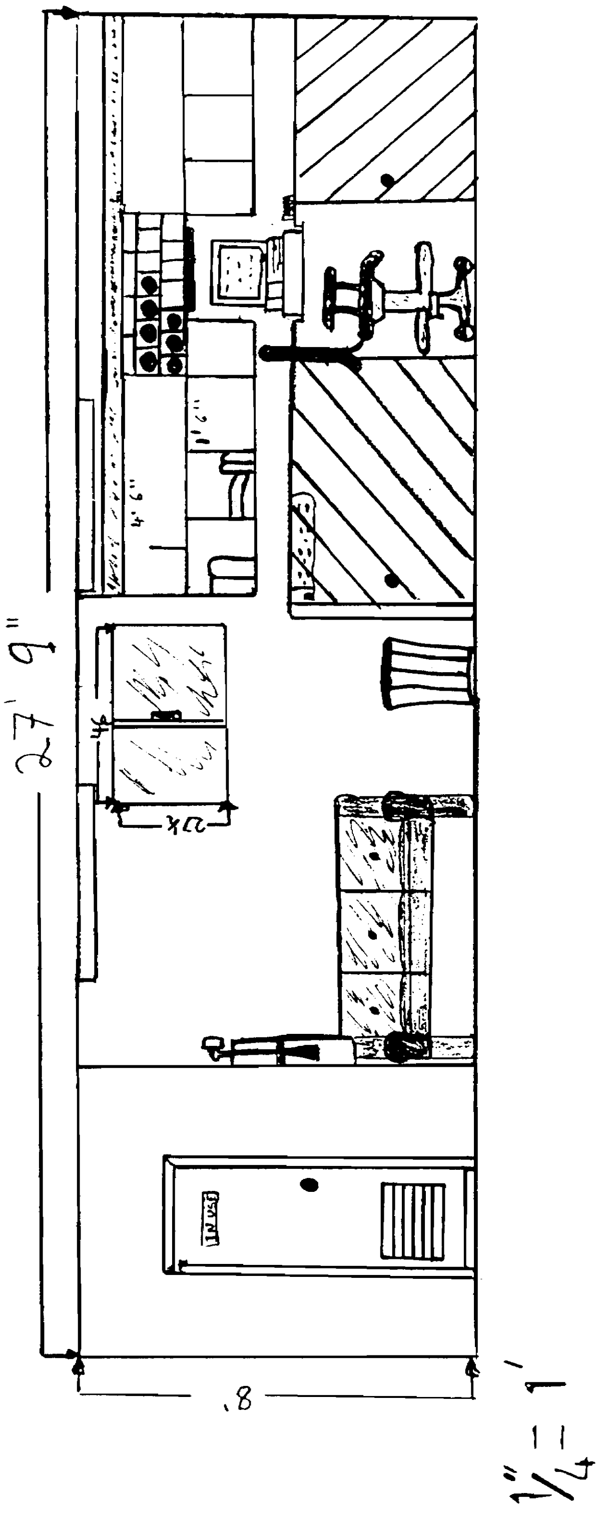


Figure 11: Conceptualized Layout Sketch of Workbench Area (Side View)

assorted small tools and utensils for easy access. A task light is clamped to the left edge of the horizontal work surface; it can be easily detached and moved up or down to use with the horizontal work surface or the computer. Figure 10 also shows a flat work table in the middle of the modular section of the trailer. This is a high table, approximately 45-inches in height, where engineers can stand around to discuss large plans or scale models displayed on the table. The high table contains storage shelves underneath it, making use of all available room in the space-constrained environment. A sofa in this work area is also shown in the figure for quiet discussions, rest periods and lunch breaks. A top view of the hardware equipment table and drinking water bottle system is also shown in Figure 10. In addition, the restroom layout is displayed, containing the sink, toilet, paper towel holder, toilet paper dispenser, light above the sink and trash can. A window is located high on the wall behind the sink and toilet. A 30-gallon water heater is located underneath the sink in a cabinet.

The conceptualized layout side view sketch in Figure 11 shows the desk with the computer and the storage cubicles in the workbench area. The desk with the computer is located to the left of the operator and horizontal work surface. It has the same height as the horizontal work surface, 42-inches, and is 12-feet, 8-inches long by 2.5-feet deep. The computer, keyboard and mouse pad (on the right side of the keyboard) are attached to the top of the desk. The mouse pad can be easily detached and placed on the left side of the keyboard for left-handed individuals. The desk contains storage cubicles below, which surround a space for legroom for the computer operator. There are roll-up doors that cover and lock the desk's storage cubicles for security and mobility. A power tree with a reset button is located behind the desk and bolted to the wall to handle the various power needs. Above the computer desk are various-sized compartmented shelves for storage. The top shelf has two large compartments on either side of numerous spaces for rolled up plans and other small items. These shelves also contain roll-up doors that cover and lock for security and mobility purposes. To the left of the computer desk is a trash can which is attached by removable brackets to the floor for ease in emptying and cleaning.

Figure 12 is a conceptualized layout side view sketch of the hardware equipment table. The figure shows the water bottle system, which contains a switch to heat the water instantly as it comes out, providing both hot and cold drinking water. Two extra water bottles are stored under the hardware equipment table on the left side for easy access. A light switch and dimmer is located to the left of the water bottle system, next to the exit door and above a hand-held fire extinguisher on the wall. A thermostat is situated on the wall to the right of the water bottle system and above an electrical outlet. The figure also shows the hardware equipment table itself, which contains (from left to right) a facsimile machine, telephone, copier and printer. A phone jack outlet with two jacks is located to the right of the facsimile machine for both a phone and the facsimile machine. A power tree with a reset button is bolted to the wall above the center of the table as a power source. Two electrical outlets are pictured in Figure 12, one on each side of the hardware equipment table. The figure also shows different-sized filing cabinets under the hardware table, another space-saving idea. Finally, Figure 12 shows a wall clock, a coat rack with eight coat hangars (two rows of four) and three shelves for placing hard hats and tool belts.

3.4 Meeting Area Design and Layout

The XYZ Construction Company requires the trailer to have a meeting room area, where up to eight engineers can meet in a conference room environment.

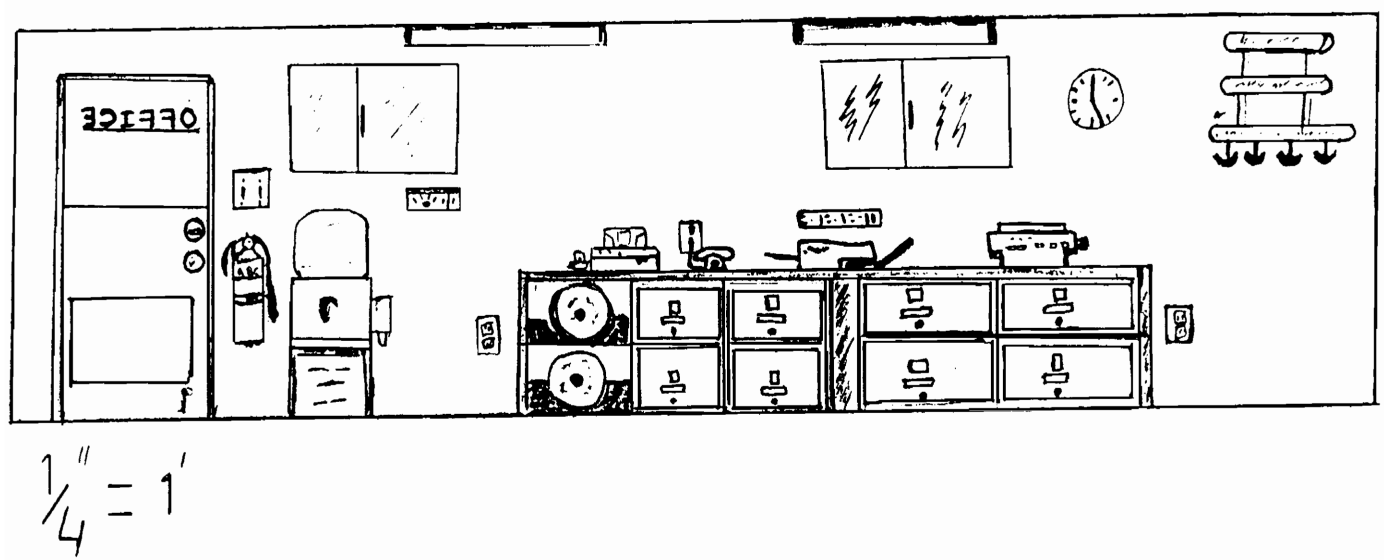
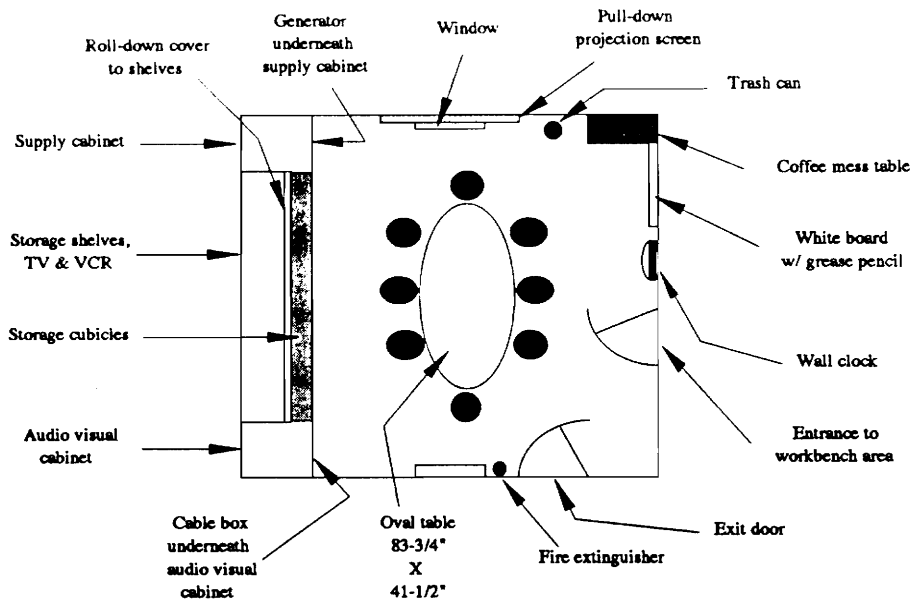


Figure 12: Conceptualized Layout Sketch of Hardware Equipment Table Area (Side View)

Figure 13 shows a top view and the location of the conference room in the trailer, which is situated in the far left modular section of the mini-headquarters, at the rear of the trailer. Figure 14 contains a conceptualized layout side view sketch of the meeting room area's back wall.

The conference room contains a long oval table measuring approximately 84-inches long by 41.5-inches wide, and eight ergonomically-designed chairs with back support similar to the chair featured in Figure D.2 (in Appendix D). The chair backs tilt both forward and back and the pan seats tilt up and down for increased comfort to the seated user in different positions. Other items in the conference room featured in Figures 13 and 14 include a pull-down projector screen, white board, coffee mess, trash can and wall clock. A large cabinet is installed on each end of the back wall. The left cabinet, situated over the electrical cable box, contains audio-visual equipment, including an overhead projector, tape recorders and teleconferencing equipment. The right cabinet, located over the slide-out diesel generator box, contains various supplies for the trailer. Both cabinets can be closed and locked for security and mobility. Different-sized storage cubicles dwarf the center of the back wall, and contain a color television set and a video cassette recorder (VCR for professional tapes), among other items. The storage cubicles contain a fold-down door that both covers and locks the entire shelf-space in the middle of the back wall. Finally, the lower back wall contains access panels to the main circuit breaker fuse box and telephone junction box in the middle, and the electric cable box and generator box on the sides.



Top View

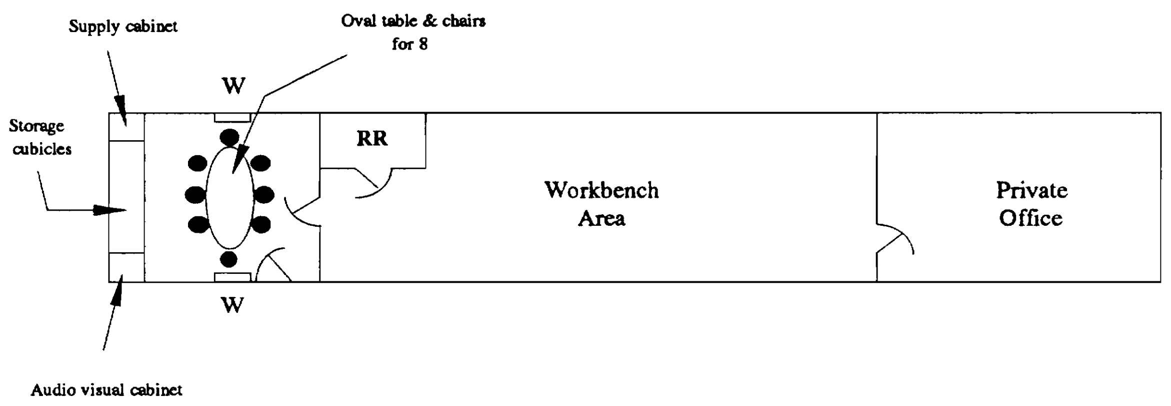
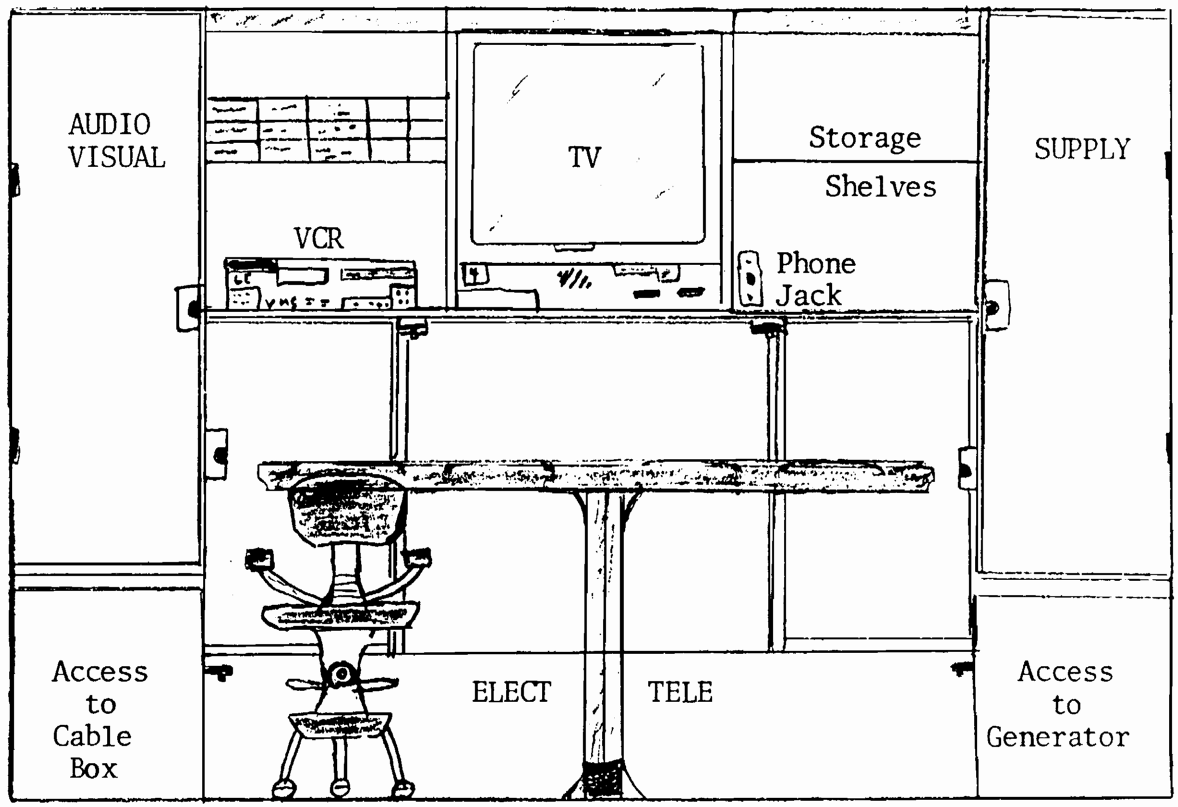


