A WORKPLACE DESIGN EXPERT SYSTEM

by

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CHAPTER I

INTRODUCTION

Scope

The field of ergonomics is rapidly becoming a key area of interest to employers who are concerned with providing a comfortable, safe, and pleasant working area for their employees as well as for themselves. The interest in applying ergonomic principles to industrial workplaces is most likely a result of recent correlations made between the design of a workplace and employee health or productivity (Tichauer 1975, Konz 1979, Grandjean 1982). However most companies do not possess the expertise necessary for applying ergonomic principles to the design of workplaces. Even with the abundance of reference material available, most facility engineers find it difficult to develop a proficiency in defining the work classification, analyzing the task requirements, quantifying the work force population, and finally coming up with an ergonomically sound workplace design. While theoretical research needs to continue, a practical method of putting the present knowledge to use is also important. The intention of this research is to develop a computer program called an expert system which will provide practical proficiency or expertise for the workplace designer.

Expert system technology is an application of a branch of artificial intelligence research concerned with developing programs that use symbolic knowledge to simulate the behavior of human experts. Professor Edward Feigenbaum (1977) of Stanford University, one of the leading researchers in expert systems, has defined an expert system as:

> ... an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. Knowledge necessary to perform at such a level, plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners of the field.
>
> The knowledge of an expert system consists of facts and heuristics. The "facts" constitute a body of information that is widely shared, publicly available, and generally agreed upon by experts in a field. The "heuristics" are mostly private, little discussed rules of good judgment (rules of plausible reasoning, rules of good guessing) that characterize expert-level decision making in the field. The performance level of an expert system is primarily a function of the size and the quality of a knowledge base it possesses.

Feigenbaum calls those who build knowledge-based expert systems "knowledge engineers" and refers to their technology as "knowledge engineering." Expert systems are knowledge-intensive computer programs with the following dimensions: expertise, symbol manipulation, uncertainty, complexity, reasoning, and explanation. They use rules of thumb, or heuristics, to focus on the key aspects of a particular problem, manipulate symbolic descriptions of the problem, and apply reasoning to the knowledge they have been given concerning the problem, to reach a conclusion. They often consider a number of competing hypotheses simultaneously, and frequently make tentative recommendations or assign weights to alternatives.

Current expert systems are confined to well-circumscribed tasks. They are not able to reason over a broad field of expertise. They cannot reason from axioms or general theories. They do not learn and, thus they are limited to using the specific facts and heuristics that they were "taught" by a human expert. They lack common sense, they cannot reason by analogy, and their performance deteriorates rapidly when problems extend beyond the narrow task they were designed to perform. On the other hand, knowledge systems do not display biased judgments, nor do they jump to conclusions. They always attend to details, and they always systematically consider all of the possible alternatives (Harmon and King 1985).

It is reasonable, then, to consider developing an expert system to assist facility engineers in the design of industrial workplaces. Workplace design is a problem domain relatively narrow enough, yet unstructured and uncertain enough to merit development of a dedicated expert system. Workplace design literature offers many guidelines and principles to the potential designer but there are no clear-cut procedures designed for direct application in an industrial setting. A workplace design expert system has the potential to utilize guidelines from the literature, borrow experience from a human expert, and apply this knowledge in a practical sense.

The progress of this project was aided by reference material (Hertzberg 1972, Ayoub 1973, Konz 1979, Grandjean 1982) and the advice of Professor M. M. Ayoub, an experienced workplace design expert.

Review of Previous Research

In order to proceed with the development of a workplace design expert system, an extensive review of previous research in the areas of both expert systems and workplace design is appropriate. The following sections will summarize previous research in these two areas, respectively.

Expert Systems

As World War II ended, separate groups of British and American scientists were working to develop what is now called a computer. Each group wanted to create an electronic machine that could be guided by a stored program of directions and made to carry out complex numerical computations. The principal British scientist, Alan Turing, argued that such a general-purpose machine would have many different uses. Turing argued that the fundamental instructions given to such a machine ought to be based on logical operators, such as "and," "or," and "not." These general operators could then be used to assemble the more specialized numerical operators needed for arithmetic calculations. Moreover, programs based on logical operators would be capable of manipulating any type of symbolic material that one might want to work with, including statements in ordinary language.

The more practical American scientists, knowing the machine was going to be expensive to build and assuming they would not build very many, decided against using logical operators. They were confident they were building a machine that would do only arithmetic calculations; therefore, they chose to use numerical operators, such as "+", "-", and ">". This decision, which the British subsequently followed as well, resulted in large computers that are essentially very fast calculating machines.

Until very recently, the decision to use numerical operators seemed like a reasonable one to most people involved with computers. However, a small group of computer scientists continued to explore the ability of computers to manipulate non-numerical symbols. At the same time, psychologists concerned with human problem solving sought to develop computer programs that would simulate human behavior. Over the years, these people have formed the interdisciplinary subfield of computer science called artificial intelligence (AI). AI researchers are concerned with developing computer systems that produce results that would normally be associated with human intelligence (Harmon and

King 1985).

The applied side of artificial intelligence research includes the areas of natural language processing, robotics, and expert systems. The latter has enjoyed much success in recent years and initiated a rush to find practical applications for this new technology. Table 1 presents an overview of the key events in the history of artificial intelligence with particular attention focused on expert systems research.

The earliest acknowledged expert system, DENDRAL, is a chemistry expert system designed to examine a spectroscopic analysis of an unknown molecule and predict the molecular structures that could account for that particular analysis. In 1964, Joshua Lederberg, a Nobel prize-winning chemist, developed the DENDRAL algorithm. In 1965, with the aid of Edward Feigenbaum and Bruce Buchanan, the DENDRAL expert system was programmed directly in the LISP computer language (Lindsay, Buchanan, Feigenbaum and Lederberg 1980).

Probably the most well-known expert system, MYCIN, is a computer program designed to provide attending physicians with advice comparable to that which they would otherwise get from a consulting physician specializing in bacteremia and meningitis infections. MYCIN was the first large expert system to perform at the level of a human expert and to provide users with an explanation of its reasoning. MYCIN was developed at Stanford University in the mid-1970's (Buchanan

Table 1. An Overview of the Key Event in the History of Artificial Intelligence (from Harmon and King 1985)

PERIOD	KEY EVENTS
Pre-World War II	Formal Logic Cognitive Psychology
The Postwar Years 1945-1954 Pre-AI	Computers Developed N. Wiener, "Cybernetics" A.M. Turing, "Computing And Intelligence"
The formative years, 1955-1960 Initiation of AI	Information processing Language I Dartmouth Seminar on AI,1956 General Problem Solver (GPS)
The years of development, 1961-1970 Search for general problem solvers	LISP Heuristics Robotics Chess programs Dendral (Stanford)
The years of specialization, 1971-1980 Discovery of knowledge based systems	MYCIN (Stanford) Hearsay II (Carnegie-Mellon) MACSYMA (MIT) EMYCIN (Stanford) PROLOG
Rush to applications 1981- International competition and commercialization	PROSPECTOR (SRI) Japan's Fifth-Generation Project E.Fergenbaum, "The Fifth Generation" INTELLECT (AIC)

and Shortliffe 1984).

A line of expert system development beginning with SAINT (Slagle 1961) culminated with MACSYMA. The design for MACSYMA was originally laid out in 1968 by Carol Engleman, William Martin, and Joel Moses at MIT and has been under continual development since 1969. MACSYMA performs differential and integral calculus symbolically and excels at simplifying symbolic expressions. It incorporates hundreds of rules, each of which expresses one way to transform an expression into an equivalent. The solution to any problem requires finding a chain of rules that transforms the original expression into one that is suitably simplified (Martin and Fateman 1971).

HEARSAY was developed to demonstrate the possibility of a speech-understanding system. Development began in the late 1960's at Carnegie-Mellon University. By the time the HEARSAY II project was finished in 1975, a system had been developed that could deal with a limited amount of spoken grammar and a vocabulary of about 1,000 words. HEARSAY II demonstrated the clear superiority of symbolic, heuristic methods over statistical methods in dealing with problems involving meaning (Erman et al. 1980).

PROSPECTOR was developed in the late 1970's at Stanford Research Institute, International by a team that included Peter Hart, Richard Duda, R. Reboh, K. Konolige, P. Barrett, and M. Einandi. The development of PROSPECTOR was funded by the U.S. Geological Survey and by the National Science Foundation. PROSPECTOR was designed to provide consultation to geologists in the early stages of investigating a site for ore-grade deposits. The program informs users of possible data interpretations and identifies additional geological observations that would be valuable to reach a more definite conclusion (Duda and Reboh 1984).

PUFF was built in 1979 using the EMYCIN knowledge system building tool at Stanford University. PUFF was designed to interpret measurements from respiratory tests administered to patients in a pulmonary function laboratory. PUFF interprets a set of test results and produces a written statement that includes a set of interpretations and a diagnosis for the patient (Aikens, 1984).

Recent systems built since 1980 are mostly commercial systems and include the following: XCON (RI) and XSEL--knowledge systems that help configure computer systems for clients, GENESIS--a package of systems that help molecular geneticists plan DNA experiments, DELTA/CATS--an expert system that aids locomotive maintenance personnel, and DRILLING ADVISOR--an expert system that helps oil rig supervisors to solve problems.

There are many tools available commercially to help build expert systems. Most tools provide an inferencing mechanism along with the means for the user to enter his knowledge base. Some tools provide help screens and debugging utilities. A list of some of the current expert system development tools include: EXPERT, KES, OPS5, S.1, TIMM, ART, KEE, LOOPS, ES/P ADVISOR, Expert Ease, INSIGHT, M.1, and Personal Consultant.

Most expert systems fall into ten generic categories of knowledge engineering applications. These ten categories, presented in Table 2, are based on the types of problems that different expert systems address. The subject system of this thesis falls into the Design-type category.

Workplace Design

Interest in industrial workplace design can be traced back to the 1880's when Frederick Taylor and Frank and Lillian Gilbreth began their work with time and motion studies. The primary objective of their work involved measuring and improving worker productivity. Consequently, they recognized the importance of workplace design, but they did not recognize its full importance. Das and Grady (1983) recognize the following five objectives in designing industrial workplaces:

1. Measure and improve worker productivity;
2. Enhance worker satisfaction and job attitudes;
3. Reduce operator fatigue;
4. Improve working environments;
5. Minimize worker safety hazards.

TABLE 2: Ten Generic Categories of Expert Systems (from Hayes-Roth et al. 1983)

CATEGORY	PROBLEMS THEY ADDRESS
INTERPRETATION	Inferring situation descriptions from sensor data
PREDICTION	Inferring likely consequences of given situations
DIAGNOSES	Inferring system malfunctions from observables
DESIGN	Configuring objects under constraints
PLANNING	Designing actions
MONITORING	Comparing observations to plan vulnerabilities
DEBUGGING	Prescribing remedies for malfunctions
REPAIR	Executing a plan to adminiter a prescribed remedy
INSTRUCTION	Diagnose, debug, and repair student behavior
CONTROL	Interpret, pred., repair, and monit. syst. behavior

Maynard (1934) proposed two general concepts of industrial workplace design. The first concept was to reduce all motions used in the performance of the task to the lowest possible class. He defined five general classes ranging from the highest: finger, wrist, forearm, upper arm, and body motion to the lowest class which involved only finger motion. Maynard's second concept was to define the normal and maximum work areas in the horizontal and vertical planes. The normal working area in the horizontal plane was determined by arcs drawn with a sweeping motion of the arms. Only the forearms were extended, and the upper arms hung at the sides of the body. The maximum horizontal work area was determined in a similar fashion with the arms fully extended. The normal work area in the vertical plane included the area defined by arcs in the sagittal plane drawn by the forearms hinged at the elbows. Similarly, the maximum vertical work area was determined by drawing arcs with the arms fully extended and hinged at the shoulders. The workplace layouts provided by Maynard were dimensionless and, therefore, of little use to a designer until Barnes (1940) applied dimensions to Maynard's layouts.

Woodson and Conover (1964) recommended that anthropometric measurements of the largest worker should be used to determine workplace clearances, while those of the smallest worker should be used to determine limits of reach. They also cautioned the designer to make allowances for clothing, which add to the clearance requirements and cause restriction of movement.

Konz (1967) conducted an experiment to investigate the effects of work surface heights on performance. Konz concluded that the best working height for a standing operator is about 2.5 cm below the elbow. Ayoub (1973) recommended work surface heights for the standing and seated operator as a function of the work classification. He proposed three classifications of standing work and four classifications of seated work. Grandjean (1982) has made similar work surface height recommendations.

In order to design a successful industrial workplace, Ayoub (1973) encouraged designers to follow ten ergonomic guidelines:

1. Reduce the static component of work.
2. Do not overload the muscular system.
3. Strive to achieve the best mechanical advantage.
4. Eliminate extreme positions of the joints.
5. Reduce unusual and stressful postures.
6. Maintain a good seating arrangement.
7. Permit change of posture on the job.
8. Accommodate large operators and give them enough space.
9. Train the operator to use the facilities.
10. Match operator capacities with the job demands.

In addition, Ayoub et al. (1982) examined the situations in which the operator should sit at the workplace, stand at the workplace, or alternately sit and stand at the workplace.

A. Seating is recommended at the workplace when:

(1) All items needed in the short-term task cycle can be easily supplied and handled within the seated workspace.

(2) The items being handled do not require the hands to work at an average level of more than 15 cm above the work surface.

(3) No large forces are required, such as handling weight greater than 4.5 kg.

(4) Fine assembly or writing is done for a majority of the shift.

B. Standing is recommended at the workplace when:

(1) The workplace does not have knee clearance for a seated operator.

(2) Objects weighting more than 4.5 kg are handled.

(3) High, low, or extended reaches, such as those in front of the body, are required frequently.

(4) Operations are physically separated and require frequent movement over a large area.

(5) Downward forces must be exerted, as in packing and wrapping operations.

C. Sit/Stand workplaces are considered in these instances:

(1) Repetitive operations are done with frequent reaches more than 41 cm forward and/or more than 15 cm above the work surface.

(2) Multiple tasks are performed, some best done sitting and others best done standing.

CHAPTER II

SYSTEM CONCEPTUALIZATION

In order to conceptualize a complex, knowledge-based workplace design system one must establish many design goals and ideals. In the case of the subject workplace design system, goals and ideas were chosen to outline the system's potential functionality, usability, and accuracy. Developing the ideal workplace design system would involve hardware, expertise, time, and resources beyond the scope of a master's thesis project; however, the aim of this project is to conceptualize an ideal system and outline the procedures required to develop the system. After performing the essential research and ground work required to begin development of the system, a subset of the conceptualized system was selected for prototyping. The working prototype can be tested and can serve as a basis for further research and development toward the completion of the ideal system.

System Components

The conceptualized workplace design system referred to above consists of three main components. These components are independent in a sense that they are not all necessary to build a workplace design system; yet the integration of all three components will provide the optimum environment for development of the ideal system. The three system components are listed below.

1. Intelligent Software
2. Symbolic Processing Hardware
3. Interactive Graphic Interface

The intelligent software component of the system ensures that, during the design phase, the user adheres to accepted ergonomic concepts and principles. The software's functionality and interactiveness are such that even a novice unfamiliar with workplace design criteria can use the system and achieve optimum results. The inherent intelligence of the software aids the user in solving problems requiring human judgment, experience, reasoning, and/or expertise.

The intelligence of the software lies in the set of knowledge-based rules contained in the system. These rules allow the system to reason and to "think" like an expert in the field of workplace design. The system can interact with the user, make conclusions during the consultation session, and respond by providing an ergonomically sound workplace design. In addition, the system can justify the design for the user by recalling the internal knowledge that the conclusions were based on.

The software acts as an aid to the workplace design engineer. By modeling the engineer's particular workplace characteristics and associated constraints, the software can provide expert advice early in the design phase. The advice can range from suggestions to increase mechanical advantage to an actual layout drawing of the proposed workplace facility. Use of the system will ensure that ergonomic problems do not arise during the workplace implementation phase. This intelligent consulting service can not only save design time, but it can save money by eliminating design errors.

The second component of the ideal workplace design system is symbolic processing hardware. This type of computer hardware enables optimum, efficient functioning of intelligent software coded in symbolic languages such as LISP or PROLOG. Conventional computers excel at problems that can be expressed in numerical terms and which lend themselves to repetitive, algorithmic solutions. However, traditional computing has not been effective in dealing with unstructured problems, interpreting information, using rules of thumb gained by experience, or dealing with uncertain or incomplete information. Symbolic processing is a technique that has been developed to address these problems. It refers to the utilization by computers of information and knowledge represented by symbols, analogous to the way humans reason with knowledge they possess.

The special features that set symbolic processing computers apart from conventional computers typically include a dedicated processor designed to optimize execution of symbolic code, large virtual address space, large amounts of physical memory, a high-resolution graphics display, and a high-performance mass storage device. Symbolic processing hardware might be customized for the ideal workplace design system by reducing some of the knowledge sets to microchips, which might be inserted in the system's hardware. This would increase the speed and efficiency of the system.

At present, no computer system exists that could be easily customized as a dedicated workplace design system. However, there are now computer systems available that utilize symbolic processing technology. Some of these systems include the Texas Instruments Explorer, the Xerox 1100, the Symbolics 3600, the LMI Lambda, and the Apollo system.

An interactive graphic interface is the third component of the ideal workplace design system. Conceptually, this device enables a graphic interactivity between the system and the user. The primary graphic output of the system is a dimensioned drawing of the workplace layout. A side view, a top view, and a three-dimensional representation showing how the operator fits into the workplace facility is included. After the system has provided the initial design, the user can customize or modify the design, based on any physical constraints he may be confronting. If any significant changes are made to the design, the system responds by highlighting the problem areas such as reduced thigh clearance or reduced knee clearance. The severity of the problem is noted graphically and any consequential reduction in the accommodated work force population will be indicated.

The Context Tree

The conceptualized ideal system can be pictured as a tree of interlocking knowledge sets or contexts. Texas Instruments (1985) defines a context as a structural unit used to separate the information in a knowledge base according to main concepts or parts. If a knowledge base is thought of as a file cabinet full of information pertaining to one subject area or domain, the contexts are the drawers that are organized according to major divisions of information. Contexts have parameters associated with them that store pieces of information used in the knowledge base. A special set of parameters, called goals, is attached to each context. After the values of all the goal parameters have been found, the context is exited.

