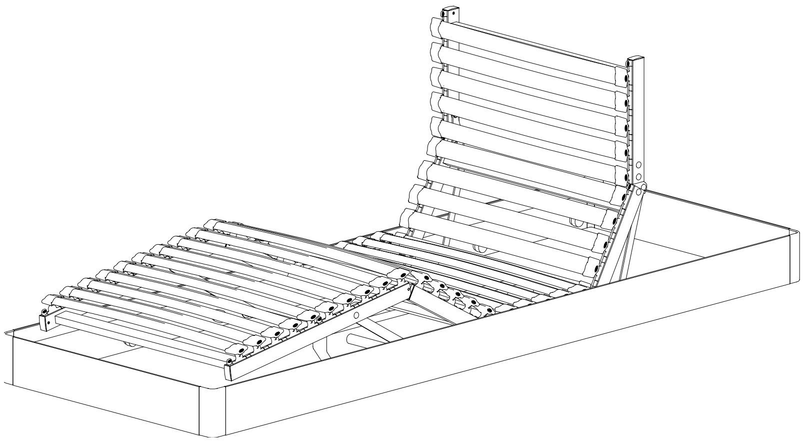
The Design Of A New Bed Adjustability Mechanism



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Abstract

The focus of this project was the development of a simple adjustable bed for the home environment. Design Mobel, a Tauranga based flexible slat bed manufacturer, initiated the project with the desire to develop an innovative and inexpensive mechanism for their new Circadian bed range that would not require an electrical supply.

The design was performed systematically using the Pahl and Beitz methodology with a number of design techniques to aid the process. The opinions of the targeted end user were gathered through a series of surveys and user trials which were processed into practical engineering requirements using the QFD technique. Patents and products in the area of adjustable beds were analysed to determine the context and the features available. Objective trees and functional analysis were also used to determine the direction of the project. All this information was collated and processed into the Product Design Specification (PDS) containing the entire list of requirements essential from the end product.

Once the design requirements were determined a series of concepts were developed with the aid of brainstorming sessions, synectics sessions, and the morphological matrix technique. The principle solution was selected from these concepts using the weighted objectives technique. A pneumatic concept was investigated as the method of actuation but was later dropped when it proved to be unviable. The final choice of actuator, which went against the initial objectives, was an off the shelf electric actuator that had been developed specifically for the adjustable bed market.

The final design uses Dewert's Duomat double electric motor actuator to move the top and bottom adjustable sections. A five bar linkage mechanism delivers a combined back and head adjustment while the bent leg adjustment is achieved with a four bar linkage mechanism. The concept was developed up until the beginning of the detail design phase where subsequent work will be performed for production and final release into the market place in August 2002.

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List of Abbreviations

ABET	Accreditation Board for Engineering and Technology
CAD	Computer Aided Drawing
CAM	Computer Aided Manufacturing
EMC	Electromagnetic Compatibility
ESD	Electrostatic Discharge
FEA	Finite Element Analysis
PDS	Product Design Specification
QFD	Quality Function Deployment
SEED	Sharing Experience in Engineering Design

1 Introduction

This chapter presents the design project that was proposed by Design Mobel including the desired aims and the approach taken to achieve these. The chapter begins with a brief description of adjustable beds to put the problem into context. Finally, the structure of the report is disclosed with an outline of the way in which the project was performed.

1.1 Adjustable Beds

As long as people have slept in beds there have been continual attempts to revise their construction in order to better accommodate the individual's particular needs for sleeping and lounging in comfort. One major initiative, which is used extensively in the health sector, was the development of the adjustable bed. Adjustable beds were originally designed with the principal purpose to accommodate the patient in a variety of positions. These "hospital-type" beds are generally unattractive, complex, and too expensive for use in the home environment.

A growing number of people place television and other media based entertainment devices in their bedrooms, and spend more time lounging in bed. For this to be enjoyable issues of posture are important. Consequently companies are taking a scientific approach to bed design with these needs in mind and with the intention of solving the inadequacies in regard to such things as comfort when sleeping or reading. The result has been the development of adjustable beds for use in residential environments by those who have no health or physical impairment. The adjustable bed is now considered by many to be an alternative piece of leisure furniture (Stroud 2000). An example of a modern adjustable bed for the home is shown in Figure 1-1.

Figure 1-1 The Franko Electro Lift SL1 (reproduced from KG 2000)

These adjustable beds can usually be moved from a fully reclining position to a sitting-up position in which at least one section is tilted up to provide a back rest. The body is supported by a series of adjustable sections that are hinged or pivotally connected together. The body support sections are mounted on a bed frame and are moved relative to each other and the frame to obtain the various positions.

The adjustment of the bed is either manual or powered. Manual beds require human effort to move the adjustable sections of the bed to the desired attitude and height, whereas powered beds use motors or actuators to perform the same result. Manual beds are less expensive than powered beds, largely due to being less complicated in construction. However, they are difficult to use and somewhat awkward as they have to be operated from outside the bed using some effort which is especially relevant if the person is incapacitated. In contrast, powered beds are convenient and can be operated with ease by those who are bedridden. Despite the advantages of adjustable beds they are more complicated in construction than conventional beds, and therefore, are generally more expensive, as well as being more difficult to disassemble, transport and reassemble.

1.2 Design Mobel

Design Mobel is a Tauranga based designer, manufacturer, and marketer of fine quality furniture, whose reputation for quality has led them to be recognised as the leading brand in the flexible slat bed market in New Zealand. They pride themselves on using state of the art technology and innovative production methods. This is reflected in the broad base of skills present in the design team, from graphic design, architecture, textiles, CAD/CAM to industrial design.

In early 2000 Design Mobel approached the Mechanical Engineering Department at Auckland University for assistance in developing a new product for their flexible slat bed range called the Circadian system. Their intention was to extend their product range to introduce an adjustable slat bed into the New Zealand market for the home environment. At the time there was no New Zealand producer of such an item. Their intention was not to target those who were unwell or convalescing at home but rather those who want to enhance their bedtime leisure. The general brief presented by Design Mobel incorporated the design of a simple and affordable adjustable mechanism to integrate into the frame of their latest bed range.

Design Mobel were aware that the mechanism required to produce the adjustment was available through third party suppliers and could be retrofitted to their bed. However, these mechanisms did not have the desired styling, and integration into their frame would have required extensive modifications to the bed. Therefore, Design Mobel made the decision to design their own mechanism.

1.3 Project Aim

The overall aims of the master's project was to:

- Design a bed adjustability mechanism within the requirements set out by Design Mobel
- Identify design methodologies best suited to the project

- Determine whether the methodology could be applied to other settings

Instead of just determining the most appropriate direction of the design based on 'gut feeling' or pragmatics, which has serious limitations, the design process was to be undertaken in a systematic manner. By taking a systematic approach the most appropriate design methodologies and aids would be discovered. Pahl and Beitz (1996) suggest that by taking a deliberate step-by-step approach to design, nothing essential is overlooked. This methodical style of practice is viewed as indispensable when executing original designs. There is a general belief that systematic design stifles your creative ability and therefore the challenge was to be able to show that by using the systematic approach to design methodology and design tools that an efficient and superior design would result.

1.4 Thesis Layout

The purpose of this thesis is to describe in detail both the process involved in designing the adjustable bed system and to describe the mechanism that resulted. This dissertation begins by outlining the background research that was carried out into systematic design, and the design process. The report then discusses the design brief and the approach to be taken in response to Design Mobel's project objectives. The processes taken to determine the design requirements are described and are followed by the concept development and evaluation. The embodiment design process steps and decisions are listed with a chapter exploring the development of the resulting prototype and the design changes required for production. The final section discusses the issues that arose regarding the systematic approach with recommendations for completing the detail design for production.

2 Background to a Systematic Approach to Design

Engineering design is not something that is easily defined. Hyman (1998) suggests that there appears to be no common definition for engineering design except that it is a methodical approach to solving a particular class of problem. This is suggested because a feature of much problem solving is that the solutions are often arrived at without an awareness of the step involved in the process. Suh (1990) describes it as being 'a continuous interplay between what we want to achieve and how we want to achieve it'. Other researchers ((Hales 1993) (Starkey 1992) (Lewis and Samuel 1989)) offer similar definitions that distinguish engineering design as a process of recognising a need and creating a system to satisfy that need.

Further helpful definitions of design are given by the Sharing Experience in Engineering Design (SEED) and by the Accreditation Board for Engineering and Technology (ABET).

The SEED definition suggests: 'Engineering design is the total activity necessary to establish and define solutions to problems not solved before, or provide new solutions to problems which have been previously been solved in a different way. The engineering designer uses intellectual ability to apply scientific knowledge and ensures the product satisfies an agreed market need and product design specification whilst permitting manufacture by the optimum method. The design activity is not complete until the resulting product is in use providing an acceptable level of performance and with clearly identified methods of disposal' (Hurst 1999).

The ABET definition (1990) states that: 'Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, analysis, construction, testing, and evaluation'.

Suh (1990) describes four components involved in the design process, each based on engineering and scientific principles: the problem definition, the creative process of generating a solution, the analytical process of determining if the solution is suitable, and the ultimate check of fidelity of the design. While this is true, the process of design often tends to be open ended with no readily identifiable closure point. Hyman (1998) suggests that this process is continuous until the cost of continuing the design process becomes greater than the benefits of a further improvement in the design.

2.1 *Systematic Design*

The design process is clearly complex and has great potential for complications. As in problem solving, the temptation is to take an undisciplined pragmatic approach. Pahl and Beitz (1996) suggest that since design is such a creative process if it is unguided the potential can be greatly limited. They recommend a systematic approach to achieve this which involves following a design process model which has a structured set of design phases with critical activities required at each stage. Within each step of a systematic approach there will be a variety of different design methods and techniques applied, and an awareness of these allows the designer to engage and progress through a design problem more proficiently.

The benefits of taking a systematic approach are claimed to include better design solutions with improved quality and efficiencies, as well as providing a clear and logical record of the development process for subsequent review and analysis. Hales (1993) suggests this approach is more professional, which inspires greater confidence from management and the customer, and provide quality solutions within the constraints of the project. Adhering to such a process will free the mind and allow more inventive and better-reasoned solutions to emerge. The designer can then step back from the design and rely on the model knowing that the key elements in the search for a design solution have not been overlooked (Hyman 1998).

Systematic design is not a constraining process; instead it offers a framework in which the designer has freedom to move about. Nor does it imply a step-by-step serial process, or a series of instruction to follow blindly. The times spent on each step and in which order they are performed is very much dependent on the particular design problem. The ability for steps to be visited several times and for designers to even unconsciously blend some of the steps together demonstrates the flexibility of a systematic approach. Because the entire process is subjective in nature, an infinite number of solutions are possible; right down to individual designers defining a totally different set of design requirements for the same perceived needs.

2.2 Design Techniques

Design techniques are tools or aids used for bringing a rational approach into the design process and a designer may combine a number of these methods during the course of the design process (Cross 1994). More often than not these design techniques appear to be too systematic and are not useful in the chaotic world of the design office. Furthermore they do not provide step-by-step instructions on how to produce amazing ideas and they cannot replace the gifts of a talented designer. Nevertheless, French (1971) suggests that they increase the size and range of the projects the designer can undertake and improve the quality and speed of their work.

Some of these techniques are common sense methods yet by formalising them into the design process they are not over looked. At times by following a design technique it may appear that the focus of the design process has been diverted from the central task of designing. While this is true, this diversion is important as it sometimes allows the designer to view a broader picture rather than viewing an immediate problem at hand.

Formalization of the design method widens the approach to the problem, externalises design thinking and encourages the designer to look beyond the first solution that enters their head. Factors that otherwise may have been overlooked with informal methods are not neglected in a more structured approach. Externalisation is the process of transferring thoughts onto paper which is done in a number of ways such as creating charts and diagrams. Cross (1994) suggests that all of this frees the designers mind from the complexities of the design to allow more intuitive and imaginative thinking. Using design techniques also reduces the size of mental steps, prompts inventive steps, reduces the chances of overlooking them, and generates design philosophies for the problem in question (French 1971).

Types of Design Techniques

The design techniques used within a systematic approach can be broken into two broad groups: creative methods and rational methods. Creative methods try to increase the flow of ideas by removing the mental blocks that inhibit creativity, or by widening the area in which the search for a solution is performed. There are many creative methods, some examples of which are listed below:

- Brainstorming
- Analogy
- Synectics
- Fantasy
- Enlarging the search space
- Method 635
- Gallery Method
- Delphi Method

Rational methods encourage a systematic approach to design but also aim to widen the search space for potential solutions, by facilitating teamwork and group decision-making. There are several rational methods that cover aspects from problem clarification to detail design:

- Quality Function Deployment
- Morphological Chart
- Value Engineering
- Objective Methods
- Function Analysis
- Weighted Objectives
- Functional Cost Analysis
- Taguchi Method

Rational methods are often misunderstood as cramping the creativity but the intentions of systematic design are to improve the quality of design decisions, and hence the end product. They are not the opposite of creative methods, and therefore the process is not one of 'straight jacketing' or stifling the creativity. Cross (1994,) states that creative methods and rational methods are complementary aspects of a systematic approach to design because they both offer unique and equally important functions to the design process.

The following section describes in brief the creative and rational techniques that were used in the design of the bed adjustability system.

Creative Design Techniques

Analogy

Analogy is a technique for suggesting solutions using stimulus from any source, particularly from outside the field in which the problem originates. The analogy may be as great as a direct transfer of a piece of equipment from one device to another or much more subtle with the analogous situation providing only the basic idea for the solution of quite a different form. Pugh (1991) states that 'analogy is the most powerful tool in the area of idea stimulation and concept generation'.

Brainstorming

Pugh (1991) suggests that brainstorming is the most widely utilised method of idea generation. Alex F. Osborn first suggested brainstorming back in the 1950s. He defined the verb 'brainstorm' as: 'To practice, a technique by which a group attempts to find a solution for a specific problem by amassing all the ideas spontaneously contributed by its members' Osborn (1963). Pahl and Beitz (1996) describe brainstorming as a method of generating an inundation of new ideas that may have been repressed or not considered in the present context utilising the association of ideas and the stimulation of memory. Miracles should not be expected from a brainstorming session as many of the ideas may not be technically or economically feasible, and those that are will often be familiar to the experts. The sessions are intended to trigger new ideas, and are not expected to produce a complete solution, as most problems are far too complex and too difficult to be solved with spontaneous ideas alone.

Synectics

Synectics is similar to brainstorming with the main difference being that its aim is to trigger the flow of fresh ideas using analogies. These analogies are frequently drawn from non-technical fields and everyday systems are examined for relevance to the current problem area. Pahl and Beitz (1996) describe synectics as the 'activity of combining various and apparently independent concepts' to generate solutions that were previously overlooked. The method is much more formal and systematic than brainstorming and much more time is spent familiarising the team with the problem. Starkey and Cross (1992; 1994) suggest the aim is to work towards a particular solution, concentrating on a single analogy, in the hope of extracting one or more ideas of genuine relevance.

Rational Design Techniques

Objective Trees Method

The purpose of the Objective Trees Method is to help in the clarification of an ill-defined problem that has been given to the designer. In the clarification of the task it is helpful to develop a set of objectives that the design must meet. The Objective Trees Method allows the designer to perform this task through outlining the objectives under consideration in a diagrammatic form. The objectives are listed in a hierarchical pattern with sub-objectives in order to show how the objectives relate to one another.

Function Analysis

Function analysis helps to determine the essential functions that the device, product, or system to be designed must satisfy, whatever physical components might be used. The product is designated a 'black box' that contains all the functions that are essential for converting the inputs into the desired outputs.

Weighted Objectives

When a set of alternative designs are created weighted objectives can be used to choose between the alternatives in a rational procedure, rather than relying on pure intuition. The evaluation is based on numerical weights assigned to the objectives that need to be achieved by the design. These weighted objectives are used to generate numerical scores that create a ranked list of the most promising concepts.

Morphological Analysis

Morphological analysis involves generating a table of possible functional options from which various combinations can be selected. This is particularly useful when a system has several functions that need to be satisfied. Pahl and Beitz (1996) suggest it is often useful to divide problems into sub-problems which can be solved individually and then recombined in order to arrive at an overall solution. To ensure that each of the potential combinations are covered a morphological chart is drawn up. On the left hand side of the table all the functions of the system are listed and opposite each are the possible methods of achieving the principle solution. A combination is formed by picking out a selection of options so that each function is satisfied. French (1992) adds that some combinations may not make sense and it is not wise to expect miracle solutions.

Quality Function Deployment (QFD)

When designing a product it is especially important to recognise that the person who buys a product is the most important person in determining its commercial success. The 'voice of the customer' should be a high priority in determining the product's attributes. Hales (1993) describes QFD as a systematic means for identifying customer needs and translating them into appropriate engineering characteristics and into a quantified design specification. The challenge that Hurst (1999) lays down for the designer is to optimise the requirements for the design while satisfying the customer need in the most cost effective way.

Value Analysis

Value analysis is used to make the designer conscious of the form that design and production methods have over the economics of producing a component. The major difference between value analysis and conventional cost cutting is the involvement of reducing the cost while maintaining or improving the functionality of the product. The process begins with an analysis of the functionality of the component, from which alternatives are developed that perform the function at the lowest cost within appropriate quality standards.

2.3 *Models of Systematic Design*

Design models can be grouped into two main types, descriptive and prescriptive. Cross (1994) describes a descriptive model as solution based with the emphasis on generating a solution early on in the process. Any flaws found in subsequent analysis mean the concept is scrapped and a new concept generated to repeat the cycle. The process is usually presented as a flow diagram with flow loops showing the iterative process. The heuristic based approach uses 'rules of thumb' and previous experience to lead the designer in a direction that may not necessarily be successful (Cross 1994). Conversely, a prescriptive model tries to encourage the designer to work in a design methodology that is more algorithmic and systematic in nature. The focus is on generating a performance specification so that the design problem is fully defined with no elements overlooked. The generation of several alternative concepts is encouraged with the final choice made with a rational selection of the alternative designs. The general progression is analysis-synthesis-evaluation (Cross 1994).

One such system is the Pahl and Beitz (1996) method which is a highly recommended methodology that has been used successfully by designers in all areas of engineering. The system is valuable because it has a comprehensive model that still retains some clarity unlike many other prescriptive models (Pugh 1991) and therefore was used as the methodology behind the development of this design. The various stages of the Pahl and Beitz model are listed in Figure 2-1.

2.4 The Four Phases of Prescriptive Design Models

It is generally accepted in a prescriptive design model that the process is broken down into the following phases: clarifying of the task, conceptual design, embodiment design and detail design. Sometimes the embodiment phase is not included so the conceptual and detail design phase are enlarged to cover its tasks. The following section looks at each of the design phases in more detail and describes the main focus and steps required.

Planning and Clarifying The Task

When a designer starts a project, more often than not the problem statement they have received is very vague. The first responsibility stated by Lewis et al. and Cross (1989; 1994) is that the designer must identify the problems that are not explicitly stated in the brief given to them, but which are implicit in the brief once it is deconstructed. Starkey (1992) points out that it is entirely counter-productive to produce a design that nobody wants or that only partially satisfies the needs of the end user.

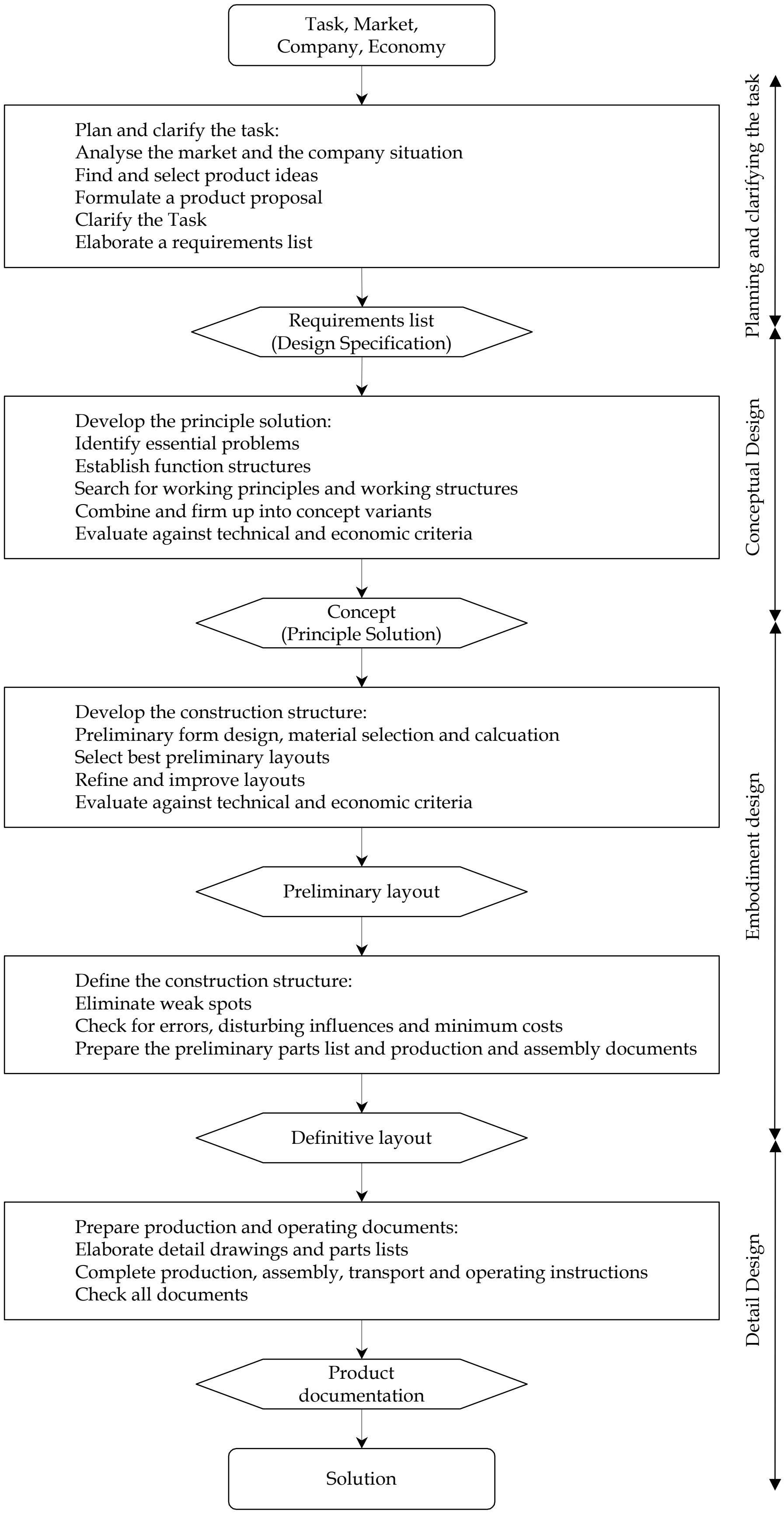


Figure 2-1 The Pahl and Beitz design process (1996)

The purpose of this phase is to collect information on the requirements that have to be fulfilled by the product and on the constraints that may arise. This begins with the creation of a design brief that lists the general properties required by the product. Various techniques are used to determine the function of the product and the system boundary of the new design. These activities lead to the formulation of a requirements list of the design, the product design specification (PDS). The subsequent phases are based on this 'living' document that is continually being updated as more information is gathered.

Design Brief

At this early stage of the design target objectives should be set, as it is unknown which objectives can be met and to what degree. As the process proceeds it becomes clearer which specific design will satisfy the users needs and as a result the objectives can become much more specific (Love 1986). The orientation changes from one of how, to one of what.

The first step in the design process is to develop a comprehensive design brief from the information provided. The brief consists of general statements regarding the essential goals that have to be fulfilled to satisfy the customer. Hyman (1998) suggests using a structured framework to overcome the balance of being too specific or too narrow by using three components: goals, objectives and constraints. A goal is a response to the need, an ideal that may not be accomplished. An objective is a quantifiable expectation of performance and constraints define the permissible range of the design and performance parameters.

Product Design Specification (PDS)

Cross (1994) suggests that performance specifications are statements of what a design must achieve or do and are different to objectives in that they are defined in terms of precise limits. These performance specifications are created in a

Product Design Specification (PDS) using the performance specification method, which emphasises the performance required rather than the physical components to achieve this operation. The intention is to define the problem while leaving an appropriate amount of freedom for the designer to develop ways of achieving a satisfactory design solution.

The definition Pugh (1991) gives for a PDS is 'an evolutionary, comprehensively written document that upon completion of the design should have evolved to match the characteristics of the final product'. The PDS represents a widespread list of constraints on the design context and can be described as a formal document interfacing between marketing and engineering functions. The perceived market needs are converted into functions and constraints covering the products design, manufacture and marketability.

The performance specification is made up of demands and wishes. Demands are requirements that must be met under all circumstances or the proposed solution is not acceptable. Wishes are requirements that should be considered where possible but dropped when they break some sort of stipulation such as increases in cost.

As the design proceeds the specifications of the product become more detailed but the objectives increase in size or scope. A performance specification limits the range of acceptable solutions. However, as it sets the target scope for the design it should not be defined too narrowly. A performance specification that is too narrow may mean that acceptable solutions will be eliminated unnecessarily, and too broad a specification will give little direction for the designer to aim at.

At this early stage it may not be possible to finalise every detail but Hales (1993) states that the process of obtaining the approval for these may help to identify specific items that have been left unresolved and the correct allowances can be made for them. Once the loose goal has been established, more detailed specifications can be drawn up. Lewis and Samuel (1989) state that the feedback that comes from new information helps to refine the objectives so it becomes clear where there are difficulties in satisfying conflicting objectives and the nature of the compromises to be made emerge.

The task clarification process is a convergent phase, where the weaker ideas are weeded out and the most promising are given more attention (Hales 1993) Once the design problem has been defined and the requirements listed in the form of a design specification, a firm base has been established for the remaining design stages to proceed from. The problems may be solved and the concepts that result can be evaluated against the design specification. No attempt should be made to create any solutions until a first draft of a PDS has been developed. Sometimes this is not possible since the design process is iterative and the PDS may be considered a fluid document, which developed along with the design.

Conceptual Design

Once the design specification has developed sufficient information, the designer is ready to being the creative work of giving substance to the product. The convergent thinking of the task clarification is changed to divergent during the conceptual phase, which involves broadening out to collect as many ideas as possible. The conceptual design phase is mainly concerned with creating solutions to the need established in the PDS. It is this phase of design that places the greatest demands on the designer and where there is the most scope for striking improvements. French (1971) suggests that this stage is where the most important design decisions are made and requires the practical knowledge of engineering science, production methods, and commercial aspects.

The problem statement is taken and broad solutions in the form of concept schemes are created. The diverse range of solutions that are developed then have to be evaluated and reduced down to the most appropriate concept, the principle solution. The conceptual phase consists of two major cyclical components; the synthesis of solutions to meet the need and the evaluation of these to determine the one that is the most appropriate in terms with the PDS (Pugh 1991). Pugh also recommends that the outcome of this phase should be a comprehensively engineered concept that the embodiment phase can be established upon.

Generating Ideas

In generating solutions to an acceptable level, the knowledge base of technology and engineering specific to the product area must be enlarged. Ideas have to be produced in as much abundance as possible because single solutions usually lead to a disaster. These ideas must also be developed to a level that is complete and recognisable, and most importantly, in balance with the laws of nature. This involves performing appropriate calculations in order to justify the particular concept.

Ideas may have already been collected from earlier thinking or other products may be available that have suitable features that can be incorporated into possible solutions. Ideas may also be generated through systematic literature and patents searches. It is also recommended to use some of the relevant design methods discussed earlier, such as brainstorming, and morphological charts to help synthesise new ideas. Pugh (1991) suggests that some of the most valuable inspirations come from bouncing ideas off others to encourage the generation of new ideas and improve existing ones. The possibility of producing a suitable concept at the outset is unlikely and it is much more probable that there will be several iterations of the process before something suitable is produced. It takes some effort to bring the alternatives to the same level of development and detail before any evaluation can take place.

An important part of the conceptual design phase is being able to communicate the ideas. This can be done graphically, diagrammatically, verbally and through modelling. Free hand sketches are very important and they may contain suggestions of key features such as overall form, loads, and operational conditions. Hyman (1998) suggests that the designer's thoughts about possible materials, size, and other features may come together and should be jotted down with the pictorial representation. The concept sketches should be of sufficient clarity to be understood by not only the designer but also those who will be evaluating them.