Figure 13: Location of Conference Room Area and Enlarged Room Layout

(Top View)



1/2" = 1'

Figure 14: Conceptualized Layout Sketch of Conference Room (Side View of Back Wall)

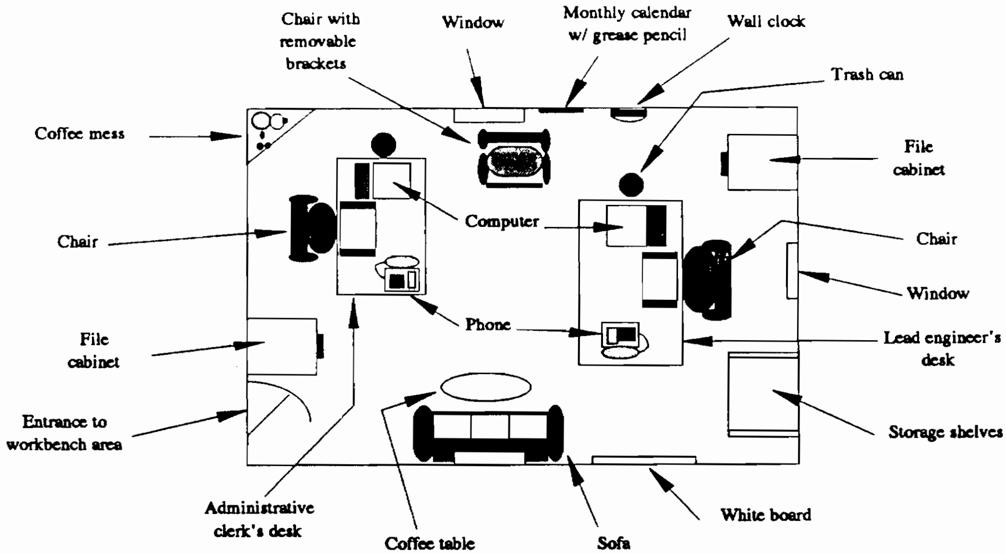
3.5 Private Office Area Design and Layout

Another requirement of the XYZ Construction Company regards the need for a private office for both the lead engineer and his/her administrative clerk. Figure 15 shows a top view sketch and the location of the private office area, which is situated in the far right modular section of the mini-headquarters, at the front end of the trailer. Figure 16 contains a conceptualized layout side view sketch of the private office area's back wall (view is facing the lead engineer's desk).

The private office area contains two desks facing each other situated on opposite sides of the modular area, with the lead engineer's desk being larger in size. Each desk contains a cellular phone (or a telephone connected to phone lines, if available), a desk top computer (including monitor, keyboard and mouse), and a modem, which ties the desk top computer to the mainframe computer at the Rockville Headquarters of the XYZ Construction Company. In addition, the office area contains a sofa and coffee table, two large file cabinets (one for each office occupant), storage shelves in back of the lead engineer, a white board, wall clock, monthly calendar schedule with grease pencils, coffee mess and a chair with removable, lift-off brackets. This chair, normally situated by the wall and held by floor brackets, can be easily detached from the brackets and moved to the front of a desk for a visitor. There is room for an additional chair with removable brackets along the same wall, if required.

3.6 Travel Mode Designs

This section details the trailer's configuration when the mini-headquarters is mobile, en route to a destination. The fact that the trailer must be mobile creates the



Top View

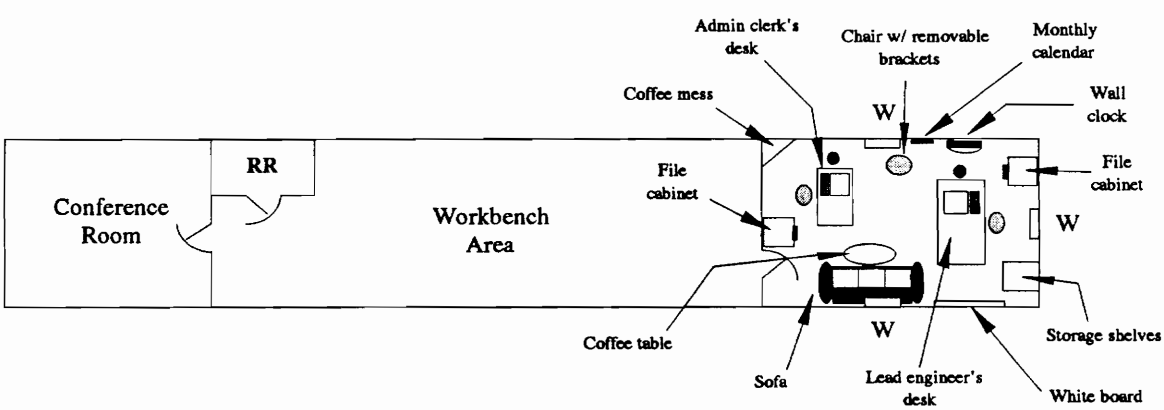
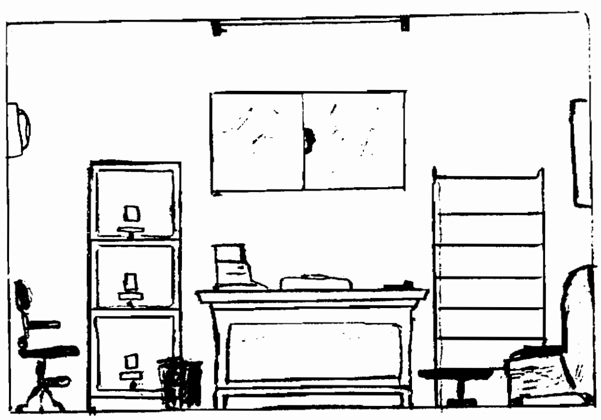


Figure 15: Location of Private Office Area and Enlarged Room Layout

(Top View)



1/4 = 1

Figure 16: Conceptualized Layout Sketch of Private Office

(Side View of Back Wall)

added burden of ensuring proper equipment storage and safety when the trailer is "on-the-road." All tools and equipment must be properly stowed away so as not to fall and cause damage or injury while the trailer is en route to or from a project site. The burden of ensuring safety and proper storage rests with the designer. Each modular section is addressed separately, as well as the exterior of the trailer.

WORKBENCH AREA:

When the trailer is mobile, the paper is taken out of the facsimile machine, copier and printer, the paper trays are removed and the machines are all turned off and closed up. The machines are all secured to the hardware equipment table, and the wall clock is fastened to the wall. The water bottle is removed from the water dispenser; the rest of the water system is secured to the floor. The two extra water bottles in storage under the hardware equipment table are secured, so they do not need to be removed. The file cabinets under the hardware table are locked and the hardware table itself is also fastened to the floor.

On the other side of the modular section, the computer desk, horizontal work surface and all surrounding shelves and cubicles are secured to the floor or wall. The roll-up doors for the storage shelves and cubicles around the computer and above the horizontal work surface are pulled down and locked for security and mobility. The computer, keyboard and mouse pad are attached to the desk, however, the mouse pad can be detached and used on either side of the keyboard for both left- and right-handed individuals. The mouse itself is detached and stored in a shelf, as are all the software packages and manuals. The workbench chair has strong magnetic tips on the front of the arms which stick to metal plates attached to the front of the horizontal work surface. These magnetic arm tips can be covered when the trailer is in use so the chair is not constantly pulled against the metal plates on the work surface desk. The horizontal work surface and the ledge tray are cleared with the exception of the swivel task light, which is clamped securely to the work surface. The trash can contains removable brackets on the bottom that can be easily removed for emptying and cleaning, yet also keep the trash can secured when the trailer is on the road. The sofa and large flat work table in the middle of the work area are both secured to the floor. The doors to the storage shelves underneath the large flat work table are closed and locked.

The facilities in the bathroom are all secured to the floor or wall in travel mode. Finally, the exit door and both entrance doors to the other modular sections are closed and locked.

MEETING ROOM AREA:

The large oval table is secured to the floor. The eight chairs around the table have magnetic tips on the front of the arms which stick to metal plates attached to the sides of the oval table. These magnetic arm tips can be covered when the chairs are in use. The two large cabinets are locked; the storage shelves and cubicles along the back wall are all covered and locked as well. The TV and VCR are secured in the shelves. The projection screen is rolled up and secured, while the coffee mess is cleared and stored. The coffee mess table is secured to the wall and floor. The white board and wall clock are both fastened to the wall. The trash can sits on removable brackets to enable easy emptying and cleaning, as well as stability when mobile.

PRIVATE OFFICE AREA:

Both desks are bolted to the floor and the desk chairs contain coverable magnetic arm tips which stick to metal plates attached to the desks. The desk top computers, keyboards, mouse pads and phones are all removed from the desks and stored in the storage shelves behind the lead engineer's desk. Therefore, the placement and viewing angle of these computers on the desks are flexible. The coffee mess is cleared of debris and the table itself is secured to the floor and wall. The extra chair and both trash cans, which contain removable brackets, are placed in the brackets and secured when mobile. The coffee table, sofa, file cabinets and storage shelves are all fastened to the floor or wall, as are the wall clock, monthly calendar and white board. The file cabinets are locked and the storage shelves are covered by a roll-down door and locked when mobile.

TRAILER EXTERIOR:

In preparation to move the trailer, both the water tank and sewage holding tank are emptied. The diesel generator box and electric cable box, shown in Figure 17, are stowed inside the trailer and secured. The figure also shows two of the four telescopic fold-down jacks, all of which are up and locked into place against the frame rails in travel mode. The frame rails are permanently attached to the underside of the trailer, with three cross braces for extra support for the water tank and sewage holding tank. The two liquid propane tanks in the front of the trailer are mounted on to the steel plate; the latter remains bolted to the tow bar in front of the trailer. The collapsible

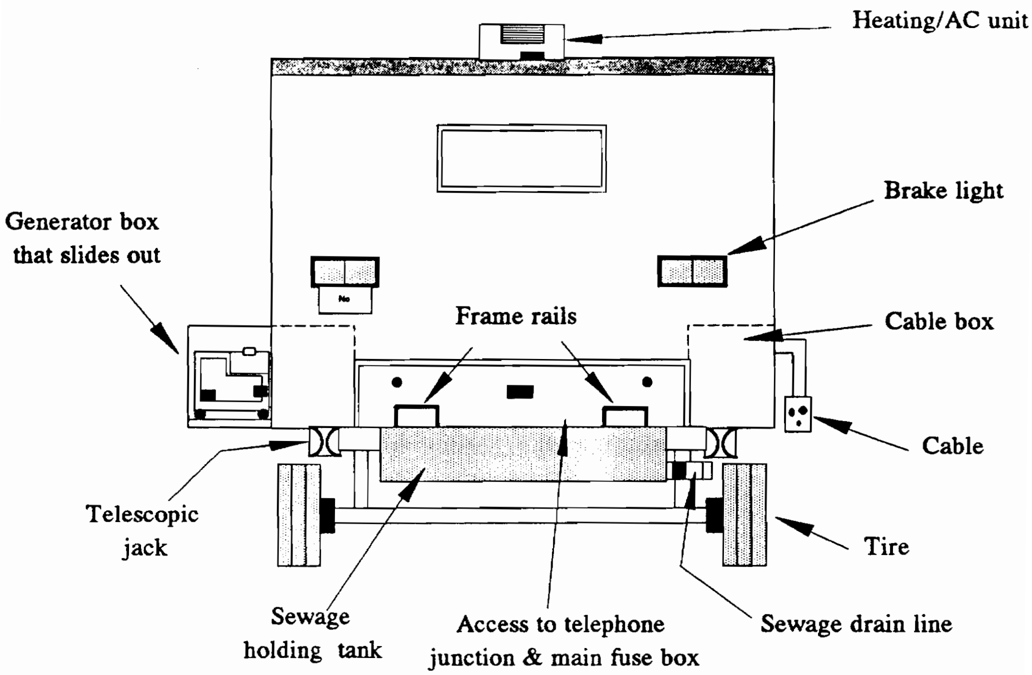


Figure 17: Modified Trailer Exterior (Back-End)

stairs are rolled up and secured, while both exit doors, as well as all windows, are closed and locked when mobile.

3.7 Utility System Designs

As part of the operating requirements, the XYZ Construction Company has required the trailer to be a self-contained mini-headquarters, to include its own power and water supplies, sewage disposal and phone connectivity. This section describes the design of the utility systems and how they interact. The design company designed the trailer's utility systems to accommodate external power and water accesses, when available at the site location. However, if access to outside power and water is not available at a site, the trailer is designed to be self-contained and can operate for up to 10 days before sewage disposal and additional water are required.

3.7.1 Power System

According to several industry representatives interviewed based on their expertise, a 5,000-watt diesel-powered generator, that is hardwired to both the main panel circuit breaker fuse box and the telephone junction box located in the back of the trailer, is sufficient power for a self-contained trailer. All of the phone wires run into this junction panel box. The diesel generator, built into the back end of the trailer off to one side, sits inside a box on metal rails that slide out, as shown in Figure 18. When the diesel generator is in use, the rails slide out to vent the diesel fumes away from the trailer's interior. Since the trailer is not used 24 hours a day (the engineers and construction crews either go home after a single shift or work two shifts per day),

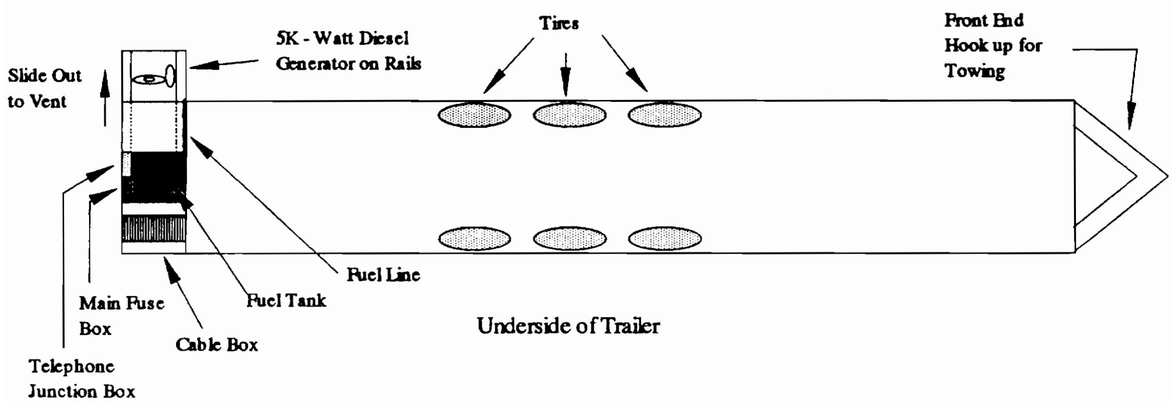


Figure 18: Trailer Power System

the generator can recharge (if it is using batteries) overnight and over most weekends. However, even without recharging, the generator is powerful enough to fulfill the trailer's power needs for five working days without recharging. The generator box is insulated with R-12 fiberglass sound dampening insulation, resulting in a quiet diesel generator only slightly louder than the hum of a kitchen refrigerator. The generator can also run off of diesel fuel from the fuel tank located above and behind the phone and fuse boxes.