The context tree for the conceptualized workplace design system is presented in Figure 1. In a context tree a parent context is the context one level higher than the child context. The parent context of the subcontext entitled Physiological Design is the subcontext entitled Biomechanical Design. The root context, Dimensional Design, has no parent. The context called Other Ergonomic Considerations has no child context but has the root context as its parent. A context's ancestors include all the contexts that are in the direct line to the root context and including the

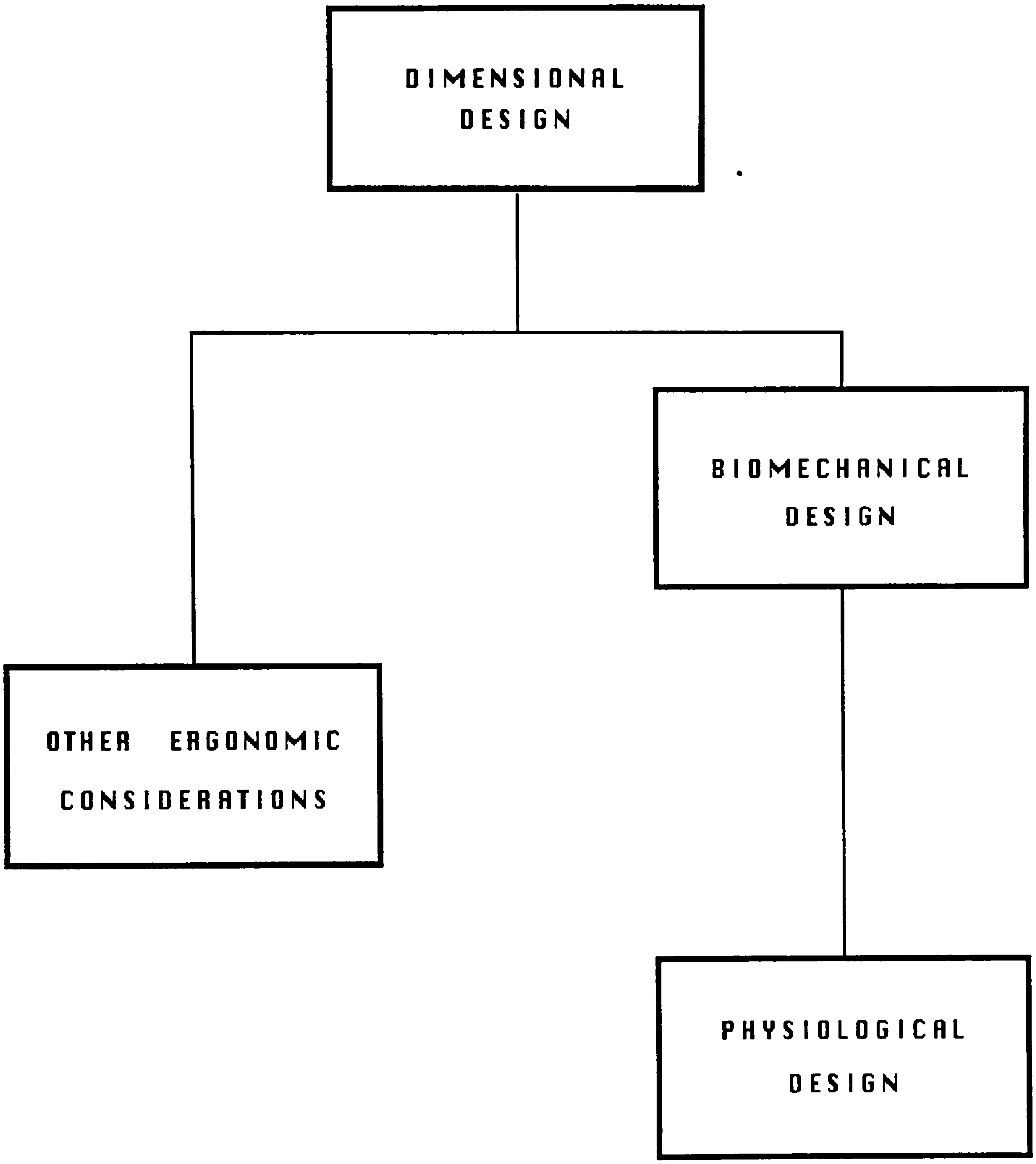

FIGURE 1. The Context Tree

root context. A child context automatically inherits all the parameters of its ancestor contexts. When a context inherits the parameters of another context, it means that it can share the use of those parameters with the other context.

The root context, Dimensional Design, has many goal parameters associated with it. These include the type of workstation, the work surface height range, the chair height range, the footrest height range, the normal and maximum vertical reach, and the normal and maximum horizontal reach. In order to ascertain these values the system uses information such as the defined work force population, anthropometric measurements from that population, the classification of the work to be performed at the workplace, the physical constraints of the workplace, and the mathematical model developed by the author.

The Biomechanical Design context more closely examines the dynamic components of the work. Factors such as the number of objects to be handled, object size, object weight, frequency of lift or movement, vertical or horizontal distance of movement, and distance between the object and the body are analyzed in this context. Goals for this context include the acceptable production rate at the workplace, the efficient arrangement of objects within the workplace, and any restrictions on the work force pertaining to operator fitness, muscular strength, or age. (An expert system that analyses manual lifting tasks has been developed by Karwowski et al. [1985].) The purpose of this context is to provide optimum mechanical advantage for the operator and to ensure that he is in no immediate danger of over-exertion, injury, or disability.

The Physiological Design context examines the energy requirements of the task to be performed at the workplace. Based upon a description of the motion components of the task and information gained from ancestor contexts, this context calculates the net energy requirements of the task in kilocalories per minute. Several models (Garg et al. 1978, Asfour 1980) have been developed that enable this type of analysis. An evaluation of worker capacity is also included in this context. The user can rely on the internal physiological capacity data base (Astrand 1977) or he can enter data collected from his specific work force population. The goal parameters for this context include the expected endurance time at this task, the required resting time, and the recommended number of rest periods for an eight hour shift.

The final context, Other Ergonomic Considerations, is designed to provide informational guidelines that should be followed during the workplace design and implementation phases. This context provides guidelines concerning design of the interface between the operator and the workplace. Advice about the machine controls, displays, warning indicators, and other ergonomic and safety factors are presented. In addition, this context is knowledgable in national and international safety standards regarding the handling of toxic, hazardous, or radioactive materials; heat stress; cold stress; noise; lighting; and vibration.

System Prototype

After conceptualization of the ideal workplace design system, a subset of the system was selected for prototyping. Neither the equipment nor the expertise to customize symbolic processing hardware or to design an interactive graphic interface device was immediately available. Therefore, it was decided that development of the system's intelligent software would be pursued. This pursuit was aided by the availability of a Texas Instruments Portable Professional Computer and the Personal Consultant Expert System Development Tool. The system's root context, Dimensional Design (as shown in Figure 1), was the subset selected for prototyping. Subsequent chapters of the thesis describe the data that was used, outline the knowledge engineering activities that were performed, and detail the development of the prototype knowledge base and the use of its inference engine.

CHAPTER III

KNOWLEDGE ENGINEERING

Knowledge engineering is perhaps the most important phase of developing an expert system. Knowledge engineers acquire knowledge from a human expert and other sources and then embed that knowledge in an expert system. The process of knowledge engineering involves knowledge acquisition and knowledge representation. Knowledge is acquired through an extensive interview with a human expert to determine the thought processes he has when he solves a problem in the defined domain. Knowledge is represented by modeling those thought processes in the form of a knowledge base which in turn can be used by an inference engine to artificially reach the same solutions. This chapter describes the knowledge engineering procedures that were used to develop a workplace design expert system.

Knowledge Acquisition

The primary source of knowledge was Professor Ayoub, an experienced workplace design expert. In order to acquire his knowledge, it was necessary to discuss his methods of approaching an industrial workplace design project. Interview questions were designed to establish the initial data that is required to begin a design project and what the output of such a project should consist of. In addition, example design projects were presented to Professor Ayoub so that he could apply his expertise to these problems and reach satisfactory solutions. His knowledge and thought processes were examined in a step by step fashion as he made intermediate conclusions in solving the example projects.

It is most helpful to have the human expert state his knowledge and thought processes in the form of IF/THEN statements. Consequently, the expert's knowledge can be acquired in a systematic, logical manner. If the expert's knowledge is acquired in this manner, it is relatively easy to represent his knowledge in a dynamic knowledge base that can be utilized by the inference engine.

It was established that anthropometric measurements from the population to be accommodated at the workplace are the most important initial data required to begin a design. In addition, the classification of the work to be performed at the workplace is important, whether it is precision work, light work, heavy work, or VDT/keyboard operation. In order to establish what type of workstation to design (sit, stand, or sit/stand combination) it is necessary to find out if the operator is required to use foot controls, if he is required to cover a large work area, and to specify his reach requirements in terms of distance and frequency. Finally, it is important to decide what range of operators will be accommodated at the workplace. It is decided that a realistic goal of a workplace design expert system is to design for a range that would accommodate the U. S. industrial population from the 5th to the 95th percentiles, unless the design is restricted by physical constraints or specific anthropometric measurements entered by the user.

Knowledge Representation

Once the workplace design knowledge had been acquired it was necessary to represent the knowledge in a usable form. Thought processes were modeled by logical rules called modus ponens rules. The application of these rules is such that when A is known to be true and if a rule states, "If A, then B," it is valid to conclude that B is true. Stated differently, when we discover that the premises of a rule are true, we are entitled to believe the conclusions. Modus ponens is the basic inferencing strategy used by most expert systems.

In addition, most expert systems apply these rules to knowledge represented as object-attribute-value (O-A-V) triplets. In the case of the workplace design expert system, the object is the root context, Dimensional Design. Attributes are equivalent to parameters. An example of a parameter might be Chair-Height. Values are the text or numerical denotations assigned to parameters. For example, the parameter, Chair-Height, might have the value 49.5 centimeters. O-A-V triplets are used to store information in a knowledge base, while rules are used to infer conclusions from the knowledge base.

In order to represent the knowledge required to make a decision on what type of workstation to design, the set of rules presented in Table 3 were developed. The outcome of a rule depends on the value of the work classification parameter, the foot controls parameter, and the large work area parameter. In general, the aim of this set of rules is to conclude the workstation type as a sit/stand combination unless restricted by one or more of the premise parameters.

The knowledge required to determine the physical dimensions of the workplace is represented by another set of rules. In order to discuss these rules, the following parameters must be defined.

Goal Parameters:

WSU - the upper work surface height;

WSL - the lower work surface height;

CHU - the upper chair height;

CHL - the lower chair height;

FRU - the upper footrest height;

FRL - the lower footrest height;

NVR - the normal vertical functional reach;

MVR - the maximum acceptable vertical reach;

NHR - the normal horizontal functional reach;

MHR - the maximum acceptable horizontal reach;

Other Parameters:

SHOULDER5 - the smallest standing shoulder height;

TABLE 3. Rules for Determining the Workstation Type

IF:			THEN:
Work-Class	Foot-Controls	Large-Area	Station-Type
Precision	yes	yes	Sit/Stand
Precision	yes	no	Sit
Precision	no	no	Sit/Stand
Precision	no	yes	Sit/Stand
Light-Work	yes	yes	Sit/Stand
Light-Work	yes	no	Sit
Light-Work	no	no	Sit/Stand
Light-Work	no	yes	Sit/Stand
Heavy Work	yes	yes	Sit/Stand
Heavy Work	yes	no	Sit/Stand
Heavy Work	no	no	Stand
Heavy Work	no	yes	Stand
VDT/Keyboard	yes	yes	Sit/Stand
VDT/Keyboard	yes	no	Sit
VDT/Keyboard	no	no	Sit
VDT/Keyboard	no	yes	Sit/Stand

SHOULDER95 - the largest standing shoulder height;

SITTING-SHOULDER5 - the smallest dimension from buttocks to shoulder;

BODY-DEPTH95 - the largest body depth dimension;

THIGH-WIDTH5 - the smallest thigh clearance dimension;

THIGH-WIDTH95 - the largest thigh clearance dimension;

FOREARM5 - the smallest forearm length;

ARM5 - the smallest arm length;

ELBOW5 - the smallest standing elbow height;

ELBOW95 - the largest standing elbow height;

SITTING-ELBOW5 - the smallest dimension from buttocks to elbow;

SITTING-ELBOW95 - the largest dimension from buttocks to elbow;

POPLITEAL5 - the smallest popliteal height;

POPLITEAL95 - the largest popliteal height;

C1 - correction factor applies to a Sit work surface;

C2 - correction factor applies to Stand or Sit/Stand work surfaces.

The aim of the following set of rules is to accommodate the entire workforce population range at the workplace. It must be kept in mind that an operator with the smallest measurement for one parameter does not necessarily have the smallest measurement for the other parameters. For example, an operator might have the smallest popliteal height but the largest body-depth dimension. Therefore, these rules were developed with this knowledge in mind. The first rule applies to all workplaces.

If: STATION - TYPE = SIT OR STAND OR SIT/STAND

Then: NHR = FOREARM5 - 1/2 (BODY-DEPTH95)

MHR = ARM5 - 1/2 (BODY-DEPTH95)

The next group of rules apply to fully adjustable workplaces in which the work surface height, chair height, and footrest height are all adjustable.

If: STATION-TYPE = SIT

Then: WSU = POPLITEAL95 + SITTING-ELBOW95 + C1

WSL = POPLITEAL5 + SITTING-ELBOW5 + C1

CHU = POPLITEAL95

CHL = POPLITEAL5

FRU = CHU - POPLITEAL5

FRL = 0

NVR = CHL + SITTING-ELBOW5 + FOREARM5

MVR = CHL + SITTING-SHOULDER5 + ARM5

If: STATION-TYPE = STAND

Then: WSU = ELBOW95 + C2

WSL = ELBOW5 + C2

CHU, CHL, FRU, FRL = NONE

NVR = ELBOW5 + FOREARM5

MVR = SHOULDER5 + ARM5

If: STATION-TYPE = SIT/STAND

Then: WSU = ELBOW95 + C2

WSL = ELBOW5 + C2

CHU = ELBOW95 - SITTING-ELBOW5

CHL = ELBOW5 - SITTING-ELBOW95

FRU = CHU - POPLITEAL5

FRL = 0

NVR = ELBOW5 + FOREARM5

MVR = SHOULDER5 + ARM5

The next group of rules apply to workplaces in which the chair height is fixed. These rules enable the design of a workplace that includes a chair with no height adjustment feature. In order to accommodate the entire range of operators, the work surface height and the footrest height must be adjustable. Since the chair height is stationary, the CHU parameter will hold the value for the fixed chair height and the CHL parameter will be neglected.

If: STATION-TYPE = SIT

Then: CHU = POPLITEAL95

CHL = NONE

WSU = CHU + SITTING-ELBOW95 + C1

WSL = CHU + SITTING-ELBOW5 + C1

FRU = CHU - POPLITEAL5

FRL = 0

NVR = CHU + SITTING-ELBOW5 + FOREARM5

MVR = CHU + SITTING-SHOULDER5 + ARM5

If: STATION-TYPE = STAND

Then: CHU, CHL = NONE

WSU = ELBOW95 + C2

WSL = ELBOW5 + C2

FRU, FRL = NONE

NVR = ELBOW5 + FOREARM5

MVR = SHOULDER5 + ARM5

If: STATION-TYPE = SIT/STAND

Then: CHU = ELBOW95 - SITTING-ELBOW5

CHL = NONE

WSU = CHU + SITTING-ELBOW95 + C2

WSL = CHU + SITTING-ELBOW5 + C2

FRU = CHU - POPLITEAL5

FRL = 0

NVR = ELBOW5 + FOREARM5

MVR = SHOULDER5 + ARM5

The next group of rules apply to workplaces in which the work surface height is fixed. These rules enable the design of a workplace that includes a work surface or table with no height adjustment feature. In order to accommodate the entire range of operators, the chair height and the footrest height must be adjustable. Since the work surface height is stationary, the WSU parameter will hold the value for the fixed work surface height, and the WSL parameter will be neglected. For the cases in which the workstation type is stand or sit/stand, the footrest dimensions refer to an adjustable platform on which the operator can adjust himself to the fixed work surface. Determining workplace dimensions for this group of rules is more difficult because the relative position of the elbow, buttocks, or foot must be solved for in relation to the fixed work surface.

If: STATION-TYPE = SIT

Then: WSU = POPLITEAL95 + SITTING-ELBOW95 + C1

WSL = NONE

Equating at the elbow,

CHU + SITTING-ELBOW5 = WSU - C1

and by substitution,

CHU = POPLITEAL95 + SITTING-ELBOW95 - SITTING-ELBOW5

CHL = POPLITEAL95

FRU = CHU - POPLITEAL5

FRL = 0

Equating at the elbow,

NVR - FOREARM5 = WSU - C1

and by substitution,

NVR = POPLITEAL95 + SITTING-ELBOW95 + FOREARM5

Equating at the buttocks,

MVR - SITTING-SHOULDER5 - ARM5 = CHL

and by substitution,

MVR = POPLITEAL95 + SITTING-SHOULDER5 + ARM5

If: STATION-TYPE = STAND

Then: WSU = ELBOW95 + C2

WSL = NONE

CHU, CHL = NONE

Equating at the foot,

FRU = WSU - C2 - ELBOW5

and by substitution,

FRU = ELBOW95 - ELBOW5

FRL = 0

Equating at the elbow,

NVR - FOREARM5 = WSU - C2

and by substitution,

NVR = ELBOW95 + FOREARM5

Equating at the foot,

MVR - SHOULDER5 - ARM5 = WSU - C2 - ELBOW95

and by substitution,

MVR = SHOULDER5 + ARM5

If: STATION-TYPE = SIT/STAND

Then: WSU = ELBOW95 + C2

WSL = NONE

Equating at the elbow,

CHU + SITTING-ELBOW5 = WSU - C2

and by substitution,

CHU = ELBOW95 - SITTING-ELBOW5

Similarly,

CHL = ELBOW95 - SITTING-ELBOW95

FRU = CHU - POPLITEAL5

FRL = 0

Equating at the elbow,

NVR - FOREARM5 = WSU - C2

and by substitution,

NVR = ELBOW95 + FOREARM5

Equating at the buttocks,

MVR - SITTING-SHOULDER5 - ARM5 = CHL

and by substitution,

MVR = ELBOW95 - SITTING-ELBOW95 +
SITTING-SHOULDER5 + ARM5

The next group of rules apply to workplaces in which all dimensions are fixed. These rules enable the design of a workplace that includes a work surface, chair, and footrest with no height adjustment features. Obviously, this type of design cannot accommodate the entire range of operators. Specifically, a percentage of the workforce population will be excluded from the workplace due to thigh clearance restrictions. In addition, closer examination of the previous rules indicate that possible restrictions could result depending on the thickness of the work surface. A set of rules that calculates the severity of the thigh clearance restriction will be presented after the following group of rules. Since the height dimensions of the following three rules are stationary, the WSU, CHU, and FRU parameters will hold the values for those fixed dimensions, and the WSL, CHL, and FRL parameters will be neglected.