The design phases should be followed systematically, but not necessarily rigidly. If a brilliant concept is developed that does not satisfy the PDS, the problem may lie with the PDS being to narrow or broad in focus. In this case, (Pugh 1991) suggests the designer should re-evaluate the PDS and modify it if required since as stated earlier, the PDS itself is evolutionary. The temptation to 'cut and run' with ideas before a full spectrum has been covered or the specification has been fully developed should be avoided at all costs as the results may not be satisfactory.

Selecting and Evaluating Concepts

With a series of concepts produced, the next stage of the conceptual design phase involves selecting and evaluating the concepts using a convergent mindset. The aim is to reduce the number of generated concepts to a short list of two or three for further detailed analysis. Hurst (1999) states that it is clearly impracticable to examine every concept in depth, but with only a small number of promising concepts the process can be increasingly straightforward. The concepts should conform to the requirements of the specification but each has to be critically examined to test its suitability as a solution. Starkey (1992) suggests that a mini-feasibility study of each alternative is required with the aim at either eliminating or passing a concept for the final solution. When a selection is made there has to be a justification for the choice, particularly regarding those that have been discarded.

Some people are particularly good at creating new ideas yet having the ability to discern the most promising option is a skill in its self. Designing by 'gut feeling' is a risky approach to take, as it is easy to favour one concept over another because one factor seems to stand out, however the other negative factors are often overlooked. Even a simple problem contains underlying factors, which are difficult to weight against each other during a subjective assessment. If an inappropriate design is chosen, there is little that can salvage the project once the design process is initiated. Often the designer involved is bias in their opinion and therefore an impartial decision is not always possible. Sometimes it is useful to involve a group of individuals in the decision process to avoid these biased judgements.

Thus the adoption of a systematic decision-making procedure is essential for students and the most experienced designers alike during concept selection. Pugh (1991) recommends that a set of criteria be established to evaluate the concepts effectively. There are many structured procedures available for the selection and evaluation of alternative concepts and these tools aid in creativity in the context of controlled convergence.

Embodiment Design

Embodiment design builds on the principle solution selected in the conceptual phase. The aim of this phase is to develop more detailed layouts of the concepts and to resolve overall geometrical, dynamic, and safety issues. In contrast to conceptual design the process is iterative in nature so analysis and synthesis are used complementarily during the many corrective steps (Pahl and Beitz 1996).

Once a concept takes shape there is a large emphasis on optimisation of the design, which is accomplished by what Hurst (1999) describes as 'attacking what are perceived to be the weak points of the design'. The embodiment phase is described as the bridge between conceptual and detail design phases. This is because there is a significant jump between the visualisation of an abstract concept and the manufacturing of a safe and reliable product. Advancement without sufficient and appropriate thought and development will usually result in design failure.

The input to this phase is usually not more than a sketch and a PDS document. The aim is to refine this initial information and develop it to the point where the detail design and production planning can commence. This will consist of definitive scheme drawings with accompanied documentation of calculations, tolerances, suggested materials and manufacturing processes. Quite often the embodiment phase will involve the production of a prototype that can be put through a rigorous test program to validate the design.

Design considerations

There are many things to consider in the embodiment of a design. Hales (1993) suggests that the design should be as simple and clear as possible as this has many advantages in the manufacture, assembly, and cost of the final product. Function, cost, and safety are paramount in the design process but the appearance of an object is also a major factor in the appeal to the customer. An engineering design with good aesthetics will be pleasing to the eye and give the visual impression of functional efficiently.

The embodiment phase involves a significant amount of iterative design. The process starts with a decision being made on the overall layout, which is then modelled, analysed, synthesised, and optimised. A revised layout is then produced which may have more detail or a modified feature. This whole process is repeated many times until the best compromise can be made.

Hurst (1999) describes the early stages as the period when the most important components are given size and strengths. Once the body and shape begin to emerge the modelling, and synthesis can begin. Scheme drawings should be created to show the motion, adequate clearances, and other information concerning such subjects as tolerances and materials. These drawings should be regularly updated and modified to reflect any changes made.

Material and process selection is an integral part of the engineering design making process. The proper selection will lead to increased product performance, greater efficiency, and reduced costs. Decisions made in this phase dictate manufacturing processes and therefore it is important that throughout the process advice is sought from manufacturing experts so that the designer can attempt to utilise existing machinery and tooling where possible. The number of components should also be optimised so that the least number of parts are used, while at the same time not increasing their complexity beyond what is suitable. Whenever possible it is generally more economical and practical to buy ready made assemblies and components.

Calculations are essential in this phase of the design and many are usually required. Hales (1993) suggests that the calculations should be carried out and recorded for later reference with annotation and documentation so that other engineers can easily understand them.

Detail Design

The final stage of the design process has been reached, whereby important decisions have been finalised and what is now required is simply fine-tuning. This involves focusing in at each of the embodied components and optimising them. The design of each component has to be verified and information regarding the manufacture should be completed. Detail design is generally more concerned with the design of the subsystem and components that make up the final design. As with all stages of the design this should be done within the constraints of the PDS. The detail design process needs the harnessing of many different areas of knowledge: materials, techniques of analysis, technology of the situation, environment of the component, quantity, life, loading, aesthetic appeal, and so forth (Pugh 1991). The input to the phase is the design intent and scheme drawings, with the output being a series of detailed drawings and accompanying documentation.

Further design decisions will be made and these will understandably influence other areas of the design. As with the embodiment design it is iterative in nature and the different design stages are continually overlapping. It is for clarity and convenience that the distinction between the phases has been made. Throughout the design process the designer becomes increasingly involved with the details of the product, especially as it converges towards the best solution.

All stages of the design process are important and detail design is no exception. The final stage of the design process is crucial in communicating the finer details of a design and should not be left as an afterthought. According to Pugh (1991) most accidents and disasters involving engineering design issues can be traced back to errors from inexperience or poor judgement in detail design. Every activity concerned with detail design is important to preserve and enhance the design work that has already been achieved. If the details are not handled conscientiously and professionally, all the hours of analysis and evaluation that have preceded this point can be nullified, and the benefits of the well design product can be lost

3 The Design Proposal

The following chapter discusses the proposal presented by Design, listing the major constraints specified from the onset of the project.

3.1 *The Brief*

The initial brief presented for the design of the adjustability mechanism was presented in writing, as shown below.

Aim: To develop a simple mechanism or means of adjustability integrated into the bed frame. This mechanism would allow in bed adjustment and be focused on providing additional features for activities in bed rather than purely convalescing.

This brief was less than adequate and far too broad to determine the direction of the design. The written documentation was further expanded through verbal communication with the Design Mobel design team to pin down the exact requirements desired.

3.2 *Determining the Problem*

As the investigations were made to determine the true nature of the project, a great deal of information surfaced. There were significant constraints on the project from dimensioning and volume limitations, to materials and aesthetic form restrictions. The time plan involved developing a full working prototype by the end of 2001, with subsequent detail design developing the product for production release in mid 2002.

The design team presented a series of brochures of products currently available on the market in the area of adjustable beds. The desire was for the information to be analysed to establish the context of the design. Another requirement for the designer was to perform research into the ergonomics of adjustable beds to ensure the design would be ergonomically sound.

One requirement stipulated from the beginning was that the adjustment would have to be performed with little effort to the user while lying in the bed. It was also hoped that the method of moving the system would be something quite innovative. Most systems use some sort of electric actuation to move the sections but there is much discontent in Europe over having electrical devices producing electromagnetic waves in the bed. Design Mobel's desire was that the final product be electricity free which would open it to a much larger market of potential customers.

Other adjustable beds available overseas are very utilitarian, performing the desired function with little consideration for style and grace. Design Mobel invests quite strongly in developing furniture that is at the cutting edge of style and this can be clearly seen in the Circadian system. To assimilate the adjustability mechanism into the system it had to be simple, sleek, and innovative.

The target market for the product is for use within the home, rather than a hospital or rest home where adjustable beds are traditionally used. The bed will be used for assisting activities such as reading and watching television, rather than aiding in the treatment of patients. Subsequently the target user's capacity to invest in such a bed is significantly lower, compared with a hospital or rest home. However, this is easily resolved as the requirements for health and safety standards, added function, and robustness are greatly reduced in the home environment, and therefore production costs are lower. The suggested cost price per single side of the bed was set in the range of $250-400 with the aim obviously for the lower end of the price bracket.

A major constraint was with the current method of grouping the slats that had been developed for the Circadian system. The slats come in 330mm groups with the choice of having three, four, or five slats in each zone. The zones cannot be broken up so the articulation points of the adjustability mechanism are set at these 330mm intervals as shown in Figure 3-1.

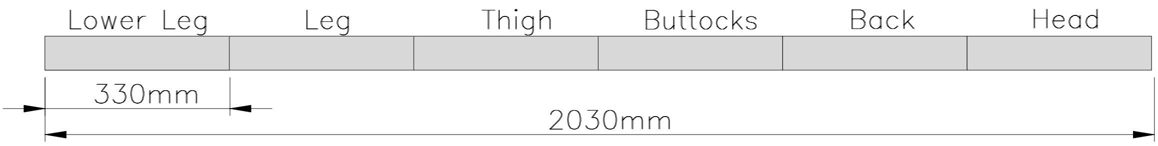


Figure 3-1 The break-up of the bed length into 330mm slat intervals

When the system is up-graded to a double bed several issues arise. Clearly it is not desirable to have one occupant trying to sleep while the other is reading with the bed in an adjusted position. Therefore, the two sides of the bed must be independent of each other, something which is particularly common with the other products available on the market. This of course creates additional problems such as separate mattresses and linen issues, yet it appears to be unavoidable and a compromise must be met, as is reflected in other adjustable products on the market.

Design Mobel had performed research into the design of mattresses for the Circadian system and the technology would carry over to the adjustable variation with minor changes. Consequently the design of the mattress is outside the scope of this project.

Design Mobel desired a single solution to the problem they had presented but there was confidence that a few other suitable alternatives may be devised. Of the alternatives that were presented several were deemed unviable at the time, however as the market for adjustable beds develops and manufacturing limitations are reduced, the ability to pursue these in the future is increased. The design was to remain open to innovative ideas, make use of new manufacturing methods and alternative materials as long as they add value to the product without added cost and major complications.

3.3 Formalising The Design Brief

The design brief was formalised using the limited information given both verbally in and writing by Design Mobel at the commencement of the project.

These design requirements were set out in a systematic manner so that those presenting the brief could verify that the designer had the same goals for the end product. The requirements were as follows: Design a bed adjustability mechanism that:

- Must be a full working prototype by the end of 2001 and in production by mid 2002 (Constraint)
- Must integrate into the frame of the latest bed range (Objective)
- Is simple and aesthetically pleasing to the eye (Goal)
- Price range approximately $250-$400 a side (Constraint)
- Not aimed purely for convalescing but for general home use in aiding activities such as watching television, reading or feeding the baby (Objective)
- Must be adjustable from within the bed by the user with minimum force (Objective)
- Avoid the use of electricity in the bed (Goal)
- Must comply with the 330mm slat spacing system established for the Circadian system (Constraint)
- In a double adjustable bed the two sides must have independent adjustment (Constraint)
- Other
    - Mattress design outside the scope of this project
    - Ergonomics outside brief
    - Need to establish the context of the product in the market

4 Approach to the Problem

As described earlier the project followed the Pahl & Beitz methodology for systematic design, starting with the clarification of the task and continuing on through to the detail design phase. This chapter gives a broad overview of the steps that were taken in each stage of the design process. These steps will be discussed in more detail in subsequent chapters.

Gantt charts were used throughout the project to establish the direction and time goals required to complete tasks on time. The diagrams below summarise the details of these charts to show the steps that were taken at each phase of the design process (Table 4-1), and the timing involved for each (Figure 4-1).

Table 4-1 The design techniques used at each step of the design process

Clarifying the Task	**Conceptual**	**Embodiment**	**Detail**
Brief	Brainstorm	Load Distribution	Value Engineering
Objective Tree	Synectics	Prototype	Production
Function Structure	Generate Alternatives	User Trial	
Patent Analysis	Morphological Chart		
Product Analysis	Evaluate Alternatives		
Adj. Activity Survey			
Bed Adj. User Trial			
QFD			
PDS			

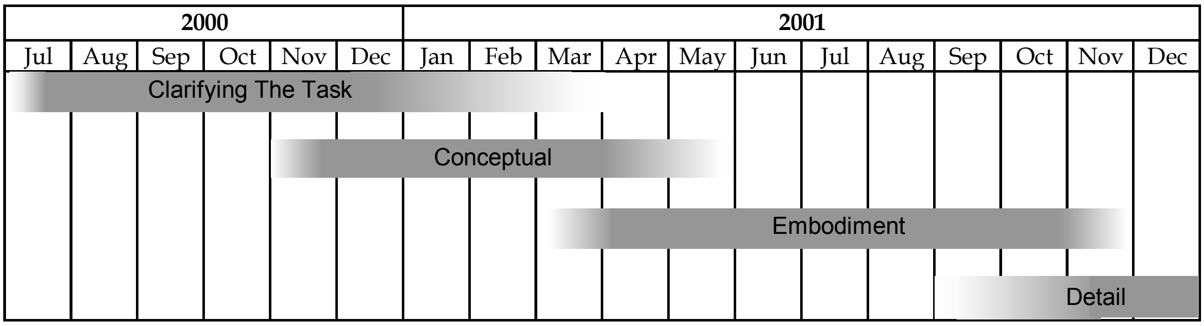


Figure 4-1 A time based distribution of each of the design phases

4.1 Design Focus

There is little point developing a product for which there is no recognised need or want. Accordingly the design should be approached with the focus of fulfilling the needs of the consumer, and as a result achieving customer satisfaction. However, there is the problem that the product being developed may not be a perceived need by the customer while it still does not actually exist. The desire is that the product is released and the customer realises its worth, and the manufacturer will have then established a need. Whether it is a perceived need or not the design should be developed so that it will meet the desires and requirements that the user would have of such a product. Wherever possible user feedback on the design and other relevant areas should be obtained to determine this 'voice'. This was done practically throughout the project through the extensive use of questionnaires and user trials.

Throughout the project a systematic approach was applied:

- Gantt charts were used to manage the timeline of events and to establish specific time goals.
- A design journal was used to record all thoughts, concepts, and calculations. Any piece of work that was performed on paper was recorded in the journal, making it easier to go back and find the information required. Earlier conclusions could be located to speed up the decision process, and important discoveries could be used to ensure the same mistakes were not made again.
- All documentation was printed and sorted into folders logically for easy access.
- At the end of each major task a summary of the work and results was created. This helped to keep all the work up to date and meant that nothing was overlooked.

Typically in a busy design office it is not possible to stand back from the design and look at the approach being taken, as there are huge time pressures of achieving results. In contrast, with this project there was the ability to stand back, and to perform considerable research into the ideal methodology with which to approach the design problem. Using the techniques discovered, documents were prepared to help the flow of ideas and information at each stage of the design process. After considering all the information, the Pahl and Beitz methodology described in the background section was the process model that was applied to the project. Design techniques were also used in conjunction with the model to aid the development of ideas and information in each of the design phases. The research was both beneficial in producing a methodology to be followed and locating other aids to help in the process, but also in instilling a design ethic that can be carried into future design projects.

The project also had to be undertaken with an environmental focus. Design Mobel is accredited with ISO 14001, which requires that the product be designed with great consideration on the affect the entire design cycle will have on the environment. This covers everything from the production and its working life, through to the retiring and recycling of the product. Consequently there has to be a focus on the materials and the manufacturing methods used.

4.2 Clarifying the Task

Clarifying the task phase involved collecting all the information on the requirements and constraints that were related to the product. To gain a firm grasp on what the problem was really about required considerable research. This started with the clarification and amplification of the design brief and extended to background research into products already on the market, those already patented, and into the ergonomics of adjustable beds. The voice of the customer was used as a focus throughout the process and this was provided as part of the task clarification with a questionnaire and user trial. Several design techniques were also applied to help in the development of the PDS: the objectives were determined using the objective tree technique, the functions were established using function analysis, and the engineering characteristics were targeted using Quality function deployment (QFD). All the information collected thus far was compiled to create the preliminary PDS document. The conceptual design phase and subsequent phases were based on this document and it was continually updated as developments were made.

Throughout the clarification of the task phase a series of questions were asked to assist the designer in thinking objectively about the problem and to continue seeing the whole without getting carried away with the specifics.

The questions were as follows:

- What is the problem really about?
- What implications, wishes and expectations are involved?
- Do the specified constraints actually exist?
- What paths are open for development?

The clarification of the task phase took longer than expected because the design brief was very broad. It was not until this document had been produced that the design could proceed with confidence, with the knowledge that the product was what Design Mobel truly desired.

4.3 Conceptual Design

The next stage of the design process was the conceptual design phase where many concepts were developed and refined down to obtain the principle solution. The plan was to use as many different design aids as possible to be able to get the broadest range of suitable concepts. Brainstorming and synectics sessions were performed with a group of people to develop some wild and varied ideas for further investigation. Techniques such as objective trees, function structures, and morphological charts were used to guide and structure the thought processes while leaving room for creativity. The development of these concepts took a little longer than planned but this process was critical due to the emphasis given to the innovative nature of the design

The large list of concepts was reduced to a few suitable solutions using an evaluation methodology. The design was broken down into four main sub-systems: the frame, the adjusting mechanism, the method of actuation, and the method of fastening the sub-assemblies together. The sub-system that affected the other assemblies in the greatest manner was the method of actuation because it influences almost every area of the design. A great deal of research was required before a final decision was made on which method of actuation to proceed with. Tentative decisions on the mechanism meant that the whole system slid into the embodiment phase. The frame and fastenings had to be moved into the next phase with assumptions of how the actuation would occur. The design teetered between the two phases for some time, with new pieces of information gathered, dead end designs discovered, and new ideas developed. Once a final decision was made on the method of actuation the fuzzy concepts in the other sub-assemblies could finally be clarified and developed further.

4.4 *Embodiment Design*

This phase involved clarifying and expanding the form design developed in the conceptual phase and the concepts that had not been fully resolved were elaborated until suitable decisions could be made. As the project progressed and new knowledge was gained the evolution of the bed sub-assemblies was iterative in nature because progress in one area would affect the design in another. As stated earlier the final actuation method had not been confirmed until more research into available techniques and the corresponding adjustment mechanisms had been performed. Pneumatics was initially pursued as a suitable actuation method but was later dropped for gas-struts, and then finally for electric actuators. The adjustment mechanism also changed greatly during the embodiment phase as improved techniques were developed and more information on the rest of the system was clarified.

Detailed calculations were required to determine information such as the dimensions, materials and velocities. The computer modelling was performed in SolidWorks, the CAD software used at Design Mobel, making the transfer of models simple and easy. A package called Dynamic Designer was used within SolidWorks to test the kinematic properties of the models. Another SolidWorks addin called Cosmos was used to perform Finite Element Analysis (FEA) calculations on the parts to determine the stresses and strains induced by the loads involved.

The concept was developed to a preliminary layout level so that a working prototype could be produced in order to have a physical, tangible model to test the theory of the design. This was also done so that all the unforeseen design implications could be ironed out at this early stage before the definitive design was developed. The prototype was used to perform a user trial to gather information about the embodied bed design: their ability to use the bed, their opinions of the system, and their perceptions of its overall comfort. Three actuators were tried on the prototype to determine which was the best method to use in the final design. The collected information was helpful in determining which areas of the design needed to be changed and which areas were satisfactory. At this stage the PDS was updated to cover the new data and changes to the design. The major constraint of avoiding the use of electricity in the bed was changed when it was discovered that the other possible actuators were not viable and the only means to achieve the PSD satisfactorily was to compromise in this area.

4.5 Detail Design

The work covered in this document finished with the review of the prototype design and the changes and recommendations that were made as a result. The prototype proved the concept would fulfil the problems set out in the PDS and as a result the goal of the project had been reached. At the time that this was written the level of development in many areas of the design was at the beginning stages of the detail design phase and consequently the detail design phase is outside the scope of this thesis. Following the writing of this thesis the project will move completely into the detail design phase where the definitive design will be developed for manufacturing processes so that it can be put into production.

5 Determining the Design Requirements

This chapter describes the techniques and methods that were used to determine the design requirements for the adjustable bed. This section essentially covers the work that was performed at the beginning of the project, during the clarifying the task phase.

5.1 Background Information

To establish the context of the project the following research studies were executed.

Ergonomics

Research was undertaken into the ergonomics of adjustable beds with Dave Tappin from South Pacific Ergonomics Ltd. Most of the relevant information was gathered from documentation on the ergonomics of seating rather than from information written specifically on sleep or lying down. This was because the databases did not contain any papers on sleep or adjustable bed research and the ergonomics of an adjustable bed are essentially that of a reclining seat. A list of books relevant to this area of research is listed in the bibliography.

Analysis of Currently Available Products

One of the first steps that was taken in gathering information for the requirements for the Design Mobel bed, was to establish the design context into which the product was to be introduced. There are many adjustable beds available around the world, with the majority of these beds originating in Europe. A few of these beds are available in New Zealand and it is these products that the Design Mobel adjustable bed will be competing with.

Two studies were performed to determine what customers would expect from an adjustable bed, in regards to the performance, adjustment and features available. The studies were also used to discover what kind of mechanism and sources of actuation have been used in the competitor's products. One study looked at the patents that had been filed in the adjustable bed area and the other looked at the products that are currently being marketed. Both of these studies were performed in much the same way, with the data that was collected analysed using matrix analysis, to build up information regarding the features available in these products and the advantages and disadvantages of each.

Patent Analysis

The patent analysis involved determining what intellectual property had been filed in the area of adjustable beds, and what features and mechanisms this covered. The search was performed through the Delphion Intellectual Property Network website (Delphion 2001) where over 250 related patents were found. A summary of the results are found in Appendix A. Many of these patents were not relevant to the research area because they covered aspects other than the mechanism for adjustability. 48 patents were found to have information applicable to the project area and within these patents were a series of different categories as shown in Table 5-1. Adjustable beds that alter the occupant's posture were the most significant group, with the other categories, such as height adjustment, safety mechanisms, mattress supports, and motive units, in much smaller numbers. The remainder of the analysis looked purely at the patents covering the adjustment of posture.

The number of beds that were designed specifically for hospital use or for the home environment (Table 5-2) was almost the same, with over half the adjustable beds patented not indicating they were specific for either. The most significant form of actuation for the home targeted beds (Table 5-3), was the use of electric motors (48%), followed by inflatable bladders (17%), cylinders (13%), and manual electric (9%). Looking at the mechanism behind this actuation (Table 5-4), the pivotal lever arm was the most significant with use in 65% of the beds.

The results also showed that 86% of these electrically actuated mechanisms used pivotal lever arms.

Table 5-1 Different types of devices covered in the adjustable bed patents

Type of Adjustment	No.	%
Adjustable Bed	31	64.6
Height Adjustable	5	10.4
Size Adjustable	2	4.2
Angle Adjustment	2	4.2
Roll Adjustment	2	4.2
Motive Unit	2	4.2
Safety Device	1	2.1
Mattress Support	1	2.1
Sleep Conformability	1	2.1
Hardness Adjustability	1	2.1

Table 5-2 Proportions of the patents designed for the hospital and the home

Target use of Design	%
Not Stated	51.6
Hospital	25.8
Home	22.6

Table 5-3 Percentages of the different actuation methods used in the bed patents

Source of Actuation	All (%)	Home & Not Stated (%)
Electric Motors	45.2	47.8
Inflatable bladders	12.9	17.4
Cylinder	12.9	13.0
Manual Crank	9.7	4.3
Not Stated	6.5	0.0
Manual/Electric	6.5	8.7
Manual Move	3.2	4.3
Body Weight	3.2	4.3

Table 5-4 Percentages of the different adjustment mechanisms in the patents

Source of Actuation	All (%)	Home & Not Stated (%)	Electrical (%)
Pivotal Lever Arm	64.5	65.2	85.7
Inflation Of Bladder	12.9	17.4	14.3
Cylinder Movement	12.9	13.0	21.4
Pivotal Slide Mechanism	16.1	8.7	0.0
Screw & Nut	12.9	8.7	0.0
Torque Tube	9.7	8.7	21.4
Pulley And Wires	6.5	8.7	7.1
Hinge Movement	6.5	8.7	14.3
Gearbox/Worm Gear	6.5	4.3	0.0
Circular/Linear Gear	3.2	4.3	0.0
Scissor Mechanism	3.2	0.0	0.0
Gear Train/Clutch	3.2	0.0	7.1

One of the features that was present in 16% of the patents (Table 5-5) was the ability to change the height the bed was off the ground. The analysis also showed that this feature was not present in any of the home targeted beds. From this data it was concluded that this would not be a necessary requirement and would not be worth including in the Design Mobel bed design.

Table 5-5 Percentages of the bed patents with height adjustment

Height Adjustment	All (%)	Home & Not Stated (%)	Home (%)
No height adjustment	83.9	91.3	100.0
Total height adjustment	16.1	8.7	0.0

Table 5-6 shows that all but one of the beds had an adjustable back section. The adjustment of the leg section was almost as significant with 87%, and the division of the leg into an adjustable thigh section was also popular with 74% of the beds featuring this adjustment. The option of adjustable head and foot sections was not very popular with only three of the beds offering this. From this research it was concluded that the basic requirement for the design would include back, leg and thigh adjustment.

Table 5-6 Proportions of the patents providing adjustment at each of the body zones of the bed

Body Zone Adjustment	All (%)	Home & Not Stated (%)	Home (%)
Back	96.8	100.0	100.0
Leg	87.1	87.0	85.7
Thigh	74.2	78.3	71.4
Head	6.5	4.3	14.3
Foot	6.5	4.3	14.3

There were additional options that were specific to a select number of models. These features are listed in Table 5-7.

Table 5-7 Features of the patented adjustable beds

Feature	Description
Add on kit	A kit that can be easily assembled at home and installed on one's bed in order to transform it into an adjustable one
Slide back	As the bed is raised to a seated position the mattress support moves backwards to keep the person in the same position relative to any objects such as a bedside table
Anti jam	A safety device is built in to stop parts of the body from being caught between the frames of the bed while moving
Butt depression	A depression in the mattress section to accommodate the buttock when the bed is in a sitting position
Removable motor	Motor is easily removed to allow for quick changeover
Power change	The adjustment mechanism can switch easily between electric and manual power
Locking Mechanism	The device uses a strap attached to a bell crank to activate a push/pull crank that locks the bed in position
Automatic knee break	A cam is used to engage or disengage the knee adjustment with movement of the back section
Angle sensors	Mercury sensors or rotary potentiometers are used to measure the angle of the bed
Vibrator	Bed can vibrate for a massaging affect

The other interesting statistic to note was that 71% of the home targeted patents for the adjustability mechanism had expired. Further research would be required to determine the reasons behind this.

Product Analysis

The product analysis involved analysing the adjustable beds available in the market place. A large number of product brochures had been gathered in preparation for designing the adjustability mechanism. A total of 129 different beds were analysed from 19 different companies. A complete summary of the results is listed in Appendix B

The analysis of the adjustment (Table 5-8) provided by the products showed that 78% of them provided back adjustment, with 66% providing a head adjustment option. For the leg, 95% provided adjustment but only 41% had bent leg options. The results imply that the adjustment of the back and leg is a minimum requirement, with the head and bent leg a possible inclusion in the design. Telescopic head sections were only provided by two models, and 11% of the head section’s mechanisms were linked to the movement of the back section.

The most common method of movement for the head section was manual (59%), followed by electrical adjustment (37%). The adjustment of the back section was split almost equally between manual (48%) and electric (46%). This was also reflected in the leg adjustment with 56% manual and 42% electric. Gas cylinders did not feature in the head adjustment and were only available in 7% of the back and 3% of leg adjustments.

Only 4% of the beds gave the option of height adjustability. For the control (Table 5-9), 82% of powered adjustable beds had cable remotes for adjustment, 8% had infrared remotes, and 9% used gas cylinder control. Table 5-10 shows the different features that were available in the products.

The results from the matrix analysis gave valuable data on the amount of adjustability required by the mechanism and the kind of features and control expected by such a bed. The information also gave a good indication of the types of mechanisms, materials, and features favoured by other manufacturers.