The trailer also has a built-in electric panel box on the opposite side of the generator, underneath the trailer (see Figure 18). This panel box, also hooked up to the main fuse box, contains 250-feet of electric cable for 210-volt electricity. This cable will plug into an outside electric power source when one is available at a site location. Although this cable box and the generator box are built inside of the trailer, they are hidden from view internally in closed boxes on the floor of the conference room area. Access to these boxes is available from both outside and inside the trailer.

Thus, the trailer's power system accommodates both operating requirements: a self-contained power system and a hook-up to an outside power source. The remaining utility systems discussed under Section 3.7 all run off of this power system, with the exception of the smoke and fire alarms, which are battery powered.

3.7.1.1 Lighting System

Many studies have focused on the impact of ambient lighting design on the performance and comfort of individuals using the environment as well as the affective responses of those people to the environment. Authors Sanders and McCormick quote from P. Boyce's book, Human Factors in Lighting, (New York: Macmillan, 1981), "...lighting itself cannot produce work output. What lighting can do is to make details easier to see and colors easier to discriminate without producing discomfort or distraction. Workers can then use this increased ease of seeing to increase output, if they have the motivation and ability to do so." [4]

The level of illumination should be sufficient to perform the tasks required without wasting energy or creating unwanted effects such as glare or display surface reflection. Where the line is drawn has been the subject of examination by illuminating engineers, human factors engineers, lighting consultants, and designers. These specialists focus on improving the visual environment for human performance. In addition, economic and environmental pressures have resulted in changes to past lighting designs, resulting in fewer fixtures and less watts per square foot. There is certainly no argument that lighting is one of the most important aspects of a work environment, both in terms of productivity and energy cost.

The standard factory-delivered trailer shell incorporates the fluorescent light as the main light source for the mobile trailer. The fluorescent is the most common light source found in office environments because it is dependable, fairly efficient (compared to the incandescent), and broadcasts good, diffused light in which to read and work, as shown in Table 5. [4] The trailer ceiling contains two 48-inch long bulbs in each fluorescent light, spaced approximately every four feet throughout each modular section, as shown in Figure 19. This is standard spacing for a "single-wide" trailer.

DEPENDABLE: Unlike incandescents, the service life of fluorescents extends as they remain in operation. Fluorescents that function less than three hours per day burn out more quickly than those functioning twelve hours per day.

Table 5: Comparison of Two Light Sources [4]

	Incandescent	Fluorescent
Wattage	75 W	30 W
Rated Life	750 h	15,000 h
Amount of Light	1,180 lm	1,530 lm

W = Watts
h = hours
lm = lumens

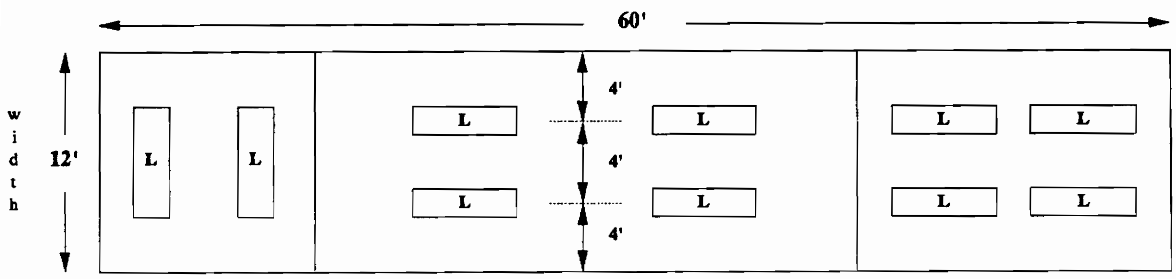


Figure 19: Ceiling View of Fluorescent Lighting

According to Elaine and Aaron Cohen, "some (fluorescents) will last an average of 24,000 hours, or nearly eight years, operating twelve hours a day, five days a week." [8]

EFFICIENT: The efficiency of a light source, called lamp efficacy, is measured in terms of the amount of light produced (lumens - lm) per unit of power consumed (watts - W). Table 5 shows that the fluorescent tube represents a 41 percent energy savings, lasts 20 times longer, and gives 30 percent more light than the incandescent.

DIFFUSED LIGHT: Fluorescents are diffused sources, that is, light is produced along the entire tube. This tends to create even illumination with a minimum of glare.

In an attempt to reduce glare and display surface reflection, as well as add to the comfort of the trailer users, dimmers will be attached to every light switch in the trailer for low-luminous fluorescent lighting, especially for those periods when the computer terminals are in use in the private office and work areas. In addition, mini-blinds will be placed in each window to further reduce glare or bright sunlight streaming into the trailer.

Task lighting, in addition to the main fluorescent light source, is required in the workspace area and private office, since more detailed work for prolonged periods of time will be involved. For the private office area, both desks (lead engineer and administrative clerk) will contain desk lamps using 100-watt soft white light bulbs for extra illumination. This type of bulb illuminates soft light sufficient for reading and other concentrated work activities, yet is not harsh on the eyes. Soft white bulbs do not produce the harsh brightness that emanates from ordinary white light bulbs, and, therefore, help to reduce glare and surface reflections, as well as eye fatigue. A standard 100-watt soft white light bulb has an average life of 765 hours and produces an average amount of light of 1710 lumens (sources: off-the-shelf General Electric and GTE 100-watt soft white bulb package advertisements). The base of the desk lamps will be clamped to the desks for when the trailer is mobile. The workspace area will also have a supplementary desk lamp with several levels of illumination available from a 100-watt soft white light bulb. The lamp, which is clamped to the left edge of the horizontal work surface and can slide up and down the edge, has a swivel head and flexible body so it can be used for both the horizontal work surface and the computer desk. This lamp will be useful when reviewing detailed plans, drafting changes to existing plans, or when the operator is using the computer.

3.7.1.2 Heating/Air Conditioning System

Heating and air conditioning for the trailer are provided by a single unit mounted on top of the trailer, as shown in Figure 20. Air comes in through a filter screen and is sucked into the unit by a suction fan. The air goes across a set of condensing coils, where it is circulated until a specified temperature is satisfied. In the cold winter months, the cold air goes across hot coils that are heated by two 60-gallon liquid propane (LP) gas tanks. These two tanks, located in the front of the trailer, will last for approximately six weeks in the winter without replenishment and could heat both the condensing coils and the water heater (located underneath the bathroom sink). In the hot summer months, the warm air goes across cold coils which are cooled by

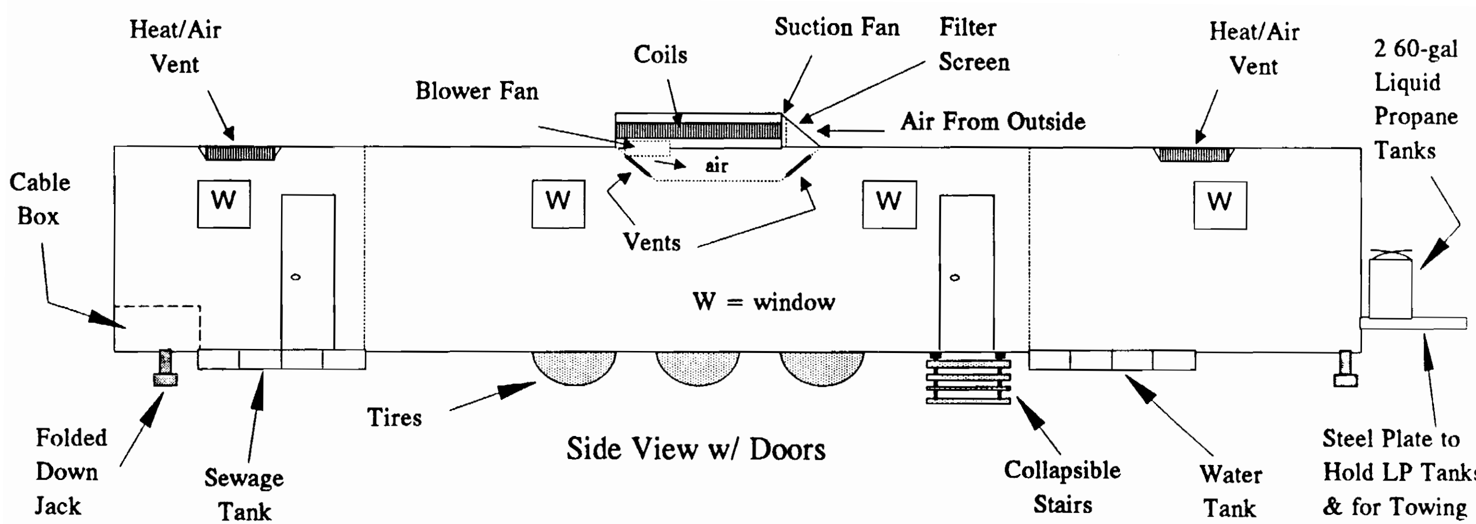


Figure 20: Heating/Air Conditioning Unit

electricity (diesel generator or outside electric power source hooked via the electric panel box of cable). The warm or cool air, after leaving the coils, is pushed down into the trailer by a blower fan and is distributed throughout the trailer by a set of vents in the ceiling of each modular section (see Figure 20). The operator can select "cool," "off," or "heat," as well as a temperature setting on a thermostat in each modular area.

This heating/air conditioning unit is very efficient and comfortable to the trailer operators for several reasons. First, the entire trailer can be efficiently heated or cooled by a single unit, thereby, saving money by eliminating the need for separate heating and air conditioning systems in each modular section. Second, the unit maintains a constant temperature throughout the trailer regardless of the weather conditions outside. The unit, with its two fans, can also be manipulated to form a closed system to recycle air, if required, for those occasions when sand and dust are in the air from outside construction activities.

3.7.1.3 Water and Sewage Disposal Systems

Although the water and sewage disposal systems are separate entities, they are both covered under one section for convenience, since both systems are located underneath the trailer.

WATER: The water system is comprised of both bottled water for drinking and tank water for the bathroom sink and toilet. The bottled or potable water system can be either rented or purchased. The rental fee for a bottled water system is about $16.00 per month, which comes to $1,920.00 over a ten-year period. The cost to buy an electric/refrigerated unit for potable water is approximately $700.00. This unit is plugged in and can provide both hot and cold water instantly. Treated drinking water is provided for a rented or purchased unit for approximately $5.00 per 5-gallon plastic bottle. A one-time initial deposit for the returnable plastic water bottles is also required. The XYZ Construction Company already owns several bottled water units, one of which will be installed in the new trailer. Therefore, the Construction Company has only to arrange for bottled water (three 5-gallon bottles) to be trucked in on a bi-monthly basis. One 5-gallon bottle should easily last a week. Two extra 5-gallon bottles are stored under the hardware equipment table (shown in Figure 12).

When outside water access is not available at the site location, a water tank must be used to meet the restroom sink and toilet needs. A 250-gallon water tank will meet these needs for up to 10 days before requiring a fill-up. A tanker truck must be brought in to fill up the water tank on a weekly basis. The water tank, located underneath the trailer, is mounted on frame rails running the length of the trailer's underside, as shown in Figure 21. The frame rails contain three cross braces for extra frame support, as well as a set of cross braces under the water tank for additional hold. A water pump is mounted next to the water tank to pump water to the sink and toilet through plastic (PVC) piping (see Figure 21). The water pump is hardwired to the main panel fuse box and runs off the diesel generator. Thought was given to burying the water tank in the ground. However, in order for the trailer to meet the operating requirements of a) being truly self-contained, and b) being able to "pick up and be towed" within four-to-eight hours of notice, a water tank mounted under the trailer on the frame rails offers the best alternative. The water tank can be emptied for mobility in less than 15 minutes. Since the tank is secured to the trailer by the frame rails and cross braces, it does not need to be jettisoned for mobility. In addition, a water line is available that hooks into the trailer to provide water from an outside source.

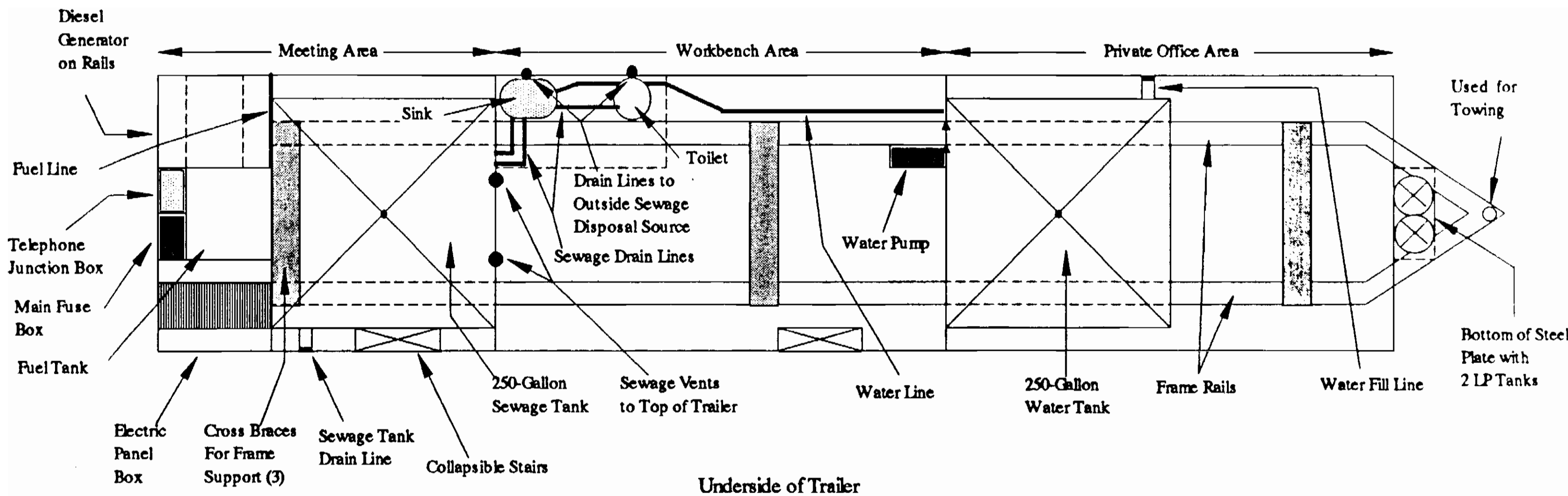


Figure 21: Water and Sewage Disposal Systems

A 30-gallon water heater is also available for the restroom sink's hot water faucet. It is powered and heated by the two liquid propane tanks in the front of the trailer. The water heater is stowed in a cabinet underneath the restroom sink.