If: STATION-TYPE = SIT

Then: WSL, CHL, FRL = NONE

WSU = POPLITEAL95 + SITTING-ELBOW95 + C1

CHU = WSU - C1 - 1/2 (SITTING-ELBOW5 + SITTING-ELBOW95)

FRU = CHU - 1/2 (POPLITEAL5 + POPLITEAL95)

NVR = CHU + SITTING-ELBOW5 + FOREARM5

MVR = CHU + SITTING-SHOULDER5 + ARM5

If: STATION-TYPE = STAND

Then: WSL, CHL, FRL = NONE

WSU = ELBOW95 + C2

CHU = NONE

FRU = WSU - C2 - 1/2 (ELBOW5 + ELBOW95)

NVR = FRU + ELBOW5 + FOREARM5

MVR = FRU + SHOULDER5 + ARM5

If: STATION-TYPE = SIT/STAND

Then: WSL, CHL, FRL = NONE

WSU = ELBOW95 + C2

CHU = WSU - C2 - 1/2 (SITTING-ELBOW5 + SITTING-ELBOW95)

FRU = CHU - 1/2 (POPLITEAL5 + POPLITEAL95)

NVR = CHU + SITTING-ELBOW5 + FOREARM5

MVR = CHU + SITTING-SHOULDER5 + ARM5

The correction factors, C1 and C2, are used to modify the work surface height based on the classification of the work to be performed at the workplace. For example, precision work requires a work surface above the elbows and closer to the eyes, while heavy work requires a work surface below the elbows to allow exertion of greater forces. The rules that determine the C1 and C2 values are listed below.

If: WORK-CLASS = PRECISION-WORK
Then: C1 = +12 cm.
C2 = +8 cm.

If: WORK-CLASS = LIGHT-WORK
Then: C1 = +5 cm.
C2 = -5 cm.

If: WORK-CLASS = HEAVY-WORK
Then: C1 = 0 cm.
C2 = -13 cm.

If: WORK-CLASS = VDT/KEYBOARD-OPERATION
Then: C1 = 0 cm.
C2 = -5 cm.

As discussed previously, the completely stationary design and the other adjustable designs present possible thigh clearance restrictions. The next set of rules determines what portion of the work force population will be excluded from the workplace due to a thigh clearance problem by calculating the approximate reduction percentage. In order to make this estimation, it is assumed that the distribution of thigh clearance measurements over the population range is normally distributed. Before these rules can be discussed, the following parameters must be defined.

TABLE-THICKNESS - vertical thickness of the work surface;

THIGH-TEST - determines the existence of a thigh clearance problem;

THIGH-CUT - severity of the restriction in centimeters;

THIGH-POP5 - the smallest thigh width/popliteal combination;

THIGH-POP95 - the largest thigh width/popliteal combination;

MU-HAT - the estimated distribution mean;

SIGMA-HAT - the estimated distribution standard deviation;

THIGH-CRITICAL - the calculated distribution Z value.

If: DESIGN-TYPE = STATIONARY, and
THIGH-WIDTH95 > (WSU - TABLE-THICKNESS) - CHU

Then: THIGH-TEST = YES

If: DESIGN-TYPE = FIXED-WORK-SURFACE, and
STATION-TYPE = SIT/STAND, and
THIGH-WIDTH95 > (WSU - TABLE-THICKNESS) - CHU

Then: THIGH-TEST = YES

If: THIGH-TEST = YES

Then: THIGH-CUT = THIGH-WIDTH95 - (WSU - TABLE-THICKNESS - CHU)

THIGH-POP5 = THIGH-WIDTH5 + POPLITEAL5

THIGH-POP95 = THIGH-WIDTH95 + POPLITEAL95

MU-HAT = 1/2 (THIGH-POP5 + THIGH-POP95)

SIGMA-HAT = (THIGH-POP95 - MU-HAT) / 1.645

THIGH-CRITICAL = THIGH-POP95 - THIGH-CUT

If: (THIGH-CRITICAL - MU-HAT) / SIGMA-HAT <= 1.645

(THIGH-CRITICAL - MU-HAT) / SIGMA-HAT > 1.28

Then: POPULATION-REDUCTION = < 5%

If: (THIGH-CRITICAL - MU-HAT) / SIGMA-HAT <= 1,28

(THIGH-CRITICAL - MU-HAT) / SIGMA-HAT > 1.035

Then: POPULATION-REDUCTION = 5-10%

If: (THIGH-CRITICAL - MU-HAT) / SIGMA-HAT <= 1.035

(THIGH-CRITICAL - MU-HAT) / SIGMA-HAT > .0675

Then: POPULATION-REDUCTION = 10-20%

If: (THIGH-CRITICAL - MU-HAT) / SIGMA-HAT <= 0.675

(THIGH-CRITICAL - MU-HAT) / SIGMA-HAT > 0.385

Then: POPULATION-REDUCTION = 20-30%

If: (THIGH-CRITICAL - MU-HAT) / SIGMA-HAT <= 0.385

(THIGH-CRITICAL - MU-HAT) / SIGMA-HAT > 0.125

Then: POPULATION-REDUCTION = 30-40%

If: (THIGH-CRITICAL - MU-HAT) / SIGMA-HAT <= 0.125

(THIGH-CRITICAL - MU-HAT) / SIGMA-HAT > 0

Then: POPULATION-REDUCTION = 40-50%

If: (THIGH-CRITICAL - MU-HAT) / SIGMA-HAT <= 0

Then: POPULATION-REDUCTION = >50%

CHAPTER IV

DEVELOPMENT OF THE SYSTEM

Once the knowledge for the Dimensional Design context was acquired and represented in rule form, it was possible to begin development of the system prototype. A personal computer-based expert system building tool was used to assist in the development of the system. The tool chosen was the Personal Consultant Expert System Development Tool. Personal Consultant is implemented in the IQLISP computer language. In other words, the inference engine and the knowledge engineer/user interfaces are coded in the underlying IQLISP language. The tool does not offer a compiler to make completed programs faster to operate. However, the existing configuration is quite adequate for the development of an expert system. Personal Consultant is composed of a development engine and an inference engine. The development engine enables the knowledge engineer to develop and maintain the knowledge base. The inference engine enables the knowledge engineer to test the knowledge base, and it enables the user to execute a consultation. The architecture of a completed expert system is presented in Figure 2.

The Development Engine

The development engine is an interactive, window-oriented interface to the knowledge engineer that helps him to build his knowledge base into an expert system. In

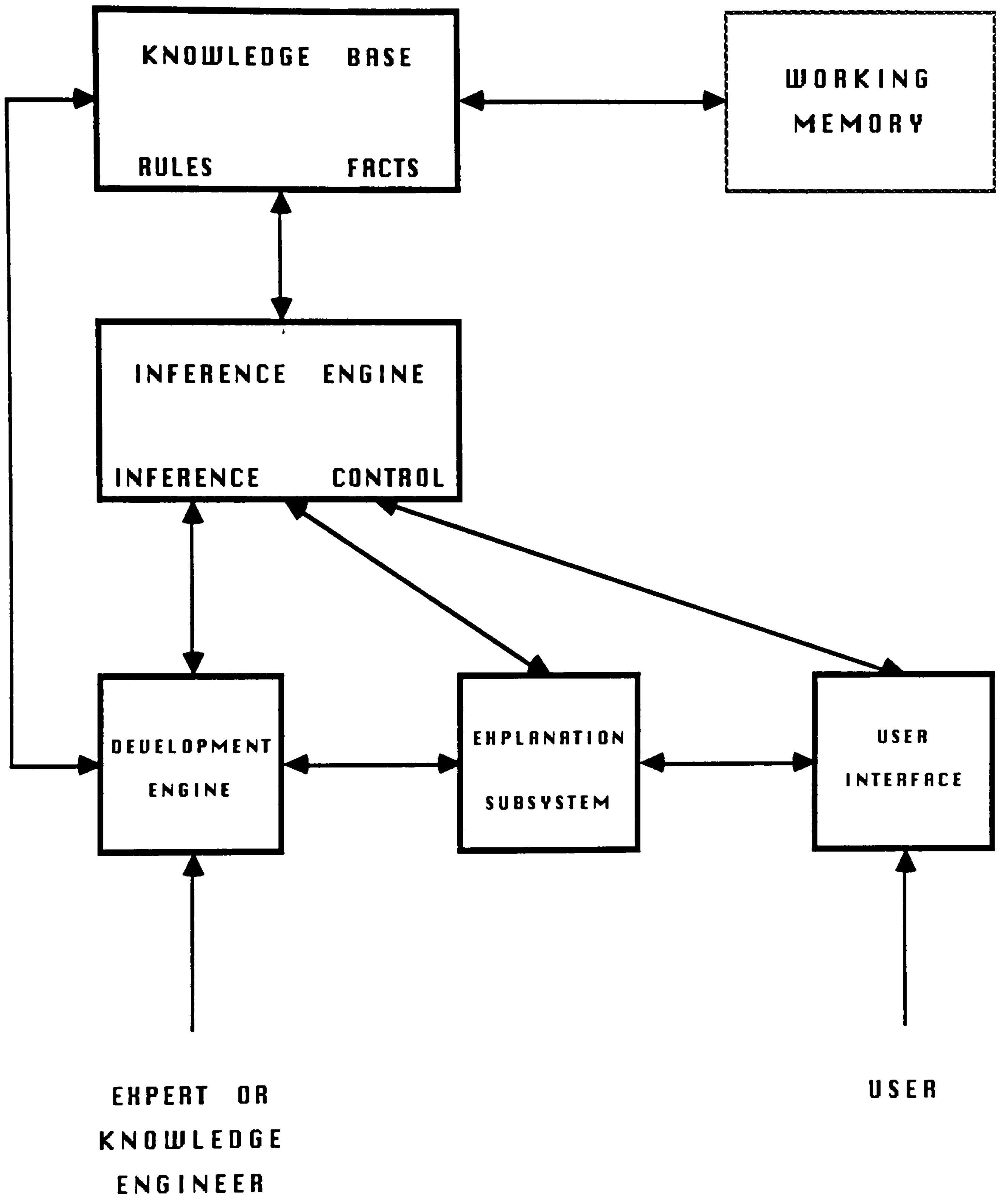

FIGURE 2. The Architecture of an Expert System (from Harmon and King 1985)

addition, the development engine's interactive structure editor allows on-line modification of an existing knowledge base. A knowledge base is entered by responding to prompts. The first prompt asks for the name of the knowledge base heading or domain. Then values for root context properties are prompted for, including a list of initial data and goal parameters. Once these parameter names have been entered, the development engine asks for information about the parameters. Next, the context tree must be described by entering the descendants of the root context. At this point, rules can be inserted into the knowledge base. Rules can be entered directly in LISP or in an Abbreviated Rule Language (ARL). ARL is a BASIC-like rule specification language that simplifies the rule specification procedure for those unfamiliar with the LISP computer language. During the definition of the rules, if a parameter name is entered that has not been specified, the development engine prompts for information about the parameter. In this manner context, parameter, and rule properties are specified by the knowledge engineer until the knowledge base is completed. Definitions of knowledge base properties are explained in Appendix A.

The main activity menu of the development engine presents a list of 13 options designed to help modify or debug a knowledge base. The first option, Go, begins a consultation with the specified knowledge base, and the second option, Quit, ends a Personal Consultant session. The third option, Lisp, allows the knowledge engineer to activate the IQLISP interpreter if he wants to write special operations to augment the knowledge base. The Parameters, Rules, Contexts, and Variables options allow properties associated with these entities to be entered or modified. The Functions option enables the knowledge engineer to define special functions written in LISP that are not immediately available in the development engine. The List option provides a complete listing of the knowledge base. The Save option writes the knowledge base to a computer file. The Trace option is a debugging utility that produces a listing of the rules applied and the parameter values used in a given consultation. The final two options, Record and Playback, are used to record a set of prompts with their respective responses from a given consultation and then use those responses in an automated session to detect changes in the logical flow of the knowledge base.

Description of the Data

A conventional computer program that accesses a data base usually stores the data in an external data file or in internal arrays. However, data used by an expert system can be inserted directly into the knowledge base with the aid of the development engine. Numerical data can be included as parameter values in rules that are needed to access the data.

The data base used by the workplace design expert system is a collection of anthropometric measurements taken from the U. S. military population (Hertzberg 1972). The data were derived on the basis of measurements from nude subjects. Therefore, the data were duly adjusted for clothing, shoe, and other allowances which were added or subtracted to the various measurements. For the standing shoulder height, 2.5 cm were added for men's and women's shoes and 1.4 cm were added for clothing. The sitting shoulder height required an additional 0.6 cm for clothing under the buttocks. 1.0 cm was added to the body depth measurement and 2.0 cm were added to the thigh width measurement for clothing allowances. For the forearm length, 7.6 cm were subtracted for thumb and forefinger manipulation. For the arm length, 5.1 cm were subtracted to account for measurement from the back of the shoulder and 7.6 cm were subtracted for thumb and forefinger manipulation. 2.5 cm were added for men's and women's shoes to the standing elbow height. No allowances were given for the sitting elbow height and 2.5 cm were added to the popliteal height for men's and women's shoes (Hertzberg 1972). The corrected anthropometric data base is presented in Table 4.

The workplace design expert system user can select the population that he wishes to accommodate at his workplace. The valid populations are male, female, and mixed. If the

TABLE 4. Corrected Anthropometric Measurements (from Hertzberg 1972, Das and Grady 1983)

PARAMETER	VALUE (cm)	
	Male	Female
Shoulder 5	138.0	127.9
Shoulder 95	156.8	146.6
Sitting-Shoulder 5	54.7	52.2
Body-Depth 95	34.0	27.6
Thigh-Width 5	14.2	12.4
Thigh-Width 95	18.5	16.5
Forearm 5	37.1	32.5
Arm 5	68.3	60.2
Elbow 5	105.6	99.0
Elbow 95	120.4	111.2
Sitting-Elbow 5	18.8	18.8
Sitting-Elbow 95	27.4	27.4
Popliteal 5	42.4	37.3
Popliteal 95	48.7	43.6

male population is chosen, 95th percentile male anthropometric measurements are used to determine clearance dimensions while 5th percentile male measurements are used to determine reach dimensions. The method is similar for the female population. If a mixed population is chosen, 95th percentile male measurements are used for clearance determinations, and 5th percentile female measurements are used to calculate the reach requirements.

Construction of the Knowledge Base

The workplace design expert system knowledge base was constructed using the development engine as described at the beginning of this chapter. The knowledge base heading property was specified to give the knowledge base a name. Henceforth, the knowledge base will be referred to by its name, "The Ergonomist."

All of the parameters used by "The Ergonomist" were defined in terms of their associated properties. See Appendix A for an explanation of knowledge base properties. A total of 41 parameters were defined for use by "The Ergonomist." All parameters belong to the parameter group called Dimensional-Design-Parms.

The workplace design knowledge represented in rule form and presented in Chapter III was entered directly into the knowledge base with the aid of the development engine. Since the knowledge was already organized as IF/THEN statements, the rules were entered with very little modification. A total of 57 rules were embedded in "The Ergonomist" and were grouped as follows: 6 Anthro-Rules, 16 Station-Type-Rules, 16 Dimensioning-Rules, 12 Thigh-Clearance-Rules, and 7 Data-Checking-Rules.

The Inference Engine

"The Ergonomist" knowledge base, when used in conjunction with the inference engine, comprises the functioning workplace design expert system prototype. The inference engine controls the expert system's reasoning process as it uses the facts and rules stored in the knowledge base, as well as the information it acquired from the user. The inference engine performs two major tasks (Harmon and King 1985). First, it examines existing facts and rules, and adds new facts when possible. Second, it decides the order in which inferences are made. In doing so, the inference engine conducts the consultation with the user.

To reach a conclusion about the goal parameters, the inference engine employs an inferencing strategy. Figure 3 presents the inferencing strategies that are utilized by various inference engines. Backward and forward chaining strategies can be utilized, as well as depth-first and breadth-first search strategies. Backward chaining inference engines, or goal-directed systems, work backward through the knowledge base in an effort to choose an answer.

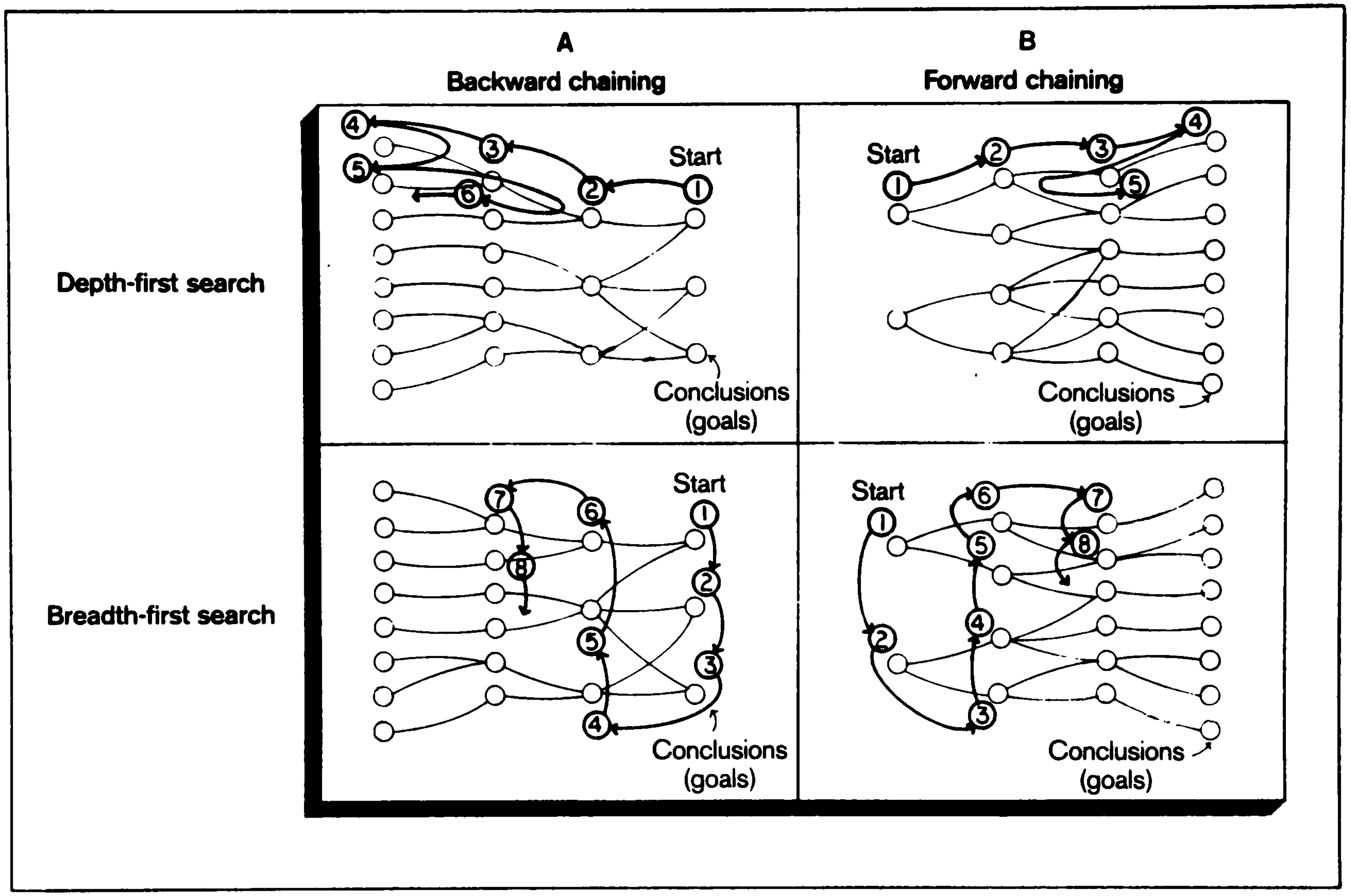

FIGURE 3. Major Categories of Search Strategies used by Inference Engines (from Harmon and King 1985)

For example, if a goal parameter is D, and there is a rule that states "if C, then D" the inference engine will attempt to ascertain the value for C. The inference engine may discover another rule that states "if A and B, then C." Then the values for A and B must be found. This is also an example of a depth-first search strategy. A breadth-first search sweeps across all of the goal parameters before digging for greater detail. In cases in which the number of possible outcomes is large, a forward chaining strategy is often used. In a forward chaining system, or data-driven system, premises of rules are examined to see whether or not they are true, given the information available at the time. If so, then the conclusions are added to the list of facts known to be true and with the new information, the system examines the rules again.