Table 5-8 The method and level of adjustment available in the products

		% Yes	% Answered
Head/Neck	Adjustable	65.89	100.00
	Telescopic	1.89	82.17
	Linked	10.62	87.60
	Manual Adjustable	59.21	58.91
	Gas Cylinder	0.00	71.32
	Electric Adjustable	36.49	57.36
Back	Adjustable	77.52	100.00
	Manual Adjustable	48.00	77.52
	Electric Adjustable	45.92	75.97
	Gas Cylinder	7.14	75.97
Buttocks	Fixed	41.09	100.00
Leg	Adjustable	94.57	100.00
	Knee Separate	40.59	78.29
	Adjustable	95.35	100.00
	Manual	55.93	91.47
	Electric	41.53	89.92
	Gas Cylinder	2.54	89.92

Table 5-9 Proportions of the different remote control adjustment methods

Remote Type	%Yes	% Answered
Cable Remote Control	82.09	51.94
Infrared Remote Control	7.46	51.94
Cylinder Control	8.96	51.94

Table 5-10 Features available in the adjustable beds

Feature	Description
Mains isolator	Of the electrical beds 20% said they had mains isolation but the rest were unknown
Fits any bed frame	6% could fit any bed frame.
Bed box access	16% could lift the leg section right up to expose a storage area
Slide back	3% could slide as they raised to keep the person the same distance from the bed side objects
Centre belt	41% of beds had a centre belt to adjust the tension down the length of the bed
Emergency lowering	Of the electrical systems, 18% stated they had an emergency lowering system

Feature	Description
Memory positions	21% of the electrical beds gave the option to record favourite positions
Power failure lock	7% of the models stated that on power failure their bed would not drop but lock in position
Removable motor	18% had motors that were easily removable

Load Distribution

For design purposes an indication of the loads that were to be expected along the surface of the bed had to be determined. A study was performed by Design Mobel to establish the load profiles of subjects based on different anthropometrical constraints. Design Mobel purchased a device called Ergo Check to perform the profiles. The device was basically a special blanket that was laid on the bed to record the pressure readings created by the weight of a subject lying on it. Screen shots from the Ergo Check computer software were taken of each profile and with the help of Adobe PhotoShop the weight distributed to each zone was calculated. The method was fairly accurate but a small amount of the participant's weight could not be accounted for. This was because when the person sank into the mattress a slight sideways force was produced which was not recorded by Ergo Check. The data from this study was used to determine the maximum weight distribution on the bed's surface and the final results are shown in Table 5-11 and Figure 5-1.

Table 5-11 The mass on each bed zone and groups of zones under the worst load case

Bed Zone	Zone Mass (kg)	Multiple Zone Mass (kg)
A = Head	9.2	60kg
B = Back	44.8	
C = Buttocks	Fixed	Fixed
D = Thigh	30.7	50kg
E = Knee	15.0	
F = Foot	6.9	

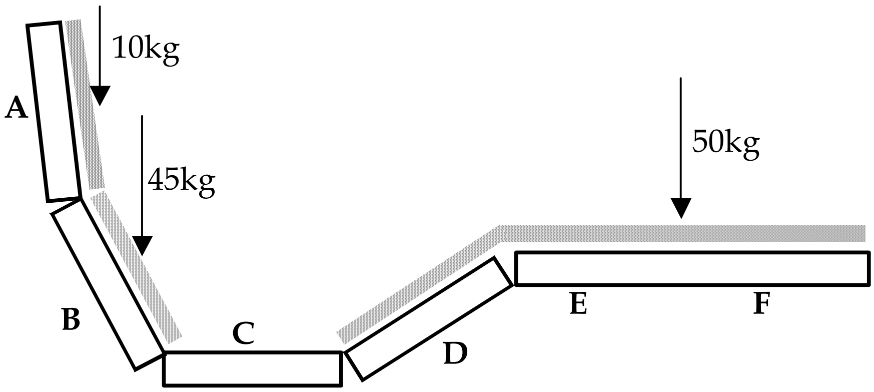


Figure 5-1 Worst case weight distribution on the head, back and leg sections

As the bed is raised from the flat position, more weight should move towards the buttocks area, reducing the weight on the adjustable sections. The person is essentially moving from a lying position to a sitting position so the weight should be more concentrated in the fixed buttocks area. To verify this hypothesis a study was performed with Ergo Check on the Dico adjustable bed used in the adjustability user trial.

The readings were taken from 14 participants who were asked to lie on their side and then on their back on both a flat and maximum configured bed. Figure 5-2 below shows an example of one of the results that was obtained from the adjustability trial with the Ergo Check. The top box shows the weight distribution of the subject lying on a flat bed with their head at the left hand end, their legs on the right, and the large depression showing the buttocks area. The image at the bottom shows the result of adjusting the bed to the maximum configuration. Here the weight has moved from the extremities and has increased the depression in the buttock’s zone

Since the study was very small no clear indication was found of the extent to which the weight distribution would change when the bed was adjusted. Nevertheless, the conclusion that can be drawn is that the weight is going to reduce, rather than increase, from the outer zones as the sections are raised. This is helpful information in the calculation of stresses for the mechanisms.

Although this is true, the shock loads created by a person jumping on the bed are much more significant and the true test of the bed will be factoring these forces into the design.

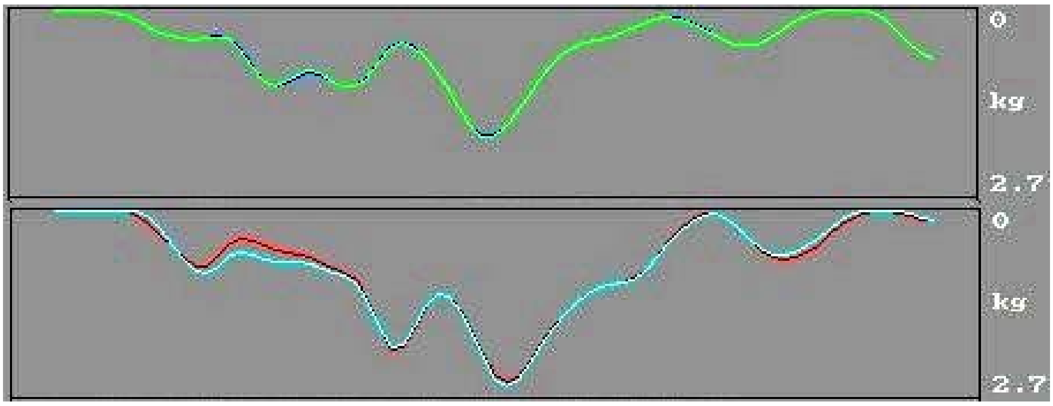


Figure 5-2 A sample screen shot of the Ergo Check software results

5.2 *Customer Needs and Preferences*

When Design Mobel presented the brief for the adjustability mechanism there had been no studies performed into the opinions of the customer. Design Mobel had suggested there was a need for an adjustable bed but had not determined exactly what this need was. A survey and a user trial were performed to gather the valuable information required to determine the product the potential customer would desire.

Adjustability Activities Survey

A survey was undertaken to determine what activities people carried out in bed and what kind of adjustment could be supplied to assist them in these activities. The questionnaire (0) was designed with help from Design Mobel and was tested for suitability with a pilot study on 16 participants. The survey was then sent out in pairs, to 275 households from Design Mobel's database of valuable customers, so that partners could also fill out the form. To increase the number of returns, surveys were sent with stamped self-addressed envelopes, and the opportunity to go into the draw for a Design Mobel wall mirror on the return of the form.

Even so, only seventy-seven individual replies were received which may have been the result of sending the survey out during the Christmas period.

The complete results can be found in Appendix D. The returns suggested that females were slightly more interested in responding (Table 5-12) and most of the respondents were between the ages of 30-40 years old (Table 5-13).

Table 5-12 Number and sex of the adjustable activity survey respondents

Total Number	82
Male	29
Female	46
Not stated	7

Table 5-13 Age distribution of the respondents to the adjustable activity survey

No. Responded Age	75
Avg Age	37.8 ±10.4
Max Age	60
Min Age	17
Avg Male	39.3 ±11.12
Avg Female	36.7 ±9.91

The first question in the survey involved asking the subjects what activities they like doing in bed (besides sleeping and the other obvious one). Each activity was rated on how much they enjoyed doing the activity in bed, how frequently they did it, and how easy it was to carry out on a scale of 1-5 (Table 5-14). The most popular activity was reading with an average pleasure rating of 4.22, followed by watching television with 3.57, and phoning 3.49. This activity also had the highest rating of ease at 3.50, with phoning and television watching following closely behind again. A summary of the activities and the general response to performing them is listed in Table 5-15.

Table 5-14 Pleasure, frequency and ease of performing the activities in bed

Activity	Question	Rating	Std Dev	No. Respond	% Respond
Read	Like	4.22	0.95	76	92.7
	Freq	3.49	1.17	76	92.7
	Ease	3.50	1.01	74	90.2
Work	Like	2.21	1.18	57	69.5
	Freq	2.04	1.13	58	70.7
	Ease	2.42	1.32	48	58.5
Feed Baby	Like	2.32	1.73	19	23.2
	Freq	1.92	1.55	26	31.7
	Ease	2.35	1.54	17	20.7
Sick	Like	2.41	1.70	63	76.8
	Freq	2.19	1.02	67	81.7
	Ease	3.84	1.14	65	79.3
Computer	Like	1.92	1.16	36	43.9
	Freq	1.67	1.06	46	56.1
	Ease	2.50	1.25	30	36.6
Phone	Like	3.49	1.18	69	84.1
	Freq	3.03	1.13	73	89.0
	Ease	3.95	1.01	70	85.4
Write	Like	2.42	1.15	53	64.6
	Freq	2.07	1.11	58	70.7
	Ease	2.40	1.11	52	63.4
Eat	Like	2.51	1.30	59	72.0
	Freq	2.35	1.11	63	76.8
	Ease	2.74	1.18	58	70.7
Television	Like	3.57	1.35	61	74.4
	Freq	2.77	1.48	66	80.5
	Ease	3.40	1.20	60	73.2

Table 5-15 Summary of the participants opinions of performing each of the activities

Activity	Opinion
Work	Most people do not like to work in bed. There is a possibility that by increasing the ease of the activity more people would try to work from bed.
Feed Baby	Obviously this is an activity only performed by a small group of people. Those who do feed babies do not appear to do it very often in bed and this may be due to the lack of ease. There could be possibility for improvement here.
Sick	Most people appear to think that the bed is suitably comfortable when stuck in bed sick. There is the possibility that if adjustment was available it would make things more comfortable but it is an unperceived need at this time for most people.
Computer	Not many people appear to have laptops that they can use in bed and again most people do not like to use them for the same reasons as doing work in bed.
Phone	Most people find that they do speak on the phone in bed relatively often but do not appear to find it that difficult. It was suggested that the main problem with speaking on the phone is the room design and position of the phone rather than the bed positioning.
Write	The difficulty in writing in bed is having a supportive surface in a suitable position. Writing while sitting in a normal bed is very and this is reflected in the number of people who actually try and the low rating in the ease of use.
Eat	Breakfast in bed during the weekend appears to be an activity that a number of people like to partake in but many do not like crumbs in their bed or the possibility of spilling food or drink through the bed. Being able to sit up properly will help the process but supporting the food is still an issue. This is an activity that could be aided with some sort of accessory tray/table that can be folded out.
Television	Participants were split in their views over watching television in bed. A number felt that a television was not necessary in the bedroom or did not actually have one in their bedroom. But the majority liked to watch television in bed and do so with moderate ease. Many also suggested that this activity could be made more comfortable by being able to raise the bed into a sitting position.

85% said they prop themselves up in bed (Table 5-16) and all but one person said they use pillows to do so. A satisfaction rating of 3.11 was given for this method (Table 5-17) suggesting that people find propping themselves up with pillows adequate but not ideal.

When the participants were asked if they would like to have independent sides for adjustment in a double bed (Table 5-18), the outcome was very much in favour for complete independence, with a rating of 4.48.

Table 5-16 Respondents who prop themselves up in bed and for what activities

		No.	%	No. Respond	% Respond
Prop up in bed		70	85.37	76	92.68
Activities to Prop	Read	50	60.98	50	60.98
	Television	27	32.93	27	32.93
	Eat	18	21.95	18	21.95
	Phone	14	17.07	14	17.07
	Write	9	10.98	9	10.98
	Study	6	7.32	6	7.32
	Work	4	4.88	4	4.88
	Computer	4	4.88	4	4.88
	Drink	3	3.66	3	3.66
	Pillow	69	84.15	69	84.15
Use Headboard to Prop		0	0.00	69	84.15

Table 5-17 Respondents satisfaction of propping themselves up in bed

	Avg Rating	Std Dev	No. Respond	% Respond
Satisfaction of propping	3.11	1.01	69	84.1

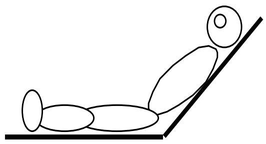
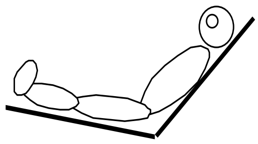
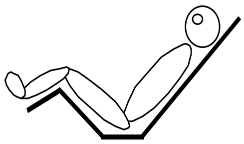
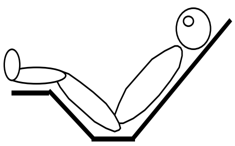
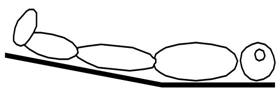
Table 5-18 Respondents desire for independently adjustable halves of the bed

	Avg Rating	Std Dev	No. Respond	% Respond
Desire for Independence	4.48	0.99	75	91.5

When presented with a series of adjustment options (Table 5-19), most people just wanted to be able to sit up in bed with as little leg movement as possible. People appeared to be weary of the possibilities of using an adjustable bed because they are unfamiliar with such a concept. It was proven with later trials that the response to using the bed was much more positive once respondents were actually able to try the bed.

The completed questionnaires were very helpful in determining some of the perceptions of the end user and what they would like in an adjustable bed system. The information gathered was collated and added to the pool of data in the PDS document.

Table 5-19 Level of adjustability desired by the participants

Position	Rating	Std Dev	% Respond
	3.59	1.51	89.0
	3.07	1.10	89.0
	3.02	1.15	89.0
	2.98	1.37	89.0
	2.33	1.48	89.0

Bed Adjustability User Trial

Up until this point no data involving the user's perception of properties such as the speeds, comfort, and desired angles of the mechanisms had been tested. Such data would be essential for the QFD study, which was still to be performed. A user trial was set up to obtain this information with the focus on the activities people carry out in bed (excluding sleeping and the other obvious one!) and how the ability to perform these activities could be improved.

The trial involved testing 32 individuals (Table 5-22) at the Design Mobel factory in Tauranga from Thursday 15th - Fri 23rd Feb, with each test taking approximately 30 minutes per subject. The subjects were selected to fit the desired target customer between the ages of 25-40; who fitted the required anthropometrical zones based on sex, height and weight. (Table 5-21, Table 5-22). The trial activities were performed on a Dico 498 adjustable bed that had been purchased from Germany. The Dico bed provided a suitable level of adjustability to test the appropriateness of an adjustable back and leg sections. The bed was set up in the design office, as seen in Figure 5-3, with made up as close tot hat as a standard bed.

Table 5-20 Total number of males and females in the user trial

Total	32
Male	22
Female	10

Table 5-21 Distribution of female participants based on height and weight

Group	Quantity	Height (mm)	Weight (kg)
A	1	1480-1580	42-60
D	0		60-78
G	0		78-96
B	2	1580-1680	42-60
E	2		60-78
H	0		78-96
C	2	1680-1780	42-60
F	2		60-78
I	1		78-96

Table 5-22 Distribution of male participants based on height and weight

Group	Quantity	Height (mm)	Weight (kg)
D	5	1610-1710	55-73
G	1		73-91
J	0		91-109
E	3	1710-1810	55-73
H	5		73-91
K	3		91-109
F	1	1810-1910	55-73
I	2		73-91
L	2		91-109

Figure 5-3 Photo showing a participant being tested in the adjustability user trial

The subjects were asked to perform six activities in the bed in the following order: reading, watching television, writing, using a phone, using a computer and eating. An indication of general comfort was all that was possible because of the time constraints of the study. Each activity was performed on the bed in the flat configuration, to represent a standard bed, and the subject was asked to rate the comfort. This same activity was then performed with the bed adjusted to the participants most desired position and again the comfort rating (out of 10) was taken and the angle of the bed recorded.

The results (Table 5-23) clearly showed that by adjusting the bed, the ease and comfort was greatly increased. Most of the activities were increased between 2-4 grades with the adjustment of the bed. Activities requiring a very upright position, such as using a computer, writing, and eating, needed large amounts of back and neck support with back angles as great as 60 degrees. The study showed that the desired angles would have to be as great as 80 degrees to satisfy the 16% of users who wanted a higher back angle. The adjustment of the leg was much more varied from activity to activity and dependent on the individual's preferences.

Table 5-23 Ratings and angles given by the participants for each activity

	Flat		Angled				Difference		
Activity	**Rating**	**Std Dev**	**Rating**	**Std Dev**	**Angle Leg**	**Angle Back**	**Avg Diff**	**Std Dev**	**t-Test**
Read	5.4	2.14	8.5	1.17	4.7	42.2	3.0	2.24	1.28×10^{-8}
Television	5.3	1.95	8.7	0.97	13.9	36.4	3.4	1.77	4.69×10^{-12}
Work	4.4	2.25	7.9	1.01	15.8	51.1	3.5	2.29	8.7×10^{-10}
Phone	5.5	2.32	8.0	1.28	9.1	24.8	2.5	2.12	2.07×10^{-7}
Computer	4.0	2.61	7.9	1.19	12.5	53.0	3.9	2.61	3.39×10^{-9}
Eat	4.5	2.30	6.8	1.54	4.7	59.2	2.4	2.83	4.33×10^{-5}

The trial was completed with a post-test questionnaire that asked a number of questions on many aspects of the bed including the performance, ease of use, and the control device. As well as a series of quantitative results (Table 5-24), many helpful qualitative results were recorded from the subject's comments. It was interesting to note that most of the participants were very impressed by the Dico system once they had used the bed and they were quite satisfied by the performance it delivered. If the performance of this model could be beaten or at least matched, the final design would be more than satisfactory.

Table 5-24 Participants average ratings from the post questionnaire

Question	Avg Rating	Std Dev
Control device ease of use	8.08	1.59
Control device understanding	8.59	1.41
Force required to operate control	8.81	1.35
Each of reaching the control	6.52	2.11
Ease of obtaining desired angles	8.39	1.42
Speed	7.86	1.48
Smoothness	9.03	1.13
Noise	9.24	1.18
How at ease they felt using the bed	9.00	0.85
Safety	8.38	1.78
Robustness	8.48	1.40
Firmness	8.59	1.37
Appearance	7.26	2.19

5.3 *Design Techniques*

Using the information collected from the background research and the customer feedback, a series of design methods were used to define the direction of the project: objective trees, function analysis, QFD, and the creation of the PDS.

Objectives Tree

The list of requirements that had been collected and developed up until this point were ordered into groups of similar function and attributes. The objective tree method detailed in Cross (1994), gave structure to the requirements through the production of a hierarchical tree of these objectives. The production of the tree was used to determine which were the most important attributes and how they might interact and affect each other. The process also made it quite clear where there were gaps in the information. Having identified these gaps they were further evaluated so the tree could be studied and filled with the appropriate objectives as shown in the final as shown in Figure 5-5.

Function Analysis

With the objectives detailed, the functions required by the adjustable bed were analysed using the method described in Cross (1994). The adjustable bed had an obvious main function, shown in Figure 5-4; where the user determines that they need to adjust the sleep surface and they use the control to move it to the desired position.

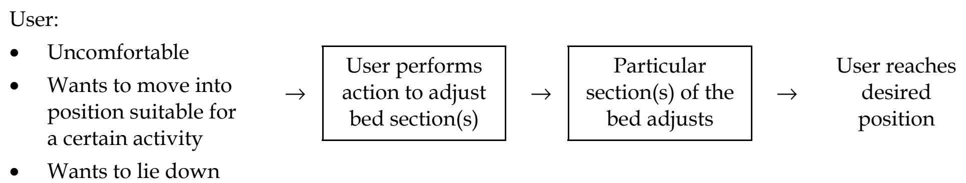


Figure 5-4 General function structure for the adjustability mechanism

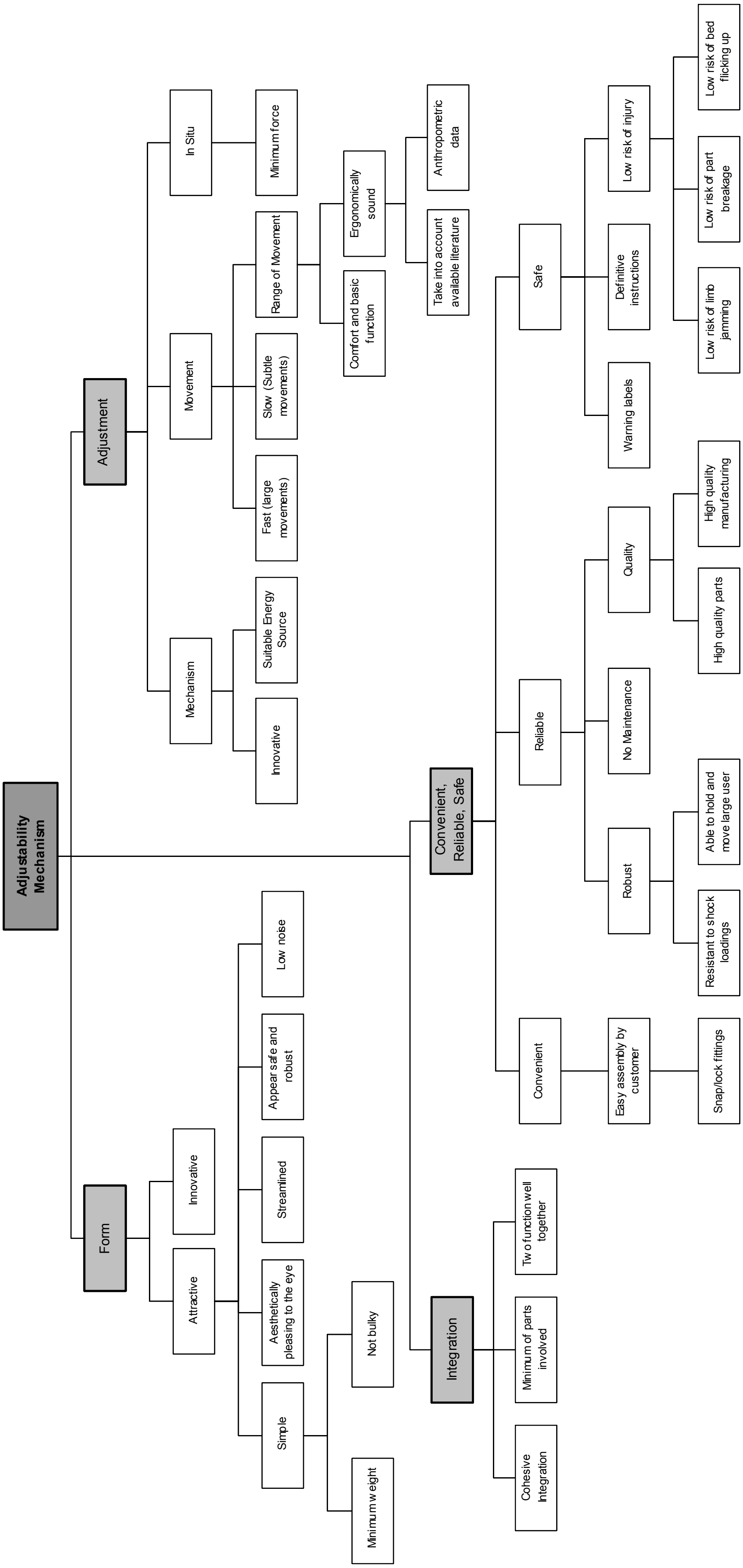


Figure 5-5 The final objectives tree developed using the objective tree method

This function can be further expanded to show the sub-functions:

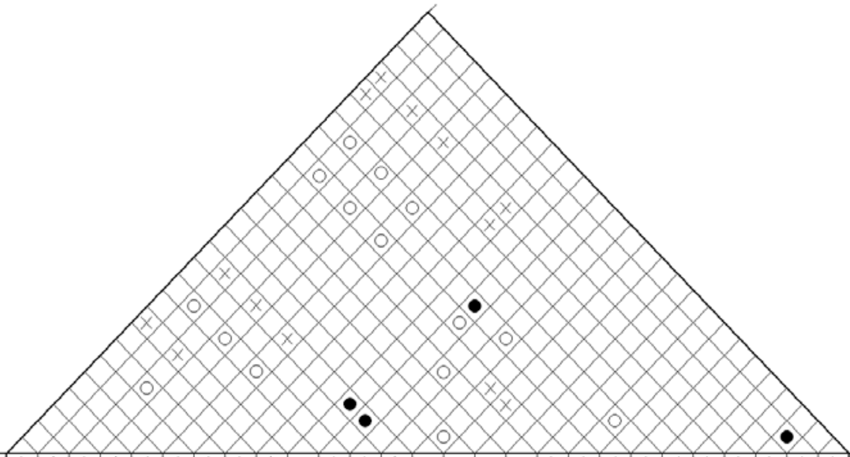
- The user's motivation
- How the actuator stores the power to make the movements
- The input the user initiates to activate the actuator
- The actual mechanism to move the bed sections

Functions could not be developed in detail until the actuation method had been developed. Once a list of possible methods of actuation had been established the function structures corresponding to these were created in detail and are shown in Appendix F. The function structure was very helpful in clarifying the processes that were required by the design so that features could be developed to meet these requirements. The method was also useful in showing the break-up of the system into subassemblies and that similar functions were shared by different structures. This meant that even though the solution to one of the structures may not be defined, progress could be continued in another area and it would still be guaranteed to be relevant to the other subassemblies.

Quality Function Deployment (QFD)

A QFD study was executed using the data collected from the survey, trial, and background research. The process that was taken followed the procedures set out in Cross (1994) and is shown in Appendix G with the final, the QFD chart shown in Figure 5-6. The large chart may appear somewhat overwhelming but is actually quite simple to follow and very useful to apply.

On the left hand side of the chart are the customer requirements and along the top the engineering characteristics required to meet these. On the right hand side the customer requirements are given a level of importance and for each of the different beds a rating out of ten is given for that attribute. The study used a standard non-adjustable bed as the benchmark and the Dico bed as the product to be compared against. Taking the values of the other beds and the relative importance, a list of targets (far right of the table) was produced that the final design should meet to satisfy the customer.