SEWAGE DISPOSAL: Figure 21 also shows the location of the 250-gallon sewage holding tank and the sewage drain lines underneath the trailer running from the toilet and sink. There are several vents located in the connecting wall between the meeting room and the workspace area that allow the ventilated air from the sewage tank to disperse above the trailer top. Typically, a sewage holding tank is set and buried underground. However, due to time restrictions and a required mobile capability, the sewage tank is mounted underneath the trailer on the frame rails, with a set of cross braces under the tank for extra support. The sewage holding tank requires emptying every 7 to 10 days, and is usually emptied on a weekly basis by a large tanker. Also worth noting, sewage draining lines are available to hook up to the restroom sink and toilet when an outside sewage disposal source is available.

3.7.2 Fire Codes and Smoke Alarms

Fire and safety building codes require a minimum of two exit doors for a standard factory-delivered "single-wide" trailer, one door at each end, which are shown in Figure 2 (bottom figure). A hand-held fire extinguisher is required next to each exit door; however, a sprinkler system is not required in trailers. The bottom of the mounting bracket is located approximately 1.5-feet off the floor, allowing the fire extinguisher to be well within reach of the entire user population. A fire extinguisher is also located on a wall outside the restroom (shown in Figure 11). Although official fire codes do not require smoke detectors in trailers, the trailer is equipped with one smoke detector in each main modular area (three total) and another one in the restroom.

4.0 LIFE-CYCLE COST ANALYSIS

Fabrycky and Blanchard write, "...in addressing the economic aspects of a system, one must look at the total cost in the context of the overall life-cycle, particularly during the early stages of conceptual design and advanced system planning." [9] They emphasize that early consideration of costs is critical because the commitment of the total cost for any system is based on decisions made early on in the system life-cycle. Therefore, costs associated with system research, design, testing, construction, consumer use and support need to be emphasized and considered in the conceptual and preliminary design phases, as well as throughout the system life-cycle. This section details how the trailer's life-cycle costs are distributed across three main categories. Then, once all the costs are specified, the differences between two alternative purchases are evaluated to determine the best buy.

4.1 Total System Cost

This section details the trailer's life-cycle costs and how they are distributed among the three main cost categories of Research and Development Cost (C_r), Procurement and Construction Cost (C_p), and Operations and Maintenance Cost (C_o). The costs associated with phase out and disposal are included in the latter category. Figure 22 shows the Cost Breakdown Structure (CBS), which allocates costs according to these three categories. The figure is adapted from the CBS developed by Fabrycky and Blanchard. [9] The life-cycle costs associated with the CBS are shown in Table 6.

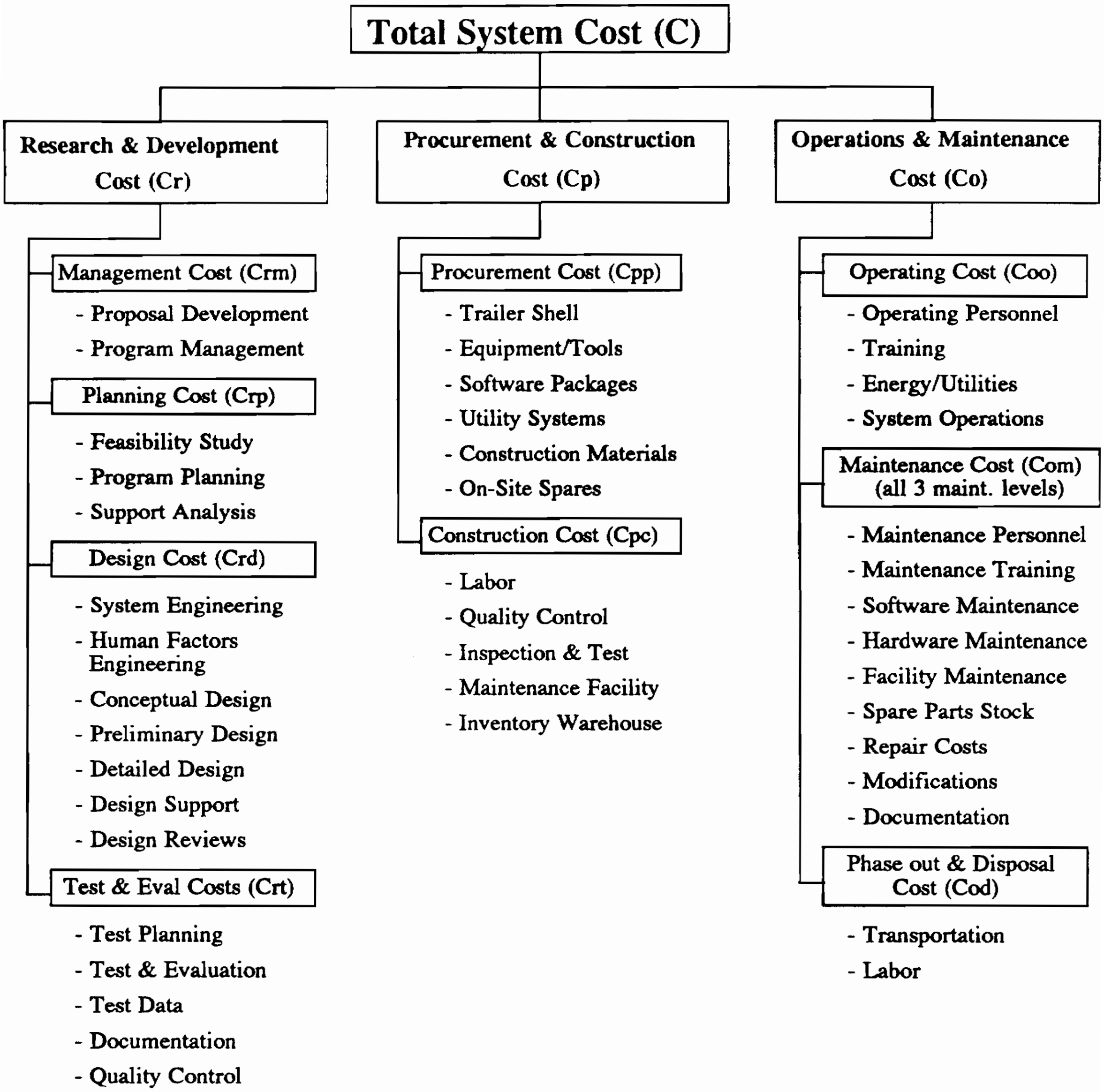


Figure 22: Cost Breakdown Structure [9]

Table 6: Budgetary Life-Cycle Cost Projections [2]
(11% interest rate)

RESEARCH & DEVELOPMENT COST (C_r)				
Cost	Category	Year 1	Years 2-10	Total
C_{rm}	Management	$15,000	$0	$15,000
C_{rp}	Planning	$1,000	$0	$1,000
C_{rd}	Design	$3,000	$0	$3,000
C_{rt}	Test & Eval	$1,000	$0	$1,000
C_r	Total	$20,000	$0	$20,000

PROCUREMENT & CONSTRUCTION COST (C_p)				
Cost	Category	Year 1	Years 2-10 *	Total
C_{pp}	Procurement			
C_{ppr}	Recurring (from Table 7)	$33,105	$10,000	$43,105
C_{ppn}	Non-Recurring	$15,000	$0	$15,000
C_{pc}	Construction (non-recurring)	$6,000	$0	$6,000
C_p	Total	$54,105	$10,000	$64,105

OPERATIONS & MAINTENANCE COST (C_o)				
Cost	Category	Year 1	Years 2-10 *	Total
C_{oo}	Operating	$6,000	$133,200	$139,200
C_{om}	Maintenance	$100	$18,000	$18,100
C_{od}	Phase out & Disposal (Year #10)	$0	$1,000	$1,000
C_o	Total	$6,100	$152,200	$158,300

TOTALS		**$80,205**	**$162,200**	**$242,405**

* Costs include a 5% inflation factor

These costs, which include an 11% interest rate and a 5% inflation rate, are projected estimates based on research, interviews and experience.

4.1.1 Research and Development Cost (C_r)

The research and development cost (C_r) involves mostly one-time, non-recurring costs and includes the initial proposal and system design costs, as well as the costs of planning, managing and testing the project.

Management costs (C_{rm}) cover the development of an initial proposal by the design company and the cost of personnel to manage the project. Program management is required to organize and oversee the research efforts, program planning, equipment development and test, and engineering design. The design company's proposal team consists of one program manager and a systems engineer to work the four-month proposal/design effort (Figure 3 shows this effort as months 3 through 7). Management costs also cover the administrative staff, procurement and configuration management personnel for the 4-month effort. Once the trailer is operational during the first year, the XYZ Construction Company requires only a lead engineer to manage, as an additional duty, the system life-cycle of the trailer. That individual will be the lead engineer on-site where the mobile mini-headquarters is located. The salary of the lead engineer is prorated and included under the operations and maintenance costs in years 2 through 10. Therefore, there are no management costs associated with Research and Development after the first year.

Planning costs (C_{rp}) cover the feasibility study, as well as other planning functions, such as vendor support, overall setup, coordination planning and initial implementation plans. Since a mini-headquarters trailer system has already been in existence and the need for the trailer has already been established by the XYZ Construction Company, the planning costs associated with research and development are minimal. The program manager and staff will perform whatever planning functions are required.

Design costs (C_{rd}) include the trailer design and development effort from conception to final design. The design company selected by the XYZ Construction Company is an experienced vendor with an excellent reputation for quality work at reasonable and fair prices. The designer must consider human factors engineering, utilities and maintainability, among other things, during the design phases. Design reviews are covered in this cost as well. The design cost is reasonable due to the use of CAD software.

The test and evaluation costs (C_{rt}) cover all testing of the equipment inside the trailer and testing of the trailer shell itself. This cost also includes quality control, test data and documentation of training and procedures. There are two important points to bring up at this time. First, although the test and evaluation of the trailer system occurs primarily during the initial phase of the system evolution (within the first year), the system's ability to meet established requirements will be continually evaluated throughout the system life-cycle. However, after the first year of testing and evaluating, subsequent testing falls under maintenance costs. Second, some readers might question how the trailer system can be tested when procurement of equipment has not yet been addressed. The answer is simple. The acquisition phase can be progressing in parallel to final design stages and testing by the vendor. Thus, several life-cycle stages can be coordinated and accomplished at the same time. This is where a good program manager can really pay off.

4.1.2 Procurement and Construction Cost (C_p)

The procurement and construction costs (C_p) are those incurred by the XYZ Construction Company in the purchase of the necessary tools, hardware equipment, furniture, utility systems and spares for the trailer system, as well as labor, quality control and inspections performed in remodelling the trailer shell to meet company specifications.

The procurement costs (C_{pp}) involve those costs incurred by the XYZ Construction Company to purchase equipment and tools for the trailer, furniture, required software packages, the trailer shell, utility system parts, spare parts, and construction materials to remodel the trailer to meet specifications on the utility systems and the trailer's interior design. Recurring costs, shown in Table 7, include the costs associated with the utility systems, hardware equipment, software packages, furniture, tools, as well as spares (air and heater filters; fire extinguishers; fluorescent light bulbs; printer ribbons; fax cartridges; computer and fax paper; etc.). Recurring costs decrease after the first year because most of the equipment listed in Table 7 is not expected to have to be replaced. However, since there is the possibility of system failures after limited warranties expire and a possible need for new software upgrades in subsequent years, an additional \$10,000 (includes a 5% inflation factor) is allotted for hardware/utility equipment, software upgrades, and spare parts for years 2 through 10. The non-recurring costs, or, one-time costs, are incurred during the initial stages

Table 7: Recurring Procurement Costs

ITEM	QUANTITY	UNIT COST	TOTAL
Utility Systems:			
Heating/AC Unit	1	$2,500	$2,500
Liquid Propane Tanks	2	$200	$400
Water Heater (30-gal)	1	$120	$120
Water Pump	1	$125	$125
Power Generator	1	$2,000	$2,000
Sewage Holding Tank (250-gal)	1	$750	$750
Water Tank (250-gal)	1	$750	$750
Spare Filters	1 (each type)	$3	$15
Spare Fluorescent Light Bulbs	case of 50	$60	$60
Task Lights	3	$20	$60
Hardware Equipment:			
Computer	3	$3,275	$9,825
Printer	1	$1,500	$1,500
Modem	3	$315	$945
Cellular Phone	3	$300	$900
Facsimile	1	$1,800	$1,800
Copier	1	$3,000	$3,000
Software Packages:			
(see section 3.1)	8	Vary	$3,000
Furniture:			
Workbench Area Chair	1	$400	$400
Table (for copier, printer, fax)	1	$175	$175
Meeting Table & Chairs for 8	1 set	$1,900	$1,900
Desks in Office Area	2	$475	$950
Workbench	1	$330	$330
Cabinets	4	$280	$1,120
Flat Work Table	1	$300	$300
Miscellaneous:			
Tools	1 set	$135	$135
Hand held Fire Extinguishers	2	$15	$30
TOTAL:			**$33,105**

of the trailer's life-cycle. Non-recurring procurement costs include the cost of the trailer shell ($15,000).

Construction costs (C_{pc}) of $6,000 include the labor and materials ($5,000) involved in remodelling the trailer shell to meet XYZ Construction Company's operating requirements, quality control, inspection and testing of the trailer system, and costs associated with constructing any required off-site maintenance facility and/or inventory warehouse ($1,000). Since the remodelling will be performed by employees of the XYZ Construction Company (based on designs by the design company), labor cost includes the combined salaries of two construction workers for the two-month development time (months 6 through 8 of the first year) shown in Figure 3. This two-month labor cost for two individuals is a non-recurring cost. In addition, since off-site maintenance activity at the organizational level (see Table 1) will be kept to basic maintenance work, no special maintenance facility needs to be constructed. Finally, the inventory spares will be kept in a trailer reserved for spare parts and equipment (a storage trailer). This trailer is already procured and has been in use by the XYZ Construction Company for several years. Room for additional storage requirements is available in the storage trailer. Therefore, the construction costs are very low, basically limited to two months of salary for two construction employees (labor cost), quality control and inspection/test efforts. Any future modifications, inspections, tests, and quality control efforts for the trailer will be covered under maintenance costs. Thus, all construction costs are considered non-recurring.

4.1.3 Operations and Maintenance Cost (C_O)

The operations and maintenance cost (C_O) includes all costs associated with operating and maintaining the trailer system throughout its life-cycle. Since these costs occur over a ten-year span, an inflation factor of 5% is applied.

Operating costs (C_{OO}) include the prorated salaries of the lead engineer and administrative clerk, operator training, and the cost of running the utility systems ($200 per month for electricity for heating/AC, lights, and hardware equipment, plus $200 per month for sewage disposal, water tank fill-up and drinking water delivery). The salaries are prorated since the lead engineer and the admin clerk will not be operating in the trailer full time all year round and since managing the trailer is only an additional duty. The cost for the first year of $6,000 includes the cost of utilities for the 4 months of operation ($400/month X 4 months = $1,600), the prorated salaries of the lead engineer and administrative clerk for the 4 months ($3,400), plus the cost for training and writing new procedures that first year ($1,000). For years 2 through 10, the cost of $133,200 includes the cost of utilities ($400/month X 12 months = $4,800), plus the prorated salaries of the lead engineer and admin clerk ($10,000 per year) over the 9-year period ($14,800/year X 9 years = $133,200).