The inference engine supplied with the Personal Consultant employs a depth-first, backward chaining strategy. The inference engine controls the flow of a consultation with "The Ergonomist." Inference control is actually spread subtly throughout "The Ergonomist." since the order of clauses within a rule determines which clause is examined in what order. For example, there is a rule in the knowledge base that states, "if WORK-CLASS = PRECISION and FOOT-CONTROLS = YES and LARGE-AREA = NO, then STATION-TYPE = SIT." As a result, the inference engine tries to find answers for those three premise clauses in the order in which they appear. Therefore, a degree of inference control is contained in the rule structure.

During a consultation, the user has the ability to query the system. A help key is provided that can help clarify the meaning of a question presented to the user. If the user does not understand the meaning of a question, he can use the help key for further clarification. The resulting help message is the value of a knowledge base parameter property called reprompt. The why key is used to clarify the logic being used by the expert system. For example, if the user is presented with a question, he has the ability to ask the system why the answer to that question is needed. The system responds by listing the rule being examined for which the answer is required in order to apply the rule. Finally, the how key enables the user to view the logic that was used to determine the value of parameters already found by the expert system. Use of this key lists a chain of rules that determined the value for a selected parameter.

Sample consultations with "The Ergonomist" are presented in Appendix C. The sample consultations simulated actual workplace design projects that could be encountered in an industrial setting and solved by "The Ergonomist" expert system.

CHAPTER V

CONCLUSION

The development of a workplace design expert system that acts as an intelligent aid to workplace designers has been described. The expert system will potentially benefit facility engineers, human factors engineers, safety engineers, and industrial engineers. In addition, the system will be useful as an educational tool for students in those areas of specialization.

The expert system will be most beneficial early in the design phase of a new workplace. Potential ergonomic problems with the design can be avoided at great savings in time and money. The system ensures that the workplace is designed to fit the operator; it does not force the operator to fit the workplace. Use of the expert system to assist in the design of workplaces should reduce incidents of overexertion and injury at the workplace. This result will in turn reduce compensation expenditures and avoid man hour losses.

In addition to designing new workplaces, the expert system has the potential to evaluate existing workplaces. After the user has responded to questions asked about the existing workplace, the system will provide a description of what the workplace characteristics should be. Comparisons can be made to the existing workplace and necessary modifications can be identified. The system can be used iteratively to evaluate all existing workplaces in an industrial plant.

The effort that went into the completion of this thesis project serves as a foundation for further research and development. "The Ergonomist" is a prototype of the ideal workplace design system conceptualized in Chapter II. As better expert system building tools and symbolic processing hardware become available, the development of a workstation dedicated to the design of industrial workplaces will become a reality.

The expert system development tool used to create "The Ergonomist" has many useful features; however, there are areas that need improvement. The tool does not permit the use of complex rules premises. For example, a rule premise such as "if A and (B or C or D)" is not valid. Premises must contain all "ands" or all "ors." In addition, it would be desirable to be able to use other logical operators such as "not," "nand," and "nor" which are not recognized by the tool. The tool does not provide a means for using a graphic user interface. It would be highly desirable to provide a graphical output of the finished workplace design. In addition, the meaning of certain questions asked by "The Ergonomist" could be clarified with graphics. For example, if the user is asked to enter the popliteal height measurement, a graphic screen could indicate how this measurement should be taken on the image of an anatomical manikin.

"The Ergonomist" expert system has yet to undergo extensive testing in industry. Only the direct application of this system over an extended period of time will prove whether the system is beneficial in avoiding ergonomic problems and reducing injury at the workplace.

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APPENDIX A

DEFINITION OF KNOWLEDGE BASE PROPERTIES

This appendix contains explanations of the concepts and terminology used by the Personal Consultant in describing properties of a knowledge base. This information is provided so that structure and context of a knowledge base can be better understood. Refer to Appendix B, Listing of the Knowledge Base, for a detailed description of "The Ergonomist" knowledge base properties. A knowledge base consists of three main components: contexts, parameters, and rules. The properties pertaining to these components are explained below as defined by Texas Instruments (1985).

Contexts

* PARMGROUP - The name of the parameter group associated with a context. The parameter group contains the names of all parameters in the group. There is only one parameter group associated with a context.

* RULETYPES - The names of all rule groups associated with a context. Like the parameter group, the rule group contains the names of all rules in the group. There can be several rule groups associated with a context.

* GOALS - A list of the parameters in a context's parameter group whose values, when determined, describe the solution to the context problem.

* DISPLAYRESULTS - A value that specifies if the value of the parameter(s) listed in the GOALS property is to be displayed when the context is exited.

* INITIALDATA - A list of the parameters in the context's parameter group whose values are always prompted for when the context is instantiated during the

consultation.

* PROMPTEVER, PROMPT1ST, PROMPT2ND, TRANS - Text that is used to describe the type of information needed in the consultation. These properties are used by the inference engine to introduce or announce the instance of a context or describe the purpose of the context.

* SYN, UNIQUE - Values that are used to translate the context instance name into a meaningful form for the client.

* PRINTID - Property whose value is used to name a context instance.

* ASSOCWITH, OFFSRING - Values used to store information about the context tree.

Parameters

* PROMPT - This property is usually the question that asks the client for the value of the parameter. If this property contains the question, the question is displayed to the client.

* REPROMPT - This property is an explanation or help message for the prompt that is displayed to the client during a consultation.

* TRANS - This property is an English phrase that describes the purpose or use of the parameter. This phrase is used to generate questions, explain the reasoning or inferencing of the inference engine, or describe the results of a consultation. Correct form in the TRANS property helps make a knowledge base easier to understand and to correct if problems exist.

* ASKFIRST - This property tells the inference engine to ask the client for the value before trying to infer it using rules.

* EXPECT - This property describes the types of input values expected from the client. This property can be any of the following:

  - A list of all appropriate values - the response can be any of the values in the list.

  - NIL - Expect a yes or no response from the client

- ANY - Any type of response is legal.

- NUMB - The input value must be a number.

- POSNUMB - The input value must be a number greater than or equal to zero.

- FIXP - The input value must be an integer.

* LEGALVALS - This property describes all possible values of a parameter. When a parameter does not have a LEGALVALS property, the inference engine assumes that the EXPECT property specifies all the legal values. This property is required for multivalued parameters. This property can be a list of all legal values, or one of these special values:

  - ANY - Any value is a legal parameter value.

  - TEXT - The parameter's value can be any text phrase. Parameters with this LEGALVALS property value can be used to store text which can explain the conclusion or recommendations of a consultation.

* MULTIVALUED - This property is used to define the type of a parameter. If this property does not exist, the parameter is single-valued.

* USED-BY, UPDATED-BY, CONTAINED-IN, ANTECEDENT-IN, UPDATED-IN - These system properties are used to identify rules that use or modify the parameter's values. These properties are automatically maintained by the development engine. These properties are useful during the debugging process for the knowledge base.

Rules

* PREMISE - This property defines all the conditions to be met before the rule action will be taken.

* ACTION - This property defines the actions taken if the premise is true.

* SUBJECT - This property is the rule group that the rule belongs to. This determines the context(s) in which the rule must be tried.

* ANTECEDENT - This property is optional and indicates that the rule is a forward-chaining rule.

APPENDIX B

LISTING OF THE KNOWLEDGE BASE

Rule Group ANTHRO-RULES

RULE001 [ANTHRO-RULES]

If the workforce population is MALE,
Then 1) it is definite (100%) that the 95 th percentile standing elbow height is 120.4, and
2) it is definite (100%) that the 5th percentile standing elbow height is 105.6, and
3) it is definite (100%) that the 95 th percentile standing shoulder height is 156.8, and
4) it is definite (100%) that the 5th percentile standing shoulder height is 138.0, and
5) it is definite (100%) that the 95 th percentile popliteal height is 48.7, and
6) it is definite (100%) that the 5th percentile popliteal height is 42.4, and
7) it is definite (100%) that the 95 th percentile sitting elbow height is 27.4, and
8) it is definite (100%) that the 5th percentile sitting elbow height is 18.8, and
9) it is definite (100%) that the 5th percentile sitting shoulder height is 54.7, and
10) it is definite (100%) that the 95 th percentile body depth is 34.0, and
11) it is definite (100%) that the length of the 5th percentile forearm is 37.1, and
12) it is definite (100%) that the length of the 5th percentile arm is 68.3.

RULE002 [ANTHRO-RULES]

If the workforce population is FEMALE,
Then 1) it is definite (100%) that the 95 th percentile standing elbow height is 111.2, and
2) it is definite (100%) that the 5th percentile standing elbow height is 99.0, and
3) it is definite (100%) that the 95 th percentile standing shoulder height is 146.6, and
4) it is definite (100%) that the 5th percentile standing shoulder height is 127.9, and
5) it is definite (100%) that the 95 th percentile popliteal height is 43.6, and
6) it is definite (100%) that the 5th percentile popliteal height is 37.3, and

7) it is definite (100%) that the 95 th percentile sitting elbow height is 27.4, and
8) it is definite (100%) that the 5th percentile sitting elbow height is 18.8, and
9) it is definite (100%) that the 5th percentile sitting shoulder height is 52.2, and
10) it is definite (100%) that the 95 th percentile body depth is 27.6, and
11) it is definite (100%) that the length of the 5th percentile forearm is 32.5, and
12) it is definite (100%) that the length of the 5th percentile arm is 60.2.

RULE003 [ANTHRO-RULES]

If the workforce population is MIXED,
Then 1) it is definite (100%) that the 95 th percentile standing elbow height is 120.4, and
2) it is definite (100%) that the 5th percentile standing elbow height is 99.0, and
3) it is definite (100%) that the 95 th percentile standing shoulder height is 156.8, and
4) it is definite (100%) that the 5th percentile standing shoulder height is 127.9, and
5) it is definite (100%) that the 95 th percentile popliteal height is 48.7, and
6) it is definite (100%) that the 5th percentile popliteal height is 37.3, and
7) it is definite (100%) that the 95 th percentile sitting elbow height is 27.4, and
8) it is definite (100%) that the 5th percentile sitting elbow height is 18.8, and
9) it is definite (100%) that the 5th percentile sitting shoulder height is 52.2, and
10) it is definite (100%) that the 95 th percentile body depth is 34.0, and
11) it is definite (100%) that the length of the 5th percentile forearm is 32.5, and
12) it is definite (100%) that the length of the 5th percentile arm is 60.2.

RULE043 [ANTHRO-RULES]

If the workforce population is MALE,
Then 1) it is definite (100%) that the 5th percentile thigh width is 14.2, and
2) it is definite (100%) that the 95 th percentile thigh width is 18.5.

RULE044 [ANTHRO-RULES]

If the workforce population is FEMALE,
Then 1) it is definite (100%) that the 5th percentile thigh width is 12.4, and
2) it is definite (100%) that the 95 th percentile thigh width is 16.5.

RULE045 [ANTHRO-RULES]

If the workforce population is MIXED,
Then 1) it is definite (100%) that the 5th percentile thigh width is 12.4, and
2) it is definite (100%) that the 95 th percentile thigh width is 18.5.

Rule Group DATA-CHECKING-RULES

RULE049 [DATA-CHECKING-RULES]

If 1) the 5th percentile standing shoulder height is less than 138, or
2) the 95 th percentile standing shoulder height is greater than 156.8, or
3) the 5th percentile sitting shoulder height is less than 54.7, or
4) the 95 th percentile body depth is greater than 34, or
5) the 5th percentile thigh width is less than 14.2, or
6) the 95 th percentile thigh width is greater than 18.5, or
7) the length of the 5th percentile forearm is less than 37.1, or
8) the length of the 5th percentile arm is less than 68.3, or
9) the 5th percentile standing elbow height is less than 105.6, or
10) the 95 th percentile standing elbow height is greater than 120.4, or
11) the 5th percentile sitting elbow height is less than 18.8, or
12) the 95 th percentile sitting elbow height is greater than 27.4, or
13) the 5th percentile popliteal height is less than 42.4, or
14) the 95 th percentile popliteal height is greater than 48.7,
Then it is definite (100%) that there is a probable error in the male anthropometric data.

RULE050 [DATA-CHECKING-RULES]

If 1) the 5th percentile standing shoulder height is less than 127.9, or
2) the 95 th percentile standing shoulder height is greater than 146.6, or
3) the 5th percentile sitting shoulder height is less than 52.2, or
4) the 95 th percentile body depth is greater than 27.6, or
5) the 5th percentile thigh width is less than 12.4, or
6) the 95 th percentile thigh width is greater than 16.5, or
7) the length of the 5th percentile forearm is less than 32.5, or
8) the length of the 5th percentile arm is less than 60.2, or
9) the 5th percentile standing elbow height is less than 99, or
10) the 95 th percentile standing elbow height is greater than 111.2, or
11) the 5th percentile sitting elbow height is less than 18.8, or
12) the 95 th percentile sitting elbow height is greater than 27.4, or
13) the 5th percentile popliteal height is less than 37.3, or
14) the 95 th percentile popliteal height is greater than 43.6,

Then it is definite (100%) that there is a probable error in the female anthropometric data.

RULE051 [DATA-CHECKING-RULES]

If 1) the 5th percentile standing shoulder height is less than 127.9, or
2) the 95 th percentile standing shoulder height is greater than 156.8, or
3) the 5th percentile sitting shoulder height is less than 52.2, or
4) the 95 th percentile body depth is greater than 34, or
5) the 5th percentile thigh width is less than 12.4, or
6) the 95 th percentile thigh width is greater than 18.5, or
7) the length of the 5th percentile forearm is less than 32.5, or
8) the length of the 5th percentile arm is less than 60.2, or
9) the 5th percentile standing elbow height is less than 99, or

10) the 95 th percentile standing elbow height is greater than 120.4, or
11) the 5th percentile sitting elbow height is less than 18.8, or
12) the 95 th percentile sitting elbow height is greater than 27.4, or
13) the 5th percentile popliteal height is less than 37.3, or
14) the 95 th percentile popliteal height is greater than 48.7,

Then it is definite (100%) that there is a probable error in the mixed anthropometric data.

RULE052 [DATA-CHECKING-RULES]

If 1) the workforce population is SPECIFIC, and
2) the sex of your specific population is MALE, and
3) there is a probable error in the male anthropometric data,

Then it is definite (100%) that DATA CHECKING is The following conclusions were made by THE ERGONOMIST concerning the current workplace design. However, a probable error was detected in the anthropometric data that you entered. Please re-check your data and run another consultation..

RULE053 [DATA-CHECKING-RULES]

If 1) the workforce population is SPECIFIC, and
2) the sex of your specific population is FEMALE, and
3) there is a probable error in the female anthropometric data,

Then it is definite (100%) that DATA CHECKING is The following conclusions were made by THE ERGONOMIST concerning the current workplace design. However, a probable error was detected in the anthropometric data that you entered. Please re-check your data and run another consultation..

RULE054 [DATA-CHECKING-RULES]

If 1) the workforce population is SPECIFIC, and
2) the sex of your specific population is MIXED, and
3) there is a probable error in the mixed anthropometric data,

Then it is definite (100%) that DATA CHECKING is The following conclusions were made by THE ERGONOMIST concerning the current workplace design. However, a probable error was detected in the anthropometric data that you entered. Please re-check your data and run another consultation..

RULE055 [DATA-CHECKING-RULES]

If 1) the workforce population is MALE, or
   2) the workforce population is FEMALE, or
   3) the workforce population is MIXED, or
   4) there is not a probable error in the male anthropometric data, or
   5) there is not a probable error in the female anthropometric data, or
   6) there is not a probable error in the mixed anthropometric data,
Then it is definite (100%) that DATA CHECKING is The following conclusions were made by THE ERGONOMIST concerning the current worplace design..

Rule Group DIMENSIONING-RULES

RULE020 [DIMENSIONING-RULES]

If the classification of the task is PRECISION-WORK,
Then 1) it is definite (100%) that the work classification correction factor-1 is 12, and
     2) it is definite (100%) that the work classification correction factor-2 is 8.

RULE021 [DIMENSIONING-RULES]

If the classification of the task is LIGHT-WORK,
Then 1) it is definite (100%) that the work classification correction factor-1 is 5, and
     2) it is definite (100%) that the work classification correction factor-2 is -5.

RULE022 [DIMENSIONING-RULES]

If the classification of the task is HEAVY-WORK,
Then 1) it is definite (100%) that the work classification correction factor-1 is 0, and
     2) it is definite (100%) that the work classification correction factor-2 is -13.

RULE023 [DIMENSIONING-RULES]

If the classification of task is VDT/KEYBOARD-OPERATION,
Then 1) it is definite (100%) that the work classification correction factor-1 is 0, and
2) it is definite (100%) that the work classification correction factor-2 is -5.

RULE024 [DIMENSIONING-RULES]

If 1) the workstation type is SIT, and
2) the design type is FULLY-ADJUSTABLE,
Then 1) it is definite (100%) that work surface upper ht. in centimeters is [[the 95 th percentile popliteal height plus the 95 th percentile sitting elbow height] plus the work classification correction factor-1], and
2) it is definite (100%) that work surface lower ht. in centimeters is [[the 5th percentile popliteal height plus the 5th percentile sitting elbow height] plus the work classification correction factor-1], and
3) it is definite (100%) that chair upper height in centimeters is [the 95 th percentile popliteal height minus 0], and
4) it is definite (100%) that chair lower height in centimeters is [the 5th percentile popliteal height minus 0], and
5) it is definite (100%) that footrest upper height in centimeters is [the 95 th percentile popliteal height minus the 5th percentile popliteal height], and
6) it is definite (100%) that footrest lower height in centimeters is 0, and
7) it is definite (100%) that normal vertical reach in centimeters is [[the 5th percentile popliteal height plus the 5th percentile sitting elbow height] plus the length of the 5th percentile forearm], and
8) it is definite (100%) that maximum vertical reach in centimeters is [[the 5th percentile popliteal height plus the 5th percentile sitting shoulder height] plus the length of the 5th percentile arm], and
9) it is definite (100%) that normal horizontal reach in centimeters is [the length of the 5th percentile forearm minus [.5 times the 95 th percentile body depth]], and
10) it is definite (100%) that maximum horizontal reach in centimeters is [the length of the 5th percentile arm minus [.5 times the 95 th

percentile body depth]].