		Head/Neck Max Angle	Head/Neck Max Velocity	Back Max Angle	Back Max Velocity	Leg Max Angle	Leg Max Velocity	Force taken off arm	Force taken off lumbar support	Distance from Wall to top bed end at max height	Button Force	Adjustment Inertia	Distance remote to bed centre	Minimum adjustment	Volume of remote	Top Area of Remote	Control button protrusion	Remote Cord Length	Remote Toughness	All velocities	Movement delay	Speed Range	Noise level	Length of dangerous jamming area	Collapsing Force	Force to move mattress	Distance of mattress slip	Mattress Ruck Height	Importance	Customer Evaluation: Standard Bed	Customer Evaluation: Dico Adj. Bed	Target
		↑	↑	↑	↑	↑	↑	↑	↑	↓	○	↓	↓	↓	○	○	○	○	↑	↑	↓	↑	↓	↓	↑	↑	↓	↓				
Adjustability	Head/Neck support	8	3																										17	0	4	7
	Back adjustment			8	3																								35	0	5	9
	Leg Adjustment					8	3																						35	0	6	9
	Arm support							9																					10	0	3	3
	Lumbar support								9																				10	0	3	3
	Bedside table reach			3		1				8																			10	0	4	8
Control	Ease of use	2	4	2	4	2	4				5	6	3	3						4	4	6							6	0	8.1	9
	Understanding																												5	0	8.6	10
	Force required to operate										9																		8	0	8.8	9
	Each of reaching control												9																21	0	6.5	8
	Ease of obtaining angles		3		3		3							9						3									21	0	8.4	8.5
	Ease of loosing remote														6	5													2	0	2	5
	Ease of using in dark																5												2	0	3	6
	Length of cord																	9											5	0	3	9
	No cord																												9	0	0	0
	Control Holder																												12	0	3	8
	Fixed control																												8	0	0	5
	Auto lower button																												16	0	0	6
	Programmable positions																												10	0	0	0
	Hardiness of control																		5										21	0	7	9
Operation	Speed		9		9		9					5									3	3							12	0	7.9	8.5
	Is the speed adjustable?																					9							4	0	0	5
	Smoothness																												12	0	9	9
	Noise																						9						12	10	9.2	9
	Do they feel at ease?																				1		2	3	3				15	10	9	9
	Safety																			4		2		8	3				20	10	8.4	9
	Robustness																								9				12	10	8.5	9
Situations	1 person up, 1 down?																												6	0	8	8
	Double bed?																												5	10	7	8
	Mattress movement																									8	8		5	10	5	8
	Mattress ruck																											9	6	10	5	8
	Cost appeal																												5	10	3	5
Extras	Built in light																												4	0	0	0
	Accessories socket																												3	0	0	0
	Massage																												2	0	0	0
	Support Surface							6																					5	0	0	0
Activities	Reading	8	6	8	6	4	3	4	1					1						2	1								28	5.5	8.5	9
	TV watching	5	4	5	4	3	2													1	1								23	5.3	8.7	9
	Working	8	6	8	6	4	3	4	1					1						2	1								15	4.4	7.9	8.5
	Phoning	2	1	3	2	1	1													1	1								22	5.5	8	8
	Computing	8	6	8	6	2	1	4	1					1						2	1								13	4	7.9	8.5
	Eating	5	4	8	6	2	1	4	1					1						2	1								16	4.5	6.8	8.5
Units		°	ms^{-1}	°	ms^{-1}	°	ms^{-1}	#	#	mm	#	#	mm	mm	cm^3	cm^2	mm	mm	#	ms^{-1}	s	ms^{-1}	#	mm	#	#	mm	mm				
Measured Performance	Standard Bed	0	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-	0	-	0	0	0	10	10	0	-				
	Dico Bed	0	0	55.4	0.044	35.7	0.017	4	2	165	4	6	600	3	170	74	2	1800	8	0.031	2.03	0	4	4970	5	4	25	65				
Desired Targets		20	0.053	80	0.053	36	0.053	4	2	0	3	5	450	3	160	70	2.5	2200	8	0.053	0.5	0.05	2	3500	8	8	10	10				

Figure 5-6 QFD Chart 19/3/01

At the bottom of the table the engineering characteristics are measured for the standard and Dico beds. Again a set of design requirements was created, this time in regards to the engineering characteristics of the final design. At the top of the table is the triangular roof that indicates the interactions between the different engineering characteristics. Just below the roof are a series of arrows and circles: an upwards arrow indicates that the greater the engineering characteristics the better, a downwards arrow being the opposite, with a circle suggesting neither up or down is necessarily better. Within the roof, a cross indicates that the interaction is negative, a hollow circle indicates a positive outcome, and a solid circle indicates a strong positive outcome.

The outcome from the study was a comprehensive set of engineering design targets, and operation and performance goals that were included in the PDS document, which ensured that the design could now progress with definite and realistic objectives to achieve.

Product Design Specification (PDS)

Collating all the information that had been gathered in this phase allowed a more complete but tentative PDS to be produced. Throughout the clarification of the task period the list of requirements was expanded so that it was clear exactly what had to be designed. It was not until the QFD had been completed that a fully developed PDS was created and the design moved into the conceptual phase. Throughout the project this document was refined and developed to cover the new discoveries that were made as well as the necessary compromises to allow for unrealistic constraints. The final PDS document is found in Table H-1.

6 Developing the Concepts

The following chapter discusses the steps that were taken to generate a series of concepts and to evaluate them down to a principle solution.

6.1 Brainstorming / Synectics Session

During the initial stages of the design process several brainstorming sessions were held to begin the construction of the concept for an adjustable bed. The sessions were designed to create a flow of ideas and flesh out the potential needs and requirements of such a system.

Initial Session

In mid December 2000 a meeting was held for all those involved in the development of the Circadian design. The members involved in this meeting were experts from a variety of fields outside of Design Mobel, from the production and design of the plastic parts to the development of the aluminium side rails. The session was performed using the method suggested by Cross (1994) where each member of the group is asked to spend a few minutes in silence writing the first ideas that enter their head in response to the initial problem statement. The next step is to have members take turns at reading out one idea from their list with the important rule for no criticism. Each group member should try to respond to every other person's ideas, using it as stimulus for other ideas, or to combine with their own ideas.

The adjustability activities questionnaire (section 5.2) showed that many people were interested in reading in bed but thought it could be made more comfortable. In response the initial problem statement used in the brainstorming sessions was, "How can we make reading in bed easier?' This lead to many off the topic responses directed at accessories rather than modification to the bed itself. Once the conversation was directed more towards how adjustability could be used to aid reading, more appropriate ideas were suggested. As the time went on, the thinking was switched to "What kind of power could be used to move the bed?" and "What kind of mechanisms could be used?"

Below is a summary of some of the ideas that were generated in terms of adjustment and accessories.

Adjustment:

- Headrest only
- Pneumatic bladder
- Cam adjustment of sleep contour
- Temperature controlled Gel
- Counterweights
- Slight knee movement to prevent slippage
- After time bed returns to flat position
- Personal movement

Accessories:

- Built in light
- Fold out armrests
- Foot stops
- Lumbar support

Once the ideas dried up the session shifted toward using synectic analogies to create some more suitable ideas. A few suggestions were made during the session but the method did not appear to work as well as planned. The absence of creative analogies may have been a result of the lack of interest in the group, potentially due to the length of time already spent in the meeting. The unsatisfactory result may have also been due to the more tangible brainstorming solutions blocking the thinking processes, or even an unclear explanation of the synectics idea.

Analogies:

- Moss
- Sand: Pile up sand to form a pillow
- Water: Floating in water
- Ligament and muscles moving a skeleton

Analogous Devices:

- Lazyboy
- Dentist chair
- Airplane seat
- Dynamic chair
- Deck chair
- Car seats
- Bean bags

The response to the array of ideas was largely constructive and positive, even toward some of the more unconventional concepts. This in turn led to participants shedding their intellectual inhibitions and allowing some more abstract and creative ideas to surface.

University Session

The second brainstorming session was performed in the mechanical engineering department in mid January where many of the postgraduate students, technical staff and lecturers were invited to participate. The designer had developed a list of concepts but the number of ideas had been exhausted, therefore it was beneficial to use the group as a bouncing board for ideas and as a source of potential solutions. The purpose of the session was to produce as many mechanisms as possible to perform the bed adjustment.

The proposed method:

- Each person has a page with four columns.
- They take two minutes to write down as many ideas in column one.
- Take a two minute break, and then finish column one entries (30 secs).
- The ideas are read in turn, as others cross of duplicate entries from their lists and write new ideas under column two.
- When the group has finished, the process is repeated, this time reading column two entries and writing down any new ideas under column three.
- The process is repeated with a fourth column until all the ideas are exhausted.

The session was not as successful as was hoped with only five people turning up and the amount of time available was limited. The planned brainstorming technique also broke down into general discussion, however in the end this was not necessarily unhelpful with many ideas being produced.

Below is a summary of some of the ideas that were generated during this session:

- Pneumatic bladder
- Mechanical Pivot Lever
  - Powered by ram action
- Temp controlled Fluid/Solid
- Body weight
  - Activated by sensor or lock
  - Requires something to push against? Car seats, or lazy boys work well but they have armrests
- Pneumatic cylinders
  - Shift air from big to small cylinder
  - Body weight produces the compression of the air
- Electric
  - People may feel most comfortable operating and using electric devices
  - Problems of electromagnetic fields in bed

6.2 *Searching for Working Principles*

The next stage was to amalgamate all the ideas that had been developed in the brainstorming sessions and in personal work. The objective was to display all of the possibilities for each sub-assembly of the system so to provide an overall scope of the concepts and to also have them laid out together to aid in further concept development. The ideas were broken into several categories; mechanisms, adjustability, power, and operations shown below.

Mechanisms

- Manual levers to move the bed sections (lazy boy)
- Button pressed to allow body weight to adjust the sections (car seat or airplane seat)
- A dynamic device that adjusts under personal movements (dynamic chair)
- Manually adjustable bed (deck chair)
- Powered pivoting sections (most current adjustable beds)
- Screw drive mechanism
- Scissors mechanism
- Pulleys and wires mechanism
- Circular/linear gear mechanism
- Telescopic mechanism

Adjustability

- Head/back section only:
  - Pivoted at top
  - Pivoted at bottom
- Cams that can be rotated to give unadjusted contour
- Adjustable headboard that can fold away
- Adjustable frame
  - Head
  - Femoral

- Back
- Fixed buttocks
- Tibial

Power

- Electric motor
- Pneumatic cylinders
- Pneumatic bladder
- Personal weight
- Counter weights
- Springs
- Gravity
- Manual

Operations

Remote control:

- Cable or infrared
- Reset function
- Memory positions
- Sleep return

Accessories:

- Foot stops
- Built in lamps
- Massage system
- Slide back
- Arm rests
- Lumbar support
- A temperature controlled gel
- Locks on power failure

6.3 *Generating Alternatives*

The morphological method listed in Cross (1994) was used to produce a series of new concepts that build on the features that had already been developed. All the essential features for the product were listed in a table with all the possible solutions to them. By taking different combinations of the feature variations new concepts were developed that may have otherwise been overlooked. Many of the concepts that were developed were redundant yet there was the odd unexpected variation that was suitable. The approach that was taken is shown in Appendix I.

One step taken in the process is the development of a table containing all the possible means of achieving the required features and functions (Table 6-1). From this list a multitude of various configurations can be drawn out representing new concepts to the solution. For example, a proposed system may have an adjustable head, non-parallel bent legs, pivotal lever arm mechanism, compressed air actuation, full assembly, and no accessories. The concepts were broken up into groups based on the form of actuation and mechanism used as shown in Table 6-2. The outcome from the process was Table I-2 that lists all the possible concepts generated from the method within these groups.

Table 6-1 The possible means to achieve each of the features and functions

Feature	Means										
Top Adj.	None	Head	Back	Head /Back							
Leg Adj.	None	Leg Straight	Leg Bent P	Leg Bent NP							
Mechanism	None	Circular /linear gear	Pivot Lever Arm	Pneumatics	Dynamic	Manual	Pulleys/ Wires	Screw Drive	Scissors	Linkages	Cams
Actuation	None	Electric	Personal Weight	Comp Air	Air Bladder	Manual move					
Integration	Full Frame	Separate 1/3 2/3 frame	Some Asm	All Asm							
Accessories	None	Built in lamps	Foldaway armrests	Slide back							

Notes: Asm = Assembly

Table 6-2 Summary of the concept groups generated in the morphological matrix

0	Benchmark beds
1	Air actuated
2	Cam electric
3	Cam manual
4	Linkage manual
5	Scissor manual
6	Screw electric
7	Pulleys/wire electric
8	Pulley/wire manual
9	Circular/linear gear electrical
10	Dynamic Personal Weight
11	Manual
12	Pivotal lever arm Electric
13	Pneumatic compressed air

6.4 Evaluating Alternatives

Once the concepts had been developed it was imperative to decide which were of value to develop further. This can simply be done in an arbitrary way, by just looking at a concept and deciding which is most appealing. Alternatively and preferably this can be done in a quantifiable way, which adds confidence in choosing the concept that is significantly better the others. The weighted objectives technique described in Cross (1994) was used to compare the utility values of the alternative design proposals. The different concepts were rated on the basis of performance against differentially weighted objectives. A summary of the weighted objectives process using the concepts from the morphological matrix technique is shown in Appendix J.

The outcome from the evaluation technique is shown in Table 6-3, which ranks the sub-concept's utility values within its general actuation and mechanism groups. The top concept from each group is highlighted with the pneumatic system rating highest (797), the dynamic system second (770) and the electrical pivotal arm system third (741). Therefore the principle solution at this point was concept 13.6, which consisted of back and head adjustment, bent non-parallel leg adjustments, pneumatic mechanism operating with compressed air with full assembly and a slide back mechanism.

Table 6-3 A ranked summary of the utility values assigned to each concept

Group	Model	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
4	Manual Linkages	527	516	549	538	525	571	560	547
3	Manual Cam	557	546	579	568	556	601	590	578
5	Scissor Manual	563	552	585	574	588	607	596	610
7	Manual Wire/Pulley	576	566	598	588	602	620	610	624
11	Manual	611	600	633	622	603	655	644	625
9	Elec Circ/Lin gear	607	596	629	618	639	651	640	661
6	Elec Screw	627	623	649	645	653	671	667	675
1	Air Bladder	648	638	670	660	654	692	682	676
2	Electric Cam	665	654	687	676	663	709	698	685
8	Electric Wire/Pulley	668	658	690	680	694	712	702	716
12	Pivot Arm Elec	697	686	719	708	695	741	730	717
10	Dynamic	726	715	748	737	738	770	759	760
13	Pneumatic	753	742	775	764	752	797	786	774

Establishing Degree of Adjustability

In response to the level of adjustability desired by the end user the system was broken into a top and a bottom half with a series of options available (as seen in Figure 6-1). The top half had three suitable options; (i) an adjustable head only, (ii) adjustable back only or (iii) a combination of both head and back adjustment. The bottom half also had three options; (i) the leg can be a single straight section, or (ii) bent in a parallel or (iii) non-parallel manner.

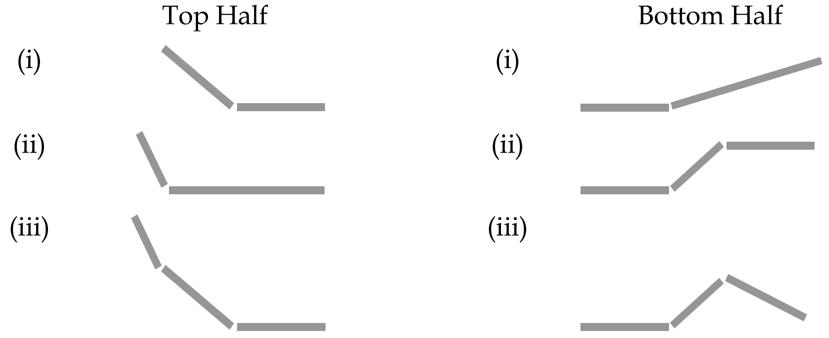


Figure 6-1 Top and bottom half adjustment options

Based on the information that was received from the different surveys and adjustability user trials it was decided to make the top half back adjustable only (top half option (i)) and the legs non-parallel bent (bottom option (iii)) as in Figure 6-2. However as the embodiment design proceeded it was found that it was not possible to obtain the angles desired without breaking the top half into a back and head section and therefore the final design was modified as shown in Figure 6-3 below.

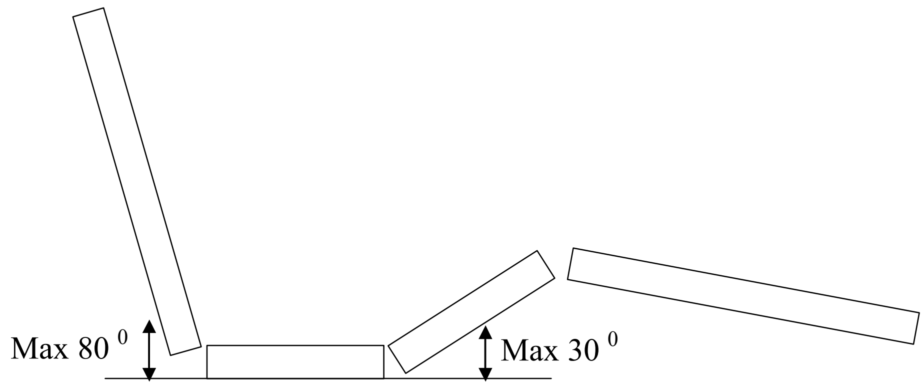


Figure 6-2 The level of adjustability initially pursued

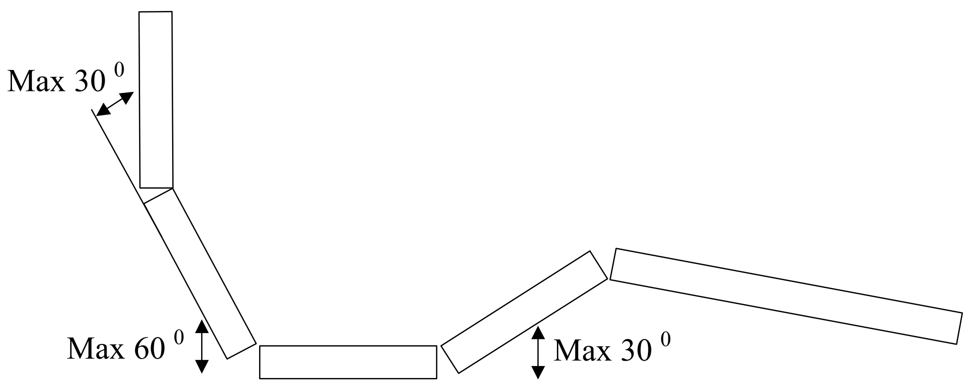


Figure 6-3 The final breakdown of the adjustability

7 Embodiment of the Design

The following chapter describes in detail the major steps that were taken in the embodiment design of the adjustable bed. During this phase the bed design was divided up into several sub-assemblies: the frame, the back mechanism, the leg mechanism, the adjustable rails, the actuation, and the method of mounting. This section shows the progression of each of the subassemblies to the point where they were developed for the prototype.

7.1 Definition of the Bed Subassemblies

The bed is of the flexible slat bed type, this means that the sleeping surface that supports the mattress is produced by a series of slats. These slats are held in place at each end by a shoe that is fixed into the bed frame as shown in Figure 7-1.

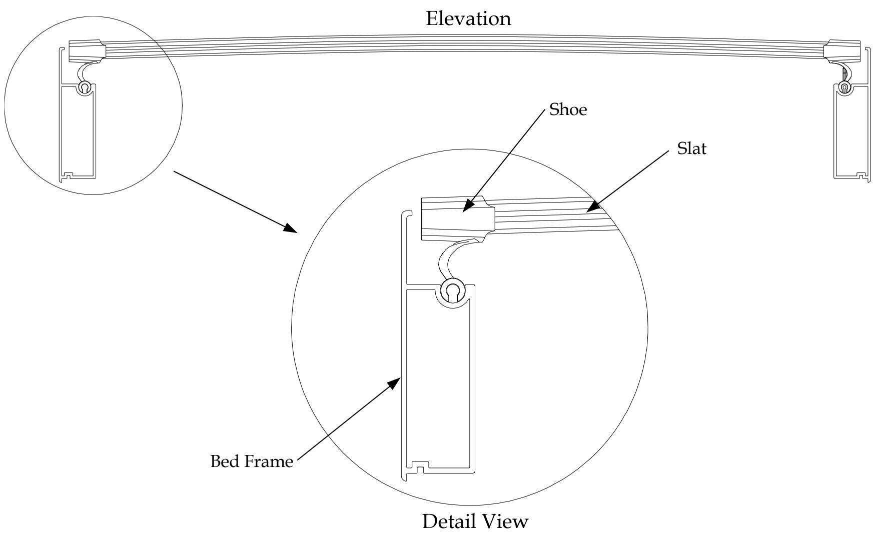


Figure 7-1 The arrangement of the slats and shoes in the bed frame

The bed frame shown below (Figure 7-2) consists of four side rails: two plain end rails (tie rails) and two side rails with grooves for mounting the slat shoes. The rails, shown in detail in Figure 7-3, are made from aluminium extrusion and are joined at the four corners by plastic brackets. The necessary modifications were made to the Circadian bed frame so that it can cradle the adjustable frame.

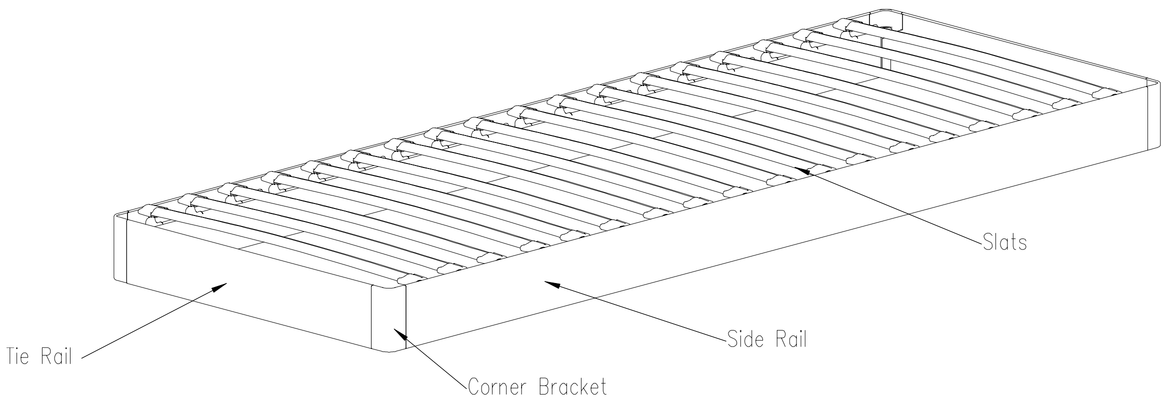


Figure 7-2 The Circadian bed frame that cradles the adjustability mechanism

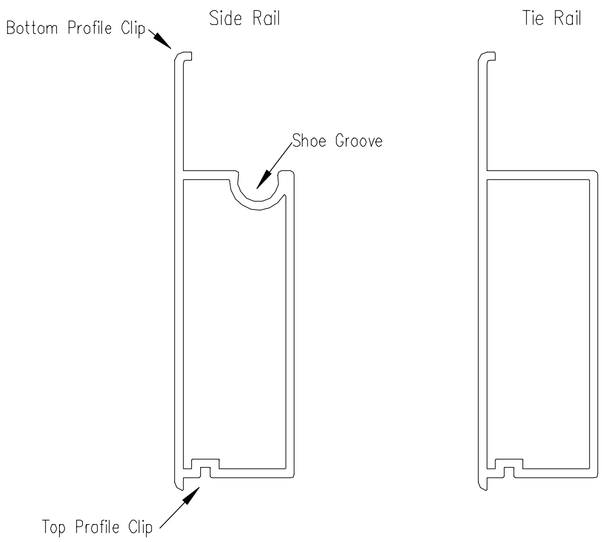


Figure 7-3 Elevations of the side rail and end rail

The adjustable frame sits inside the bed frame and is made up of moveable sections, which rotate up and down to give the desired contour of the sleeping surface. The other purpose of the adjustable frame is to hold the slat shoes in place. One of the major constraints of the Circadian system are the six 330mm slat zones that control the articulation points of the adjustable frame as shown in Figure 7-4.

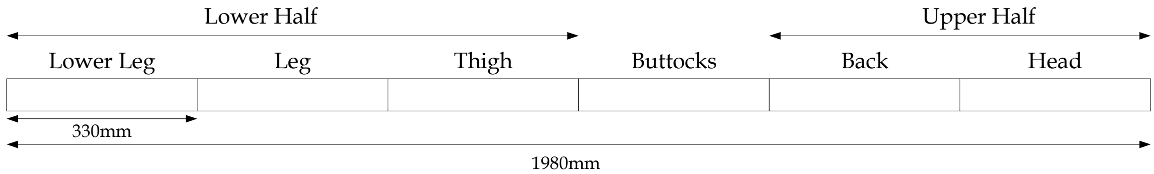


Figure 7-4 The break up of the bed length into 330mm zones

The back mechanism is the subassembly that performs the adjustment of the top half of the bed including the back and head sections. Similarly the leg mechanism is the subassembly that performs the movement of the lower half of the adjustable frame. The method of actuation delivers the power to move these mechanisms and has significant control over their final form and design. The method of mounting relates to how each of the subassemblies comes to together to mount on to the bed frame and is largely dictated by the design of the other subassemblies.

7.2 *The Adjustability Mechanism*

This section looks at the various features of the adjustability mechanisms. The items that are common to adjustability of both the leg and back sections are considered first while their individual mechanisms are described in more detail in sections 7.5 and 7.6.

Roller Mechanism

The first concept that was evaluated fully was a mechanism that operated using pivoting arms to push the adjustable sections of the frame up. The strut pivots at one end and moves freely at the other so that when it is rotated, the movement of the free end causes the adjustable section to rise or fall. A roller was introduced to the concept to reduce the friction that would be created if the two surfaces rubbed against each other. There are many possibilities for the positioning of the roller and the pivoting point within the mechanism layout. After considering many factors such as the positioning of the actuators and interferences it was decided that the strut would pivot from the bed frame with the roller starting close to the head end and moving towards the buttocks to produce the lifting motion (Figure 7-5).

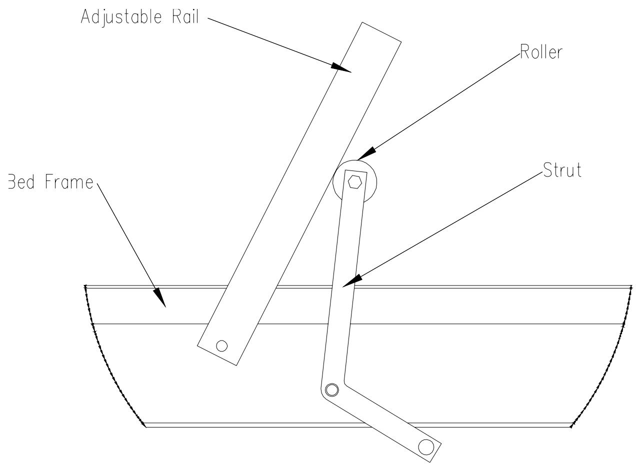


Figure 7-5 The final arrangement of the roller concept

The purpose of the strut is to lift the adjustable section by rotating about the pivot point under the power from the actuator. The length and size of the strut is dependent on geometry and layout of the mechanism, the size of the frame side rail, the method and position of the actuator, and the forces involved. Maximum torque is produced from the actuator when the force is perpendicular to the centre of rotation which can be achieved by adding a bend to the strut. Many methods of mounting the roller to the strut were conceptualised and they were all dependent on the form of the strut. The two most suitable concepts involved producing them from a flat sheet or extruded metal strut (Figure 7-6) but both had manufacturing problems that needed to be resolved.

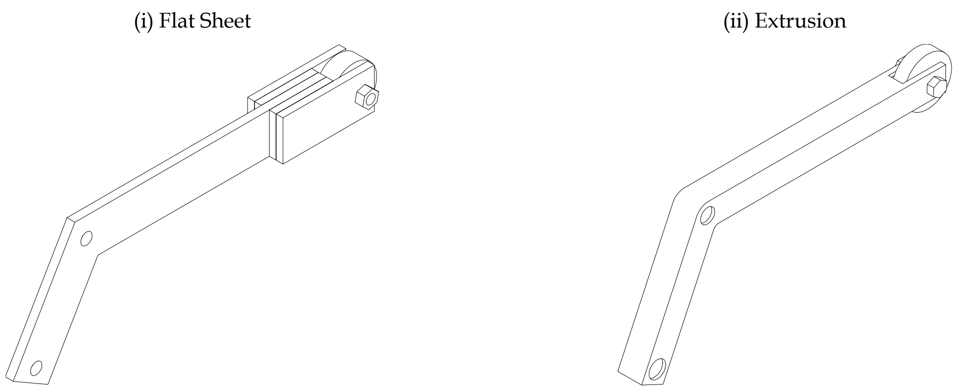


Figure 7-6 Strut arrangements (i) flat sheet or (ii) extrusion

To produce the lifting motion on the adjustable rail, the wheel has to be free to roll up and down on some sort of track. Many ideas were suggested but the most suitable concept involved running the roller on the bottom of the adjustable rail between a set of guides to keep it inline and the sidewalls of the rail were increased to hide the roller as in Figure 7-7.