The maintenance costs (C_{OM}) cover the maintenance and support personnel, maintenance training, hardware and software upkeep costs, facility maintenance costs, and costs to maintain documentation, as well as costs to repair and modify the trailer over its life-cycle. The maintenance costs cover all three maintenance levels shown in Table 1. However, the reader should keep in mind that the trailer has a very high reliability rate, with very little down time. In addition, maintenance training is minimal since the XYZ Construction Company has maintenance personnel with prior experience in maintaining trailer systems. Facility upkeep of the trailer is taken care of by existing site cleaning crews, therefore, no additional hiring is required. Finally, since no single maintenance individual will be assigned to maintain the trailer system full time, that is, maintenance personnel will spend their time divided among many facilities and systems, the salaries and maintenance costs are prorated, that is, they are proportionately allocated to each facility and system. This appropriately keeps the maintenance costs minimal for the trailer system. During the first year, with only 4 months of operation, maintenance is negligible. Scheduled maintenance costs are expected to be less than $100, and no unscheduled maintenance is anticipated over the 4 months. For years 2 through 10, scheduled maintenance costs ($500 per year) and unscheduled maintenance costs ($1,000 to $1,500 per year) over the 9-year period are expected to total $18,000 ($2,000/year X 9 years).

The final cost under C_O is the phase out and disposal costs of the trailer system. The effective life span of the trailer is anticipated to be 10 years, as shown in Figure 3. After this time period, a review of the trailer system is necessary to determine if the system's components are obsolete and if maintenance costs prohibit continued operational use. The decision to continue use or dispose of the trailer will be based on several factors, including available funds, priority, system performance, cost benefits to replace or upgrade, maintenance costs, availability of spare parts, available vendor support, and competition for construction jobs. When disposal is deemed appropriate, the phase out and disposal costs of $1,000 cover the transportation fees to a scrap yard and the labor involved. There is no storage fee involved. In fact, a scrap yard dealer will pay the XYZ Construction Company a salvage value of $5,000 for the used trailer's metal and parts. If the XYZ Construction Company decides to keep the trailer, there will be no phase out and disposal fees involved. In the latter case, the trailer will then be used for spare parts on other company-owned construction trailers and vehicles.

4.2 Inflation Consideration

In order to predict cost growth, the life-cycle cost analysis should consider the affect of inflation in the future. The economic analysis should apply inflation factors to the labor costs, procurement costs, operating costs and overhead costs throughout the trailer's life-cycle. These include costs of activities directly and indirectly involved in the system's design and development, operation and maintenance, and retirement.

The current economic analysis in Section 4.1 assumes an inflation factor of 5% on the system's operations and maintenance costs over the last nine years in the life-cycle of the trailer. This assumption on the effects of inflation is reasonable given the current economic conditions of low increases in labor and material costs, in part due to the on-going recession. However, future more detailed analyses of the trailer must evaluate the affect of inflation on all system costs to adequately determine the system's feasibility.

4.3 Cost Evaluation of Two Alternative Purchases

In response to the functional requirement of a factory-delivered "single-wide" trailer shell (see Section 2.2, Feasibility Analysis), a cost comparison of the differences between two alternative "single-wide" trailer shells by different manufacturers is required before the trailer shell can be purchased and modified for the XYZ

Construction Company. This section is an attempt to show a typical application of life-cycle economic evaluations between two mutually exclusive purchase alternatives. Fabrycky and Blanchard point out that "when two mutually exclusive alternatives provide essentially the same service, it is desirable to compare them directly to each other on the basis of life-cycle cost." [9] Clearly, the alternative that provides the desired service at the least cost is the obvious choice.

In order to analyze the economic feasibility of the trailer system, the Present Equivalent Evaluation and the Annual Equivalent Evaluation Methods are used to compare the equivalent costs of the two trailer alternatives. [9] In addition, the system's costs over the trailer's expected life-cycle are evaluated using the Present Worth-Cost Method. [10] Since only costs are known and considered, the latter method is expressed as present worth-cost, or PW-C. (Note: If both costs and profits or receipts are known and considered, the term is <u>net</u> PW. [10]) Assuming each alternative has the same benefits, the trailer with the lowest total equivalent cost should be selected. [10]

This economic analysis section does not account for learning curves, inflation (see Section 4.2) and the possibility of cost variations based on geographic location. The analysis using PW-C, however, does vary the interest rate or minimum rate of return (MARR) to show the impact of changes on the trailer system's economic feasibility. The MARR should be the minimum return that could be obtained by investing elsewhere at comparable risk. This return should be charged to, or expected of, the alternatives under consideration. [10]

In order to exercise the economic evaluation process, two trailer manufacturing companies are evaluated in terms of which company can provide the trailer shell that meets the operating requirements of the XYZ Construction Company at the least cost:

Manufacturer #1 produces a "single-wide" trailer shell that meets all but two of the operating requirements in its delivered state. Trailer #1 contains columns inside the trailer and does not come with vinyl gypsum board walls along the interior walls. However, Trailer #1 does contain the desired efficient single-unit heating/air conditioning system that eliminates the need for more costly separate systems. The factory-delivered cost of Trailer #1 is $14,000 and the trailer can be expected to last 10 years, with a salvage value of $4,000. Operating costs will be $15,000 per year. During the first year of operations, however, operating costs will be $6,200, which includes the costs of utilities, salaries and training over the four-month operational period (see Figure 3).

Manufacturer #2 produces a "single-wide" trailer that meets all of the operating requirements in its delivered state. Trailer #2 contains steel "I" beams in the roofing and flooring metal trusses, eliminating the need for columns inside the trailer, and vinyl gypsum board walls along the interior walls. However, the trailer contains separate heating and air conditioning systems. Although this meets the operating requirement of adequate heating and cooling systems, the separate units are not as efficient nor economical as the combined heating/AC single-unit system. The factory delivered cost of Trailer #2 is $15,000, and this trailer can also be expected to last 10 years, but with a higher salvage value of $5,000. Operating costs will be $15,500 per year. Operating costs for the first year will be $6,400, including the costs of utilities, salaries and training over a four-month operational period.

The service provided by each trailer is identical. However, the cost of modifying each trailer to meet the operating requirements must also be included in the evaluation. For Trailer #1 to meet operating requirements, the cost for materials and labor to remodel the trailer with steel "I" beams and vinyl gypsum board walls in the interior is $8,000. This includes the cost to extract the columns currently located in the trailer shell and repair the trailer ceiling. For Trailer #2 to meet operating requirements and stay within the allocated budget, the cost for materials and labor to replace the two separate utility systems with the single heating/AC unit is $5,000. Once this replacement is performed, operating costs decrease due to a more efficient and cost-effective system. Thus, the operating costs for Trailer #2 are reduced to $14,800 per year for years 2 through 10 (from $15,500 per year). The operating costs for the first year are reduced to $6,000 (from $6,400), which include the cost of utilities, pro-rated salaries and training over the four-month operational period. Table 8 shows the new associated costs, which take into account the remodelling cost for materials and labor to meet the XYZ Construction Company's operating requirements and stay within the allocated budget. Basically, Table 8 shows that the purchase cost, remodelling cost, operating cost and salvage value differ between the two alternatives. The disparity between costs are due to different equipment models or brands in each trailer. This equipment varies in price and runs at varied peak efficiencies, which impact the operating costs. Table 8 also shows that all other associated costs, such as R&D, materials, construction and maintenance costs are identical for both trailers.

Table 8: Comparison of Two Alternative "Single-Wide" Trailers [9]

		Trailer #1	Trailer #2
	R&D Cost	$20,000	$20,000
	Procurement Cost (Recurring - Yr #1)	$33,105	$33,105
	Procurement Cost (Recurring - Yrs #2-10)	$10,000	$10,000
*	Factory Delivered Cost (Non-Recurring - Yr #1)	$14,000	$15,000
*	Remodelling Cost (Non-Recurring - Yr #1)	$8,000	$5,000
	Other Construction Cost (Non-Recurring - Yr #1)	$1,000	$1,000
*	Operating Cost (Yr #1)	$6,200	$6,000
*	Operating Cost (Yrs #2-10)	$135,000	$133,200
	Maintenance Cost (Yr #1)	$100	$100
	Maintenance Cost (Yrs #2-10)	$18,000	$18,000
	Phase Out & Disposal Cost (Yr #10)	$1,000	$1,000
	Cost:	$246,405	$242,405
	Salvage Value:	-$4,000	-$5,000
	Total Cost:	$242,405	$237,405

* Differences in Cost Identified

Note: All costs are extracted from Tables 6 and 7 and explained in Section 4.1.

Figure 23 illustrates the money flow diagram for the estimated costs and salvage values for each trailer alternative.

4.3.1 Present Equivalent Evaluation

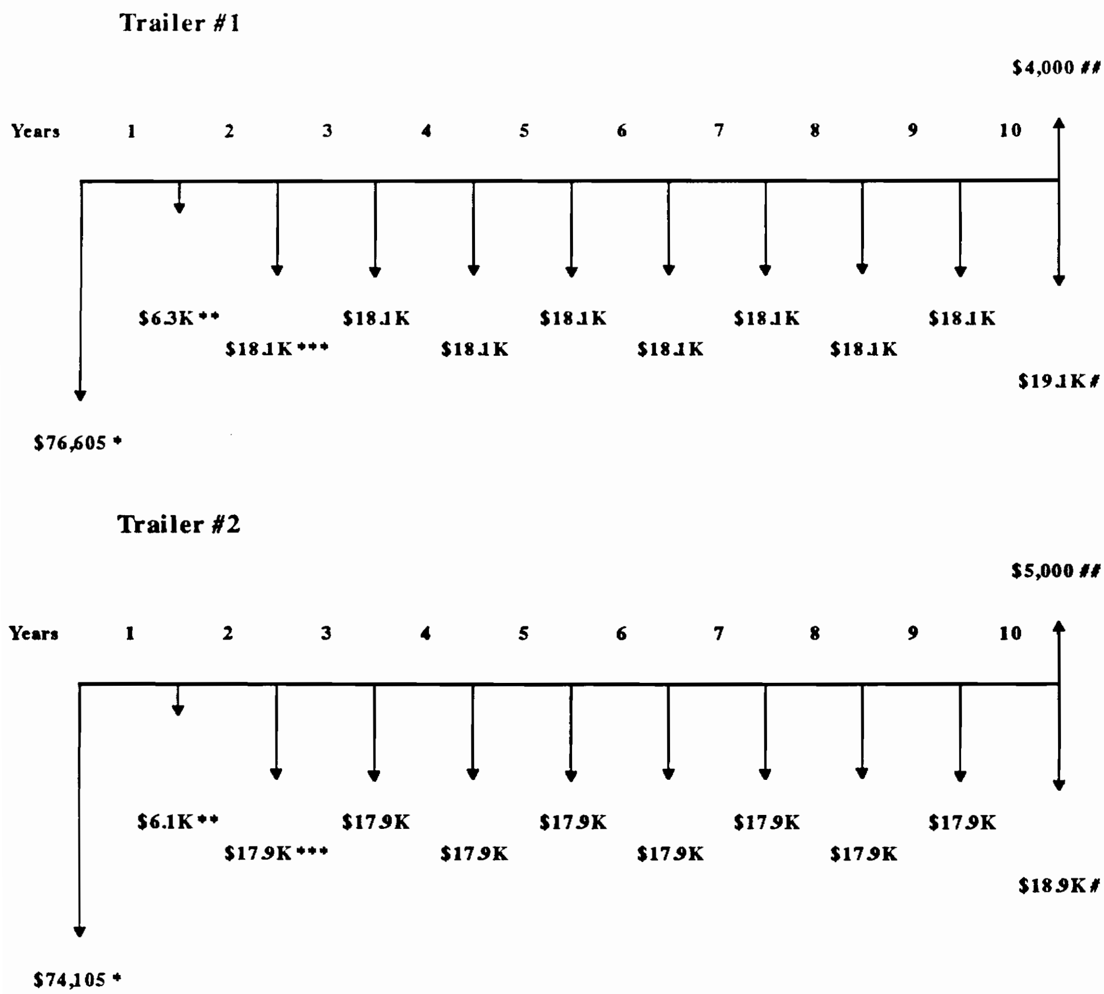
Using the present equivalent cost evaluation method, detailed by Fabrycky and Blanchard, the two alternatives are compared using equivalent costs at a time taken to be the present. [9] With an assumed interest rate of 11 percent, the present equivalent cost of Trailer #1 is

$$\$76{,}605 + \$15{,}000\overset{P/A,11,10}{(5.8893)} - \$4{,}000\overset{P/F,11,10}{(0.3522)} = \$163{,}536.$$

The present equivalent cost of Trailer #2 is

$$\$74{,}105 + \$14{,}800\overset{P/A,11,10}{(5.8893)} - \$5{,}000\overset{P/F,11,10}{(0.3522)} = \$159{,}506.$$

This comparison shows the present equivalent cost of Trailer #2 to be less than the present equivalent cost of Trailer #1 by $4,030 ($163,536 - $159,506). The Interest Factors for Annual Compounding Values for a wide range of interest rates are taken from Interest Factor Tables. [9] These interest factor numbers are standard computational values.



* Initial Cost includes the R&D Cost ($20K) and Procurement and Construction Cost ($56,105 for Trailer #1 and $54,105 for Trailer #2) from Table 6

** $6.3K and $6.1K are the operating and maintenance costs for the two alternatives, respectively, during the first year (see Table 8) over 4 months of operation (Figure 3 shows only four months of operations during the first year of the trailer's life-cycle)

*** Annual Cost (Yrs 2-10) includes recurring procurement cost (10K ÷ 9 yrs = $1,111/yr), operating cost ($15K for Trailer #1 and $14.8K for Trailer #2), and maintenance cost ($2K/yr) from Table 6

\# Year 10 includes annual cost plus a phase out and disposal cost of $1K from Table 6

\## Salvage Value

Figure 23: Money Flow Diagrams for Two Alternatives [9]

4.3.2 Annual Equivalent Evaluation

The annual equivalent costs, according to Fabrycky and Blanchard, are taken as an equal-cost series over the life of the trailers. [9] The annual equivalent cost of Trailer #1 is

$$\$76{,}605 \underset{A/P,11,10}{(0.1698)} + \$15{,}000 - \$4{,}000 \underset{A/F,11,10}{(0.0598)} = \$27{,}768.$$

The annual equivalent cost of Trailer #2 is

$$\$74{,}105 \underset{A/P,11,10}{(0.1698)} + \$14{,}800 - \$5{,}000 \underset{A/F,11,10}{(0.0598)} = \$27{,}084.$$

The annual equivalent difference of $27,768 minus $27,084, or $684, is the annual equivalent cost superiority of Trailer #2. As a verification, the present equivalent amount of the annual equivalent difference is

$$\$684 \underset{P/A,11,10}{(5.8893)} = \$4{,}030.$$

Therefore, using either the present equivalent cost evaluation method or the annual equivalent method results in the same conclusion. The best alternative in terms of purchase cost, operating cost and salvage value, is Trailer #2. These are the costs that differ between the two alternatives and, thus, are the basis of the cost consideration.

4.3.3 Present Worth-Cost Method

This analysis method determines the trailer's economic feasibility by evaluating the system's costs over the trailer's expected life-cycle by discounting these costs using the present worth-cost (PW-C) evaluation technique. [10] Using the costs and salvage values shown in Figure 23 (Money Flow Diagrams for Two Alternatives), a comparison of the two trailers using the PW-C method and MARR = 15% yields the PW-C totals shown in Table 9. [10] The resulting total PW-C costs displayed in Table 9 indicate that Trailer #2 is a cheaper alternative in terms of present worth-cost. Thus, Trailer #2 is verified once again as the better alternative.