RULE025 [DIMENSIONING-RULES]

If 1) the workstation type is STAND, and
2) the design type is FULLY-ADJUSTABLE,
Then 1) it is definite (100%) that work surface upper ht. in centimeters is [the 95 th percentile standing elbow height plus the work classification correction factor-2], and
2) it is definite (100%) that work surface lower ht. in centimeters is [the 5th percentile standing elbow height plus the work classification correction factor-2], and
3) it is definite (100%) that chair upper height in centimeters is NONE, and
4) it is definite (100%) that chair lower height in centimeters is NONE, and
5) it is definite (100%) that footrest upper height in centimeters is NONE, and
6) it is definite (100%) that footrest lower height in centimeters is NONE, and
7) it is definite (100%) that normal vertical reach in centimeters is [the 5th percentile standing elbow height plus the length of the 5th percentile forearm], and
8) it is definite (100%) that maximum vertical reach in centimeters is [the 5th percentile standing shoulder height plus the length of the 5th percentile arm], and
9) it is definite (100%) that normal horizontal reach in centimeters is [the length of the 5th percentile forearm minus [.5 times the 95 th percentile body depth]], and
10) it is definite (100%) that maximum horizontal reach in centimeters is [the length of the 5th percentile arm minus [.5 times the 95 th percentile body depth]].

RULE026 [DIMENSIONING-RULES]

If 1) the workstation type is SIT/STAND, and
2) the design type is FULLY-ADJUSTABLE,
Then 1) it is definite (100%) that work surface upper ht. in centimeters is [the 95 th percentile standing elbow height plus the work classification correction factor-2], and
2) it is definite (100%) that work surface lower ht. in centimeters is [the 5th percentile standing elbow height plus the work classification

correction factor-2], and
3) it is definite (100%) that chair upper height in centimeters is [the 95 th percentile standing elbow height minus the 5th percentile sitting elbow height], and
4) it is definite (100%) that chair lower height in centimeters is [the 5th percentile standing elbow height minus the 95 th percentile sitting elbow height], and
5) it is definite (100%) that footrest upper height in centimeters is [[the 95 th percentile standing elbow height minus the 5th percentile sitting elbow height] minus the 5th percentile popliteal height], and
6) it is definite (100%) that footrest lower height in centimeters is 0, and
7) it is definite (100%) that normal vertical reach in centimeters is [the 5th percentile standing elbow height plus the length of the 5th percentile forearm], and
8) it is definite (100%) that maximum vertical reach in centimeters is [the 5th percentile standing shoulder height plus the length of the 5th percentile arm], and
9) it is definite (100%) that normal horizontal reach in centimeters is [the length of the 5th percentile forearm minus [.5 times the 95 th percentile body depth]], and
10) it is definite (100%) that maximum horizontal reach in centimeters is [the length of the 5th percentile arm minus the 95 th percentile body depth].

RULE027 [DIMENSIONING-RULES]

If 1) the workstation type is SIT, and
2) the design type is FIXED-WORK-SURFACE,

Then 1) it is definite (100%) that work surface upper ht. in centimeters is [[the 95 th percentile popliteal height plus the 95 th percentile sitting elbow height] plus the work classification correction factor-1], and
2) it is definite (100%) that work surface lower ht. in centimeters is NONE, and
3) it is definite (100%) that chair upper height in centimeters is [[the 95 th percentile popliteal height plus the 95 th percentile sitting elbow height] minus the 5th percentile sitting elbow height], and
4) it is definite (100%) that chair lower height in centimeters is [the 95 th percentile popliteal

height minus 0], and
5) it is definite (100%) that footrest upper height in centimeters is [[[the 95 th percentile popliteal height plus the 95 th percentile sitting elbow height] minus the 5th percentile sitting elbow height] minus the 5th percentile popliteal height], and
6) it is definite (100%) that footrest lower height in centimeters is 0, and
7) it is definite (100%) that normal vertical reach in centimeters is [[the 95 th percentile popliteal height plus the 95 th percentile sitting elbow height] plus the length of the 5th percentile forearm], and
8) it is definite (100%) that maximum vertical reach in centimeters is [[the 95 th percentile popliteal height plus the 5th percentile sitting shoulder height] plus the length of the 5th percentile arm], and
9) it is definite (100%) that normal horizontal reach in centimeters is [the length of the 5th percentile forearm minus [.5 times the 95 th percentile body depth]], and
10) it is definite (100%) that maximum horizontal reach in centimeters is [the length of the 5th percentile arm minus [.5 times the 95 th percentile body depth]].

RULE028 [DIMENSIONING-RULES]

If 1) the workstation type is STAND, and
2) the design type is FIXED-WORK-SURFACE,

Then 1) it is definite (100%) that work surface upper ht. in centimeters is [the 95 th percentile standing elbow height plus the work classification correction factor-2], and
2) it is definite (100%) that work surface lower ht. in centimeters is NONE, and
3) it is definite (100%) that chair upper height in centimeters is NONE, and
4) it is definite (100%) that chair lower height in centimeters is NONE, and
5) it is definite (100%) that footrest upper height in centimeters is [the 95 th percentile standing elbow height minus the 5th percentile standing elbow height], and
6) it is definite (100%) that footrest lower height in centimeters is 0, and
7) it is definite (100%) that normal vertical reach in centimeters is [the 95 th percentile standing elbow height plus the length of the 5th percentile

forearm], and
8) it is definite (100%) that maximum vertical reach in centimeters is [the 5th percentile standing shoulder height plus the length of the 5th percentile arm], and
9) it is definite (100%) that normal horizontal reach in centimeters is [the length of the 5th percentile forearm minus [.5 times the 95 th percentile body depth]], and
10) it is definite (100%) that maximum horizontal reach in centimeters is [the length of the 5th percentile arm minus [.5 times the 95 th percentile body depth]].

RULE029 [DIMENSIONING-RULES]

If 1) the workstation type is SIT/STAND, and
2) the design type is FIXED-WORK-SURFACE,

Then 1) it is definite (100%) that work surface upper ht. in centimeters is [the 95 th percentile standing elbow height plus the work classification correction factor-2], and
2) it is definite (100%) that work surface lower ht. in centimeters is NONE, and
3) it is definite (100%) that chair upper height in centimeters is [the 95 th percentile standing elbow height minus the 5th percentile sitting elbow height], and
4) it is definite (100%) that chair lower height in centimeters is [the 95 th percentile standing elbow height minus the 95 th percentile sitting elbow height], and
5) it is definite (100%) that footrest upper height in centimeters is [[the 95 th percentile standing elbow height minus the 5th percentile sitting elbow height] minus the 5th percentile popliteal height], and
6) it is definite (100%) that footrest lower height in centimeters is 0, and
7) it is definite (100%) that normal vertical reach in centimeters is [the 95 th percentile standing elbow height plus the length of the 5th percentile forearm], and
8) it is definite (100%) that maximum vertical reach in centimeters is [[[the 95 th percentile standing elbow height minus the 95 th percentile sitting elbow height] plus the 5th percentile sitting shoulder height] plus the length of the 5th percentile arm], and
9) it is definite (100%) that normal horizontal reach in centimeters is [the length of the 5th

percentile forearm minus [.5 times the 95 th percentile body depth]], and

10) it is definite (100%) that maximum horizontal reach in centimeters is [the length of the 5th percentile arm minus [.5 times the 95 th percentile body depth]].

RULE030 [DIMENSIONING-RULES]

If 1) the workstation type is SIT, and

2) the design type is FIXED-CHAIR,

Then 1) it is definite (100%) that work surface upper ht. in centimeters is [[the 95 th percentile popliteal height plus the 95 th percentile sitting elbow height] plus the work classification correction factor-1], and

2) it is definite (100%) that work surface lower ht. in centimeters is [[the 95 th percentile popliteal height plus the 5th percentile sitting elbow height] plus the work classification correction factor-1], and

3) it is definite (100%) that chair upper height in centimeters is [the 95 th percentile popliteal height minus 0], and

4) it is definite (100%) that chair lower height in centimeters is NONE, and

5) it is definite (100%) that footrest upper height in centimeters is [the 95 th percentile popliteal height minus the 5th percentile popliteal height], and

6) it is definite (100%) that normal vertical reach in centimeters is [[the 95 th percentile popliteal height plus the 5th percentile sitting elbow height] plus the length of the 5th percentile forearm], and

7) it is definite (100%) that maximum vertical reach in centimeters is [[the 95 th percentile popliteal height plus the 5th percentile sitting shoulder height] plus the length of the 5th percentile arm], and

8) it is definite (100%) that normal horizontal reach in centimeters is [the length of the 5th percentile forearm minus [.5 times the 95 th percentile body depth]], and

9) it is definite (100%) that maximum horizontal reach in centimeters is [the length of the 5th percentile arm minus [.5 times the 95 th percentile body depth]].

RULE031 [DIMENSIONING-RULES]

If 1) the workstation type is STAND, and
2) the design type is FIXED-CHAIR,
Then 1) it is definite (100%) that work surface upper ht. in centimeters is [the 95 th percentile standing elbow height plus the work classification correction factor-2], and
2) it is definite (100%) that work surface lower ht. in centimeters is [the 5th percentile standing elbow height plus the work classification correction factor-2], and
3) it is definite (100%) that chair upper height in centimeters is NONE, and
4) it is definite (100%) that chair lower height in centimeters is NONE, and
5) it is definite (100%) that footrest upper height in centimeters is NONE, and
6) it is definite (100%) that footrest lower height in centimeters is NONE, and
7) it is definite (100%) that normal vertical reach in centimeters is [the 5th percentile standing elbow height plus the length of the 5th percentile forearm], and
8) it is definite (100%) that maximum vertical reach in centimeters is [the 5th percentile standing shoulder height plus the length of the 5th percentile arm], and
9) it is definite (100%) that normal horizontal reach in centimeters is [the length of the 5th percentile forearm minus [.5 times the 95 th percentile body depth]], and
10) it is definite (100%) that maximum horizontal reach in centimeters is [the length of the 5th percentile arm minus [.5 times the 95 th percentile body depth]].

RULE032 [DIMENSIONING-RULES]

If 1) the workstation type is SIT/STAND, and
2) the design type is FIXED-CHAIR,
Then 1) it is definite (100%) that work surface upper ht. in centimeters is [[[the 95 th percentile standing elbow height minus the 5th percentile sitting elbow height] plus the 95 th percentile sitting elbow height] plus the work classification correction factor-2], and
2) it is definite (100%) that work surface lower ht. in centimeters is [the 95 th percentile standing elbow height plus the work classification correction factor-2], and

3) it is definite (100%) that chair upper height in centimeters is [the 95 th percentile standing elbow height minus the 5th percentile sitting elbow height], and
4) it is definite (100%) that chair lower height in centimeters is NONE, and
5) it is definite (100%) that footrest upper height in centimeters is [[the 95 th percentile standing elbow height minus the 5th percentile sitting elbow height] minus the 5th percentile popliteal height], and
6) it is definite (100%) that footrest lower height in centimeters is 0, and
7) it is definite (100%) that normal vertical reach in centimeters is [the 5th percentile standing elbow height plus the length of the 5th percentile forearm], and
8) it is definite (100%) that maximum vertical reach in centimeters is [the 5th percentile standing shoulder height plus the length of the 5th percentile arm], and
9) it is definite (100%) that normal horizontal reach in centimeters is [the length of the 5th percentile forearm minus [.5 times the 95 th percentile body depth]], and
10) it is definite (100%) that maximum horizontal reach in centimeters is [the length of the 5th percentile arm minus [.5 times the 95 th percentile body depth]].

RULE046 [DIMENSIONING-RULES]

If 1) the workstation type is SIT, and
2) the design type is STATIONARY,

Then 1) it is definite (100%) that work surface upper ht. in centimeters is [[the 95 th percentile popliteal height plus the 95 th percentile sitting elbow height] plus the work classification correction factor-1], and
2) it is definite (100%) that work surface lower ht. in centimeters is NONE, and
3) it is definite (100%) that chair upper height in centimeters is [[the 95 th percentile popliteal height plus the 95 th percentile sitting elbow height] minus [[the 5th percentile sitting elbow height plus the 95 th percentile sitting elbow height] divided by 2]], and
4) it is definite (100%) that chair lower height in centimeters is NONE, and
5) it is definite (100%) that footrest upper height in centimeters is [chair upper height in centimeters

minus [[the 5th percentile popliteal height plus the 95 th percentile popliteal height] divided by 2]], and
6) it is definite (100%) that footrest lower height in centimeters is NONE, and
7) it is definite (100%) that normal vertical reach in centimeters is [[chair upper height in centimeters plus the 5th percentile sitting elbow height] plus the length of the 5th percentile forearm], and
8) it is definite (100%) that maximum vertical reach in centimeters is [[chair upper height in centimeters plus the 5th percentile sitting shoulder height] plus the length of the 5th percentile arm], and
9) it is definite (100%) that normal horizontal reach in centimeters is [the length of the 5th percentile forearm minus [the 95 th percentile body depth divided by 2]], and
10) it is definite (100%) that maximum horizontal reach in centimeters is [the length of the 5th percentile arm minus [the 95 th percentile body depth divided by 2]].

RULE047 [DIMENSIONING-RULES]

If 1) the workstation type is STAND, and
2) the design type is STATIONARY,
Then 1) it is definite (100%) that work surface upper ht. in centimeters is [the 95 th percentile standing elbow height plus the work classification correction factor-2], and
2) it is definite (100%) that work surface lower ht. in centimeters is NONE, and
3) it is definite (100%) that chair upper height in centimeters is NONE, and
4) it is definite (100%) that chair lower height in centimeters is NONE, and
5) it is definite (100%) that footrest upper height in centimeters is [the 95 th percentile standing elbow height minus [[the 5th percentile standing elbow height plus the 95 th percentile standing elbow height] divided by 2]], and
6) it is definite (100%) that footrest lower height in centimeters is NONE, and
7) it is definite (100%) that normal vertical reach in centimeters is [[footrest upper height in centimeters plus the 5th percentile standing elbow height] plus the length of the 5th percentile forearm], and
8) it is definite (100%) that maximum vertical reach

in centimeters is [[footrest upper height in centimeters plus the 5th percentile standing shoulder height] plus the length of the 5th percentile arm], and

9) it is definite (100%) that normal horizontal reach in centimeters is [the length of the 5th percentile forearm minus [the 95 th percentile body depth divided by 2]], and

10) it is definite (100%) that maximum horizontal reach in centimeters is [the length of the 5th percentile arm minus [the 95 th percentile body depth divided by 2]].

RULE048 [DIMENSIONING-RULES]

If 1) the workstation type is SIT/STAND, and
2) the design type is STATIONARY,

Then 1) it is definite (100%) that work surface upper ht. in centimeters is [the 95 th percentile standing elbow height plus the work classification correction factor-2], and

2) it is definite (100%) that work surface lower ht. in centimeters is NONE, and

3) it is definite (100%) that chair upper height in centimeters is [the 95 th percentile standing elbow height minus [[the 5th percentile sitting elbow height plus the 95 th percentile sitting elbow height] divided by 2]], and

4) it is definite (100%) that chair lower height in centimeters is NONE, and

5) it is definite (100%) that footrest upper height in centimeters is [chair upper height in centimeters minus [[the 5th percentile popliteal height plus the 95 th percentile popliteal height] divided by 2]], and

6) it is definite (100%) that footrest lower height in centimeters is NONE, and

7) it is definite (100%) that normal vertical reach in centimeters is [[chair upper height in centimeters plus the 5th percentile sitting elbow height] plus the length of the 5th percentile forearm], and

8) it is definite (100%) that maximum vertical reach in centimeters is [[chair upper height in centimeters plus the 5th percentile sitting shoulder height] plus the length of the 5th percentile arm], and

9) it is definite (100%) that normal horizontal reach in centimeters is [the length of the 5th percentile forearm minus [the 95 th percentile body depth divided by 2]], and

10) it is definite (100%) that maximum horizontal reach in centimeters is [the length of the 5th percentile arm minus [the 95 th percentile body depth divided by 2]].

Rule Group STATION-TYPE-RULES

RULE004 [STATION-TYPE-RULES]

If 1) the classification of the task is PRECISION-WORK, and
2) the requirement to use foot controls, and
3) the requirement to cover a large work area,
Then it is definite (100%) that the workstation type is SIT/STAND.

RULE005 [STATION-TYPE-RULES]

If 1) the classification of the task is PRECISION-WORK, and
2) the requirement to use foot controls, and
3) the requirement to cover a large work area is not true,
Then it is definite (100%) that the workstation type is SIT.

RULE006 [STATION-TYPE-RULES]

If 1) the classification of the task is PRECISION-WORK, and
2) the requirement to use foot controls is not true, and
3) the requirement to cover a large work area is not true,
Then it is definite (100%) that the workstation type is SIT/STAND.

RULE007 [STATION-TYPE-RULES]

If 1) the classification of the task is PRECISION-WORK, and
2) the requirement to use foot controls is not true, and
3) the requirement to cover a large work area,
Then it is definite (100%) that the workstation type is SIT/STAND.

RULE008 [STATION-TYPE-RULES]

If 1) the classification of the task is LIGHT-WORK, and
2) the requirement to use foot controls, and
3) the requirement to cover a large work area,

```
Then it is definite (100%) that the workstation type is
     SIT/STAND.


RULE009 [STATION-TYPE-RULES]
-------
If 1) the classification of the task is LIGHT-WORK, and
   2) the requirement to use foot controls, and
   3) the requirement to cover a large work area is not
      true,
Then it is definite (100%) that the workstation type is
     SIT.


RULE010 [STATION-TYPE-RULES]
-------
If 1) the classification of the task is LIGHT-WORK, and
   2) the requirement to use foot controls is not true, and
   3) the requirement to cover a large work area is not
      true,
Then it is definite (100%) that the workstation type is
     SIT/STAND.


RULE011 [STATION-TYPE-RULES]
-------
If 1) the classification of the task is LIGHT-WORK, and
   2) the requirement to use foot controls is not true, and
   3) the requirement to cover a large work area,
Then it is definite (100%) that the workstation type is
     SIT/STAND.


RULE012 [STATION-TYPE-RULES]
-------
If 1) the classification of the task is HEAVY-WORK, and
   2) the requirement to use foot controls, and
   3) the requirement to cover a large work area,
Then it is definite (100%) that the workstation type is
     SIT/STAND.


RULE013 [STATION-TYPE-RULES]
-------
If 1) the classification of the task is HEAVY-WORK, and
   2) the requirement to use foot controls, and
   3) the requirement to cover a large work area is not
      true,
Then it is definite (100%) that the workstation type is
     SIT/STAND.
```

RULE014 [STATION-TYPE-RULES]

If 1) the classification of the task is HEAVY-WORK, and
2) the requirement to use foot controls is not true, and
3) the requirement to cover a large work area is not true,
Then it is definite (100%) that the workstation type is STAND.