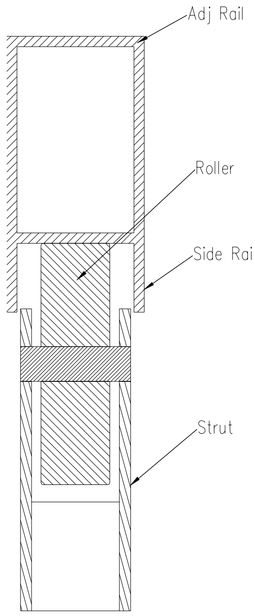


Figure 7-7 Roller wheel running on the underside of the adjustable rail

Slide Back

Slide back describes the concept of maintaining the subject's body position relative to a fixed point e.g. the bedside table or the wall, as the bed is adjusted upwards. The mechanism slides back as the back section rises up to compensate for the motion of the bed. A carriage concept (Figure 7-8) was conceptualised that achieves this motion but it was found to be very complex as the whole of the adjustable frame and mechanisms would have to move on this carriage. It was also discovered soon after the idea was developed that the idea had already been patented as seen in Figure 7-9. The slide back system was discarded as it was too complicated and therefore would compromise the PDS desire for a simple and inexpensive system.

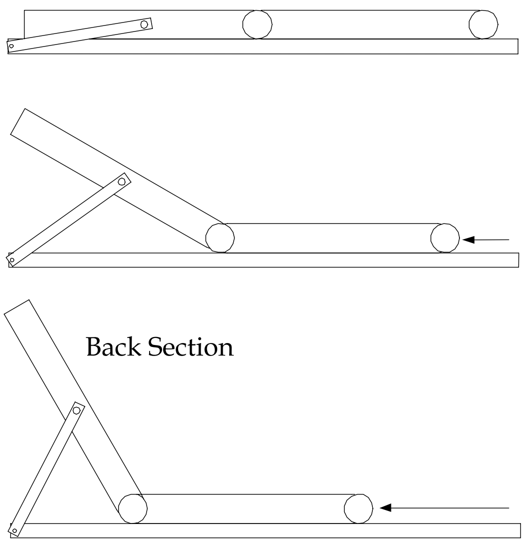


Figure 7-8 The motion of the slide back carriage system

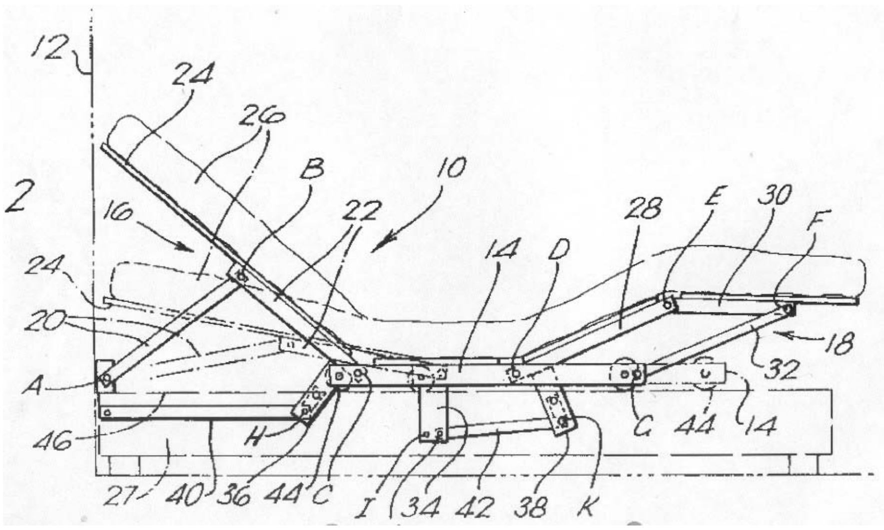


Figure 7-9 Slide back patent (WO9730614A1)

Adjustable Frame Form

The adjustable frame has to be strong and rigid enough to lift a body and be capable of holding the slats in position to do so. The Circadian frame has grooves along the length of its side rails to hold the shoes that maintain the slats in place. These have to be mimicked in the adjustable rails and have to be at the same height so that the slats sit inline with the rest of the slats along the length of the bed. The only suitable positioning for the groove in the adjustable rail is so it sits inline with the bed frame grove as shown in Figure 7-10. In keeping with the styling of the frame side rails the adjustable rails are made from aluminium extrusion.

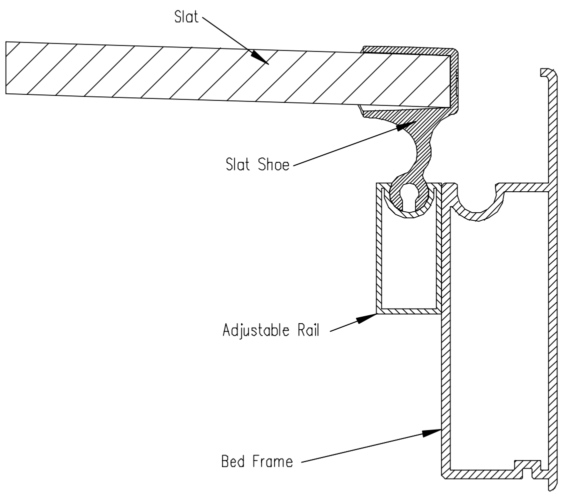


Figure 7-10 Positioning of the adjustable rail groove so that the slats sit inline along the length of the bed

The adjustable side rails have to be joined to a cross rail to give a rigid, strong, independently moveable section. Only one cross bar per section is required and is best positioned at the end furthest from the point that the adjustable rail is mounted to the side wall, as shown in Figure 7-11.

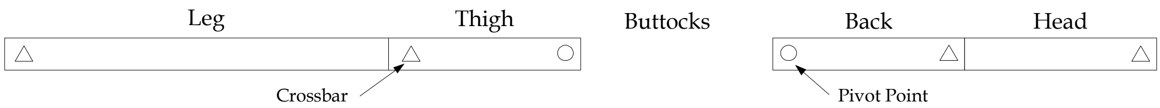


Figure 7-11 The adjustable frame showing the pivot points and cross bars

To avoid the complications and cost of developing a series of brackets to hold the adjustable frame together it was decided to weld the frame together. Since the frame will be made from aluminium, welding the frame together is a suitable option and produces a pleasant style. The most suitable concept (Figure 7-12) was to weld a standard aluminium extrusion to the inside of the parallel adjustable rails, keeping the depth of the frame low and removing the need for extra plugs to fill the ends of the cross bars.

There were major decisions to be made on whether to include the buttocks section in the adjustable frame or not. The assembly will look tidy and uniform along the length if the buttocks section is included but will be greatly simplified when removed. The buttocks section was removed from the adjustable frame helping divide the top and bottom halves of the mechanism as well as removing the need for a special hinge to perform the articulation between both the back and thigh sections with the buttocks. The disadvantage though is that when the buttocks section is mounted on the bed frame, two different sized slats are now required (Figure 7-13).

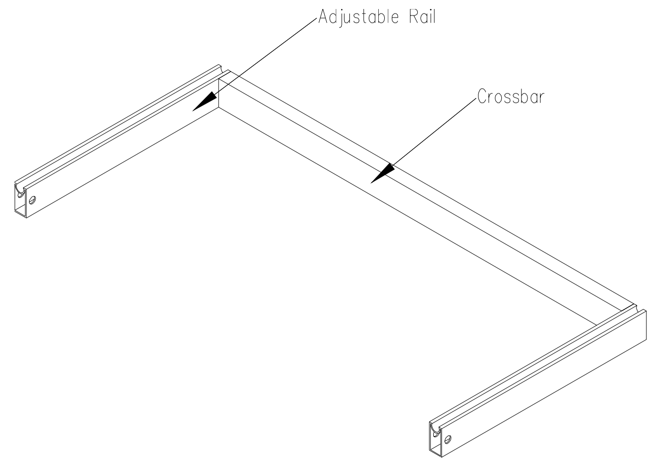


Figure 7-12 One crossbar is welded to the inside of the parallel adjustable rails at the end furthest from the mounting end

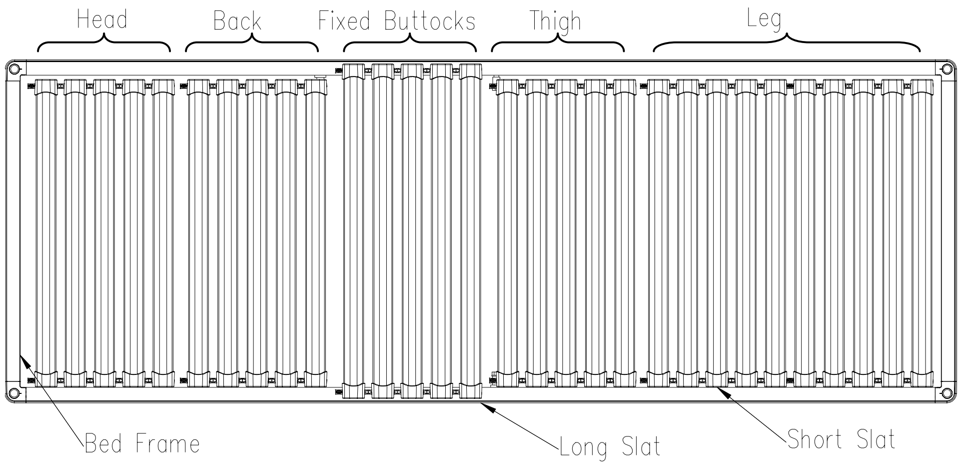


Figure 7-13 Top view of frame showing the buttocks section mounted in the bed frame and the two sizes of slats

A frame that would cradle the mechanisms and aid in the ease of assembly of the system was considered as seen in Figure 7-14. The assembly is simplified with only a few fasteners required but the concept was discarded, as it would add weight, extra parts, and be unattractive.

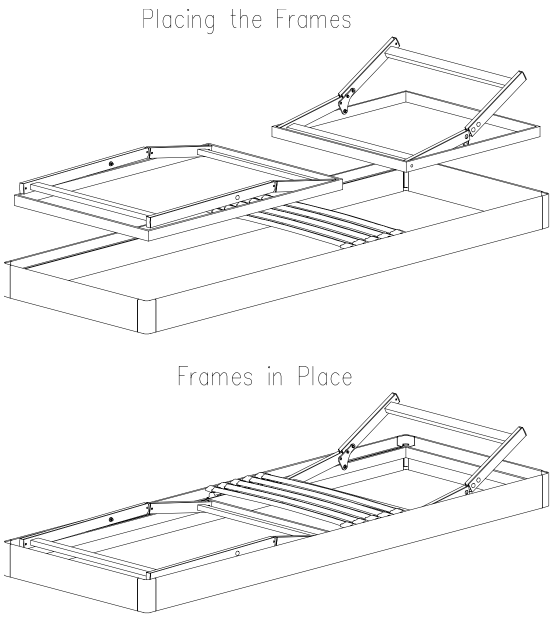


Figure 7-14 The adjustable frames being assembled with a cradle frame

The total length of the bed was constrained at 2050mm leaving 70mm for hinges and movement clearance after removing the 1980mm for the slatted zones. When the slat zones were modelled in SolidWorks it was discovered that only a 35-degree angle could be achieved between the buttock and back slats before interference occurred, as seen in Figure 7-15. A sliding pivot was devised to overcome this problem but was not viable because it required movement from an extra actuator. Utilising a permanent gap between the zones solves the problem but to achieve the desired 80 degrees would require all of the available 70mm. Major developments in the back mechanism design at this stage allowed for a separate head and back section, reducing the required angle of the back to 60 degrees to achieve a head adjustment of 90 degrees (Figure 7-16). To achieve this reduced angle, a permanent clearance gap of only 45mm between the buttocks and back sections is required, leaving 25mm for the remaining hinges and clearances.

Further developments made the roller concepts looks unsuitable and as a result the off the shelf fittings for retrofitting to the bed were revisited. The concepts behind some of these designs were able to be adapted to the model being developed. The Electro Lift plus adjustable bed by Franko (Figure 7-17) was found to be a system that delivered adjustment close to that which was desired. The dimensions and styling are vastly different but the general five bar linkage mechanism can be adapted to meet the needs of the Design Mobel system. This system gives the ability for one actuator to adjust both a back and head section while keeping the system very simple.

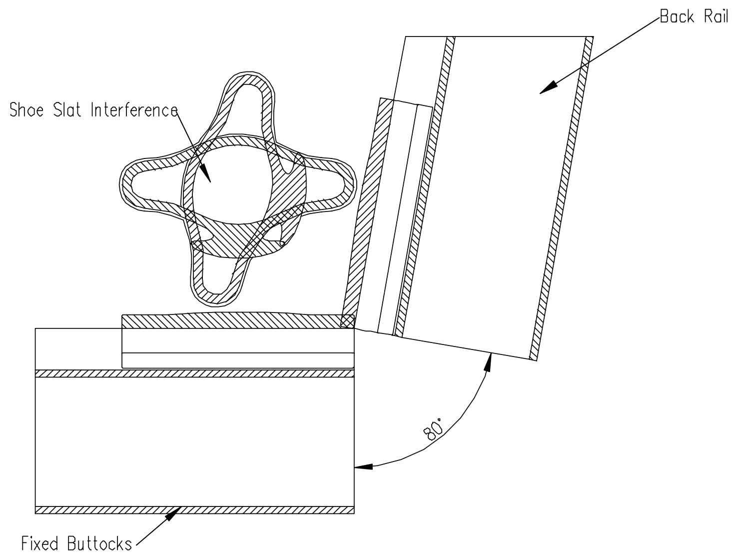


Figure 7-15 Cross section view showing the interference of the slats as the back section is raised

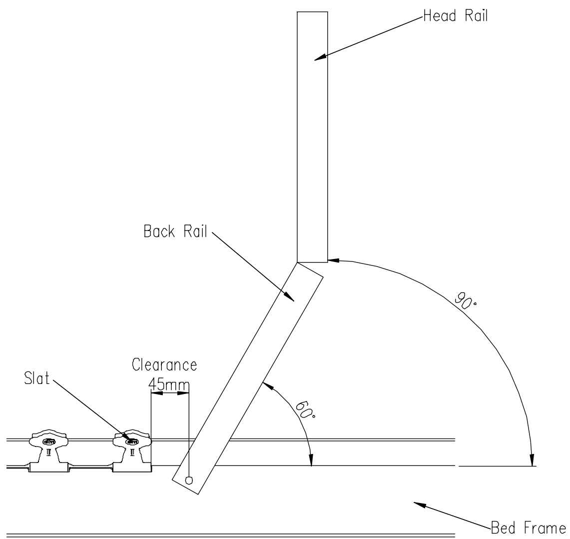


Figure 7-16 The modified back mechanism with reduced angle and clearance requirements

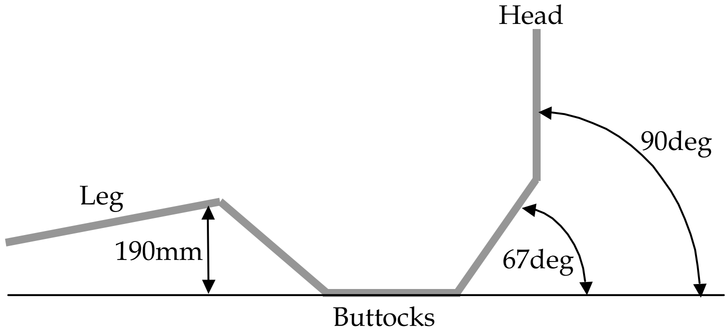


Figure 7-17 The layout of the Franko lift plus system

7.3 *Actuation*

The source of the actuation controls the whole of the design of the adjustability mechanism. Several different methods of actuation were investigated and this section details the steps and decisions that were made.

Pneumatics System

A considerable amount of time was spent developing the initial concept of using pneumatics to adjust the sections of the bed. The desire to avoid having electricity running to the bed removed the possibility of using compressors for supplying pressurised air. Development meetings were conducted with SMC Pneumatics to determine the most appropriate system, which was found to be a hydro-pneumatic concept (an air-oil system). In this approach a large reservoir stores all the pre-pressurised air and oil so that when the valve is opened the cylinder lifts up the bed section in a smooth fashion. The problem comes in retracting the cylinder, which requires some effort from the occupier of the bed who would have to force the raised section back down. The next problem involves the varied weight of individuals, meaning that the force required to lift a heavy person will be much greater than for a smaller person. The force required to push the section back down again will be equal to this lifting force and thus impossible for a smaller person to push down if it can lift the heavy man as well. One solution is to make the driving force adjustable to the weight of the person but this still requires the sections to be pushed down with effort. The other possibility is to work the mechanism similar to that used for an adjustable office chair where the weight is taken off the seat when it is raised. This means that a much smaller force is required to lift the bed section and in turn it is much easier to push back down. However, this is more difficult to perform when in a reclining position than in a sitting position.

Yet another problem with this system is the expense involved. The retail price of the cylinders required are approximately $200 each which almost exceeds the budget before other parts and materials are even considered. In the end the number of negative factors for this concept meant that it had to be put aside. Unless some new technology is released or the price of the required items decreases dramatically, such a system is not viable.

Gas Strut System

A gas strut works in much the same way as the proposed pneumatic system but instead of pressurised air, high-pressurised gas is used in a sealed unit. This means that the same force can be produced with a much smaller cylinder. The gas strut has many advantages over the pneumatic system such as the reduced size, the cost ($50 instead of $200) and the self-containment of the unit (no reservoir or piping required). A major problem with both the gas strut and pneumatic systems is the difficultly in controlling them in a simple and easy manner. The controller that comes with the gas strut is an awkward cable system so the idea of operating the trigger with a solenoid controlled by an electric hand remote was conceived. This was the point at which the requirement of avoiding electricity in the operation of the bed was reconsidered since the control and operation desired would not be achievable with the current solutions. Electricity was initially ruled out because of the danger of magnetic waves on the body, however the magnitude of these waves can be minimised by using low voltages, modifying and shielding the components involved. Many of the electrical devices designed for the bed market have developed their products to European standards for EMC (electromagnetic compatibility) and ESD (electrostatic discharge). This led to the led to the elimination of the gas strut system as electrically based solutions were pursued.

Electrical Actuators

With the possibility of using electricity now an option, electric actuators were researched. Suppliers within New Zealand were approached and web based searches were used to determine the possibilities that were available. Below is a summary of the information that was found.

Linear Actuator

Linear actuators are devices that use electrical power to drive a shaft linearly up and down and therefore can be used to actuate the bed's adjustable sections. Many different manufacturers make these linear actuators and they come in many different shapes and forms. They differ mainly in the stroke length, the force available, the power source (AC/DC), the durability, the mechanism, and the general layout. The research uncovered a whole range of linear actuators (examples shown in Figure 7-18) designed specifically for adjustable beds which tend to be less robust than the industrial models but much more affordable and suited for the purpose.

Using linear actuators has several disadvantages:

- They will protrude well below the bed frame as they extend
- A control box has to also be located and fixed to the frame
- The wires between the actuators and control box are untidy and unsafe

Using the specifications for the desired actuator and other factors such as size, appearance and price, it was found the Gentact and Dewert models best suited this application. There were two suitable models from Dewert: the Dymat and

Megamat shown in Figure 7-19. The Megamat is slightly more expensive but faster with a greater load capacity and therefore was the model of choice. For prototyping purposes, this model and the Gentact, a cheap Taiwanese Gentact model, were purchased.

Figure 7-18 A selection of different actuators showing the difference in shape and form

Megamat Dymat

Figure 7-19 The Dewert linear actuators (reproduced from Dewert (2001))

Rotational Actuator

Linak produce a rotational actuator (Figure 7-20) that seemed like a very good solution for the actuation requirements of the bed. Instead of having to convert the linear motions of the actuator through a pivoting lever arm, a rotational actuator can produce the rotational motion directly. When more detailed specifications were found, it turned out that the device was larger than initially perceived and was the same height as the side frame. The angle of movement was limited to 85 degrees and the method of mounting was difficult. The maximum speed it can produce (not even under load) is 0.56RPM and a complete adjustment takes 40 seconds which is far to long. In the end this form of actuation was eliminated because it did not prove to be what it initially suggested it could be.

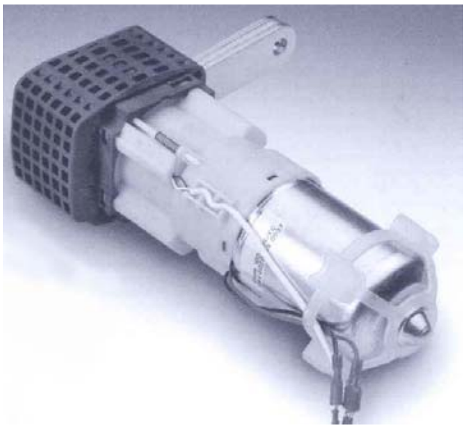


Figure 7-20 Linak Rotational Actuator (Reproduced from Linak (2001))

Duomat

Another type of actuator system by Dewert is the Duomat (Figure 7-21), an actuator system that has all the motors and control units within the one assembly. This means that there is no problem with untidy wires and trying to mount the control box. Initially this type of actuator was not considered since they were in common use by other bed manufacturers and was relatively big and bulky. Their most attractive feature turned out to be that they were half the price of the other linear actuators and would be easier to mount. To compare with the linear actuators for prototyping purposes one of these actuators was also purchased.

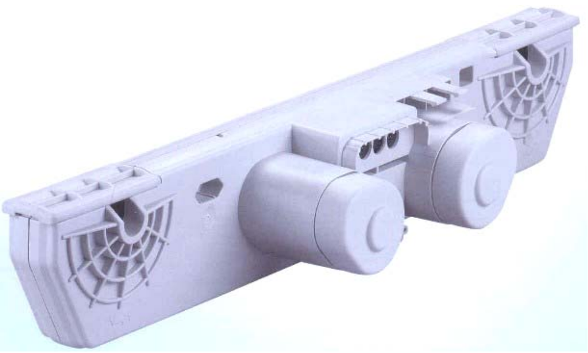


Figure 7-21 The Dewert Duomat actuator (reproduced from Dewert (2001))

7.4 *The Bed Features*

This section looks at the decisions and development behind some of the more specific parts of the adjustability mechanism.

Hinge

The purpose of the hinge is to create a point that two adjustable rail sections can rotate about each other. Ideally an off the shelf item would be desired but there are a number of constraints involved that make this impossible. Specially designed hinges can be designed from plastic or aluminium to suit the rest of the system. Many concepts were suggested but the most suitable option was a two piece part that slides into the end of the extrusion and is fastened in place as in Figure 7-22.

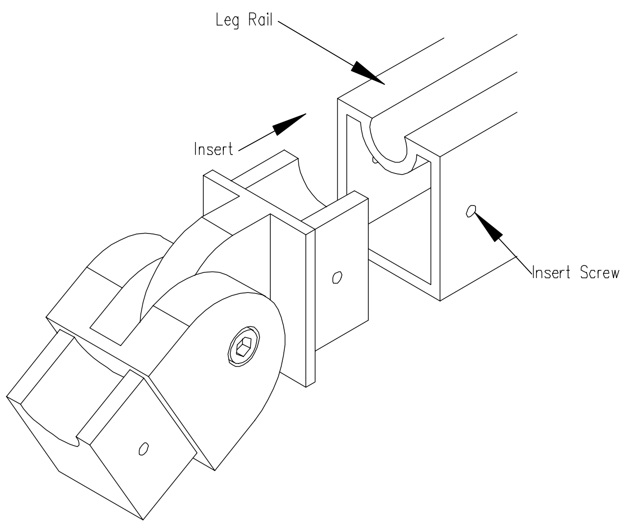


Figure 7-22 The leg hinge concept slotting into the adjustable rail

The position of the pivoting with regards to the adjustable rail is very important. It is not possible to pivot exactly about the end of the rail or the two sides will interfere (Figure 7-23). The rail can be cut away so that the interference is removed (Figure 7-24) but the more that is cut away the more unpleasant it looks. In all cases the groove for the shoe has to be complete and clear all the way to the end of the rail for the shoes and spacers to sit comfortably.

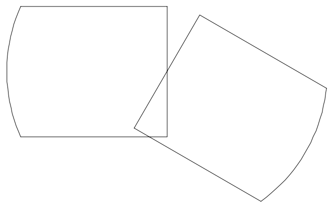


Figure 7-23 Pivoting about the end of the rail causes interference

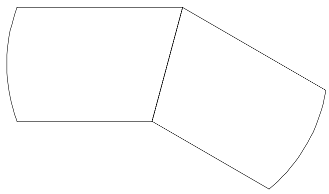


Figure 7-24 The rail can be cut away to stop interference

The alternative is to have the pivot point about the top or bottom the rail. The pivot can be about the bottom edge for the knee hinge (Figure 7-25) and about the top edge for the back and thigh hinges (Figure 7-26) but in both cases this leave a dangerous finger jamming gap.

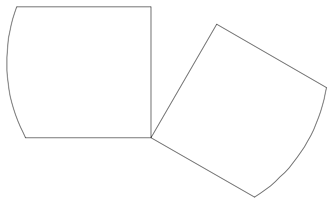


Figure 7-25 Bottom pivoting for knee joint

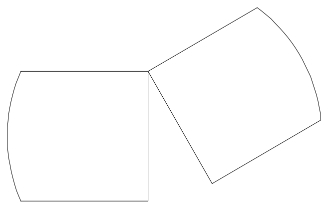


Figure 7-26 Top pivoting for back and thigh joint

To help in the safety of the hinge, a special protective cover such as a flexible film that sits over the gap can be used. The other option is to include special slots on the outside that cross the hinge and keep the gap covered as it slides in and out.

Cross Tube

The purpose of the cross tube is to deliver the torque from the actuator to the mechanism resulting in the adjustment motion. To be able to rotate freely a bush can be used to help reduce the friction and wear on the tube and contact points.

The cross tube can be mounted in a number of different variations, below are some of the concepts that were developed.

- Pivot brackets that bolt onto the bed frame and mount the tube below the level of the frame.

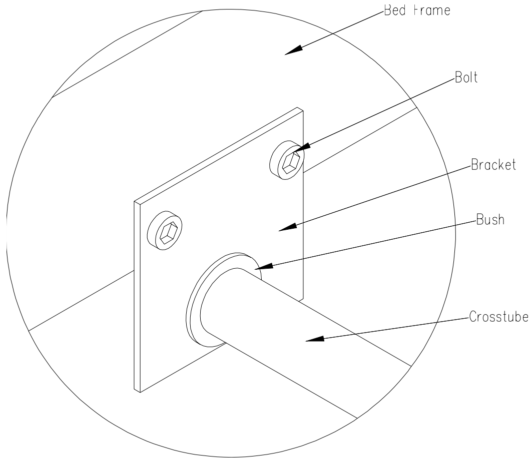


Figure 7-27 Pivot bracket used to mount the cross tube below the level of the frame

- To raise the cross tube into the frame, a bracket that holds the cross tube and fastens directly onto the frame is used. This makes assembly of the system easier because the subassembly is just dropped down and fastened into place.

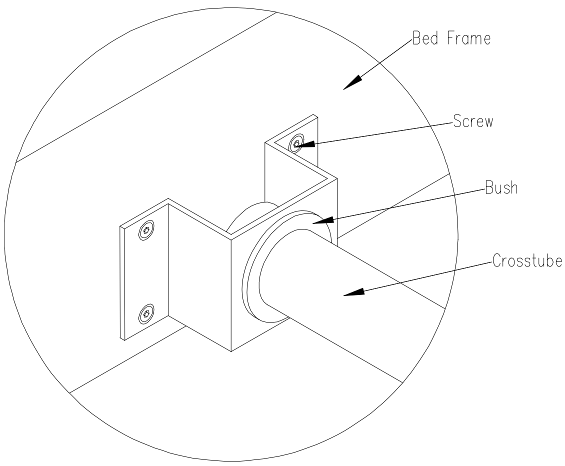


Figure 7-28 Pivot bracket that fastens directly to the sidewall to mount the cross tube within the height of the bed frame

- Mount the cross tube straight into the frame to keep the system simple and avoid the need for using any extra parts. This was the chosen method because it was so simple with its only draw back being that the bar has to be inserted during the assembly of the bed frame, which turned out to not be as difficult as initially assumed.