4.3.4 Sensitivity Analysis Using PW-C and MARR

The analysis needs to evaluate the trailer's economic feasibility under varying conditions of input data. For example, variations in the trailer prices from different manufacturers or variations in the MARR can be analyzed to show the impact of changes on the trailer system's economic feasibility. This analysis, using the PW-C method, evaluates the uncertainty associated with the MARR used in the original economic analysis in Table 9. The interest rate used in the feasibility calculations in Table 9 is varied by 33 percent around the chosen MARR of 15 percent, holding all other parameters constant. The sensitivity analysis uses interest rates of 10 and 20 percent; the PW-C results are shown in Table 10. Several conclusions can be drawn from comparing Tables 9 and 10. First, no matter what discount rate is used, Trailer #2 clearly and consistently evolves as the superior alternative in terms of present worth-cost. Second, the project remains feasible even if interest rates were to vary between

Table 9: Present Worth-Cost Comparison [10]

	Present Worth-Cost *	
	Trailer #1	Trailer #2
Investments	$76,605	$74,105
	6,300	6,100
Annual Costs		
$18,100 (P/A, 15%,8)	81,220	
$19,100 (P/A, 15%,1)	16,609	

$17,900 (P/A, 15%,8)		80,323
$18,900 (P/A, 15%,1)		16,435
Salvage Value		
$-4,000 (P/F, 15%, 10)	-989	

$-5,000 (P/F, 15%, 10)		-1,236
TOTAL PW-C	$179,745	$175,727

* Note: "+" is used for costs

Table 10: Sensitivity Analysis using MARR

	Present Worth-Cost			
	MARR = 10%		MARR = 20%	
	Trailer #1	Trailer #2	Trailer #1	Trailer #2
Investments	$76,605	$74,105	$76,605	$74,105
	6,300	6,100	6,300	6,100
Annual Costs				
$18,100 (P/A, XX%,8) *	96,562		69,453	
$19,100 (P/A, XX%,1) *	17,364		15,916	

$17,900 (P/A, XX%,8) *		95,495		68,686
$18,900 (P/A, XX%,1) *		17,182		15,749
Salvage Value				
$-4,000 (P/F, XX%, 10) *	-1,542		-646	

$-5,000 (P/F, XX%, 10) *		-1,928		-808
TOTAL PW-C	$195,289	$190,954	$167,628	$163,832

Note: "+" is used for costs

* XX% = 10% and 20%, respectively, for above Table

10 and 20 percent, since all the PW-C totals fall well within the budgetary life-cycle cost projections shown in Table 6. Third, as the interest rate increases, the difference in present worth-cost decreases. Thus, the lower the interest rate, the more money the company will save in terms of cost between alternatives.

4.4 Total System Cost

The economic analysis summarized in this report indicates that the trailer system is economically feasible and that, if it came to a decision between the two trailer alternatives outlined in Section 4.3, Trailer #2 is clearly the superior choice in terms of cost.

The total system cost of $242,405 for the trailer system over the ten-year life span takes into consideration all costs incurred in bringing the mobile mini-headquarters into being. The significant costs are identified in Table 6 and concentration is given to the highest contributors. As expected, Research and Development Costs combined with Procurement and Construction Costs make up 92% of the total costs for the first year, while Operations and Maintenance activities are 94% of the costs in the subsequent years. Discussions and interviews with various construction personnel indicate that these total system costs are reasonable and fair for the system life-cycle. In addition, the total cost remains within the allocated budget of the XYZ Construction Company.

5.0 CONCLUSION AND RECOMMENDATIONS

This project has attempted to use the systems engineering life-cycle approach in the preliminary design of a mini-headquarters construction trailer. Although the scope of the project has been limited to the actual conceptual and preliminary design phases, the processes discussed in this report are fully applicable to the actual life-cycle design of such a trailer system.

5.1 ANALYSIS REVIEW

This preliminary design effort will fulfill the needs of the XYZ Construction Company, as stated in the operating requirements, for a mini-headquarters trailer. Every effort has been made to remain flexible in the design, keep costs low, and allow for an easy transition to the new trailer system.

The key decisions in the preliminary design of the mini-headquarters trailer are based on the operating requirements and considerations for human factors engineering. Specifically, this design emphasizes such factors as safety, costs, quality, integration, value and reliability. This project has attempted to identify areas where system performance will be improved by well-designed human-machine interfaces. The workspace area, workbench seat design, trailer lighting system, private office space, conference room and utility systems were all designed with human factors in mind. Substantial energy and cost savings resulted from effective efforts in choosing the appropriate trailer size, designing an efficient internal layout, and comparing costs between two different "single-wide" trailers. Such savings is a worthy goal for any human factors design effort.

5.2 Design Concerns During the Trailer's Life-Cycle

There are a number of concerns that need to be addressed in the later stages of the design analysis that are critical to the proper design and length of service life of the trailer system. These concerns include design activities, such as determining the availability of trailer parts and supplies in the marketplace; defining the trailer's detailed final layout; identifying design methods that will extend the expected life of the trailer beyond ten years; and designing trailers for recycling so that they can be disassembled easily at the end of their useful life in order to recover and process materials which retain some economic value, at least more than the currently collected salvage value from scrap dealers.

Another concern involves cost estimating. This project's analysis obtained cost input data from materials and equipment catalogs, industry representatives, and off-the-shelf pricing. Detailed cost analyses need to use more accurate data to adequately determine the trailer system's feasibility in terms of cost. Sources for the data include collating actual price listings from numerous trailer manufacturers for comparison of trailer shells and parts; examining historical records used to account for existing system components and operations; developing data through research by simulating process designs and operations; applying the experience and knowledge of individuals involved in designing and operating similar systems; and performing analyses that establish process component design requirements.

In addition, future analyses of the trailer system must evaluate the affect of inflation on all system costs in more detail to adequately determine the system's feasibility and more accurately predict cost growth. Finally, more sensitivity analyses could be performed in the Life-Cycle Cost Analysis Section to better determine how sensitive the final results are to changes in the values of estimates used throughout this project. For example, sensitivity analysis can be performed using better-defined trailer prices, varying the inflation factor, or using additional interest rates (MARR values). Such analyses could lead to different alternatives and results.

5.3 RECOMMENDATIONS

The recommendation made to XYZ Construction Company management is to accept this preliminary design and continue with subsequent phases of design and construction in the systems engineering life-cycle. It is also recommended that the XYZ Construction Company conduct additional research and investigation into prerequisite details of the actual design, which are beyond the scope of this project, prior to the actual construction of the trailer.

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Appendix A
Computerized Layout Planning

Introduction

This appendix describes a computerized layout planning approach to facilities layout planning using computer-aided design (CAD) systems. This approach is used during the planning phase of the trailer layout to determine a) the appropriate trailer size required by the XYZ Construction Company, and b) the most efficient internal layout in terms of cost (construction, installation, material handling and operational), safety, ease of operation, and resource management (water, energy, and waste). [11] Since the XYZ Construction Company already owns the necessary hardware and CAD software packages required for computerized layout planning, the cost for this service is minimal. Computerized layout planning has two major advantages over the standard manual pencil and paper method. First, many alternatives can be generated and explored with little time and effort expended, as well as relatively little expense or risk. Second, computers are not constrained by narrow points of view because they lack bias and any preconceived ideas. [11] The ability to simulate various layouts or models in design at reasonable cost and using standard computer graphics facilities for expanding and contracting detail is considered critical if totally integrated design systems are to be achieved.

Components of Computer-Aided Design

According to Canada and Sullivan, computer-aided design involves the use of computerized tools to improve productivity in the areas of design, drafting and testing. [10] They indicate a typical CAD system includes:

- A cathode-ray tube (CRT) workstation where the engineering staff can create or modify a part by "drawing it" on the screen using a number of different devices, such as:
  - •• A standard computer terminal keyboard
  - •• A mouse
  - •• An electronic stylus that the engineer uses like a pen to draw on the screen
  - •• An electronic sensitive menu tablet of commands that the engineer can select
- A digitizer that can convert an existing print to X-Y or X-Y-Z coordinate points which can be stored in the CAD system and retrieved on the terminal
- Automatic drafting machines that produce high-quality drawings from data stored in the system [10]

In most CAD systems, a wide variety of analytical software is available for mathematical testing and modeling of part designs. [10] The XYZ Construction

Company uses System Design Language (SDL), which allows the user to describe facility items, components, structures and buildings in diagrammatic or detailed form.

Trailer Layout Analysis

Mistakes in the actual layout of the trailer can be very costly since the XYZ Construction Company employees must work in the trailer for up to 10 years. Therefore, careful layout planning in the early stages of design is of primary importance. The XYZ Construction Company, in conjunction with the design company, used CAD software to develop various layout studies, including alternative layouts.

Prior to actually using the CAD software, a REL (Relationship) Chart was developed that shows the desired closeness of the different facilities within the trailer, according to the engineering staff. [11] In constructing the activity REL Chart, shown in Figure A.1, the trailer's three main areas (conference room, workspace area and private office) are broken down by activity or function and a closeness desirability rating is assigned to each paired combination. Table A.1 shows a set of ratings proposed by Muther, as described by Turner, Mize and Case. [11] There are other rating scales available on the market, however, Muther's proposed set of ratings are widely accepted and seem to work very well, according to Turner, Mize and Case. [11] Using Muther's set of ratings, for any paired combination, an "A" rating means that it is absolutely necessary that the two areas be located adjacent to each other. At the other extreme, an "X" rating means that it is not desirable for the two areas to be adjacent. The REL Chart in Figure A.1 is the activity relationship diagram for the trailer and is based on averaging the ratings received from the XYZ Construction

Activity or Function	Activity or Function Number																			
	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1. Ofc. Desks/Chairs	X	U	U	U	U	U	U	O	O	O	U	U	U	U	U	A	I	E	I	
2. Ofc. Sofa & Table	X	U	U	U	U	U	U	U	U	U	U	U	U	U	U	I	U	I		
3. Ofc. File Cabinets	U	U	U	U	U	U	U	O	O	O	U	U	U	U	U	O	I			
4. Ofc. Storage Shelves	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U				
5. Ofc. Desk Top PC's	X	U	U	U	U	U	U	O	O	O	U	U	U	U	U					
6. Mtg Rm Tables/Chrs	X	U	U	U	U	U	U	U	U	U	A	U	A	A						
7. TV and VCR	U	U	U	U	U	U	U	U	U	U	A	U	A							
8. Audio Visual Equip	U	U	U	U	U	U	U	U	U	U	A	I								
9. Supply Cabinet	U	U	U	U	U	U	U	U	U	U	O									
10. Projection Screen	U	U	U	U	U	U	U	U	U	U										

Figure A.1: Activity Relationship Diagram for Trailer

Activity or Function	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
11. Printer	U	I	U	A	E	A	U	A	A											
12. Copier	U	I	U	A	E	A	U	A												
13. Facsimile	U	I	U	A	E	A	U													
14. Water Bottle Sys.	X	O	U	U	O	U														
15. Wrk Area Computer	X	A	O	A	E															
16. Work Table	X	E	I	E																
17. HW Equip Table	U	I	O																	
18. Work Area Sofa	U	O																		
19. Wrk Area Desk/Chr	X																			
20. Restroom																				

Figure A.1: Activity Relationship Diagram for Trailer (continued)

Table A.1: Activity Relationship Diagram Symbols [10]

Letter	Closeness
A	Absolutely Necessary
E	Especially Important
I	Important
O	Ordinary Closeness OK
U	Unimportant
X	Not desirable

Company's engineering staff. This REL Chart served to set priorities for the engineers to use in the layout planning process.

Another input to layout planning is the area requirements for the various facilities located in the trailer. These area requirements are a major input to determine the actual trailer size required to fulfill the needs of the XYZ Construction Company. Figure A.2 displays the area requirements for the trailer facilities.

Now that the activity relationship chart and the area requirements have been determined for the trailer, the next step in constructing a trailer system layout is to set up the grid lines and other relevant system parameters. First, a sketch of the general layout of each trailer compartment (meeting room, workspace area and private office) is made using the prioritized relationship chart shown in Figure A.1, and with dimensions set down from the area requirements listed in Figure A.2. This rough sketch is then placed on the drawing area of the digitizer, stored in the CAD software, and subsequently turned into an accurate drawing that can be viewed on the CRT. [12] The drawing can now be accurately constructed and documentation, such as drawings of plans, elevations and isometrics, can be produced. [12]

The drawing data in a CAD software system is filed under a code; each file may be subdivided into a number of levels which are identified by a number. This permits a complex drawing to be digitized in a number of discrete parts, and each part may be overlaid with another to make up the complete drawing. [12]

The next step is to enter each of the trailer's discrete compartment runs together with the standard components, such as partitions, flooring, cladding, doors and windows. [12] Components are called by name to which there corresponds graphic

	Trailer Activity	Area (Inches^2)
1.	Office Desk/Chairs	72
2.	Office Sofa & Table	72
3.	Office File Cabinets	36
4.	Office Storage Shelves	36
5.	Office Desk Top PC's	15
6.	Meeting Room Table/Chairs	84
7.	TV and VCR	30
8.	Audio Visual Equipment	36
9.	Supply Cabinet	36
10.	Projection Screen	36
11.	Printer	15
12.	Copier	15
13.	Facsimile	15
14.	Water Bottle System	20
15.	Work Area Computer & Desk	160
16.	Work Table	96
17.	HW Equipment Table	48
18.	Work Area Sofa	72
19.	Work Area Desk/Chair	60
20.	Restroom	96

Figure A.2: Area Requirements for Trailer Facilities data and other parameters provided at the project initialization stage. Generally, a component would be automatically located relative to a grid coordinate, otherwise, the component is assigned to any position relative to origin or the most recently defined point. Components can be nested within each other so that quite complex forms can be generated from basic sets. The components are detailed by either using a detailing mode of the SDL, or by means of an interactive graphics display system. Once all the components have been located properly, the trailer centerlines may be digitized. When the trailer runs are entered, the straight runs are digitized first using CAD command functions. [12]

Each level of digitized data can be displayed in turn for final checking, and levels superimposed to obtain the complete layout. During the digitizing stage, if any area of the drawing becomes difficult to visualize or too complex, that area may be windowed or blown up on the screen. [12] Once the models have been established, elevations and isometrics can be applied to the layout simply by allocating the drawing or window (one portion of the screen) for elevated or isometric viewing. [12] Elevations and isometrics can also have the various horizontal zone and vertical grid ordinate lines superimposed on them, if required. The final layout of the trailer's interior can be displayed either by trailer compartment or in its entirety. Figure A.3 shows the preliminary layout for each trailer compartment based on CAD software output.