RULE015 [STATION-TYPE-RULES]

If 1) the classification of the task is HEAVY-WORK, and
2) the requirement to use foot controls is not true, and
3) the requirement to cover a large work area,
Then it is definite (100%) that the workstation type is STAND.

RULE016 [STATION-TYPE-RULES]

If 1) the classification of the task is VDT/KEYBOARD-OPERATION, and
2) the requirement to use foot controls, and
3) the requirement to cover a large work area,
Then it is definite (100%) that the workstation type is SIT/STAND.

RULE017 [STATION-TYPE-RULES]

If 1) the classification of the task is VDT/KEYBOARD-OPERATION, and
2) the requirement to use foot controls, and
3) the requirement to cover a large work area is not true,
Then it is definite (100%) that the workstation type is SIT.

RULE018 [STATION-TYPE-RULES]

If 1) the classification of the task is VDT/KEYBOARD-OPERATION, and
2) the requirement to use foot controls is not true, and
3) the requirement to cover a large work area is not true,
Then it is definite (100%) that the workstation type is SIT.

RULE019 [STATION-TYPE-RULES]

If 1) the classification of the task is VDT/KEYBOARD-OPERATION, and
2) the requirement to use foot controls is not true, and
3) the requirement to cover a large work area,
Then it is definite (100%) that the workstation type is SIT/STAND.

Rule Group THIGH-CLEARANCE-RULES

RULE033 [THIGH-CLEARANCE-RULES]

If there is not a thigh clearance problem,
Then it is definite (100%) that the approximate reduction to the population that is to be accommodated at this workplace, due to a thigh clearance problem is NO-REDUCTION.

RULE034 [THIGH-CLEARANCE-RULES]

If there is a thigh clearance problem,
Then 1) it is definite (100%) that the thigh clearance difference is [the 95 th percentile thigh width minus [[work surface upper ht. in centimeters minus the table thickness] minus chair upper height in centimeters]], and
2) it is definite (100%) that the 5th percentile thigh-width / popliteal combination is [the 5th percentile thigh width plus the 5th percentile popliteal height], and
3) it is definite (100%) that the 95 th percentile thigh width / popliteal combination is [the 95 th percentile thigh width plus the 95 th percentile popliteal height], and
4) it is definite (100%) that the estimated thigh width mean is [[the 5th percentile thigh-width / popliteal combination plus the 95 th percentile thigh width / popliteal combination] divided by 2], and
5) it is definite (100%) that the estimated thigh width standard deviation is [[the 95 th percentile thigh width / popliteal combination minus the estimated thigh width mean] divided by 1.645], and
6) it is definite (100%) that the critical thigh-clearance height is [the 95 th percentile thigh width / popliteal combination minus the thigh clearance difference].

RULE035 [THIGH-CLEARANCE-RULES]

If 1) [[the critical thigh-clearance height minus the estimated thigh width mean] divided by the estimated thigh width standard deviation] is less than or equal to 1.645, and

2) [[the critical thigh-clearance height minus the estimated thigh width mean] divided by the estimated thigh width standard deviation] is greater than 1.28,

Then it is definite (100%) that the approximate reduction to the population that is to be accommodated at this workplace, due to a thigh clearance problem is <5%.

RULE036 [THIGH-CLEARANCE-RULES]

If 1) [[the critical thigh-clearance height minus the estimated thigh width mean] divided by the estimated thigh width standard deviation] is less than or equal to 1.28, and

2) [[the critical thigh-clearance height minus the estimated thigh width mean] divided by the estimated thigh width standard deviation] is greater than 1.035,

Then it is definite (100%) that the approximate reduction to the population that is to be accommodated at this workplace, due to a thigh clearance problem is 5-10%.

RULE037 [THIGH-CLEARANCE-RULES]

If 1) [[the critical thigh-clearance height minus the estimated thigh width mean] divided by the estimated thigh width standard deviation] is less than or equal to 1.035, and

2) [[the critical thigh-clearance height minus the estimated thigh width mean] divided by the estimated thigh width standard deviation] is greater than .675,

Then it is definite (100%) that the approximate reduction to the population that is to be accommodated at this workplace, due to a thigh clearance problem is ¼10-20%¶.

RULE038 [THIGH-CLEARANCE-RULES]

If 1) [[the critical thigh-clearance height minus the estimated thigh width mean] divided by the estimated thigh width standard deviation] is less than or equal to .675, and

2) [[the critical thigh-clearance height minus the estimated thigh width mean] divided by the estimated thigh width standard deviation] is greater than .385,

Then it is definite (100%) that the approximate reduction to the population that is to be accommodated at this workplace, due to a thigh clearance problem is ¼20-30%¶.

RULE039 [THIGH-CLEARANCE-RULES]

If 1) [[the critical thigh-clearance height minus the estimated thigh width mean] divided by the estimated thigh width standard deviation] is less than or equal to .385, and

2) [[the critical thigh-clearance height minus the estimated thigh width mean] divided by the estimated thigh width standard deviation] is greater than .125,

Then it is definite (100%) that the approximate reduction to the population that is to be accommodated at this workplace, due to a thigh clearance problem is ¼30-40%¶.

RULE040 [THIGH-CLEARANCE-RULES]

If 1) [[the critical thigh-clearance height minus the estimated thigh width mean] divided by the estimated thigh width standard deviation] is less than or equal to .125, and

2) [[the critical thigh-clearance height minus the estimated thigh width mean] divided by the estimated thigh width standard deviation] is greater than 0,

Then it is definite (100%) that the approximate reduction to the population that is to be accommodated at this workplace, due to a thigh clearance problem is ¼40-50%¶.

RULE041 [THIGH-CLEARANCE-RULES]

If [[the critical thigh-clearance height minus the estimated thigh width mean] divided by the estimated thigh width standard deviation] is less than or equal to 0,

Then it is definite (100%) that the approximate reduction to the population that is to be accommodated at this workplace, due to a thigh clearance problem is >50%.

```
RULE042 [THIGH-CLEARANCE-RULES]
-------
If 1) the design type is FULLY-ADJUSTABLE, or
   2) the design type is FIXED-CHAIR, or
   3) the workstation type is SIT, or
   4) the workstation type is STAND,
Then it is definite (100%) that the approximate reduction
     to the population that is to be accommodated at this
     workplace, due to a thigh clearance problem is
     NO-REDUCTION.


RULE056 [THIGH-CLEARANCE-RULES]
-------
If 1) the design type is STATIONARY, and
   2) the 95 th percentile thigh width is greater than [ [
      work surface upper ht. in centimeters minus  the
      table thickness ] minus  chair upper height in
      centimeters ],
Then it is definite (100%) that there is a thigh clearance
     problem.


RULE057 [THIGH-CLEARANCE-RULES]
-------
If 1) the design type is FIXED-WORK-SURFACE, and
   2) the workstation type is SIT/STAND, and
   3) the 95 th percentile thigh width is greater than [ [
      work surface upper ht. in centimeters minus  the
      table thickness ] minus  chair upper height in
      centimeters ],
Then it is definite (100%) that there is a thigh clearance
     problem.



    Parameter Group  CONTEXTTYPES

DIMENSIONAL-DESIGN [CONTEXTTYPES]
------------------
PROMPTEVER:  (THE ERGONOMIST is a knowledge-based workplace
              design program developed to provide sound
              ergonomic advice to the industrial
              workstation designer. :line :line :line The
              current objective is to: :line (1) Decide
              what type of workstation to design and :line
              (2) Provide critical dimensions required to
              construct the workstation and :line (3)
              Determine if there is a reduction in the
              accommodated population due to physical
              constraints.)
PRINTID:  WORKPLACE-
```

```
PARMGROUP:  DIMENSIONAL-DESIGN-PARMS
RULETYPES:  (DATA-CHECKING-RULES THIGH-CLEARANCE-RULES
             DIMENSIONING-RULES STATION-TYPE-RULES
             ANTHRO-RULES)
INITIALDATA:  (WORK-CLASS POPULATION)
GOALS:  (HEADER STATION-TYPE WSU WSL CHU CHL FRU FRL NVR
         MVR NHR MHR POPULATION-REDUCTION)
DISPLAYRESULTS:  T
UNIQUE:  T


    Parameter Group  DIMENSIONAL-DESIGN-PARMS

ARM5 [DIMENSIONAL-DESIGN-PARMS]
----
TRANS:  (the length of the 5th percentile arm)
PROMPT:  (For your specific population, enter the SMALLEST
          Arm Length in centimeters.)
REPROMPT:  (The Arm Length - is the horizontal distance
            from the posterior surface of the shoulder to
            the tip of the extended middle finger.)
EXPECT:  POSNUMB
CONTAINED-IN:  (RULE024 RULE025 RULE026 RULE027 RULE028
                RULE029 RULE030 RULE031 RULE032 RULE046
                RULE047 RULE048)
USED-BY:  (RULE049 RULE050 RULE051)
UPDATED-BY:  (RULE001 RULE002 RULE003)


BODY-DEPTH95 [DIMENSIONAL-DESIGN-PARMS]
------------
TRANS:  (the 95 th percentile body depth)
PROMPT:  (For your specific population, enter the LARGEST
          Body Depth Measurement in centimeters.)
REPROMPT:  (The Body Depth Measurement - is the maximum
            horizontal distance between the vertical planes
            passing through the most anterior and posterior
            on the trunk.)
EXPECT:  POSNUMB
CONTAINED-IN:  (RULE024 RULE025 RULE026 RULE027 RULE028
                RULE029 RULE030 RULE031 RULE032 RULE046
                RULE047 RULE048)
USED-BY:  (RULE049 RULE050 RULE051)
UPDATED-BY:  (RULE001 RULE002 RULE003)


C1 [DIMENSIONAL-DESIGN-PARMS]
--
TRANS:  (the work classification correction factor-1)
EXPECT:  NUMB
CONTAINED-IN:  (RULE024 RULE027 RULE030 RULE046)
UPDATED-BY:  (RULE020 RULE021 RULE022 RULE023)
```

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C2 [DIMENSIONAL-DESIGN-PARMS]
--
TRANS:  (the work classification correction factor-2)
EXPECT:  NUMB
CONTAINED-IN:  (RULE025 RULE026 RULE028 RULE029 RULE031
                RULE032 RULE047 RULE048)
UPDATED-BY:  (RULE020 RULE021 RULE022 RULE023)


CHL [DIMENSIONAL-DESIGN-PARMS]
---
TRANS:  (chair lower height in centimeters)
EXPECT:  POSNUMB
DICTIONARY:  INTERNAL
CONTAINED-IN:  NIL
UPDATED-BY:  (RULE024 RULE025 RULE026 RULE027 RULE028
              RULE029 RULE030 RULE031 RULE032 RULE046
              RULE047 RULE048)


CHU [DIMENSIONAL-DESIGN-PARMS]
---
TRANS:  (chair upper height in centimeters)
EXPECT:  POSNUMB
DICTIONARY:  INTERNAL
CONTAINED-IN:  (RULE034)
USED-BY:  (RULE056 RULE057)
UPDATED-BY:  (RULE024 RULE025 RULE026 RULE027 RULE028
              RULE029 RULE030 RULE031 RULE032 RULE046
              RULE047 RULE048)


DESIGN-TYPE [DIMENSIONAL-DESIGN-PARMS]
-----------
TRANS:  (the design type)
PROMPT:  (What type of design do you wish to construct?
          :line :line FULLY ADJUSTABLE - with adjustable
          worksurface, chair, and footrest :line FIXED WORK
          SURFACE - with adjustable chair and footrest
          :line FIXED CHAIR - with adjustable worksurface
          and footrest :line STATIONARY - with no
          adjustable features)
ASKFIRST:  T
EXPECT:  (FULLY-ADJUSTABLE FIXED-WORK-SURFACE FIXED-CHAIR
          STATIONARY)
USED-BY:  (RULE024 RULE025 RULE026 RULE027 RULE028 RULE029
           RULE030 RULE031 RULE032 RULE046 RULE047 RULE056
           RULE048 RULE042 RULE057)
```

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ELBOW5 [DIMENSIONAL-DESIGN-PARMS]
------
TRANS:  (the 5th percentile standing elbow height)
PROMPT:  (For your specific population, enter the SMALLEST
          Standing Elbow Height in centimeters.)
REPROMPT:  (The Standing Elbow Height - is the vertical
            distance from the floor to the depression at
            the elbow between the bones of the upper arm
            and forearm.)
EXPECT:  POSNUMB
CONTAINED-IN:  (RULE025 RULE026 RULE028 RULE031 RULE032
                RULE047)
USED-BY:  (RULE049 RULE050 RULE051)
UPDATED-BY:  (RULE001 RULE002 RULE003)


ELBOW95 [DIMENSIONAL-DESIGN-PARMS]
-------
TRANS:  (the 95 th percentile standing elbow height)
PROMPT:  (For your specific population, enter the LARGEST
          Standing Elbow Height in centimeters.)
REPROMPT:  (The Standing Elbow Height - is the vertical
            distance from the floor to the depression at
            the elbow between the bones of the upper arm
            and forearm.)
EXPECT:  POSNUMB
CONTAINED-IN:  (RULE025 RULE026 RULE028 RULE029 RULE031
                RULE032 RULE047 RULE048)
USED-BY:  (RULE049 RULE050 RULE051)
UPDATED-BY:  (RULE001 RULE002 RULE003)


FEMALE-DATA-ERROR [DIMENSIONAL-DESIGN-PARMS]
-----------------
TRANS:  (there is a probable error in the female
         anthropometric data)
USED-BY:  (RULE053 RULE055)
UPDATED-BY:  (RULE050)


FOOT-CONTROLS [DIMENSIONAL-DESIGN-PARMS]
-------------
TRANS:  (the requirement to use foot controls)
PROMPT:  (For this task, is the operator required to use
          any foot controls?)
REPROMPT:  (Is it necessary for the operator to operate
            footpedals, foot switches, or otherwise use his
            feet at the workplace?)
ASKFIRST:  T
USED-BY:  (RULE004 RULE005 RULE006 RULE007 RULE008 RULE009
           RULE010 RULE011 RULE012 RULE013 RULE014 RULE015
           RULE016 RULE017 RULE018 RULE019)
```

FOREARM5 [DIMENSIONAL-DESIGN-PARMS]

TRANS: (the length of the 5th percentile forearm)
PROMPT: (For your specific population, enter the SMALLEST Forearm Length in centimeters.)
REPROMPT: (The Forearm Length - is the horizontal distance from the tip of the elbow to the tip of the longest finger.)
EXPECT: POSNUMB
CONTAINED-IN: (RULE024 RULE025 RULE026 RULE027 RULE028 RULE029 RULE030 RULE031 RULE032 RULE046 RULE047 RULE048)
USED-BY: (RULE049 RULE050 RULE051)
UPDATED-BY: (RULE001 RULE002 RULE003)

FRL [DIMENSIONAL-DESIGN-PARMS]

TRANS: (footrest lower height in centimeters)
EXPECT: POSNUMB
DICTIONARY: INTERNAL
UPDATED-BY: (RULE024 RULE025 RULE026 RULE027 RULE028 RULE029 RULE031 RULE032 RULE046 RULE047 RULE048)

FRU [DIMENSIONAL-DESIGN-PARMS]

TRANS: (footrest upper height in centimeters)
EXPECT: POSNUMB
DICTIONARY: INTERNAL
UPDATED-BY: (RULE024 RULE025 RULE026 RULE027 RULE028 RULE029 RULE030 RULE031 RULE032 RULE046 RULE047 RULE048)

HEADER [DIMENSIONAL-DESIGN-PARMS]

TRANS: (*)
EXPECT: ANY
UPDATED-BY: (RULE052 RULE053 RULE054 RULE055)

LARGE-AREA [DIMENSIONAL-DESIGN-PARMS]

TRANS: (the requirement to cover a large work area)
PROMPT: (Does the short-cycle performance of this task require the operator to cover a large work area?)
REPROMPT: (Is the operator required to get up and move about a large work area frequently to stock parts, check equipment, etc. as part of his duties at the workplace?)

```
ASKFIRST:  T
USED-BY:  (RULE004 RULE005 RULE006 RULE007 RULE008 RULE009
           RULE010 RULE011 RULE012 RULE013 RULE014 RULE015
           RULE016 RULE017 RULE018 RULE019)


MALE-DATA-ERROR [DIMENSIONAL-DESIGN-PARMS]
---------------
TRANS:  (there is a probable error in the male
         anthropometric data)
USED-BY:  (RULE052 RULE055)
UPDATED-BY:  (RULE049)


MHR [DIMENSIONAL-DESIGN-PARMS]
---
TRANS:  (maximum horizontal reach in centimeters)
EXPECT:  POSNUMB
DICTIONARY:  INTERNAL
UPDATED-BY:  (RULE024 RULE025 RULE026 RULE027 RULE028
              RULE029 RULE030 RULE031 RULE032 RULE046
              RULE047 RULE048)


MIXED-DATA-ERROR [DIMENSIONAL-DESIGN-PARMS]
----------------
TRANS:  (there is a probable error in the mixed
         anthropometric data)
USED-BY:  (RULE054 RULE055)
UPDATED-BY:  (RULE051)


MU-HAT [DIMENSIONAL-DESIGN-PARMS]
------
TRANS:  (the estimated thigh width mean)
EXPECT:  POSNUMB
USED-BY:  (RULE035 RULE036 RULE037 RULE038 RULE039 RULE040
           RULE041)
UPDATED-BY:  (RULE034)


MVR [DIMENSIONAL-DESIGN-PARMS]
---
TRANS:  (maximum vertical reach in centimeters)
EXPECT:  POSNUMB
DICTIONARY:  INTERNAL
UPDATED-BY:  (RULE024 RULE025 RULE026 RULE027 RULE028
              RULE029 RULE030 RULE031 RULE032 RULE046
              RULE047 RULE048)
```

NHR [DIMENSIONAL-DESIGN-PARMS]

TRANS: (normal horizontal reach in centimeters)
EXPECT: POSNUMB
DICTIONARY: INTERNAL
UPDATED-BY: (RULE024 RULE025 RULE026 RULE027 RULE028
RULE029 RULE030 RULE031 RULE032 RULE046
RULE047 RULE048)

NVR [DIMENSIONAL-DESIGN-PARMS]

TRANS: (normal vertical reach in centimeters)
EXPECT: POSNUMB
DICTIONARY: INTERNAL
UPDATED-BY: (RULE024 RULE025 RULE026 RULE027 RULE028
RULE029 RULE030 RULE031 RULE032 RULE046
RULE047 RULE048)

POPLITEAL5 [DIMENSIONAL-DESIGN-PARMS]

TRANS: (the 5th percentile popliteal height)
PROMPT: (For your specific population, enter the SMALLEST
Sitting Popliteal Height in centimeters.)
REPROMPT: (The Sitting Popliteal Height - is the vertical
distance from the floor to the underside of the
thigh immediately behind the knee.)
EXPECT: POSNUMB
CONTAINED-IN: (RULE024 RULE026 RULE027 RULE029 RULE030
RULE032 RULE034 RULE046 RULE048)
USED-BY: (RULE049 RULE050 RULE051)
UPDATED-BY: (RULE001 RULE002 RULE003)