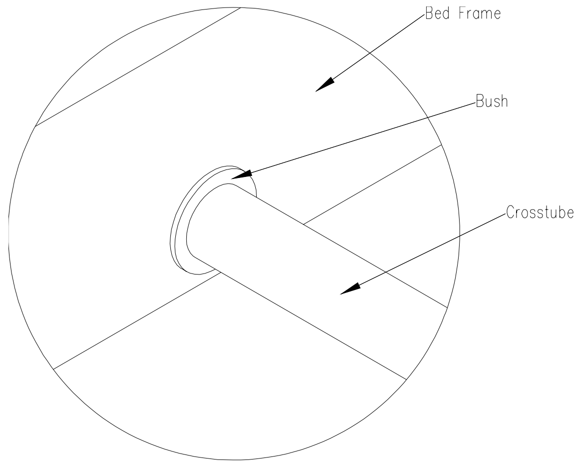


Figure 7-29 Mounting the cross tube directly into the bed frame side wall

Fastening to The Frame

The adjustable rails and adjustable mechanisms have to be mounted to the bed frame side rail but the aluminium wall is only 2.5mm thick (Figure 7-30) so that a normal fastener just rips out when a large load is applied. The fasteners cannot pass through the outer wall because this area has to remain untouched to preserve the aesthetic form of the rail. Therefore some way had to be developed to mount the parts to the inside wall of the extrusion.

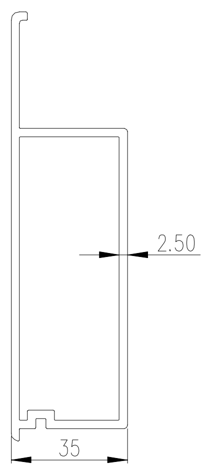


Figure 7-30 Schematic of the bed frame side rail

Ideally all the fastening should be performed with the same type of fastener to reduce the complexity and costs involved. The fastener should also be small, unobtrusive, aesthetic and quick, easy, and cheap to manufacture and install.

The only off the shelf product that seemed to be suitable was a thin wall fastener with an internal thread called a Rivnut as shown in Figure 7-31. The Rivnut is inserted like a rivet with the end crumpled as it is drawn against the wall using a pneumatic applicator. A sample piece of aluminium was tested with a rivnut but it ripped away from the wall under even a small load.

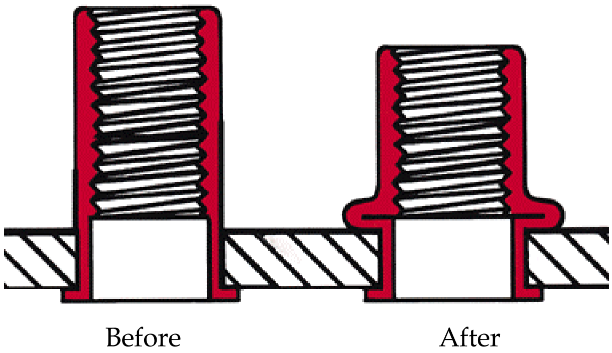


Figure 7-31 Rivnut in a thin wall sheet

The fastener suppliers suggested developing a plate bracket (Figure 7-32) that will strengthen the wall and distribute the load over several fasteners. This bracket can either be screwed or riveted on to the bed frame and the devices mounted to it through a centrally located thread.

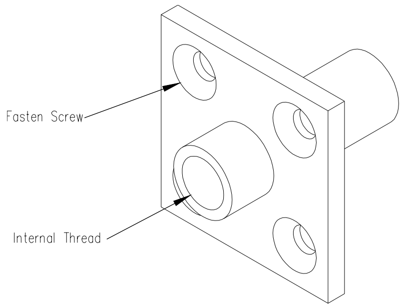


Figure 7-32 Plate bracket for mounting devices to the bed frame

A suitable fastener was eventually discovered in the aircraft industry (Figure 7-33) but was far outside the allowable price range. The military type fastener may be copied and developed for this project at a much more affordable price but this was also scrapped when another stronger rivnut was sourced. Another rivnut was sourced that was much stronger than the first one that was tested. The rivnut was fastened to a test piece of aluminium and a series of weights were hung off it from a bolt. A single rivnut was capable of holding over 80kg without ripping out or deforming the bed frame. This rivnut was certainly the most suitable solution considering its ability to withstand the loads while still being very simple, cheap and unobtrusive.

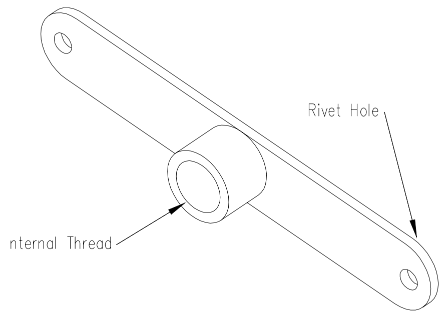


Figure 7-33 The aircraft fastener is riveted to the aluminium sheet

Adjustable Rail Mounting

The adjustable rail has to be mounted to the bed frame and be allowed to rotate freely to produce the desired adjustment. The simplest way to achieve this is to allow it to rotate about a bolt that is fastened directly to the side rail. It is not possible to have metal rubbing directly on the thin aluminium wall or the parts will wear out too quickly and therefore a bush is used to distribute the load and reduce the wear. The simple method of mounting that was developed using a bolt and bush arrangement is shown in Figure 7-34.

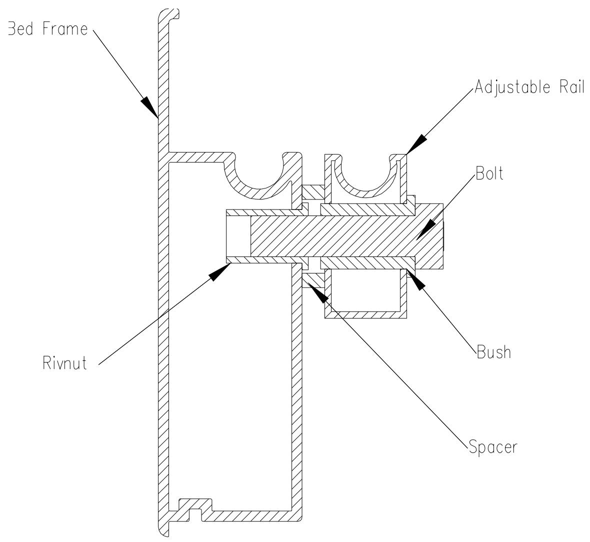


Figure 7-34 Example of pivot mounting using a bolt and bush arrangement

A universal fastener was designed to fasten struts and other items to the adjustable rails and allow them to rotate freely, as shown in Figure 7-35. The fastener is held in place with a circlip and has a corresponding bush that acts as a spacer to reduce friction between the strut and rail as well as distributing the load over the fastener surface.

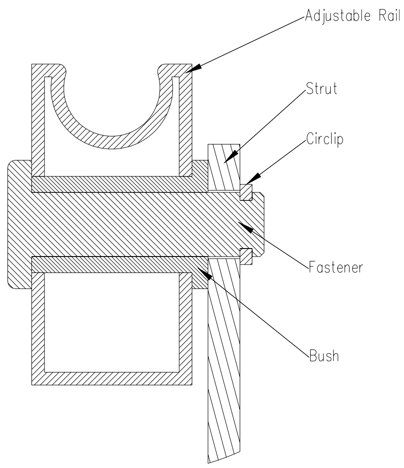


Figure 7-35 Adjustable rail attachment fastener

Actuator Mount

All the linear actuators investigated have clevis mounts and in this case they mount directly to a lever arm that delivers the torque to the cross tube. If was found that during the full motion of the actuator it was impossible to avoid collisions with the lever. To overcome this problem a special yoke was designed (Figure 7-36) that sits around the clevis head of the actuator allowing a much greater range of motion.

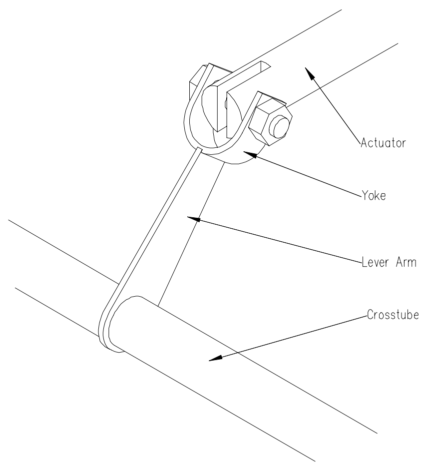


Figure 7-36 Mounting the actuator clevis with a yoke attachment

Stoppers

The bed is held rigidly in place in the flat configuration using stoppers that take up any excessive force applied to the mechanism. The stopper is made of a material such as plastic or rubber to avoid noise when the rail is dropped down on it. Doorstops were the closest off the shelf parts that would be suitable since they can be relatively attractive, have a rubber coating to stop the noise and are easily mounted to the bed frame. A Heaffle doorstop sample looked quite suitable except it had a weak internal plastic mount. The internal mount could be replaced by one manufactured from metal to increase the maximum possible loading to make use of the attractive clip on rubber outer. The stoppers are located, like the crossbars, away from the mounting points of the adjustable rails sections as shown in Figure 7-37.

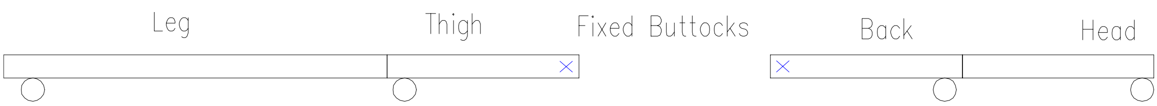


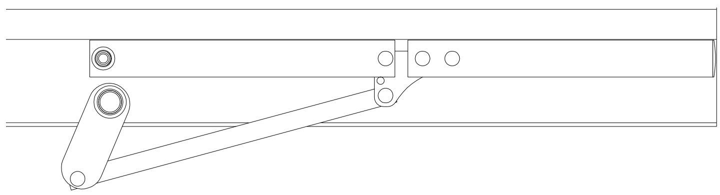
Figure 7-37 The location of the stopper I relation to the fixed buttocks

7.5 Back Mechanism

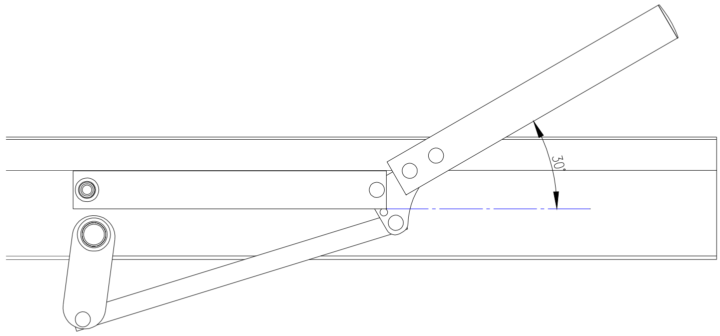
A new level in detail was achievable with the decision to develop a five bar mechanism for the back section. The preliminary design of the back mechanism was clarified and the mechanism of operation clairfied. The actuator moves the head section up to an angle of 30 degrees and is locked in place with the back section. As the actuator continues to lift the head, the back is also bought up to an angle of 60 degrees as shown in Figure 7-38.

The locking is achieved with a peg that rests against the back rail and is mounted to the back mechanism hinge. As the back hinge rotates the peg follows an arc, taking it from resting on the rail, away from the rail and back to the rail to lock the head section at the 30-degree extreme as seen in (Figure 7-39).

Minimum Configuration:



Head Max/Back Min:



Maximum Configuration:

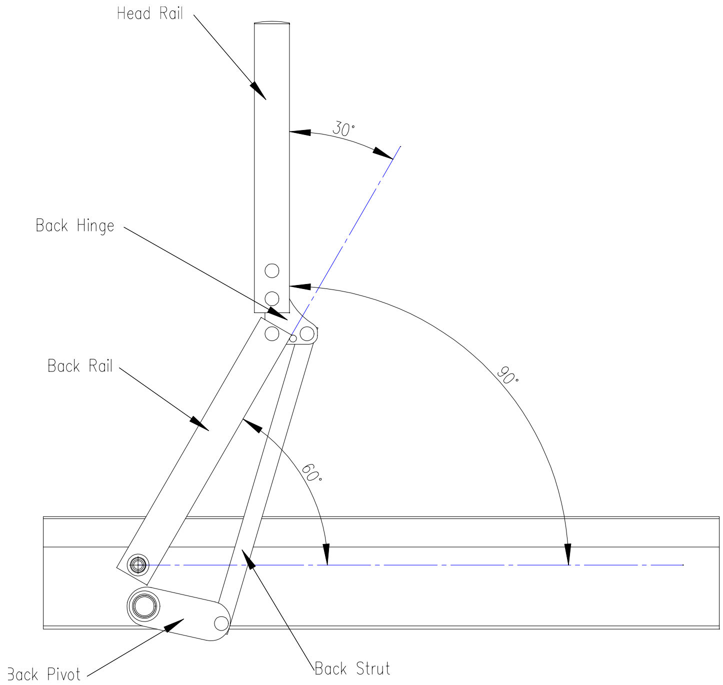


Figure 7-38 Head section movement

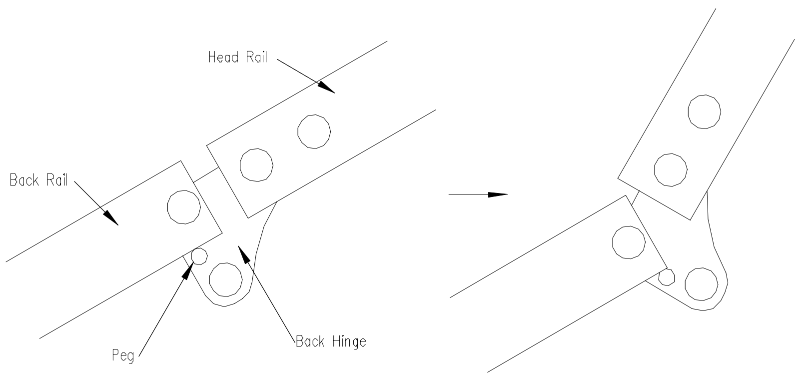


Figure 7-39 The movement of the peg in the head hinge

To aid in the solving of the kinematics of the mechanism a piece of software called 'Five Bar' was utilised. A screen shot of the software in use is shown in Figure 7-40. The output from the programme gave valuable information on the forces, torques and speeds of the linkages.

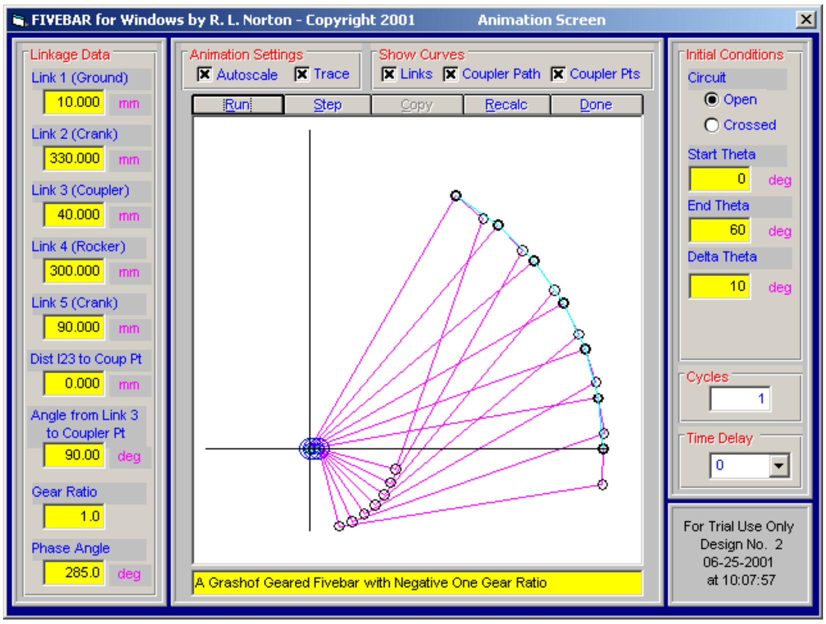


Figure 7-40 Screen shot of the kinematics software 5-Bar

With the development of the new 5 bar system, a back pivot was required to provide the extra link to the mechanism as seen in Figure 7-41. Since all the parts involved are made from steel, the pivot is easily manufactured from sheet and welded to the cross tube. The longer the length of the pivot, the smaller the rotation and force required, but this results in a pivot that protrudes well below the frame.

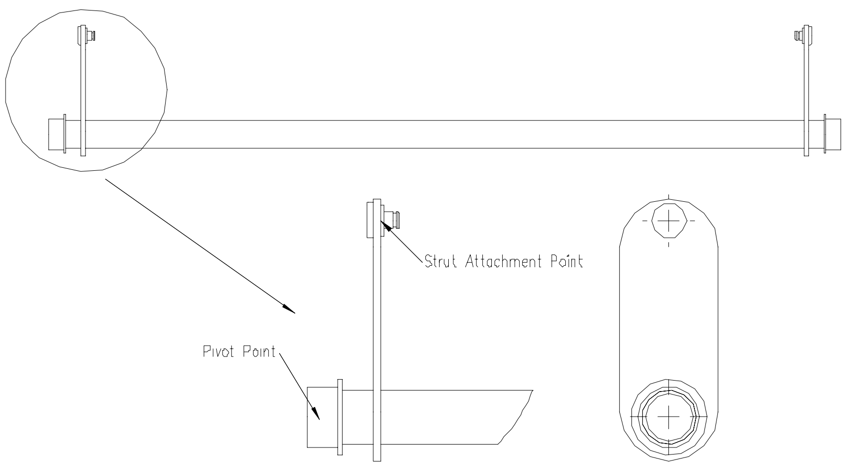


Figure 7-41 Back pivot and cross rail

The final layout of the back mechanism assembly is shown in (Figure 7-42).

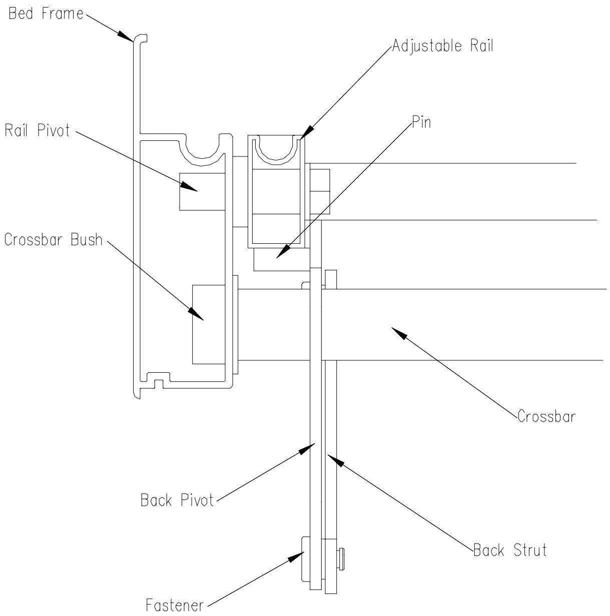


Figure 7-42 The final configuration of the back mechanism

7.6 Leg Mechanism

A simple four bar mechanism was developed for producing the bent leg adjustment for the bottom mechanism (Figure 7-43). Since the motion was so simplistic the roller concept was never considered. The actuator delivers the movement to the strut in the same way as the back mechanism, with the rotation of the crosstube.

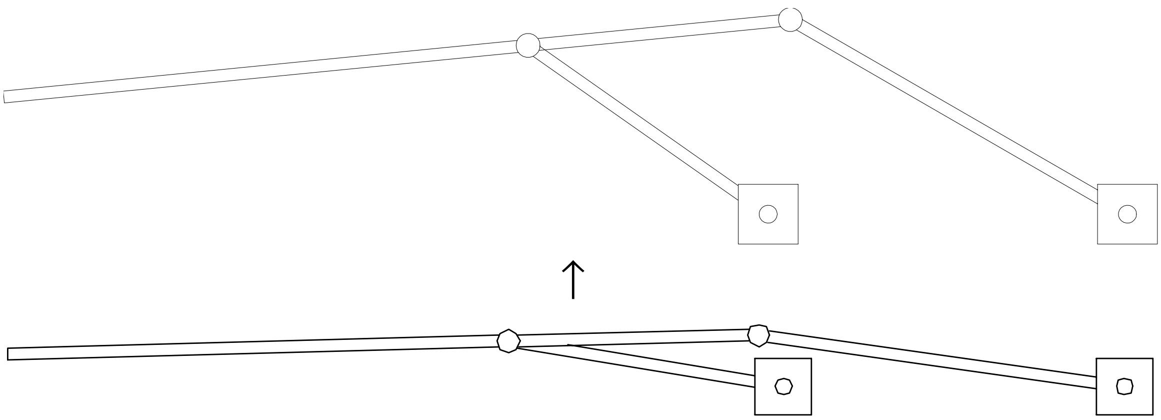


Figure 7-43 Leg 4 bar mechanism concept

Based on the factors already described a male/female hinge design was developed within the size constraints that slots into the thigh and leg adjustable rails (Figure 7-44).

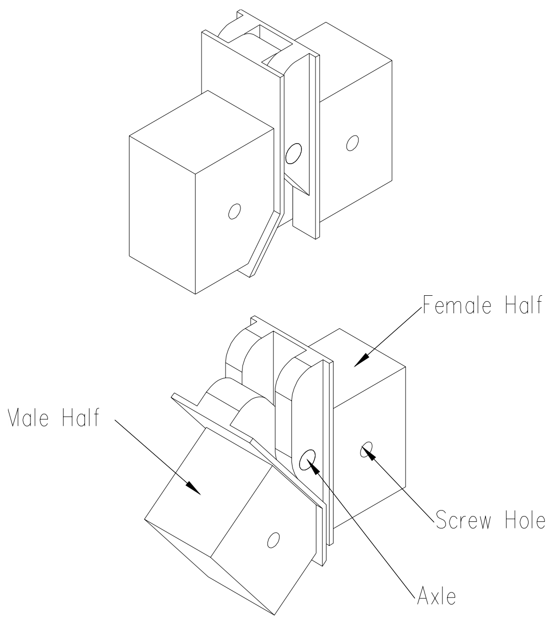


Figure 7-44 The final design of the leg hinge

The final layout of the leg mechanism assembly is shown in (Figure 7-45) below.

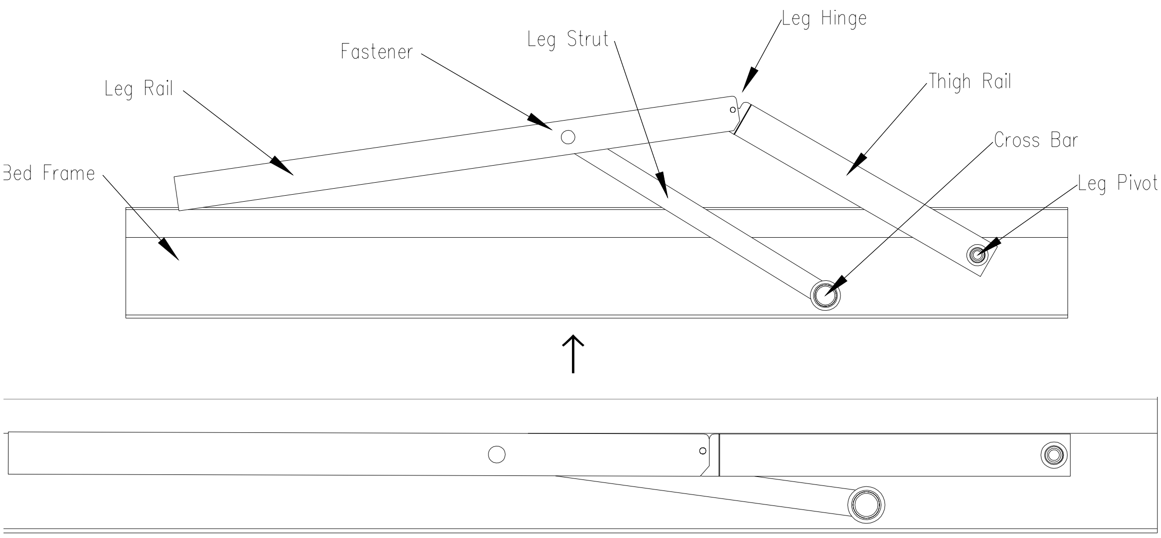


Figure 7-45 The final configuration of the leg mechanism

7.7 Summary

After many iterations of the subassemblies the preliminary design was completed. The layout and form of this design turned out to be very simple and aesthetically pleasing while still conforming to the requirements set out in the PDS. The final method of actuation was still undecided but the system was easily modified to accommodate the three systems since they all deliver the adjustment through the rotation of the crosstube. Rotation of the top crosstube lifts the head and back sections through the five bar linkage mechanism while the bottom crosstube four bar linkages lift and bend the leg sections. A rendered view of the final SolidWorks model is shown in Figure 7-46.

Figure 7-46 A rendered CAD model of the adjustable bed

8 Prototype

With the completion of the preliminary design the concept was ready to be tested with the production of a prototype. Once completed, the prototype was used to perform a user trial to get information from the user on the performance and appearance of the mechanism. The model was also scrutinised under a design review to determine what changes had to be made.

8.1 Problems to Overcome in the Making of the Prototype

The prototype was used to compare and test three actuators to determine which would be the most suitable for the final product: the Dewert Megamat, the Dewert Duomat, and the Gentact linear actuator. The mechanism had to be modified to accommodate the different actuators but since only one of these actuator types would be used in the production model the design modifications for this would only be relevant to the prototype. The two linear actuators used the same mechanism but the Duomat had a varied mounting mechanism that was much simpler.

Since the prototype is only a one off product it is not possible to create the parts exactly as they would be made in production. This is a problem when one of the critical parts is difficult and costly to make. The adjustable rails were an example of this as they required the development of a tool for aluminium extrusion which was considered not to be viable until the design was established. To overcome this problem a rail had to be fabricated as close as possible to that of the final production part shown in Figure 8-1. The solution that was pursued involved creating an insert with the shoe groove cut into it and welding it into a rectangular extrusion with its top cut off as seen in Figure 8-2.

A man who specialises in creating prototype models mocked up the plastic leg hinges. The design turned out to be very safe as the hinge pushed the fingers out rather than jamming as the gap closed up between the two halves. While the prototype was being assembled and the leg assembly motion was being tested, the leg hinge broke. There was insufficient clearance between the thin walls and were not tough enough for the side loads so they broke off. To solve this problem quickly and at the same time introduce a new idea to reduce the number of parts, a simple aluminium hinge similar to the male side of the plastic hinge was developed. Instead of requiring two parts, a simple single cast hinge is used with the female side removed and the axle sits in the wall of the adjustable rail (Figure 8-3).

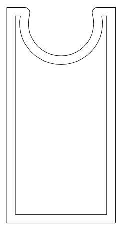


Figure 8-1 The desired adjustable rail extrusion

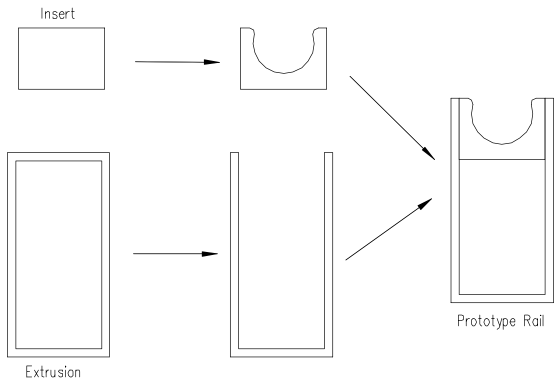


Figure 8-2 The final solution for the prototype adjustable rail

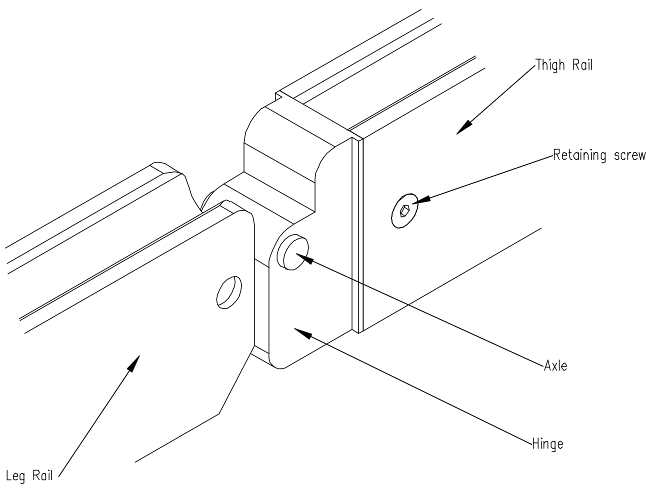


Figure 8-3 Single piece aluminium hinge

8.2 *Prototype User Trial*

The prototype had been developed so that it was a working model capable of performing a user trial. The main purpose of the trial was to gather information from the participants on: their ability to use the bed, their perceptions of its overall comfort and their opinions about the system. The specific questions that need to be answered were as follows:

- Does the prototype perform to the levels set in the design specification?
- What is the users subjective reaction to the operation, structure and aesthetics of the mechanism?
- Does the articulation positioning give the user a high level of comfort under the various activities?