Conclusion

The final proposed layout represents numerous modifications to previous runs. Each successive run of the software should satisfy a greater number of the required

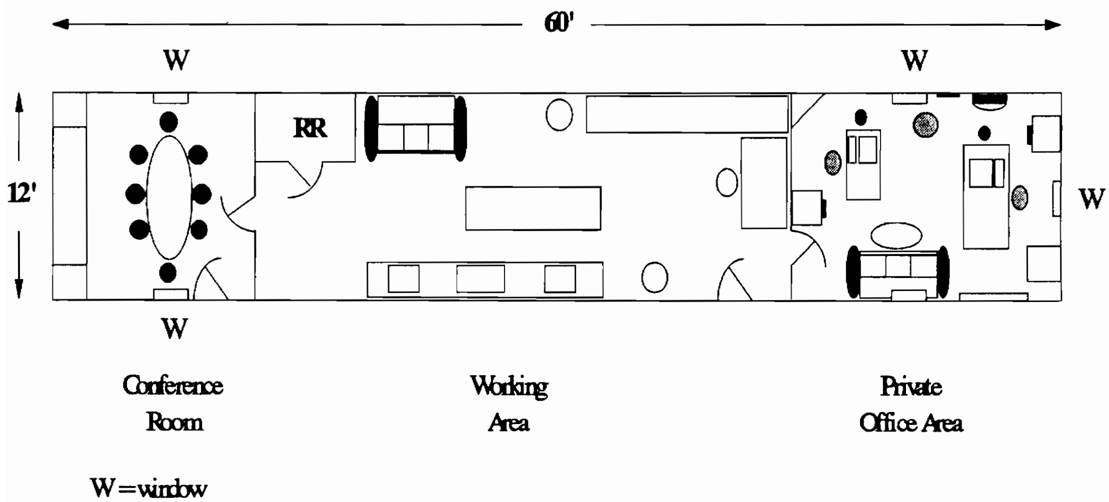


Figure A.3: Preliminary Layout of Trailer Compartments

Based on CAD (Top View)

close relationships identified in Figure A.1. This computerized layout planning approach using CAD software allows the XYZ Construction Company to consider a large number of alternatives with little time and money expended.

The various computerized runs indicate a "single-wide" trailer shell measuring 12-feet wide by 60-feet long by 9-feet high meets both the size and shape requirements of the XYZ Construction Company. In addition, the standard factory-delivered "single-wide" trailer shell already comes divided into three compartments to accommodate a meeting room, a workspace area with a restroom, and a private office space.

The CAD output reveals that the next trailer shell larger in size is too large for the Construction Company's needs, which would result in cost overruns and wasted space. On the other extreme, the next smaller-sized trailer does not have enough space to accommodate the three functional areas required by the XYZ Construction Company.

Appendix B
Anthropometric Factors

Introduction

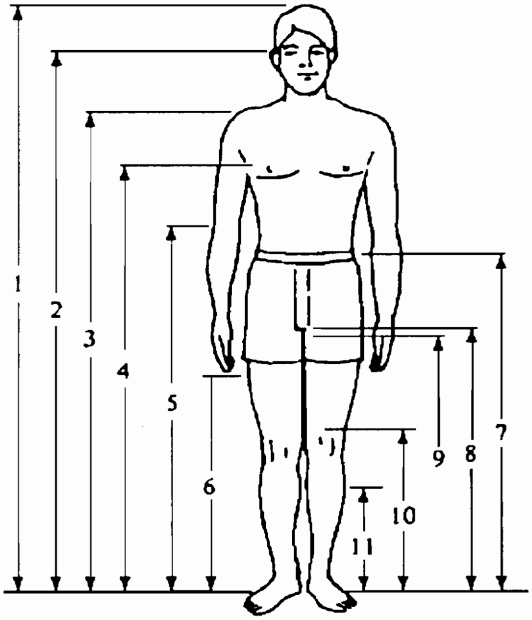
This appendix discusses the five design principles (listed in Table 3) offered by Sanders and McCormick in Section 2.6.2.2.1 that should be followed when applying anthropometric data to any preliminary design project. In addition, various measurements relevant to the design of workstations are detailed in anthropometric charts.

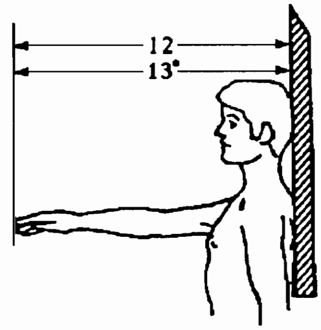
Five Design Principles

The following paragraphs respond to the five design principles listed in Table 3.

Design Principle #1

The important body dimensions in the design of a construction trailer are standing height, sitting height and reach envelopes. For a mobile mini-headquarters in a construction site environment, the operators may be engaged in two types of tasks: one requiring a seated operation, the other a standing operation. Figures B.1 and B.2 show examples of static body measurements in the standing and sitting positions, respectively. [2] According to Blanchard and Fabrycky, the data in both figures originated from MIL-STD-1472, Military Standard, Human Engineering Design Criteria for Military Systems, Equipment



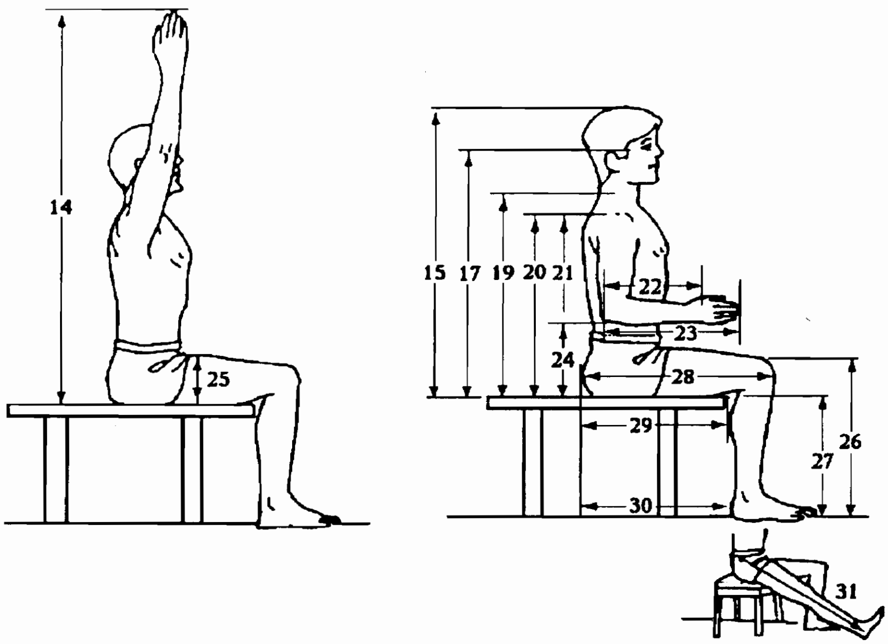


*SAME AS 12, HOWEVER, RIGHT SHOULDER IS EXTENDED AS FAR FORWARD AS POSSIBLE WHILE KEEPING THE BACK OF THE LEFT SHOULDER FIRMLY AGAINST THE BACK WALL.

Factors	Percentile Values (in)			
	5th Percentile		95th Percentile	
	Men	Women	Men	Women
Weight (lbs)	127.7	102.3	206.7	164.3
Standing Body Dimensions				
1. Stature	64.4	60.0	73.5	68.5
2. Eye Height (standing)	59.7	55.5	68.1	63.9
3. Shoulder (acromiale) height	52.6	48.4	60.8	56.6
4. Chest (nipple) height	47.0	43.0	54.1	50.3
5. Elbow (radiale) height	40.1	37.4	47.8	43.6
6. Fingertip (dactylion) height	24.2	N/A*	28.8	N/A*
7. Waist height	38.2	36.6	45.8	43.4
8. Crotch height	29.7	26.8	36.1	33.0
9. Gluteal furrow height	29.1	26.2	34.6	31.9
10. Knee cap height	18.6	17.2	23.0	20.7
11. Calf height	12.2	11.4	15.8	14.4
12. Functional reach	28.6	26.2	35.1	31.7
13. Functional reach, extended	32.8	28.9	38.9	36.5

* N/A: Data not available

Figure B.1: Standing Body Dimensions and Weights of Adults [2]



Factors	Percentile Values (in)			
	5th Percentile		95th Percentile	
	Men	Women	Men	Women
Seated Body Dimensions				
14. Vertical arm reach, sitting	51.8	46.2	59.3	54.9
15. Sitting height, erect	33.1	31.1	38.5	35.8
16. Sitting height, relaxed	32.5	30.5	37.7	35.3
17. Eye height, sitting erect	29.2	26.6	33.6	31.2
18. Eye height, sitting relaxed	27.7	26.1	32.8	30.7
19. Mid-shoulder height	22.7	21.2	27.0	24.6
20. Shoulder height, sitting	21.4	19.8	26.8	23.7
21. Shoulder-elbow length	13.1	12.1	15.5	14.4
22. Elbow-grip length	12.7	11.6	15.5	14.0
23. Elbow-fingertip length	17.5	15.7	20.5	18.7
24. Elbow rest height	7.2	6.4	11.2	10.6
25. Thigh clearance height	4.9	4.1	7.4	6.9
26. Knee height, sitting	19.4	18.5	23.7	21.8
27. Popliteal height	15.4	15.0	19.1	18.0
28. Buttock-knee length	21.8	20.9	25.9	24.9
29. Buttock-popliteal length	17.8	17.1	21.6	20.7
30. Buttock-heel length	18.4	N/A*	22.2	N/A*
31. Functional leg length	42.2	39.2	48.9	46.7

* N/A: Data not available

Figure B.2: Seated Body Dimensions of Adults [2] and Facilities, Department of Defense, Washington, D.C. [2] However, a later version, MIL-STD-1472D, dated 14 March 1989, is used to update the figures in this paper. The data presented represents the 5th and 95th percentiles for men and women for a given sample population. [2]

Design Principle #2

The user population of the mobile mini-headquarters will be mostly average-sized male construction engineers. However, the XYZ Construction Company does employ several female engineers who could potentially use the mini-headquarters occasionally.

Design Principle #3

According to Sanders and McCormick, there are three general policies to consider when applying anthropometric data to this design project, and each policy applies to a different type of situation. [4]

a. Design for Extreme Individuals:

There are certain features of the trailer that should try to accommodate most, if not all, of the user population. Examples of designs for the maximum population (95th percentile) include heights of doorways, strengths of supporting devices for the workbench area, and ceiling heights for trailers. Examples of designs for the minimum population (5th percentile) include the distance of control buttons or critical tools from the operator and the force required to operate the tools/controls.

Burgess claims that when the extremes have been accommodated, all average body sizes, that is, the majority of users, are also included. [13] However, it is not always necessary to accommodate 100 percent of the population in all design features. For example, it would be unreasonable to design all doorways over 9 feet high to accommodate extra tall men. Instead, the usual practice is to use the 95th and 5th percentiles of the distributions of relevant population characteristics as the maximum and minimum design parameters, respectively. [4] The data in Figures B.1 and B.2 represent the 5th and 95th percentiles for men and women for a given sample population. For the most part, this project will be designed with the 5th and 95th percentiles in mind.

b. Design for Adjustable Range:

Some types of equipment in a trailer can be designed so they can be adjusted to various individuals, usually covering the range from the 5th to the 95th percentiles of the relevant population. [4] When adjustability is included in the design, especially vertically, an extreme range can be accommodated. Equipment in this category would include seats, workbenches and adjustable task lighting sources over the work area. For this project, the seats and workplace light source(s) will be adjustable; however, the workbench height will be a fixed height.

c. Design for the Average

There are some workplace areas where it is appropriate to design for an "average" individual. For the mini-headquarters, the horizontal work surface area, the bathroom facilities and the major reach envelopes will be designed with commonly accepted standards for average individuals in mind. This is not stating that the design would be optimum for all individuals, but that, collectively, the design would cause less inconvenience and difficulty than one which might be lower or higher. [4]

Design Principle #4

Figures B.1 and B.2 contain the relevant anthropometric information required for this design project. Again, this project will design using the 5th and 95th percentiles of the population.

Design Principle #5

The special clothing that may be required at a construction site include a hard hat, a tool belt and possibly a jacket in the cooler seasons, creating the need for a slightly larger workspace. However, the hard hat and tool belt can be taken off when inside the trailer, and, since the trailer will be heated inside during the cold months, jackets and other outer clothing can also be discarded once inside the mini-headquarters. A set of coat hooks (eight total) will be set up along one side of a wall for hanging various pieces of clothing/equipment. These conditions eliminate the need for allowances for special clothing.

In addition to the anthropometric data provided in this appendix, there are numerous other factors that are directly affected by design decisions. Data exists covering many other facets of workspace dimensions, such as operator consoles and control panel designs. However, the type of anthropometric data considered relevant for this project has already been divulged and addressed.

Appendix C
Human Sensory Factors of Sight and Sound

Introduction

This appendix briefly discusses the two senses of sight and sound as they pertain to system design.

SIGHT

The primary visual tasks for engineers using the mini-headquarters include reading, reviewing detailed blueprints and plans, and using a computer. The maximum allowable values for degrees of eye and head rotation for operator efficiency and comfort are shown in Figure C.1. [2] These vertical and horizontal visual fields are applicable for any function in the trailer requiring vision. Any requirements outside of the recommended visual fields shown in Figure C.1 will result in operator inefficiency and fatigue, and ultimately, if not corrected, component or system failures. It is the primary visual functions that normally establish a workplace layout's principal lighting orientation. The level of illumination required for the trailer is discussed in Section 3.7.1.1 (Lighting System).

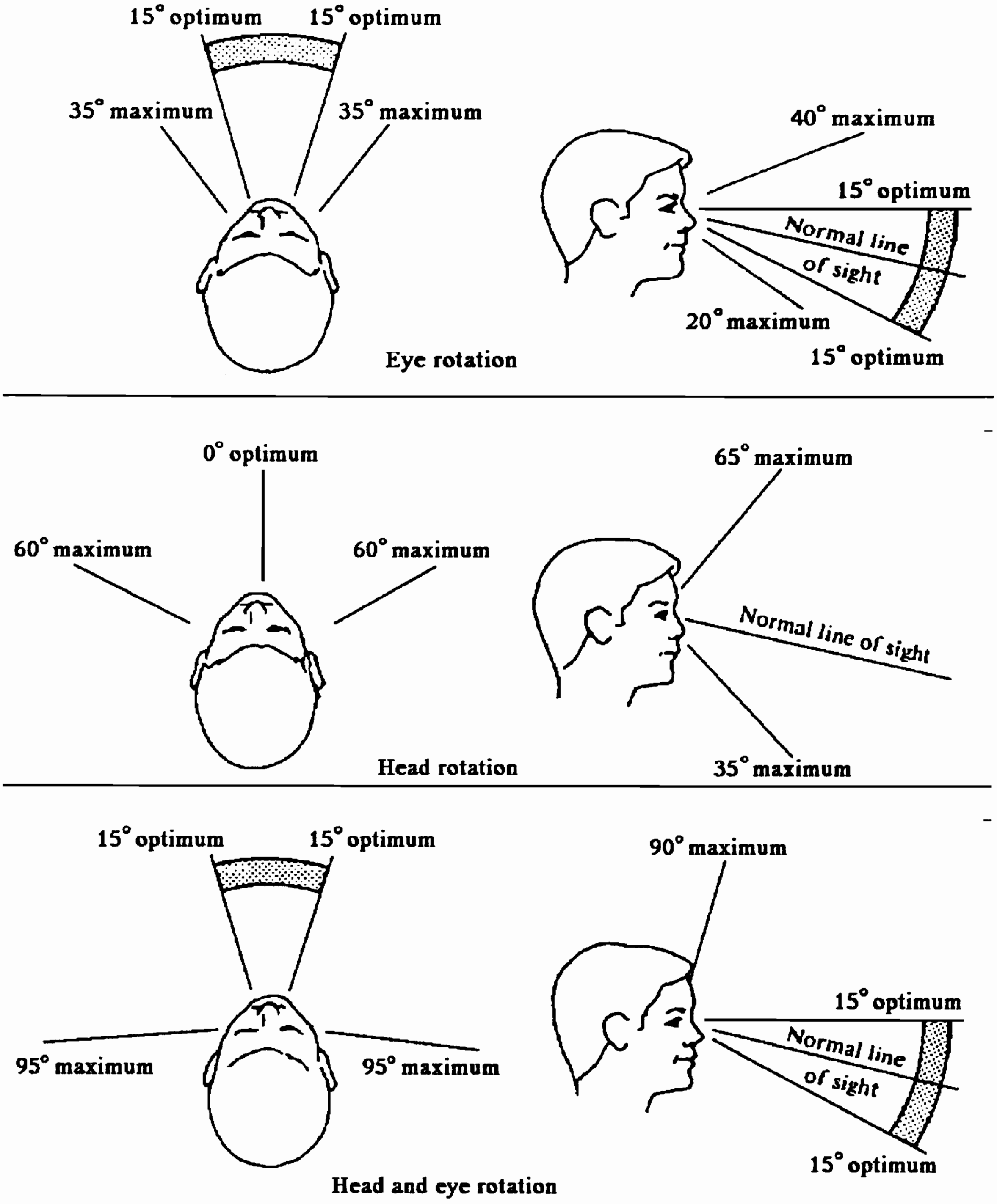


Figure C.1: Vertical and Horizontal Visual Field [2]

SOUND

In addition to sight, human task performance in the trailer is also heavily dependent on sound, both in terms of oral communication and the impacts of noise. The designer must create an environment in the trailer that allows effective oral communication, both between trailer occupants and over the phone. There is no sense in having a conference room if the noise level from outside construction activities prevents effective communication inside the trailer. Therefore, the effect of noise, which has become a pervasive aspect of working conditions, must be a critical concern for the designer.