POPLITEAL95 [DIMENSIONAL-DESIGN-PARMS]

TRANS: (the 95 th percentile popliteal height)
PROMPT: (For your specific population, enter the LARGEST
Sitting Popliteal Height in centimeters.)
REPROMPT: (The Sitting Popliteal Height - is the vertical
distance from the floor to the underside of the
thigh immediately behind the knee.)
EXPECT: POSNUMB
CONTAINED-IN: (RULE024 RULE027 RULE030 RULE034 RULE046
RULE048)
USED-BY: (RULE049 RULE050 RULE051)
UPDATED-BY: (RULE001 RULE002 RULE003)

```
POPSPEC [DIMENSIONAL-DESIGN-PARMS]
-------
TRANS:  (the sex of your specific population)
PROMPT:  (In regard to the anthropometric measurements that
          you entered, what is the sex of your specific
          work force population?)
ASKFIRST:  T
EXPECT:  (MALE FEMALE MIXED)
USED-BY:  (RULE052 RULE053 RULE054)


POPULATION [DIMENSIONAL-DESIGN-PARMS]
----------
TRANS:  (the workforce population)
PROMPT:  (Describe the population of people who will use
          this workplace as: :line GENERAL MALE POPULATION
          - 5th to 95 th male percentiles :line GENERAL
          FEMALE POPULATION - 5th to 95 th female
          percentiles :line GENERAL MIXED POPULATION - 5th
          percentile female to 95 th percentile male :line
          YOUR SPECIFIC POPULATION - anthropometric
          measurements entered by you.)
ASKFIRST:  T
EXPECT:  (MALE FEMALE MIXED SPECIFIC)
USED-BY:  (RULE001 RULE002 RULE003 RULE043 RULE044 RULE045
           RULE052 RULE053 RULE054 RULE055)


POPULATION-REDUCTION [DIMENSIONAL-DESIGN-PARMS]
--------------------
TRANS:  (the approximate reduction to the population that
         is to be accommodated at this workplace, due to a
         thigh clearance problem)
EXPECT:  (NO-REDUCTION <5% 5-10% ¼10-20%¶ ¼20-30%¶ ¼30-40%¶
          ¼40-50%¶ >50%)
DICTIONARY:  INTERNAL
UPDATED-BY:  (RULE035 RULE036 RULE037 RULE038 RULE039
              RULE040 RULE041 RULE042 RULE033)


SHOULDER5 [DIMENSIONAL-DESIGN-PARMS]
---------
TRANS:  (the 5th percentile standing shoulder height)
PROMPT:  (For your specific population, enter the SMALLEST
          Standing Shoulder Height in centimeters.)
REPROMPT:  (The Standing Shoulder Height - is the vertical
            distance from the floor to the upper-most point
            on the lateral edge of the shoulder with the
            operator standing erect.)
EXPECT:  POSNUMB
CONTAINED-IN:  (RULE025 RULE026 RULE028 RULE031 RULE032
                RULE047)
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```
USED-BY:  (RULE049 RULE050 RULE051)
UPDATED-BY:  (RULE001 RULE002 RULE003)


SHOULDER95 [DIMENSIONAL-DESIGN-PARMS]
----------
TRANS:  (the 95 th percentile standing shoulder height)
PROMPT:  (For your specific population, enter the LARGEST
          Standing Shoulder Height in centimeters.)
REPROMPT:  (The Standing Shoulder Height - is the vertical
            distance from the floor to the upper-most point
            on the lateral edge of the shoulder with the
            operator standing erect.)
EXPECT:  POSNUMB
USED-BY:  (RULE049 RULE050 RULE051)
UPDATED-BY:  (RULE001 RULE002 RULE003)


SIGMA-HAT [DIMENSIONAL-DESIGN-PARMS]
---------
TRANS:  (the estimated thigh width standard deviation)
EXPECT:  POSNUMB
USED-BY:  (RULE035 RULE036 RULE037 RULE038 RULE039 RULE040
           RULE041)
UPDATED-BY:  (RULE034)


SITTING-ELBOW5 [DIMENSIONAL-DESIGN-PARMS]
--------------
TRANS:  (the 5th percentile sitting elbow height)
PROMPT:  (For your specific population, enter the SMALLEST
          Sitting Elbow Height in centimeters.)
REPROMPT:  (The Sitting Elbow Height - is the vertical
            distance from the sitting surface to the bottom
            of the elbow.)
EXPECT:  POSNUMB
CONTAINED-IN:  (RULE024 RULE026 RULE027 RULE029 RULE030
                RULE032 RULE046 RULE048)
USED-BY:  (RULE049 RULE050 RULE051)
UPDATED-BY:  (RULE001 RULE002 RULE003)


SITTING-ELBOW95 [DIMENSIONAL-DESIGN-PARMS]
---------------
TRANS:  (the 95 th percentile sitting elbow height)
PROMPT:  (For your specific population, enter the LARGEST
          Sitting Elbow Height in centimeters.)
REPROMPT:  (The Sitting Elbow Height - is the vertical
            distance from the sitting surface to the bottom
            of the elbow.)
EXPECT:  POSNUMB
CONTAINED-IN:  (RULE024 RULE026 RULE027 RULE029 RULE030
```

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                  RULE032 RULE046 RULE048)
USED-BY:  (RULE049 RULE050 RULE051)
UPDATED-BY:  (RULE001 RULE002 RULE003)


SITTING-SHOULDER5 [DIMENSIONAL-DESIGN-PARMS]
-----------------
TRANS:  (the 5th percentile sitting shoulder height)
PROMPT:  (For your specific population, enter the SMALLEST
          Sitting Shoulder Height in centimeters.)
REPROMPT:  (The Sitting Shoulder Height - is the vertical
            distance from the sitting surface to the
            upper-most point on the lateral edge of the
            shoulder with the operator sitting erect.)
EXPECT:  POSNUMB
CONTAINED-IN:  (RULE024 RULE027 RULE029 RULE030 RULE046
                RULE048)
USED-BY:  (RULE049 RULE050 RULE051)
UPDATED-BY:  (RULE001 RULE002 RULE003)


STATION-TYPE [DIMENSIONAL-DESIGN-PARMS]
------------
TRANS:  (the workstation type)
EXPECT:  (SIT STAND SIT/STAND)
DICTIONARY:  INTERNAL
USED-BY:  (RULE024 RULE025 RULE026 RULE027 RULE028 RULE029
           RULE030 RULE031 RULE032 RULE046 RULE047 RULE048
           RULE042 RULE057)
UPDATED-BY:  (RULE004 RULE005 RULE006 RULE007 RULE008
              RULE009 RULE010 RULE011 RULE012 RULE013
              RULE014 RULE015 RULE016 RULE017 RULE018
              RULE019)


TABLE-THICKNESS [DIMENSIONAL-DESIGN-PARMS]
---------------
TRANS:  (the table thickness)
PROMPT:  (Enter the work surface table thickness in
          centimeters.)
REPROMPT:  (The thickness of the work surface table is the
            vertical depth dimension of the table that is
            to be used as the work surface.)
ASKFIRST:  T
EXPECT:  POSNUMB
CONTAINED-IN:  (RULE034)
USED-BY:  (RULE056 RULE057)


THIGH-CRITICAL [DIMENSIONAL-DESIGN-PARMS]
--------------
TRANS:  (the critical thigh-clearance height)
```

```
EXPECT:  POSNUMB
USED-BY:  (RULE035 RULE036 RULE037 RULE038 RULE039 RULE040
           RULE041)
UPDATED-BY:  (RULE034)


THIGH-CUT [DIMENSIONAL-DESIGN-PARMS]
---------
TRANS:  (the thigh clearance difference)
EXPECT:  POSNUMB
UPDATED-BY:  (RULE034)


THIGH-POP5 [DIMENSIONAL-DESIGN-PARMS]
----------
TRANS:  (the 5th percentile thigh-width / popliteal
         combination)
EXPECT:  POSNUMB
UPDATED-BY:  (RULE034)


THIGH-POP95 [DIMENSIONAL-DESIGN-PARMS]
-----------
TRANS:  (the 95 th percentile thigh width / popliteal
         combination)
EXPECT:  POSNUMB
UPDATED-BY:  (RULE034)


THIGH-TEST [DIMENSIONAL-DESIGN-PARMS]
----------
TRANS:  (there is a thigh clearance problem)
USED-BY:  (RULE034 RULE033)
UPDATED-BY:  (RULE056 RULE057)


THIGH-WIDTH5 [DIMENSIONAL-DESIGN-PARMS]
------------
TRANS:  (the 5th percentile thigh width)
PROMPT:  (For your specific population, enter the SMALLEST
          thigh width measurement in centimeters.)
REPROMPT:  (The Thigh Width - is the vertical distance from
            the sitting surface to the top of the thigh at
            its intersection with the abdomen.)
EXPECT:  POSNUMB
CONTAINED-IN:  (RULE034)
USED-BY:  (RULE049 RULE050 RULE051)
UPDATED-BY:  (RULE043 RULE044 RULE045)
```

```
THIGH-WIDTH95 [DIMENSIONAL-DESIGN-PARMS]
-------------
TRANS:  (the 95 th percentile thigh width)
PROMPT:  (For your specific population, enter the LARGEST
          thigh width measurement in centimeters.)
REPROMPT:  (The Thigh Width - is the vertical distance from
            the sitting surface to the top of the thigh at
            its intersection with the abdomen.)
EXPECT:  POSNUMB
CONTAINED-IN:  (RULE034)
USED-BY:  (RULE049 RULE050 RULE051 RULE056 RULE057)
UPDATED-BY:  (RULE043 RULE044 RULE045)


WORK-CLASS [DIMENSIONAL-DESIGN-PARMS]
----------
TRANS:  (the classification of the task)
PROMPT:  (How would you classify the task that is to be
          performed at this workplace?)
REPROMPT:  (Example tasks categorized by Work
            Classification: :line :line PRECISION WORK -
            Inspection, Fine Assembly, Soldering, etc.
            :line LIGHT WORK - Manual Assembly, Load/Unload
            of Machine, Objects < 4.5 kg. :line HEAVY WORK
            - Packing, Wrapping, Objects > 4.5 kg. :line
            VDT/KEYBOARD OPERATION - Data Processing,
            Secretarial, Programming, etc.)
ASKFIRST:  T
EXPECT:  (PRECISION-WORK LIGHT-WORK HEAVY-WORK
          VDT/KEYBOARD-OPERATION)
USED-BY:  (RULE004 RULE005 RULE006 RULE007 RULE008 RULE009
           RULE010 RULE011 RULE012 RULE013 RULE014 RULE015
           RULE016 RULE017 RULE018 RULE019 RULE020 RULE021
           RULE022 RULE023)


WSL [DIMENSIONAL-DESIGN-PARMS]
---
TRANS:  (work surface lower ht. in centimeters)
EXPECT:  POSNUMB
DICTIONARY:  INTERNAL
CONTAINED-IN:  NIL
USED-BY:  NIL
UPDATED-BY:  (RULE024 RULE025 RULE026 RULE027 RULE028
              RULE029 RULE030 RULE031 RULE032 RULE046
              RULE047 RULE048)


WSU [DIMENSIONAL-DESIGN-PARMS]
---
TRANS:  (work surface upper ht. in centimeters)
EXPECT:  POSNUMB
```

```
DICTIONARY:  INTERNAL
CONTAINED-IN:  (RULE034)
USED-BY:  (RULE056 RULE057)
UPDATED-BY:  (RULE024 RULE025 RULE026 RULE027 RULE028
              RULE029 RULE030 RULE031 RULE032 RULE046
              RULE047 RULE048)
```

Domain Variables

```
$$TITLE [DOMAIN.VARIABLES]
-------
Value:  ("                              THE ERGONOMIST" :line
         :line "                      Workplace Design Expert
         System" :line :line :line :line :line "
         copyright Thomas B. DeGreve 1985")
```

System parameters

```
DOMAIN [SYSVARS]
------
Value:  "THE ERGONOMIST"


TREEROOT [SYSVARS]
--------
Value:  DIMENSIONAL-DESIGN
```

System parameters

```
ANTHRO-RULES [RULEGROUPS]
------------
SVAL:  (ANTHROPOMETRIC DATA)
CONTEXT:  (DIMENSIONAL-DESIGN)
Value:  (RULE001 RULE002 RULE003 RULE043 RULE044 RULE045)


DATA-CHECKING-RULES [RULEGROUPS]
-------------------
CONTEXT:  (DIMENSIONAL-DESIGN)
SVAL:  (DATA CHECKING)
Value:  (RULE049 RULE050 RULE051 RULE052 RULE053 RULE054
         RULE055)


DIMENSIONING-RULES [RULESGROUPS]
------------------
CONTEXT:  (DIMENSIONAL-DESIGN)
SVAL:  (WORKPLACE DIMENSIONS)
Value:  (RULE020 RULE021 RULE022 RULE023 RULE024 RULE025
```

```
        RULE026 RULE027 RULE028 RULE029 RULE030 RULE031
        RULE032 RULE046 RULE047 RULE048)


STATION-TYPE-RULES [RULEGROUPS]
------------------
CONTEXT:  (DIMENSIONAL-DESIGN)
SVAL:  (WORKSTATION TYPE)
Value:  (RULE004 RULE005 RULE006 RULE007 RULE008 RULE009
         RULE010 RULE011 RULE012 RULE013 RULE014 RULE015
         RULE016 RULE017 RULE018 RULE019)


THIGH-CLEARANCE-RULES [RULEGROUPS]
---------------------
CONTEXT:  (DIMENSIONAL-DESIGN)
SVAL:  (THIGH CLEARANCE)
Value:  (RULE033 RULE034 RULE035 RULE036 RULE037 RULE038
         RULE039 RULE040 RULE041 RULE042 RULE056 RULE057)


    System parameters

CONTEXTTYPES [PARMGROUPS]
------------
Value:  (DIMENSIONAL-DESIGN)


DIMENSIONAL-DESIGN-PARMS [PARMGROUPS]
------------------------
Value:  (WORK-CLASS POPULATION STATION-TYPE WSL CHL CHU FRL
         FRU NVR MVR NHR MHR WSU ARM5 FOREARM5 BODY-DEPTH95
         SITTING-SHOULDER5 SITTING-ELBOW95 POPLITEAL5
         POPLITEAL95 SHOULDER5 SHOULDER95 ELBOW5 ELBOW95
         SITTING-ELBOW5 C2 C1 DESIGN-TYPE FOOT-CONTROLS
         LARGE-AREA TABLE-THICKNESS THIGH-WIDTH95
         POPULATION-REDUCTION THIGH-CUT MU-HAT SIGMA-HAT
         THIGH-WIDTH5 THIGH-POP95 THIGH-CRITICAL THIGH-POP5
         MALE-DATA-ERROR FEMALE-DATA-ERROR MIXED-DATA-ERROR
         POPSPEC HEADER THIGH-TEST)
```

APPENDIX C

SAMPLE CONSULTATIONS

```
Knowledge Base :: THE ERGONOMIST

CURRENT OBJECTIVE:

THE ERGONOMIST is a knowledge-based workplace design program
developed to provide sound ergonomic advice to the
industrial workstation designer.

The current objective is to:
(1) Decide what type of workstation to design and
(2) Provide critical dimensions required to construct the
workstation and
(3) Determine if there is a reduction in the accommodated
population due to physical constraints.
     ... end  --  press RETURN

Up   Down   CF Unknwn   Done  --   Why  How   Help Undo   Stop
F1     F2   F3    F4     F5    F6  F7    F8   F9   F10     ESC
```

```
Knowledge Base :: THE ERGONOMIST

How would you classify the task that is to be performed at
this workplace?
Select one of the following:  (Press `F3' for selection help.)
        > PRECISION-WORK
          LIGHT-WORK
          HEAVY-WORK
          VDT/KEYBOARD-OPERATION

Up   Down   CF Unknwn   Done  --   Why  How   Help Undo   Stop
F1     F2   F3    F4     F5    F6  F7    F8   F9   F10     ESC
```

```
Knowledge Base :: THE ERGONOMIST

Describe the population of people who will use this
workplace as:
GENERAL MALE POPULATION - 5th to 95 th male percentiles
GENERAL FEMALE POPULATION - 5th to 95 th female percentiles
GENERAL MIXED POPULATION - 5th percentile female to 95 th
percentile male
YOUR SPECIFIC POPULATION - anthropometric measurements
entered by you.
Select one of the following:  (Press `F3' for selection help.)
          MALE
        > FEMALE
          MIXED
          SPECIFIC

 Up   Down   CF Unknwn    Done  ---   Why   How    Help Undo      Stop
 F1     F2   F3     F4    F5     F6   F7     F8    F9    F10       ESC
```

```
Knowledge Base :: THE ERGONOMIST

For this task, is the operator required to use any foot
controls?
Select one of the following:  (Press `F3' for selection help.)
        > YES
          NO

 Up   Down   CF Unknwn    Done  ---   Why   How    Help Undo      Stop
 F1     F2   F3     F4    F5     F6   F7     F8    F9    F10       ESC
```

```
Knowledge Base :: THE ERGONOMIST

Does the short-cycle performance of this task require the
operator to cover a large work area?
Select one of the following:  (Press `F3' for selection help.)
          YES
        > NO

 Up   Down   CF Unknwn    Done  ---   Why   How    Help Undo      Stop
 F1     F2   F3     F4    F5     F6   F7     F8    F9    F10       ESC
```

```
Knowledge Base :: THE ERGONOMIST

What type of design do you wish to construct?