Methodology

The usability test consisted of four parts: and each participant took about 45 minutes to complete them:

1. Greeting and orientation
2. Pre-test Questionnaire: given to the user to determine first impressions of the bed.
3. Performance Test: The participant was asked to perform three activities (reading, watching television, and writing) on the bed and to rate these activities for comfort between a flat and adjusted position. Ratings of comfort were also directed at specific areas of the body: neck, arms, back, buttock, leg and thighs.
4. Post-test questionnaire: given to the user to determine the performance, operation and comfort of the bed.

A total of 19 participants, 10 male and 9 female (Table 8-1), were tested during the week of September 24th, 2001 at the Harbour City motel conference room in Tauranga. The participants came from an opportunity sample of people between the ages of 25-55 from businesses in the local area. The reading activity involved giving the participants a book to read, postcards were given to the subjects to perform the writing test, and a television was set up in 1.5m of the ground in front of the bed for the television watching activity. The atmosphere was kept as constant as possible for each participant and made as comfortable as allowable within the limitations of the room. The participants were asked to make themselves comfortable by removing any footwear and uncomfortable outer clothing.

Table 8-1 The number of male and female participants in the user trial

Total	19
Male	10
Female	9

There were many potential limitations to the trial. Below are listed some of the obvious limitations:

- Small sample size
- Unrepresentative data sample (gender, age socially, physically, ethically)
- Effects of incentives to participate. A meal voucher to a local restaurant was offered to each participant.
- Effects of clothing. Participants were not using their standard sleepwear
- Limited length of time in each activity. Ideally the activities should be performed for an extended time to overcome the initial comfort to discover the true comfort
- Variations in the subject's level of relaxation. Some people may have been having a stressful day or the environment may cause some to be more relaxed than others
- Time of day variations. The participants were tested at various times of the day and this may cause them to be more or less relaxed.
- Participant nervousness affecting relaxation

The Gentact linear actuators were used for the trial because the Dewert ones had not arrived in time. The Duomat was the preferred actuator so the performance of the bed was not as good as intended. This was taken into account in the interpretation of the results. Photos of the prototype bed are shown from Figure 8-5 - Figure 8-10.

Results

The full summary of results is shown in Appendix K. The pre-test questionnaire gave valuable information on the users first perception of the bed (Table 8-2). Most people initially appear to be scared of using an adjustable bed but once they give it a try they usually want to buy one for themselves. The average rating for the appearance of robustness, simplicity to use, user friendliness, and general interest were all very positive with ratings well above four out of five. The initial appeal of the bed was not quite as high at 3.79±0.92 but was to be expected as stated earlier.

Table 8-2 Pre-Questionnaire average ratings

Question	Avg Rating	Std Dev
Robust	4.32	0.58
Simple	4.42	0.69
Friendly	4.42	0.61
Appeal	3.79	0.92
Interest	4.32	0.75

Note: Ratings are out of 5 with 1 being the most negative and 5 being the most positive

Once the subjects became comfortable with using the bed they responded more positively to performing the three activities (Table 8-3). The overall comfort of adjusting the bed rose by 1.47±1.30 for reading, 1.21±0.77 for watching television and 2.03±1.14 for writing. The subject's perception of the support provided by the bed also rose in similar proportions but not to the same extent.

In the case of watching television the neck has to be tilted forward to see the screen and with writing the neck has to be even more bent forward. The adjusted bed seems to greatly aid the support and comfort of the neck with the greatest benefits coming in writing and watching television (Reading =1.11±1.70, Writing =1.50±1.46, Television =1.53±1.35). The back comfort is also greatly enhanced through the adjustment of the bed for similar reasons (Reading =1.32±1.30, Writing =1.24±1.51, Television =1.16±0.83).

The back angle was greatest when writing to give the head support and the body a more upright stance (Reading =30.00±10.20deg, Writing =38.34±8.42deg, Television =29.71±10.48deg). The maximum angle for the back was reached by 26% of participants when writing but only 10% for reading and 5% for television watching (Table 8-4). A number of participants felt that their head sat above the head zone and were unsupported, this tended to be the taller subjects with long torsos. This was shown in the lower average rating of 3.61±1.09 for the head support in the post questionnaire (Table 8-5) but a very a positive average rating for the back adjustment of 4.29±0.80.

The increase in rating of the buttocks region is not as high as the back and neck but it is still significant (Reading =0.92±1.42, Writing =0.74±0.87, Television =0.84±1.17 from Table 8-3). The users tended to find that as they adjust the bed upwards the buttocks region became more comfortable. There were some exceptions to this though, with some who felt that as they moved into a more seated position, more pressure was developed in the buttocks.

The increase in comfort to the legs was not nearly as significant as for the upper body (Reading =0.68±1.00, Writing =1.08±1.00, Television =0.68±0.82 from Table 8-3) and many people did not even adjust the leg section much at all (Reading =8.89±4.50deg, Writing =9.66±4.41deg, Television =0.68±0.82deg). The number of people who adjusted the leg to the maximum position was similar to that of the back, except in reading where the percentage was raised from 10% to 21% (Table 8-4). The greater the leg angle the more support given to the material being held in the lap of the subject and this was most popular in writing and reading rather than television watching. Generally the satisfaction of the leg adjustment was high and was confirmed in the post questionnaire with an average rating of 4.42±0.77 (Table 8-5). The main desire expressed by a number of the participants was the possibility of having more angle available in the leg adjustment.

When questioned on the specifics of the mechanisms control the results were very favourable with all the significant questions indicating positive responses above 4.2 (Table 8-5). Two sample infrared remotes had not arrived in time for the trial and would have only improved these results. The cord length problem would be removed but the chances of loosing the remote would rise greatly.

The operation of the bed also seems to be adequate with all of the post questionnaire responses giving average ratings of 4.7 and above (Table 8-5). The only area that was not as high was the quietness, which had a reading of 3.97±0.95. The results of the mattress questioning gave mattress movement = 4.68±0.58 and mattress bunching = 4.53±0.61 suggesting that the mattress is certainly adequate for the job.

Table 8-3 The results of performing the three activities in the flat and adjusted configurations

	Reading						
	Flat		Adjusted		Difference		
Activity	Rating	Std Dev	Rating	Std Dev	Rating	Std Dev	t-Test
Comfort	3.03	1.11	4.50	0.60	1.47	1.30	0.0001
Support	3.58	1.12	4.42	0.53	0.84	1.29	0.0108
Neck	2.84	1.50	3.95	0.78	1.11	1.70	0.0109
Arms	3.13	1.08	4.34	0.75	1.21	1.10	0.0001
Back	3.05	1.22	4.37	0.70	1.32	1.30	0.0003
Buttocks	3.42	1.22	4.34	0.58	0.92	1.42	0.0110
Leg	3.84	0.83	4.43	0.70	0.68	1.00	0.0081
Thigh	3.84	0.90	4.58	0.61	0.74	1.15	0.0118
Back Angle			30.00	10.20			
Leg Angle			8.89	4.50			

	Writing						
	Flat		Adjusted		Difference		
Activity	**Rating**	**Std Dev**	**Rating**	**Std Dev**	**Rating**	**Std Dev**	**t-Test**
Comfort	2.26	1.10	4.29	0.56	2.03	1.14	0.0000
Support	3.00	1.29	4.34	0.47	1.34	1.23	0.0002
Neck	2.29	0.84	3.79	0.98	1.50	1.46	0.0003
Arms	2.47	0.96	3.97	0.72	1.50	1.07	0.0000
Back	2.68	1.29	3.92	0.95	1.24	1.51	0.0022
Buttocks	3.26	1.05	4.00	0.88	0.74	0.87	0.0017
Leg	3.32	1.11	4.39	0.59	1.08	1.00	0.0002
Thigh	3.47	0.96	4.34	0.67	0.87	1.05	0.0021
Back Angle			38.34	8.42			
Leg Angle			9.66	4.41			

	Television						
	Flat		Adjusted		Difference		
Activity	**Rating**	**Std Dev**	**Rating**	**Std Dev**	**Rating**	**Std Dev**	**t-Test**
Comfort	3.50	0.83	4.71	0.45	1.21	0.77	0.0000
Support	3.68	1.16	4.71	0.45	1.03	1.23	0.0019
Neck	2.68	1.34	4.21	0.79	1.53	1.35	0.0001
Arms	3.47	1.07	4.61	0.59	1.13	1.10	0.0003
Back	3.37	0.96	4.53	0.61	1.16	0.83	0.0000
Buttocks	3.68	1.06	4.53	0.51	0.84	1.17	0.0056
Leg	3.95	0.62	4.63	0.50	0.68	0.82	0.0019
Thigh	3.95	0.62	4.63	0.47	0.68	0.77	0.0011
Back Angle			29.71	10.48			
Leg Angle			6.18	3.82			

Table 8-4 The proportions of participants who set the desired position to the maximum allowable back and leg angles

	Max Back		Max Leg	
Activity	**Number**	**%**	**Number**	**%**
Reading	2	10.53	4	21.05
Writing	5	26.32	5	26.32
Television	1	5.26	1	5.26

Table 8-5 Post Questionnaire results

	Question	Avg Rating	Std Dev
Adjustability	Head support	3.61	1.09
	Back adjustment	4.29	0.80
	Leg adjustment	4.42	0.77
	Lumbar support	4.08	0.92
	Bed side table reach	3.37	1.01
Control	Ease of adjustment	4.89	0.32
	Ease of button pushing	4.84	0.50
	Ease of control reach	4.68	0.58
	Obtaining desired angle	4.68	0.48
	Ease of loosing control	2.53	1.12
	Ease of using in the dark	3.16	1.12
	Control length adequacy	4.53	0.84
	Remote holder adequacy	4.21	0.79
	Remote toughness	4.32	0.58
	Remote understanding	4.58	0.90
Operation	Adjustment speed adequacy	4.79	0.42
	Smoothness of adjustment	4.84	0.37
	Quietness of adjustment	3.97	0.95
	How at ease is the operator?	4.89	0.32
	How safe does it feel to operate?	4.89	0.32
	How robust does it feel?	4.89	0.32
Mattress	Mattress movement	4.68	0.58
	Mattress bunching	4.53	0.61

Conclusions

Even though the prototype was completed the day before the scheduled trials and extensive fine-tuning was not possible, it lasted the three busy days of trials without any problems. The bed worked better than anticipated and everyone seemed to be happy with the performance it delivered. As the Gentact linear actuators were used instead of the preferred Dewert actuators it was anticipated that the trial would have shown even larger scores had the preferred actuator been available.

8.3 *Design Review*

After the trial it was possible to compare the different actuator models on the prototype with the arrival of the Dewert actuators. It was found that the Duomat was far superior in performance and was able to deliver a greater range of movement, was quieter and faster than the other two. These features would certainly have satisfied those subjects who were unhappy about these aspects during the user trial. The Duomat is half the price and has a much simpler mounting arrangement with a much cleaner look. The prototype confirmed the belief that the Duomat would be the actuator of choice for the system.

The QFD chart was updated to include (Figure 8-4) the latest information. This gave a good indication of how the prototype compares to the targets that were set out at the start of the project. From the chart it was possible to see what areas of the mechanism were adequate and which required more work to bring them to the desired level. The only areas that did not reach the targets for user evaluations were: the bed side table reach which can only be improved by using a slide back mechanism (already ruled out), the ease of loosing the remote and the remote holder which are both not big issues.

There were many more engineering characteristics that did not measure up but this was because some of the expectations were unrealistic and had been based on what seemed to be suitable at the creation of the initial QFD chart. The desired speed of adjustment was set at $0.053ms^{-1}$ but the Duomat could only deliver $0.044ms^{-1}$ which turned out to be a suitable adjustment speed. Any faster than this and the movement becomes dangerous. The desired back angle was set at 80 degrees, which only just missed at 76 degree and therefore is not an issue. The movement delay was 0.25s longer than desired but this is almost insignificant and cannot be improved since it is mainly dependent on the off the shelf actuator. Initially the ability to adjust the speed of operation was desired but this option is not available with these standard actuators. The mattress bunching height was also much higher than desired but the studies showed that this was not a significant problem.

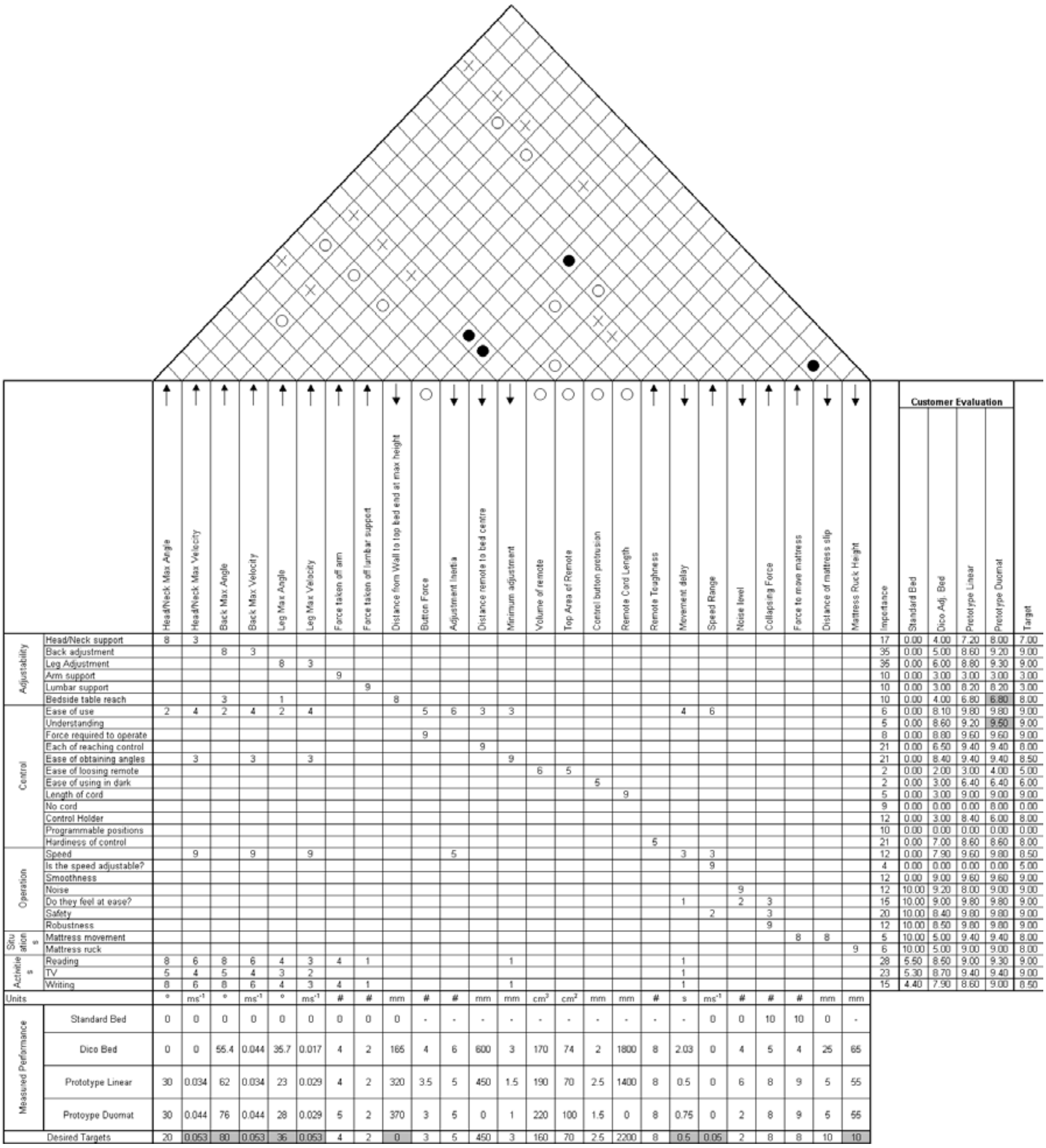


Figure 8-4 QFD chart 29/10/01

A design review meeting for the adjustability mechanism was performed and as with any prototype situation there were many problems that need to be alleviated. A summary of the main proposed design changes and future steps to be performed are summarised below:

- Fasteners:
    - Make uniform throughout
    - Make the circlip groove deeper so it doesn't pop off
- Stoppers:
    - Reposition the leg stopper
- Crosstube:
    - Requires some sort of positioning spacer to stop lateral movement
- Back Hinge:
    - Increase pegs size to avoid breakage
    - Add another peg to stop backward movement of back section
- Buttocks slats:
    - Need to have a bracket made to hold the slats in place on the bed frame
- Shoes and Spacers:
    - Tend to be pulled out and move around so require some sort of method of clamping them in place. This may be incorporated into the end caps.

During the user trial many of the taller people found that their heads tended to stick out over the end of the bed with no support available. The positioning of the adjustable sections is a problem because of the differences in the sizes of people bodies; it is not possible to satisfy everyone on the same bed. Further investigations has to be performed to determine whether the adjustable section layout has to be changed, which would break the substantial constraint set out by the 330mm slat spacing system. The ideal would be to have a compromised layout that is suitable for the greatest number of people.

Taking these changes into account a second prototype will be produced and more extensive testing will be performed. This will need to include use over a more extended time frame to test the durability and life of the parts. The bed will be given to potential customers to trial over a few days to acquire comments and recommendations on its performance. The design will also undergo cyclic testing to confirm that it can withstand the loads over the length of its working life.

Figure 8-5 Photo of the fully adjusted bed with mattress

Figure 8-6 Photo of the bed with a subject testing the adjustment

Figure 8-7 Photo of the fully adjusted mechanism

Figure 8-8 Side on photo of the fully adjusted mechanism

Figure 8-9 Close up photo of the prototype leg adjustment with mattress

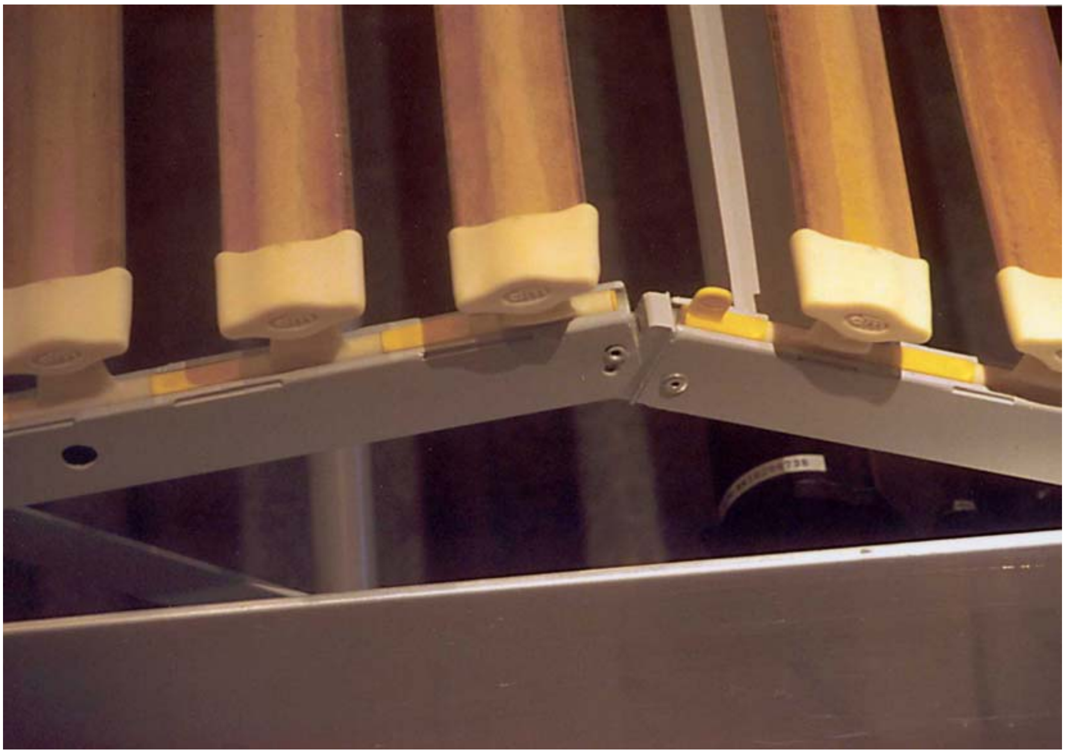


Figure 8-10 Close up photo of the prototype leg hinge

9 Discussion

The aim of this project was to design an adjustable bed and to do so in a systematic and methodical way. This chapter discusses some of the issues that arose at each stage of the design process.

9.1 "Clarifying the Task" Step

It is essential when developing a product that the task is clearly defined. If the task is not clarified the final product may not be entirely what the company intended. Many design techniques were used to help clarify the problem presented by Design Mobel and these techniques were very useful in determining the functions and objectives required by the end product. This formal framework was important in the way it stopped the designer from rushing into solving the problem and potentially overlooking important aspects of the final design. Even though using this framework caused the design process to take longer than was desired, it provided the designer with confidence that the design will closely match what the client had desired.

The brief that was presented by Design Mobel was too vaguely defined and required much work to determine the specifics of what was wanted. The company wanted to produce an adjustable bed but had not done any research to find out what was required. As a result a large amount of research was performed, involving analysis of patents and other products on the market, to querying customers on what they would want from such a product. One problem that arose from questioning customers was that many did not see the product as a need until they actually tried the adjustable bed during user trials. Nonetheless the interaction that was carried out with the end user during the project lifted many of these customers past their preconceptions that adjustable beds are just for use in hospitals, to viewing these beds as a desirable piece of furniture to purchase.

The final outcome from the clarifying phase was the creation of the preliminary PDS document. This document was a living document that was never fully complete because it continually changed and developed as more information was gathered. At many stages during the project a point was reached that could not be passed until a requirement or constraint was clarified or created and added to the PDS. Nevertheless it was also important not to make the PDS too specific without clarifying the necessity of the constraint and in doing removing a number of very suitable designs. This was evident in the project with the significant change in the direction of the design when the limitation of avoiding the use of electrical devices was eliminated.

The ideal situation for a designer would be to be given a complete PDS, with the only requirement being to solve the problem through design. The drawback with this is that much of the information that was required from the customer could not be gathered solely by marketing but required engineering knowledge. However, some of the work that was completed during this project, such as customer questionnaires, could have been performed by marketing personnel who are experts in this area. This in turn would have saved the designer a considerable amount of time.

9.2 *"Concept Design" Step*

The conceptual phase is considered the most demanding on the designer because for the design to be successful a suitable concept must be developed. This phase demands a great deal of creative ability and is very much open for things to go wrong. To avoid such a possibility this stage of the project was strongly guided by design techniques to help in the development and evaluation of the concepts. It is hard to determine to what extent these techniques improved the final outcome of the design, but the comment that can be made is that by using these techniques a large number of possible concepts resulted, from which a very successful final design was produced.

The final concept that was developed turned out to be similar to the majority of products already on the market. The range of possible design outcomes were relatively narrow because the functions required could only be satisfied in a small number of ways within the constraints.

Since the designer performed most of the project singularly, regular meetings and general input from others was important. This input was valuable both for the development of ideas but also in keeping the design heading in the right direction as people with a more objective view of the situation were able to contribute. The brainstorming sessions worked well and enabled people to bounce their ideas off each other. It was interesting to note that there were many good ideas developed during these group sessions but most of these ideas had already been conceptualised by the designer. If the sessions were performed within a group of people developing the product the sessions may have been of more value. Conversely it can be good to get outsiders to be involved because they can bring in new ideas that may not have been thought of by the designer because he or she have become stuck in a single mind set.

The single synectics session did not prove to be very useful and the process should be tried a few more times before any conclusions can be made on how suitable synectics are as a design aid in this context. Many analogies were suggested in the session but none of them seem to lead to any suitable new concepts. This may be due to the nature of the project, since the number of possible options may be very small and may have already been reached in the brainstorming sessions. The other problem was that participants found it hard to get into the right mind set to come up with the analogies and this may have been due to the way the session were run, or the environment.

The list of concepts that were developed were then expanded utilising the morphological matrix technique. This greatly expanded the list of possible solutions as planned but only a fraction of the concepts were actually worth while investigating. Nonetheless, if this is what is required to generate even one possible concept that may result in the principle solution, the time spent cannot be seen as wasted. The way in which this technique was successful was in making the designer consider every aspect of a concept before it was written off as unsuitable. Since the system was already broken up into different functional components it was quite easy to match them up to configurations that were practical which in turn led to the flow of further ideas.

Looking back in retrospect the rating system that was used for the evaluation should be changed. A lot more is now known about the system and other additional materials have been collected so that the initial decisions that were made during the conceptual phase would be quite different if performed at this stage. The two concepts that were considered the highest rating by the evaluation technique were later found to be less attractive than the ratings suggested because of unforeseen complexity and costs. At the time, limited knowledge was used to create a selection criteria that was not developed to a level that eliminated these concepts. If the process were repeated at this time the concept that was third in the evaluation, and the concept finally pursued, would now be the top choice. Even so, the selection that was finally pursued would still be the concept of choice if the evaluation was repeated at this time. When the evaluation was performed it was based on the current PDS information. This information was not necessarily mature enough to be used so the designer has to be careful to make sure that the PDS has matured to a suitable level before making serious design decisions from it.

It has to be accepted that sometimes the design process has to go down a dead end in order for the designer to discover information that will direct the PDS in the right direction. This was seen with the pneumatic concept. It was not until detailed research had been performed that the idea was discovered to be unviable. A concept is still a loose idea until a feasibility study has been performed to assess its suitability. Attractive features of the concept may not be as simple and cost effective as were initially thought. The other possibility is that at this stage the concept is not viable until new technology or new products are released. For example if a very cheap pneumatic cylinder or some sort of human operated pump was developed, the pneumatic system may suddenly became a viable option.

9.3 "Embodiment Design" Step

The main purpose of the embodiment phase was to develop the idea generated in the conceptual phase so that it could be developed for production. The embodiment phase must not be overlooked. This is to avoid rushing into the development of a product that may seem viable but will not perform as desired. In this project the embodiment phase was investigated in much detail so that the output design, even though still rough, was guaranteed to operate as intended.

During the embodiment phase the system was broken up into four distinct subassemblies to keep the design work simple: the mechanism, the actuator, the frame and the fastening. This was done to help make the distinction between the embodiment and conceptual design phases more distinct. Each of the subassemblies were at very different stages at any one point and their order jumped around significantly during the development process. The frame and method of actuation were quite developed at the onset of this phase but the mechanism still required a great deal of work.

Each of these distinct areas had a huge effect on the other areas. This was seen when the method of actuation was changed and the mechanism and the frame had to be reworked and further developed to bring them back to the stage they were at before the change. These iterations were quite frequent and the subassembly required a design change whenever a stumbling block was reached.

The large number of blocks that were reached and the resulting iterations became quite frustrating because it felt like the design was constantly starting over again and all the time spent going down one path had been wasted. While this was true, once the changes were made and the new idea progressed it was usually found that the number of steps taken back were not as many as originally thought. The knowledge that was gained from the previous concept was hugely valuable in developing information on what areas to develop and what to avoid in further designs. In a sense this was a waste of time, but if this road had not been taken a very innovative system may have bee missed out on.

The method of actuation first pursued in detail was the pneumatic system and this was developed to the level of the embodiment phase before being dropped for the gas strut. The gas strut proved to be essentially the same form of actuation but in a much more simple, compact, and inexpensive form. The problem with both of these concepts was that they violated the PDS in the area of control and operation. None of the proposed concepts satisfied the PDS at this point so the least damaging compromise had to be made. The collected information suggested that the most suitable method of actuation would involve electricity but this violated the requirement set out in the PDS. By opening this constraint many other options became available that much more closely met the targets set by the PDS requirements. The final actuation solution turned out to be very suitable and had major benefits in regards to the frame and mechanism.

The mechanism went through much iteration that started with a roller design and ended with a five bar linkage design. The changes to the frame were not major but the number of mounting points and points of fastening were greatly affected by the other two subassemblies.

Looking back, it would seem best to have gone straight to the final design and ignored the other concepts. This is idealism since the path to the final design was a process, which involved the development of these concepts, which in turn helped to bring forth the flow of ideas.