The human ear is not equally sensitive to all frequencies of sound. According to Sanders and McCormick, "...in general, the ear is less sensitive to low-frequency sounds (20 to approximately 500 Hz) and more sensitive to higher frequencies (1000 to approximately 5000 Hz)." [4] Therefore, a 2000-Hz tone at a given sound-pressure level will seem louder than, say, a 300-Hz tone at the same sound-pressure level (equal intensity). At a construction site, occupational hearing loss is a real concern for individuals exposed to the loud and continuous noises emanating from the various construction machines and equipment. Blanchard and Fabrycky, indicate that "the desired intensity level (of noise generated by the system and its surroundings) will likely fall within a range of 50 to 80 dB." [2] Meanwhile, Sanders and McCormick indicate that permissible levels of noise depend on the duration of exposure. They cite standards set by the Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor. Table C.1 shows permissible noise exposures, according to OSHA. [4] Sanders and McCormick reveal that the OSHA requirements are based on the key concept of noise dose. A listener incurs a partial dose of noise with exposure

Table C.1: Permissible Noise Exposures According to OSHA [4]

Sound level, dBA	Permissible time, h
80	32
85	16
90	8
95	4
100	2
105	1
110	0.5
115	0.25
120*	0.125*
125*	0.063*
130*	0.031*

*Exposures above 115 dBA are not permitted regardless of duration; but should they exist, they are to be included in computations of the noise dose.

to any sound level at or above 80 dBA. The two authors claim exposures to sound levels less than 80 dBA are ignored by OSHA in calculating doses. OSHA calculates a partial dose for each specified sound-pressure level at or above 80 dBA as follows [4]:

$$\frac{\text{time actually spent at sound level}}{\text{max permissible time at sound level}} \cdot$$

(from Table C.1)

The total or daily noise dose is equal to the sum of the partial doses. Sanders and McCormick go on to state, "The noise dose can then be converted to an 8-hour time-weighted average (TWA) sound level." [4] This is done by using Table C.2. "The TWA is the sound level that would produce a given noise dose if an employee were exposed to that sound level continuously over an 8-hour workday." [4] Table C.2 shows that a noise dose of 50 percent (TWA = 85 dBA) is designated as the "action level," or the point at which the XYZ Construction Company must implement a continuing, effective hearing conservation program. The program must include audiometric testing, exposure monitoring, hearing protection, employee training, and record keeping. However, Table C.2 indicates that a noise dose of 100 percent (TWA = 90 dBA), designated as the "permissible exposure level," is the point at which the employee must use feasible engineering and administrative controls to reduce noise exposure. [4]

For individuals outside of buildings or trailers, hearing protection devices are usually required. However, given the three main functions of the mini-headquarters trailer (administrative, engineering and conferencing), it is inconvenient and impractical to expect trailer occupants to wear hearing protection gear. Since it is also unrealistic to control all the noise at a construction site at the source(s) (it is assumed the construction equipment already contains dampening materials), ear protection or sound

Table C.2: Converting Noise Dose to TWA [4]

Noise Dose %	TWA, * dBA
10	73
25	80
50 (action level)	85
75	88
100 (permissible exposure level)	90
115	91
130	92
150	93
175	94
200	95
400	100

***Values are rounded to nearest decible. The exact conversion from noise, D, to TWA is given by**

$$TWA = 16.61 \log \frac{D}{100} + 90$$

attenuation must be built into the trailer itself. To this end, the standard requirement of 3.5-inches of fiberglass insulation is inserted within the exterior walls to help absorb noise and maintain internal temperatures. In addition, vinyl gypsum board walls are constructed along the interior walls in each of the three main areas, which helps to further dampen noise inside the trailer. Furthermore, the interior side of the two exit doors, as well as both sides of the doors dividing the three main trailer areas, are covered by the vinyl gypsum material for increased sound attenuation. In addition, each trailer windowpane is thicker than the industry standard for added noise dampening. While the one-time cost for such sound attenuation features is higher than the cost of non-dampening materials, the resulting benefits are considered worth the cost, which remains within the overall allocated budget. These sound attenuation efforts maintain the level of noise inside the trailer below the required 80 dBA, where human efficiency can be maximized.

Appendix D
Seat Design in the Work Environment

Introduction

This appendix contains additional details on ergonomically-designed chairs for the workplace environment. It includes design principles for proper seating with back support, and recommended design features and dimensions for a chair with back support.

Seating Effects on the Lumbar Region

Figure D.1 shows what Mandal claims are the effects of seat height, slope of the seat, and table height on the flexion of the lumbar (lower) section of the spine. [4] Mandal's preferred postures, according to Sanders and McCormick, for better lower back support are highlighted in the figure. Figure D.1 shows that the use of higher seats, forward-sloping seats, and higher tables results in less lumbar flexion. However, a word of caution: the use of higher seats must be weighed against the need to avoid excessive pressure on the underside of the thigh. The use of lower seats minimizes under-thigh pressure. Continued excessive pressure can reduce blood circulation to the lower leg. The designer will select a workbench area chair with a flexible seat and an adjustable footrest on the chair, thereby reducing lumbar flexion while at the same time minimizing under-thigh pressure.

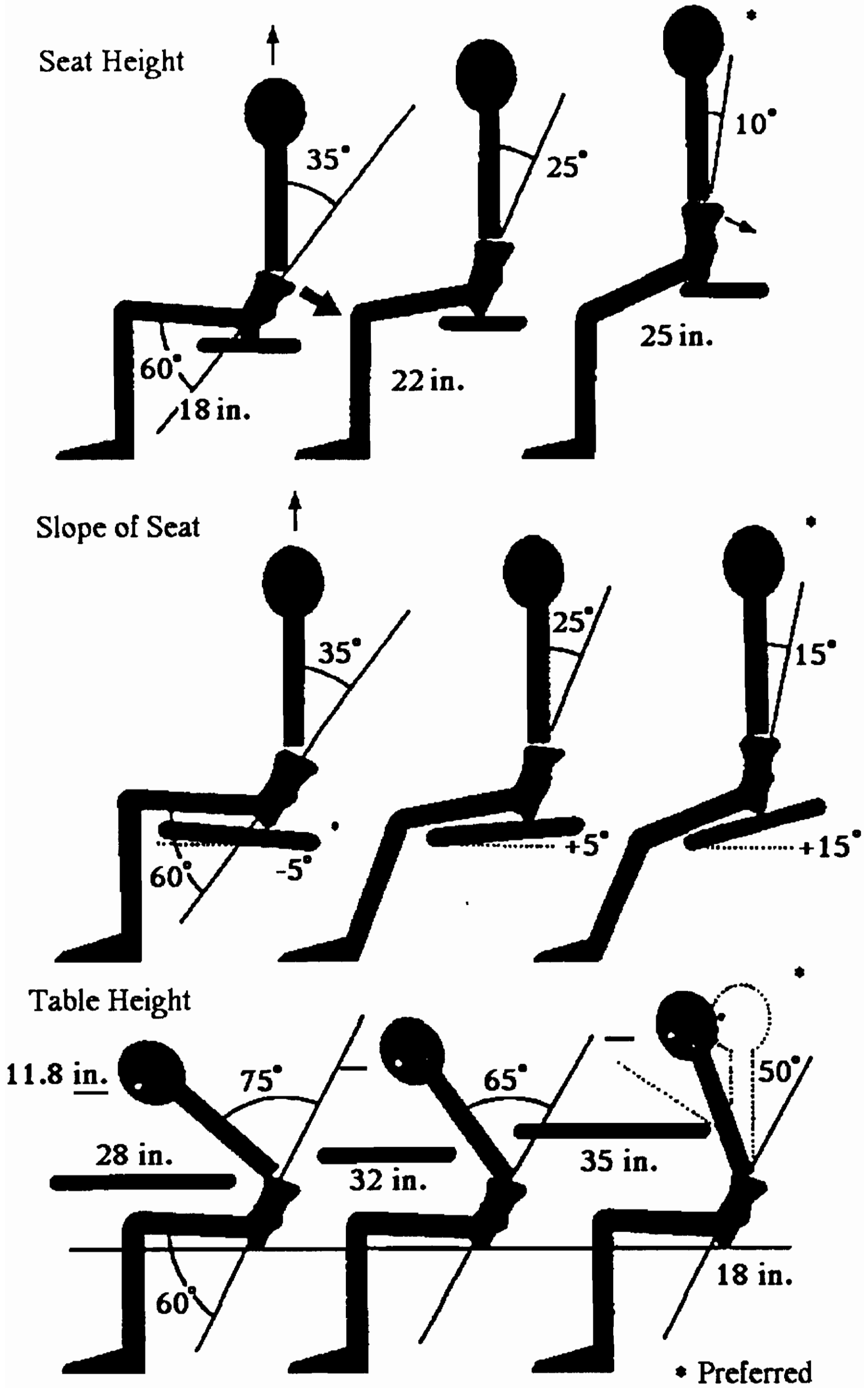


Figure D.1: Seating Effects on the Lumbar Region [4]

Seat Design Principles

Recognizing the various tasks required of the construction engineer, the seat design selected should meet a number of design principles or guidelines. Although there is no single, inflexible set of principles that applies across the board to all aspects of seating, there are a few guidelines that are recognized for supporting good posture. After all, improper design of chairs or seats can contribute to backaches and back problems, which arise from the pressures exerted by the vertebrae on the disks between them. [4] The following list summarizes a few design principles offered by Sanders and McCormick for proper seating with back support; these design features are shown in Figure D.2. [4]

1. The seat back should provide support for the lumbar area.
2. The seat back should be flexible to a moderate angle (10 to 30 degrees from the vertical).
3. The seat usually should slope back slightly to account for when the seat back is angled.
4. The angle between the seat pan and back should be between 95 and 120 degrees.
5. When feasible, the seat height and backrest should be adjustable.
6. For most multi-purpose chairs, the seat height should be set for small people (the workbench seat height in this case will be adjustable), and the seat width for large people.

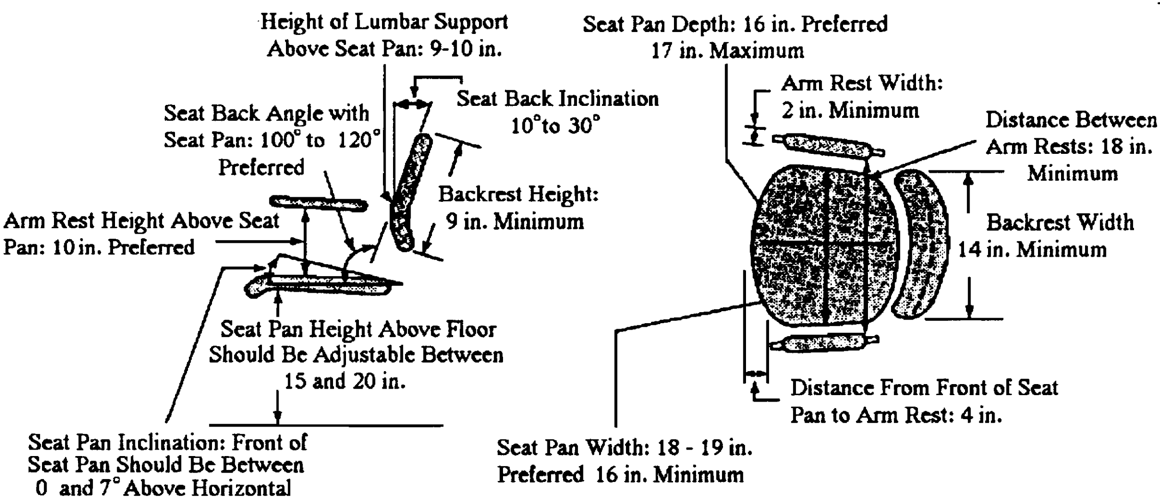


Figure D.2: Recommended Design Features and Dimensions For a Chair with Back Support [4]

7. When feasible, provide for concentration of weight on the sitting bones with decreasing weight over the entire buttocks, as by the use of a moderately contoured seat pan.

When back support is not used (as when the individual is leaning over a desk to write):

8. Minimize lumbar flexion required by the task by use of a higher and possible forward-sloping seat.

Thus, a designer will use a seat with adjustable height and an adjustable footrest on the chair. The seat pan will be able to slope back (as shown in Figure D.2) when the operator requires back support, and slope forward (as shown in Figure D.1) when the operator is seated and leaning forward over the horizontal work surface. These design considerations should prevent operator back and neck pain, as well as under-thigh pressure, yet allow flexibility to adjust to any individual height. These trailer chairs, with their built in flexibility, should accommodate both sitting and standing operators, different-sized operators, as well as provide back support and a forward leaning posture.

VITA

Linda Garcia Cubero was born on May 14, 1958 in Shreveport, Louisiana, to Air Force Major Juan and Sara Garcia. In 1976, she graduated from Chicopee Comprehensive High School in Chicopee, Massachusetts, and entered the United States Air Force Academy as one of 156 women in the academy's first class to include women. Linda graduated in 1980 (one of only 88 women to survive) with a Bachelor of Science in Political Science/International Affairs, a minor in Engineering and her military parachute wings. Linda spent the next seven years on active duty where she was awarded three Joint Service Commendation and Achievement medals for her contributions to the Defense Intelligence Agency, the Office of the Secretary of Defense and the U.S.A.F. Linda is especially proud of her contribution as Special Assistant to a Deputy Assistant Secretary of Defense; she supervised the development of a U.S. Commemorative stamp honoring Hispanics in America's defense. The stamp was designed by Hispanic Congressional Medal of Honor recipients and unveiled by former President Reagan at the White House.

After resigning from the U.S.A.F. in 1987, Linda joined General Electric as a Senior Systems Engineer. She currently is a Program Manager in Reston, Virginia. In 1986, Linda married Frank Cubero, Jr., an employee with the U.S. Department of Housing and Urban Development (HUD). They reside in Falls Church, Virginia, with their three-year-old daughter, Jennifer Ashley.