FULLY ADJUSTABLE - with adjustable worksurface, chair, and
footrest
FIXED WORK SURFACE - with adjustable chair and footrest
FIXED CHAIR - with adjustable worksurface and footrest
STATIONARY - with no adjustable features
Select one of the following: (Press `F3' for selection help.)
          FULLY-ADJUSTABLE
          FIXED-WORK-SURFACE
        > FIXED-CHAIR
          STATIONARY

 Up   Down   CF Unknwn   Done  ---  Why  How   Help Undo      Stop
 F1     F2   F3    F4    F5    F6   F7    F8   F9    F10       ESC
```

WORKPLACE-1 is as follows: The following conclusions were made by THE ERGONOMIST concerning the current workplace design.

The workstation type is as follows: SIT

Work surface upper ht. in centimeters is as follows: 83.0

Work surface lower ht. in centimeters is as follows: 74.4

Chair upper height in centimeters is as follows: 43.6

Chair lower height in centimeters is as follows: NONE

Footrest upper height in centimeters is as follows: 6.3

I was unable to make any conclusions regarding footrest lower height in centimeters.

Normal vertical reach in centimeters is as follows: 94.9

Maximum vertical reach in centimeters is as follows: 156.0

Normal horizontal reach in centimeters is as follows: 18.7

Maximum horizontal reach in centimeters is as follows: 46.4

The approximate reduction to the population that is to be accommodated at this workplace, due to a thigh clearance problem is as follows: NO-REDUCTION

Knowledge Base :: THE ERGONOMIST

CURRENT OBJECTIVE:

THE ERGONOMIST is a knowledge-based workplace design program developed to provide sound ergonomic advice to the industrial workstation designer.

The current objective is to:
(1) Decide what type of workstation to design and
(2) Provide critical dimensions required to construct the workstation and
(3) Determine if there is a reduction in the accommodated population due to physical constraints.
... end — press RETURN

Up	Down	CF	Unknwn	Done	—	Why	How	Help	Undo	Stop
F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	ESC

Knowledge Base :: THE ERGONOMIST

How would you classify the task that is to be performed at this workplace?
Select one of the following: (Press 'F3' for selection help.)

PRECISION-WORK
LIGHT-WORK
>HEAVY-WORK
VDT/KEYBOARD-OPERATION

Up	Down	CF	Unknwn	Done	—	Why	How	Help	Undo	Stop
F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	ESC

Knowledge Base :: THE ERGONOMIST

Describe the population of people who will use this workplace as:
GENERAL MALE POPULATION - 5th to 95 th male percentiles
GENERAL FEMALE POPULATION - 5th to 95 th female percentiles
GENERAL MIXED POPULATION - 5th percentile female to 95 th percentile male
YOUR SPECIFIC POPULATION - anthropometric measurements entered by you.
Select one of the following: (Press 'F3' for selection help.)

>MALE
FEMALE
MIXED
SPECIFIC

Up	Down	CF	Unknwn	Done	—	Why	How	Help	Undo	Stop
F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	ESC

```
  Knowledge Base :: THE ERGONOMIST

For this task, is the operator required to use any foot
controls?
Select one of the following:  (Press `F3' for selection help.)
           YES
         > NO

  Up    Down   CF Unknwn    Done  ---   Why   How     Help Undo         Stop
  F1      F2   F3     F4    F5     F6   F7     F8     F9    F10          ESC
```

```
  Knowledge Base :: THE ERGONOMIST

Does the short-cycle performance of this task require the
operator to cover a large work area?
Select one of the following:  (Press `F3' for selection help.)
         > YES
           NO

  Up    Down   CF Unknwn    Done  ---   Why   How     Help Undo         Stop
  F1      F2   F3     F4    F5     F6   F7     F8     F9    F10          ESC
```

```
  Knowledge Base :: THE ERGONOMIST

What type of design do you wish to construct?

FULLY ADJUSTABLE - with adjustable worksurface, chair, and
footrest
FIXED WORK SURFACE - with adjustable chair and footrest
FIXED CHAIR - with adjustable worksurface and footrest
STATIONARY - with no adjustable features
Select one of the following:  (Press `F3' for selection help.)
           FULLY-ADJUSTABLE
           FIXED-WORK-SURFACE
           FIXED-CHAIR
         > STATIONARY

  Up    Down   CF Unknwn    Done  ---   Why   How     Help Undo         Stop
  F1      F2   F3     F4    F5     F6   F7     F8     F9    F10          ESC
```

```
Knowledge Base :: THE ERGONOMIST

Enter the work surface table thickness in centimeters.
Enter a positive number.

    10

Up   Down   CF  Unknwn   Done  —   Why   How    Help  Undo        Stop
F1     F2   F3     F4     F5   F6  F7     F8    F9     F10         ESC
```

WORKPLACE-1 is as follows: The following conclusions were made by THE ERGONOMIST concerning the current workplace design.

The workstation type is as follows: STAND

Work surface upper ht. in centimeters is as follows: 107.4

Work surface lower ht. in centimeters is as follows: NONE

Chair upper height in centimeters is as follows: NONE

Chair lower height in centimeters is as follows: NONE

Footrest upper height in centimeters is as follows: 7.4

Footrest lower height in centimeters is as follows: NONE

Normal vertical reach in centimeters is as follows: 150.1

Maximum vertical reach in centimeters is as follows: 213.7

Normal horizontal reach in centimeters is as follows: 20.1

Maximum horizontal reach in centimeters is as follows: 51.3

The approximate reduction to the population that is to be accommodated at this workplace, due to a thigh clearance problem is as follows: NO-REDUCTION

```
Knowledge Base :: THE ERGONOMIST

CURRENT OBJECTIVE:

THE ERGONOMIST is a knowledge-based workplace design program
developed to provide sound ergonomic advice to the
industrial workstation designer.

The current objective is to:
(1) Decide what type of workstation to design and
(2) Provide critical dimensions required to construct the
workstation and
(3) Determine if there is a reduction in the accommodated
population due to physical constraints.
     ... end   --  press RETURN

Up   Down   CF Unknwn    Done  ---   Why   How    Help Undo        Stop
F1     F2   F3     F4     F5    F6   F7     F8    F9    F10        ESC
```

```
Knowledge Base :: THE ERGONOMIST

How would you classify the task that is to be performed at
this workplace?
Select one of the following:  (Press `F3' for selection help.)
        PRECISION-WORK
        LIGHT-WORK
        HEAVY-WORK
        VDT/KEYBOARD-OPERATION

Up   Down   CF Unknwn    Done  ---   Why   How   >Help Undo        Stop
F1     F2   F3     F4     F5    F6   F7     F8    F9    F10        ESC
```

```
Knowledge Base :: THE ERGONOMIST

Example tasks categorized by Work Classification:

PRECISION WORK - Inspection, Fine Assembly, Soldering, etc.
LIGHT WORK - Manual Assembly, Load/Unload of Machine.
Objects < 4.5 kg.
HEAVY WORK - Packing, Wrapping, Objects > 4.5 kg.
VDT/KEYBOARD OPERATION - Data Processing, Secretarial,
Programming, etc.
Select one of the following:  (Press `F3' for selection help.)
        PRECISION-WORK
        LIGHT-WORK
        HEAVY-WORK
     >  VDT/KEYBOARD-OPERATION

Up   Down   CF Unknwn    Done  ---   Why   How    Help Undo        Stop
F1     F2   F3     F4     F5    F6   F7     F8    F9    F10        ESC
```

Knowledge Base :: THE ERGONOMIST

Describe the population of people who will use this workplace as:
GENERAL MALE POPULATION - 5th to 95 th male percentiles
GENERAL FEMALE POPULATION - 5th to 95 th female percentiles
GENERAL MIXED POPULATION - 5th percentile female to 95 th percentile male
YOUR SPECIFIC POPULATION - anthropometric measurements entered by you.
Select one of the following: (Press `F3' for selection help.)

MALE
FEMALE
> MIXED
SPECIFIC

Up	Down	CF	Unknwn	Done	---	Why	How	Help	Undo	Stop
F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	ESC

Knowledge Base :: THE ERGONOMIST

For this task, is the operator required to use any foot controls?
Select one of the following: (Press `F3' for selection help.)

YES
> NO

Up	Down	CF	Unknwn	Done	---	Why	How	Help	Undo	Stop
F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	ESC

Knowledge Base :: THE ERGONOMIST

Does the short-cycle performance of this task require the operator to cover a large work area?
Select one of the following: (Press `F3' for selection help.)

YES
> NO

Up	Down	CF	Unknwn	Done	---	Why	How	Help	Undo	Stop
F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	ESC

```
Knowledge Base :: THE ERGONOMIST

What type of design do you wish to construct?

FULLY ADJUSTABLE - with adjustable worksurface, chair, and
footrest
FIXED WORK SURFACE - with adjustable chair and footrest
FIXED CHAIR - with adjustable worksurface and footrest
STATIONARY - with no adjustable features
Select one of the following:  (Press `F3' for selection help.)
      > FULLY-ADJUSTABLE
        FIXED-WORK-SURFACE
        FIXED-CHAIR
        STATIONARY

 Up    Down   CF Unknwn     Done  ---   Why   How     Help Undo          Stop
 F1      F2   F3      F4    F5      F6  F7      F8    F9    F10           ESC
```

WORKPLACE-1 is as follows: The following conclusions were made by THE ERGONOMIST concerning the current workplace design.

The workstation type is as follows: SIT

Work surface upper ht. in centimeters is as follows: 76.1

Work surface lower ht. in centimeters is as follows: 56.1

Chair upper height in centimeters is as follows: 48.7

Chair lower height in centimeters is as follows: 37.3

Footrest upper height in centimeters is as follows: 11.4

Footrest lower height in centimeters is as follows: 0

Normal vertical reach in centimeters is as follows: 88.6

Maximum vertical reach in centimeters is as follows: 149.7

Normal horizontal reach in centimeters is as follows: 15.5

Maximum horizontal reach in centimeters is as follows: 43.2

The approximate reduction to the population that is to be accommodated at this workplace, due to a thigh clearance problem is as follows: NO-REDUCTION

```
  Knowledge Base :: THE ERGONOMIST

  CURRENT OBJECTIVE:

THE ERGONOMIST is a knowledge-based workplace design program
developed to provide sound ergonomic advice to the
industrial workstation designer.

The current objective is to:
(1) Decide what type of workstation to design and
(2) Provide critical dimensions required to construct the
workstation and
(3) Determine if there is a reduction in the accommodated
population due to physical constraints.
     ... end   --  press RETURN

 Up   Down  CF Unknwn     Done  ---   Why   How      Help Undo       Stop
 F1     F2  F3     F4     F5     F6   F7     F8      F9    F10        ESC
```

```
  Knowledge Base :: THE ERGONOMIST

How would you classify the task that is to be performed at
this workplace?
Select one of the following:  (Press `F3' for selection help.)
        PRECISION-WORK
      > LIGHT-WORK
        HEAVY-WORK
        VDT/KEYBOARD-OPERATION

 Up   Down  CF Unknwn     Done  ---   Why   How      Help Undo       Stop
 F1     F2  F3     F4     F5     F6   F7     F8      F9    F10        ESC
```

```
  Knowledge Base :: THE ERGONOMIST

Describe the population of people who will use this
workplace as:
GENERAL MALE POPULATION - 5th to 95 th male percentiles
GENERAL FEMALE POPULATION - 5th to 95 th female percentiles
GENERAL MIXED POPULATION - 5th percentile female to 95 th
percentile male
YOUR SPECIFIC POPULATION - anthropometric measurements
entered by you.
Select one of the following:  (Press `F3' for selection help.)
        MALE
        FEMALE
      > MIXED
        SPECIFIC

 Up   Down  CF unknwn     Done  ---   Why   How      Help Undo       Stop
 F1     F2  F3     F4     F5     F6   F7     F8      F9    F10        ESC
```

```
  Knowledge Base :: THE ERGONOMIST

For this task, is the operator required to use any foot
controls?
Select one of the following:  (Press `F3' for selection help.)
          YES
          NO

 Up   Down   CF Unknwn    Done  ---> Why   How    Help Undo         Stop
 F1     F2   F3     F4    F5     F6  F7     F8     F9   F10          ESC
```

```
  Knowledge Base :: THE ERGONOMIST

For this task, is the operator required to use any foot
controls?
 Why this question is needed:

Whether the requirement to use foot controls is needed to determine
 the workstation type

RULE008
If 1) the classification of the task is LIGHT-WORK, and
   2) the requirement to use foot controls, and
   3) the requirement to cover a large work area,
Then it is definite (100%) that the workstation type is
     SIT/STAND.

     ... end   --  press RETURN

 Up   Down   CF Unknwn    Done  ---   Why   How    Help Undo         Stop
 F1     F2   F3     F4    F5     F6  F7     F8     F9   F10          ESC
```

```
  Knowledge Base :: THE ERGONOMIST

For this task, is the operator required to use any foot
controls?
Select one of the following:  (Press `F3' for selection help.)
          YES
        > NO

 Up   Down   CF Unknwn    Done  ---   Why   How    Help Undo         Stop
 F1     F2   F3     F4    F5     F6  F7     F8     F9   F10          ESC
```

```
  Knowledge Base :: THE ERGONOMIST

Does the short-cycle performance of this task require the
operator to cover a large work area?
Select one of the following:  (Press `F3' for selection help.)
           YES
         > NO

 Up    Down   CF Unknwn     Done  ---  Why   How     Help Undo         Stop
 F1      F2   F3      F4    F5     F6  F7     F8     F9    F10         ESC
```

```
  Knowledge Base :: THE ERGONOMIST

What type of design do you wish to construct?

FULLY ADJUSTABLE - with adjustable worksurface, chair, and
footrest
FIXED WORK SURFACE - with adjustable chair and footrest
FIXED CHAIR - with adjustable worksurface and footrest
STATIONARY - with no adjustable features
Select one of the following:  (Press `F3' for selection help.)
           FULLY-ADJUSTABLE
         > FIXED-WORK-SURFACE
           FIXED-CHAIR
           STATIONARY

 Up    Down   CF Unknwn     Done  ---  Why   How     Help Undo         Stop
 F1      F2   F3      F4    F5     F6  F7     F8     F9    F10         ESC
```

```
  Knowledge Base :: THE ERGONOMIST

Enter the work surface table thickness in centimeters.
Enter a positive number.


      10

 Up    Down   CF Unknwn     Done  ---  Why   How     Help Undo         Stop
 F1      F2   F3      F4    F5     F6  F7     F8     F9    F10         ESC
```

WORKPLACE-1 is as follows: The following conclusions were made by THE ERGONOMIST concerning the current workplace design.

The workstation type is as follows: SIT/STAND

Work surface upper ht. in centimeters is as follows: 115.4

Work surface lower ht. in centimeters is as follows: NONE

Chair upper height in centimeters is as follows: 101.6

Chair lower height in centimeters is as follows: 73.0

Footrest upper height in centimeters is as follows: 54.2

Footrest lower height in centimeters is as follows: 0

Normal vertical reach in centimeters is as follows: 152.9

Maximum vertical reach in centimeters is as follows: 205.4

Normal horizontal reach in centimeters is as follows: 15.5

Maximum horizontal reach in centimeters is as follows: 43.2

The approximate reduction to the population that is to be accommodated at this workplace, due to a thigh clearance problem is as follows: >50%

APPENDIX D

DEFINITION OF ANTHROPOMETRIC MEASUREMENTS

(A) Shoulder Height - the vertical distance from the floor to the upper most point on the lateral edge of the shoulder with the operator standing erect.

(B) Sitting Shoulder Height - the vertical distance from the sitting surface to the upper most point on the lateral edge of the shoulder with the operator sitting erect.

(C) Body Depth - the maximum horizontal distance between the vertical planes passing through the most anterior and posterior points on the trunk.

(D) Thigh Clearance - the vertical distance from the sitting surface to the top of the thigh at its intersection with the abdomen.

(E) Forearm Length - the horizontal distance from the tip of the elbow to the tip of the longest finger.

(F) Arm Reach - the horizontal distance from the posterior surface of the shoulder to the tip of the extended middle finger.

(G) Elbow Height - the vertical distance from the floor to the depression at the elbow between the bones of the upper arm and forearm.

(H) Sitting Elbow Height - the vertical distance from the sitting surface to the bottom of the elbow.

(I) Popliteal Height - the vertical distance from the floor to the underside of the thigh immediately behind the knee.

Refer to Figure 4 for a sketch of these measurements.

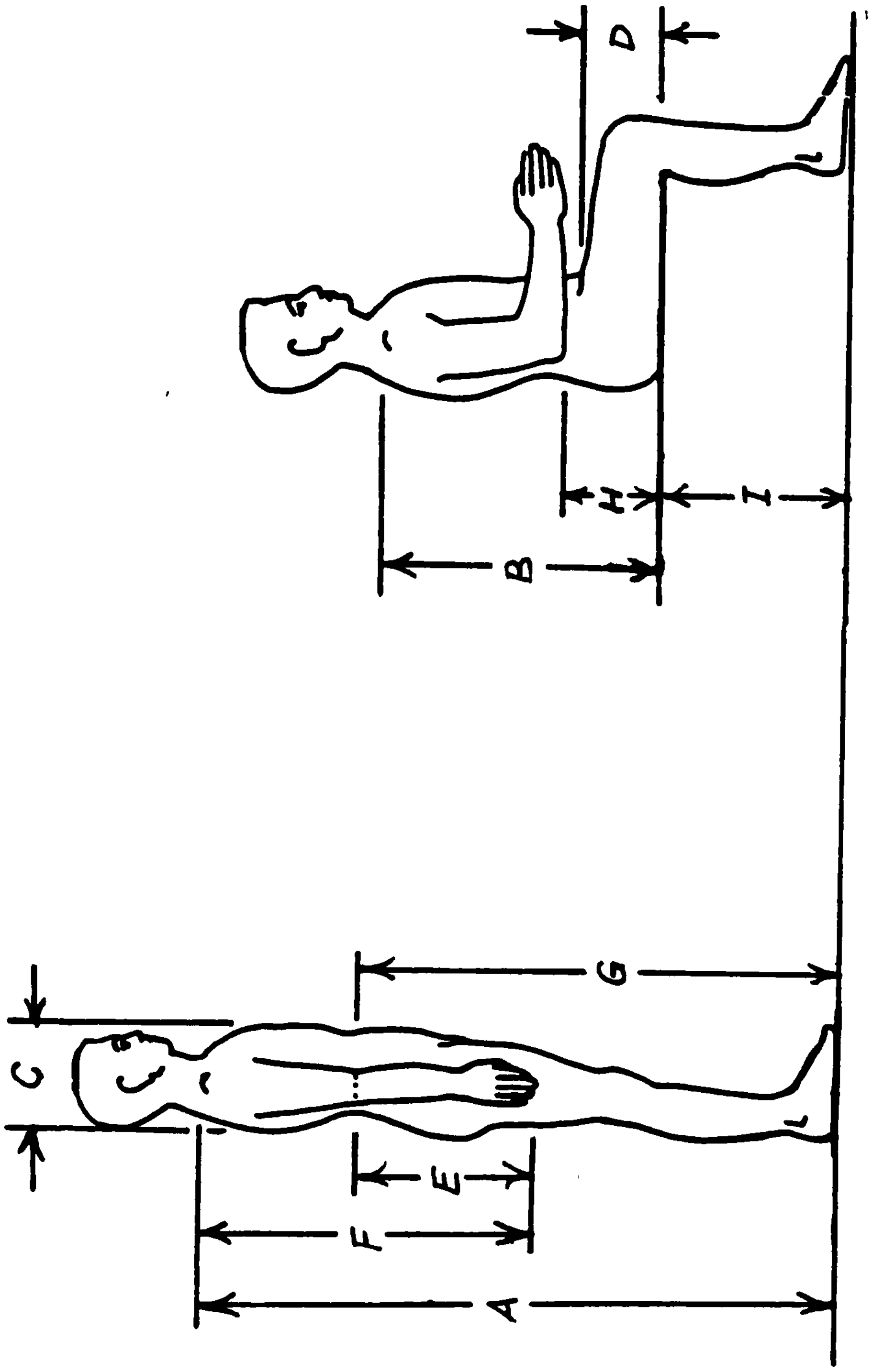

FIGURE 4. Sketch of Anthropometric Measurements