The development of the prototype from the preliminary design was very beneficial because it provided a great deal of valuable information on the validity of the developed concept. The user trial brought important feedback from the customer to the new product. The physical model also helped to determine the real design issues remaining and whether the design should move forward into the detail design phase. The model also determined if the QFD targets and PDS requirements were reached or if changes needed to be made to reach these. These design changes will lead to a definitive design, which can be refined in the detail design phase to develop the product for production. During this stage a technique called value engineering will be used to help reduce the unnecessary costs by bringing more value to the essential parts. The product will also be developed further for manufacturing factors that will create a device that is ready to be put into production.

10 Conclusions

The design of the adjustable bed was approached with a customer and environmental focus, and in a systematic manner using the Pahl & Beitz methodology. The process involved determining the design requirements, creating concepts to solve these, and then building on the most promising design with the goal of developing it for production.

Approaching the design in this manner meant that the phase of clarifying the task was dwelt on for longer than would normally be expected but as a result the problem was more fully defined. The design techniques forced the designer to look at everything in far greater detail minimising the chance of overlooking critical issues while they also helped to take a wider approach to the problem. As a result the rest of the design process was performed with greater confidence with the knowledge that the product would closely match what the client had desired.

The framework of the Pahl and Beitz methodology for PDS provided the opportunity to explore a variety of methods for creating solutions and evaluating them which were very helpful in guiding the thought processes and keeping the design on track.

The strengths and weaknesses of the methods became apparent and identified the approaches that might be taken in any further development. One strength was while the designer generated ideas individually, the addition of brainstorming sessions helped to develop more concepts in a shorter time, including ones that had been overlooked or not even considered. Some methods, for example the synectics sessions, did not prove to be very useful. Under different circumstances, with more experience and more extensive preparation the technique might be more constructive. Due to the simplicity of the function structures and design requirements some of the techniques including the morphological matrix were somewhat limited in their potential. Using the weighted objectives technique to select the principle solution was limited in success because it was based on immature information. The solution that was finally pursued was rated the third system in the selection technique because it could not take into account information that was discovered later in the process.

Ideally the designer would want to start the design with the complete PDS from the client, with the user, the marketing and the environmental requirements well defined. Such an expectation is not reasonable, as much of the documentation requires engineering knowledge and interpretation. It is critical in the design process for the full development of the PDS not to be compromised, however much time has to be devoted to it. Consequently the PDS document became a living iterative document with changes and compromises made as further information came to light. A large proportion of the knowledge came from developing ideas that eventually turned out to be dead ends. Sometimes it was one step forward and two back but with the subsequent realisation that it was the information gained going down a sidetrack that provided the critical perspective for development of other more fruitful ideas.

The outcome from the production of the prototype was very satisfactory. The design review meeting that followed the testing and reporting of the first prototype was very positive. The prototype that was produced met most of the design requirements set out by Design Mobel. The design was able to meet the very tight cost constraint of under $500 while still providing the level of style and operation required. The solution was also successful in overcoming the difficult constraints produced by the construction features of the Circadian bed frame.

A number of the wishes set out in the PDS were unmet but the only major demand that was not achieved was the initial requirement to avoid the use of electricity in the bed. Sometimes the client sets unrealistic demands and constraints that conflict, or simply are not achievable within the engineer's framework. In this particular case the engineer had to compromise the electricity requirement to provide the cheap and simplistic in-bed adjustment desired.

The prototype adjustable bed was successfully produced and tested with a better than expected outcome. It would seem as this point that there will be only minor design changes required to develop it for production levels. The next stage is to fully develop the product in the detail design phase. This will include applying the value engineering technique in order to bring more marketing value to the product by removing any identifiable unnecessary costs. The final design goal is to have the mechanism ready to be in production in August 2002, which at the present time appears to be a very real possibility.

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Appendix A Patent Analysis

Function and Feature	Patent Number																																																48		
	US3795018	US3824638	US3898702	US3900906	US3965500	US3974530	US4025972	US4095296	US4104749	US4222137	US4227269	US4324010	US4385410	US4395786	US4407030	US4463463	US4494259	US4499618	US4527298	US4651365	US4660236	US4774732	US4873731	US4979246	US4979246	US4996731	US5095562	US5105486	US5134731	US5155881	US5160010	US5161274	US5165129	US5170522	US5224228	US5337428	US5425150	US5640729	US5685035	US5687437	US5870784	US5903940	US5996145	US6000077	US6101647	USRE035201	WO016663A1	WO9730614A1	Total	Percentage	Visual Representation
Safety Device															1																																			1	2.1	II
Adjustable Bed				1		1	1	1	1	1		1		1	1		1	1	1	1	1	1	1	1		1	1	1	1			1	1	1	1			1		1		1				1	1	1		31	64.6	IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
Height Adjustable																									1					1							1				1								1	5	10.4	IIIIIIIIII
Mattress Support																														1																				1	2.1	II
Size Adjustable		1																																											1							2	4.2	IIII
Sleep Conformability	1																																																		1	2.1	II
Angle Adjustment				1																																											1								2	4.2	IIII
Hardness Adjustability											1																																								1	2.1	II
Roll Adjustment																																				1			1													2	4.2	IIII
Motive Unit													1																																1					2	4.2	IIII
Hospital			1	1			1												1	1									1		1				1		1					1							1								11	22.9	IIIIIIIIIIIIIIIIIIIIII
Home										1		1											1	1		1	1		1																	1	1	1				10	20.8	IIIIIIIIIIIIIIIIIIII
Not Stated	1	1			1	1		1		1		1	1	1	1	1			1			1						1	1	1		1		1	1	1	1		1	1	1					1	1	1	27	56.3	IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
Electric							1	1	1		4		1	2	2	2	4			2												4	2						2		2			1			1		16	33.3	IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
Manual Crank																		1			1				1																								3	6.3	IIIIII
Manual/Electric			3																									2		2																						3	6.3	IIIIII
Inflatable																			1				1												1			1												4	8.3	IIIIIIII
Manual Move						1																			1																									2	4.2	IIII
Cylinder				1																						1		1			2																		1			5	10.4	IIIIIIIIII
Body Weight																						1																												1	2.1	II
Not Given	1	1			1				1		1																					1					1	1		1		1		1	1	1	1			1	15	31.3	IIIIIIIIIIIIIIIIIIIIIIIIIIIIII
Scissor Mechanism																															1																			1	2.1	II
Pivotal Lever Arm						1		1	1	1		1		1	1	1	1	1	1								1	1	1	1				1							1		1				1	1	1	1	22	45.8	IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
Pivotal Slide Mechanism			1																			1	1												1		1																		5	10.4	IIIIIIIIII
Gearbox/Worm Gear			1														1																																2	4.2	IIII
Screw & Nut											1			1	1		1	1											1																				6	12.5	IIIIIIIIIIII
Gear Train/Clutch																		1																														1	2.1	II
Torque Tube							1																																	1		1								3	6.3	IIIIII
Pulley And Wires								1																					1											1											3	6.3	IIIIII
Circular/Linear Gear																				1																												1	2.1	II
Hinge Movement						1																1																											2	4.2	IIII
Cylinder Movement				1																																														1	2.1	II
Inflation Of Bladder																			1				1												1			1												4	8.3	IIIIIIII
Not Given	1	1									1		1												1						1					1	1		1		1		1	1	1					13	27.1	IIIIIIIIIIIIIIIIIIIIIIIIII
Head							1																			1																						2	4.2	IIII
Back			1		1	1		1	1		1		1	1	1	1	1	1	1	1	1	1	1		1	1	1	1			1	1	1	1			1		1		1				1	1	1	1	32	66.7	IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
Thigh					1	1		1			1		1	1	1	1		1			1	1	1		1	1	1	1			1	1	1	1					1		1				1	1		1	25	52.1	IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
Leg					1	1	1	1			1		1	1	1	1	1	1	1	1	1	1	1		1	1	1	1			1	1	1	1					1		1				1	1		1	29	60.4	IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
Foot			1																						1																						2	4.2	IIII
None	1	1		1						1		1											1				1	1					1	1		1		1		1	1	1					15	31.3	IIIIIIIIIIIIIIIIIIIIIIIIIIIIII
Butt			1		1		1	1					1		1	1	1	1	1	1							1					1	1	1							1				1			1	18	37.5	IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
Leg			1																																														1	2.1	II
None	1	1		1		1			1	1	1	1		1							1	1	1	1	1	1		1	1	1	1				1	1	1	1	1	1		1	1	1		1	1		30	62.5	IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
Total																	1	1							1			1	1			1																		6	12.5	IIIIIIIIIIII
Front				1																				1																								2	4.2	IIII
Back				1																				1																								2	4.2	IIII
None	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1			1	1	1	1	1			1	1			1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	40	83.3	IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
Wall Hugger																																									1				1			1	3	6.3	IIIIII
Anti Jam															1																		1															2	4.2	IIII
Any Size Bed																			1	1			1														1												4	8.3	IIIIIIII
Crib																									1																							1	2.1	II
Cage																									1																							1	2.1	II
Butt Depression																										1																						1	2.1	II
Removable Motor																											1																					1	2.1	II
Power Change																											1																					1	2.1	II
Mechanical Lock							1				1											1						1																				4	8.3	IIIIIIII
Side Rail																															1																	1	2.1	II
PA Locking Mechanism																															1																	1	2.1	II
Wire Frame																														1																1			2	4.2	IIII
Moveable Link																																														1			1	2.1	II
Automatic Knee Break					1																																											1	2.1	II
Add On Kit										1									1	1																	1												4	8.3	IIIIIIII
Angle Sensors																																1																1	2.1	II
Motors Coupled																																1																1	2.1	II
Vibrator																																		1														1	2.1	II
Telescopic Ends																																							1									1	2.1	II
Left/Right Roll				1																																												1	2.1	II
	1	1	1	1	1	1	1	1	1				1	1		1	1		1	1	1	1	1	1	1	1	1	1													1				1								23	47.9	IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII

Appendix B Product Analysis

Features				Unit
Body Adjustability	Head/Neck	Adjustable		Yes/No
			Angle	Angle
		Telescopic		Yes/No
		Linked		Yes/No
		Manual Adjustable		Yes/No
			Number of Adjustments	Number
		Gas Cylinder		Yes/No
		Solid Block		Yes/No
		Electric Adjustable		Yes/No
	Back	Adjustable		Yes/No
			Angle	Angle
		Manual Adjustable		Yes/No
			Number of Adjustments	Number
		Electric Adjustable		Yes/No
		Gas Cylinder		Yes/No
	Buttocks	Fixed		Yes/No
	Leg	Adjustable		Yes/No
		Straight		Yes/No
		Knee Separate		Yes/No
	Femoral	Adjustable		Yes/No
			Angle	Angle
		Powered		Yes/No
		Manual		Yes/No
			Number of Adjustments	Number
		Electric		Yes/No
	Tibial	Adjustable		Yes/No
			Angle	Angle
		Powered		Yes/No
		Manual		Yes/No
			Number of Adjustments	Number
		Electric		Yes/No
		Gas Cylinder		Yes/No
Height	Adjustable			Yes/No
Supports	Adjustability	Position Adjustable		Yes/No
		Fixed Number		Yes/No
		Firmness adjustable	Each Slat	Yes/No
			Zones	Yes/No
			Shoulder Area	Yes/No
	Type of Support	Flexible Mat		Yes/No
		Individual Slats		Yes/No
		Individual Spring Elements		Yes/No
		Wire mesh		Yes/No
	Fixtured	Side Fixed		Yes/No
		Centre Fixed		Yes/No
	Material	Wood		Yes/No
		Metal		Yes/No
		Glass Fibre		Yes/No
		Plastic		Yes/No
Frame	Frame Height			cm
	Distance Below			cm
	Material	Wood		Yes/No
		Metal		Yes/No
Accessories	Mattress Retainer			Yes/No
	Side Mattress Bar			Yes/No
	Mains Isolator			Yes/No
Other	Fits Any Bed Frame			Yes/No
	Bed Box Access			Yes/No
	Side Back			Yes/No
	Dismantable			Yes/No
	Two Hand Operation			Yes/No
	Centre Belt			Yes/No
	Emergency Lowering			Yes/No
	Reset Function			Yes/No
	Memory Positions			Yes/No
	Locks on Power Failure			Yes/No
	Removable Motor			Yes/No
Control	Cable Remote Control			Yes/No
	Infar-red Remote Control			Yes/No
	Cylinder Control			Yes/No

Make and Model	
DICO	497; 491; 495; 498
Awek	2X Hand Verstelbaar; Gasveer Verstelbaar; Gasveer Dubbel VerstelBaar; Elektrisch Verstelbaar; 2x Elektrisch Dubbel Verstelbaar
Auping	Handverstelling; Automat; Automat E; Electromat; Electromat Plus
Kuperus	Relax; UNomatic; Duomatic; Sitter; Sitter Elektro
Pozzoli	1401; 1101; 1201; 501; 601
EBA	Basis; Evolution; Evolution Bis; Optimum
Elomed	Sitz-MZV; Variabel-MZV; Variabel-MZV+Gas; TFK-MZV; TFK-MZV+Gas; Mot-2
Germania	Swing/Gemma Flex (Manual); Swing/Gemma Flex (Motor); Swing/Gemma Med (Manual); Swing/Gemma Med (Motor); Swing/Gemma Lux (Manual); Swing/Gemma Lux (Motor); Duo Flex (Manual); Duo Flex (Motor); Duo Med (Manual); Duo Med (Motor); Duo Lux (Manual); Duo Lux (Motor); Trio Lux; Trio Flex
Essedue	Pangi; Malta Mod. 1 Color; Malta Mod. 1 Total; Malta Mod. 2; Ferrari Elettrica Mod. 1; Ferrari Elettrica Mod. 2
Breckle	Standard; Alfa K+F MZ; Optimal K+F, MZ; Solid K+F, MZ; Taschomed K+F, MZ; Starflex K+F, MZ; BoNoflex K+F, MZ; Star de luxe K+F, MZ; Superflex K+F, MZ; Luxoflex K+F, MZ; Doflex K+F, MZ; Mediflex K+F, MZ; Maxiflex K+F, MZ; Maxiflex Bio K+F, MZ; Bioralmen K+F, MZ; Flexomat; Star de Luxe Elektro; Luxomat II; Triomat

Group	Part	Feature	Detail	129	Yes	No	-	?	% Yes	%Yes(- (-?))	%Yes(-(-))	% Answered	Max	Min	Average
			Total												
Body Adjustability	Head/Neck	Adjustable		Yes/No	85	44	0	0	65.89	65.89	65.89	100.00			
			Angle	Angle			44	74	0.00			8.53	100	25	73.73
		Telescopic		Yes/No	2	104	23	0	1.55	1.89	1.89	82.17			
		Linked		Yes/No	12	101	16	0	9.30	10.62	10.62	87.60			
		Manual Adjustable		Yes/No	45	31	53	0	34.88	59.21	59.21	58.91			
			Number of Adjustments	Number			84	41	0.00			3.10	6	2	5.00
		Gas Cylinder		Yes/No	0	92	37	0	0.00	0.00	0.00	71.32			
		Solid Block		Yes/No	1	110	17	0	0.78	0.89	0.89	86.82			
		Electric Adjustable		Yes/No	27	47	55	0	20.93	36.49	36.49	57.36			
	Back	Adjustable		Yes/No	100	29	0	0	77.52	77.52	77.52	100.00			
			Angle	Angle			29	90	0.00			7.75	80	50	66.90
		Manual Adjustable		Yes/No	48	52	29	0	37.21	48.00	48.00	77.52			
			Number of Adjustments	Number			81	46	0.00			1.55	19	4	11.50
		Electric Adjustable		Yes/No	45	53	31	0	34.88	45.92	45.92	75.97			
		Gas Cylinder		Yes/No	7	91	31	0	5.43	7.14	7.14	75.97			
	Buttocks	Fixed		Yes/No	53	76	0	0	41.09	41.09	41.09	100.00			
	Leg	Adjustable		Yes/No	122	7	0	0	94.57	94.57	94.57	100.00			
		Straight		Yes/No	76	48	5	0	58.91	61.29	61.29	96.12			
		Knee Separate		Yes/No	41	60	28	0	31.78	40.59	40.59	78.29			
	Femoral	Adjustable		Yes/No	50	77	0	0	38.76	38.76	38.76	100.00			
			Angle	Angle			79	50	0.00			0.00			
		Powered		Yes/No	8	42	79	0	6.20	16.00	16.00	38.76			
		Manual		Yes/No	2	6	121	0	1.55	25.00	25.00	6.20			
			Number of Adjustments	Number			127	2	0.00			0.00			
		Electric		Yes/No	6	2	121	0	4.65	75.00	75.00	6.20			
	Tibial	Adjustable		Yes/No	123	6	0	0	95.35	95.35	95.35	100.00			
			Angle	Angle			9	116	0.00			3.10	8	5	6.75
		Powered		Yes/No	110	14	5	0	85.27	88.71	88.71	96.12			
		Manual		Yes/No	66	52	11	0	51.16	55.93	55.93	91.47			
			Number of Adjustments	Number			63	63	0.00			2.33	6	3	5.00
		Electric		Yes/No	49	67	11	2	37.98	42.24	41.53	89.92			
		Gas Cylinder		Yes/No	3	113	11	2	2.33	2.59	2.54	89.92			
Height	Adjustable			Yes/No	5	124	0	0	3.88	3.88	3.88	100.00			
Supports	Adjustability	Position Adjustable		Yes/No	0	129	0	0	0.00	0.00	0.00	100.00			
		Fixed Number		Yes/No	110	19	0	0	85.27	85.27	85.27	100.00			
		Firmness adjustable	Each Slat	Yes/No	5	124	0	0	3.88	3.88	3.88	100.00			
			Zones	Yes/No	74	55	0	0	57.36	57.36	57.36	100.00			
			Shoulder Area	Yes/No	28	101	0	0	21.71	21.71	21.71	100.00			
	Type of Support	Flexible Mat		Yes/No	1	128	0	0	0.78	0.78	0.78	100.00			
		Individual Slats		Yes/No	91	38	0	0	70.54	70.54	70.54	100.00			
		Individual Spring Elements		Yes/No	18	111	0	0	13.95	13.95	13.95	100.00			
		Wire mesh		Yes/No	19	110	0	0	14.73	14.73	14.73	100.00			
	Fixtured	Side Fixed		Yes/No	127	2	0	0	98.45	98.45	98.45	100.00			
		Centre Fixed		Yes/No	2	127	0	0	1.55	1.55	1.55	100.00			
	Material	Wood		Yes/No	83	46	0	0	64.34	64.34	64.34	100.00			
		Metal		Yes/No	19	110	0	0	14.73	14.73	14.73	100.00			
		Glass Fibre		Yes/No	7	120	0	2	5.43	5.51	5.43	98.45			
		Plastic		Yes/No	21	108	0	0	16.28	16.28	16.28	100.00			
Frame	Frame Height			cm			0	100	0.00			22.48	10	4.5	7.00
	Distance Below			cm			0	122	0.00			5.43	13	13	13.00
	Material	Wood		Yes/No	84	45	0	0	65.12	65.12	65.12	100.00			
		Metal		Yes/No	45	84	0	0	34.88	34.88	34.88	100.00			
Accessories	Mattress Retainer			Yes/No	33	96	0	0	25.58	25.58	25.58	100.00			
	Side Mattress Bar			Yes/No	10	119	0	0	7.75	7.75	7.75	100.00			
	Mains Isolator			Yes/No	11	0	74	44	8.53	100.00	20.00	8.53			
Other	Fits Any Bed Frame			Yes/No	8	121	0	0	6.20	6.20	6.20	100.00			
	Bed Box Access			Yes/No	21	108	0	0	16.28	16.28	16.28	100.00			
	Slide Back			Yes/No	4	125	0	0	3.10	3.10	3.10	100.00			
	Dismantable			Yes/No	7	122	0	0	5.43	5.43	5.43	100.00			
	Two Hand Operation			Yes/No	76	53	0	0	58.91	58.91	58.91	100.00			
	Centre Belt			Yes/No	53	76	0	0	41.09	41.09	41.09	100.00			
	Emergency Lowering			Yes/No	10	10	72	37	7.75	50.00	17.54	15.50			
	Reset Function			Yes/No	11	12	72	34	8.53	47.83	19.30	17.83			
	Memory Positions			Yes/No	12	9	73	35	9.30	57.14	21.43	16.28			
	Locks on Power Failure			Yes/No	4	0	73	52	3.10	100.00	7.14	3.10			
	Removable Motor			Yes/No	10	15	73	31	7.75	40.00	17.86	19.38			
Control	Cable Remote Control			Yes/No	55	12	62	0	42.64	82.09	82.09	51.94			
	Infrared Remote Control			Yes/No	5	62	62	0	3.88	7.46	7.46	51.94			
	Cylinder Control			Yes/No	6	61	62	0	4.65	8.96	8.96	51.94			

Appendix C Adjustability Activities Questionnaire

The questionnaire listed in this section is the form that was sent to Design Mobel's valuable customers for important feedback on performing activities in bed.

DESIGN mobel® Customer Survey 12/2000

Gender: Male ☐ Female ☐

1. Age (Optional): ___________

2. We understand sleep is the primary purpose of a bed, however we often use a bed for other activities. We would like to know what activities you do in bed apart from sleep, and what activities you would like to be able to do but find difficult or cannot do because the bed limits you.

Below is a list of some activities and space for adding any others. Could you please indicate, by circling the appropriate number, how much you would like to do the activity (the 'Like' column), how often you do it at the moment (the 'Frequency' Column), and how easy the task is to do in bed (the 'Ease' column). If the activity does not apply to your situation, please leave it blank.

	Like					**Frequency**					**Ease**				
Activity	Like				Dislike	Often				Never	Easy Difficult				
Read	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1
	Comments:														
Work/Study	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1
	Comments:														
Feed baby	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1
	Comments:														
Sickness	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1
	Comment:														
Computer / laptop	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1

	Comments:														
Talk on the phone	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1
	Comments:														
Write	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1
	Comments:														
Eat	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1
	Comments:														
Watch television	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1
	Comments:														
Other:	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1
	Comments:														
Other:	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1
	Comments:														
Other:	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1
	Comments:														

3. What features could be added to a bed to improve functionality or performing the activities listed on the previous page?

____

____

____

____

____

____

4. Do you sit or prop yourself up in bed? Yes ☐ No ☐

What activities do you do this for?

____

____

____

____

____

____

a. If you prop yourself up in bed, what method do you normally use?

Please Tick One

Pillows	
Moveable Headboard	
Other:	

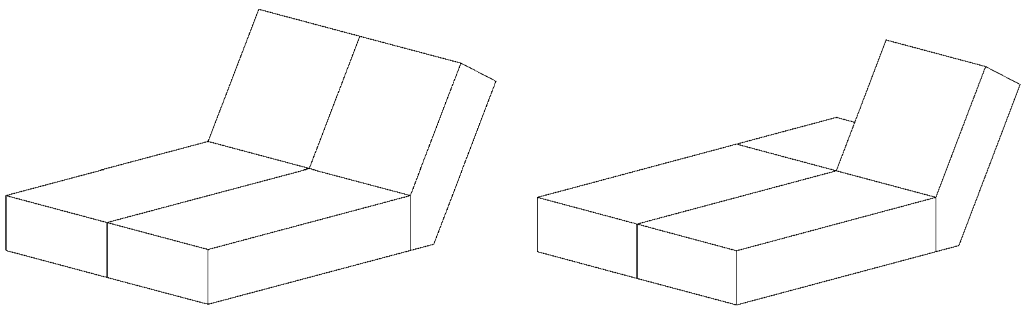
b. How would you rate the satisfaction and comfort of this method?

Please Circle One

Good		Acceptable		Bad
5	4	3	2	1

5. The following questions relate to adjustability in a bed frame.

a. If you could purchase a cost effective method of adjustability for a bed frame would you see it as important that each person could adjust their surface independently? (Ref diagram below)

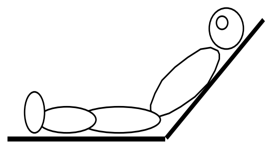
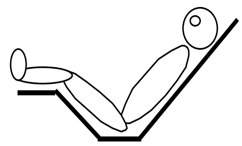
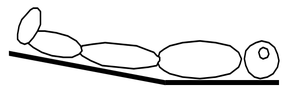
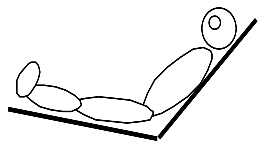
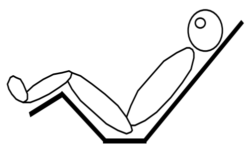


Please Circle One

Important		Don't mind		Unimportant
5	4	3	2	1

b. Please rank in order the types of adjustability you would prefer.

(1 = lowest, 5 = highest)

Method of Adjustability	**Diagram**	**Rank**
Upright back with flat base		
Back tilted with knee raised		
Leg raised (Good for people with circulation problems)		
Back and legs raised		
Back and leg raised with knee bend.		

6. If there is anything else you feel could improve the functionality of **DM** beds please comment here:

Appendix D Adjustability Activities Survey Summary

Questions			Participant																						
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1 Male/Female			M	F	M	F	F	M	F	F	M	F	M	F	M	F	F	F	F	F	-	F	F	M	-
Age			29	32	31	35	-	17	31	38	40	31	45	42	35	30	28	23	36	27	24	33	-	38	-
2 Activities:	Read	Like	4	4	4	5	5	3	4	5	3	5	4	3	5	5	5	5	5	3	-	5	5	4	5
		Freq	4	3	3	4	4	2	2	5	2	3	3	2	3	5	4	4	5	3	3	5	5	4	4
		Ease	4	5	5	5	4	5	4	4	1	4	3	2	4	4	4	3	3	3	3	5	4	3	4
	Work	Like	-	3	3	2	1	-	5	3	3	2	2	2	-	1	3	3	-	-	-	-	2	3	2
		Freq	-	3	2	2	1	-	5	2	1	2	2	1	-	1	2	2	-	1	3	-	1	4	2
		Ease	-	3	4	5	-	-	4	4	1	4	3	2	-	1	4	3	-	-	2	-	1	3	3
	Feed Baby	Like	-	-	-	-	-	-	-	-	-	-	-	1	-	5	-	-	-	-	-	-	-	-	-
		Freq	-	-	-	-	-	-	-	-	-	-	-	1	-	5	-	-	-	1	-	-	1	-	1
		Ease	-	-	-	-	-	-	-	-	-	-	-	1	-	3	-	-	-	-	-	-	-	-	-
	Sickness	Like	4	5	1	1	5	-	1	5	5	-	5	5	1	3	-	3	1	1	-	5	1	4	-
		Freq	2	2	2	3	3	-	2	2	5	3	5	5	3	2	-	3	3	1	2	2	1	2	1
		Ease	4	4	5	3	5	-	3	5	5	4	5	5	5	4	-	3	3	3	3	5	4	4	-
	Computer	Like	-	-	2	3	-	-	2	-	3	2	1	3	-	-	-	-	-	-	-	-	1	-	-
		Freq	-	-	2	3	-	-	2	-	2	1	1	1	-	-	-	-	-	1	3	-	1	-	1
		Ease	-	-	4	4	-	-	2	-	1	3	1	4	-	-	-	-	-	-	3	-	-	-	-
	Phone	Like	2	4	4	5	-	1	5	2	3	3	2	5	2	4	3	5	3	4	-	5	5	4	-
		Freq	2	4	3	5	-	1	5	1	3	3	1	4	2	4	3	4	3	4	3	4	3	4	1
		Ease	5	5	4	5	-	-	5	5	5	5	2	5	2	4	5	5	3	4	4	5	5	4	-
	Write	Like	-	-	3	3	-	-	3	4	3	-	1	2	-	-	-	-	4	-	-	-	4	4	2
		Freq	-	-	3	4	-	-	3	3	2	-	1	1	-	-	-	-	3	1	3	-	4	4	2
		Ease	-	-	3	4	-	-	3	2	1	-	1	1	-	-	-	-	3	-	3	-	4	4	3
	Eat	Like	-	-	2	3	-	-	5	-	1	3	1	1	3	-	-	-	3	3	-	3	5	4	1
		Freq	-	-	2	3	-	-	5	-	1	3	1	1	2	-	1	-	3	3	3	3	4	4	1
		Ease	-	-	4	4	-	-	5	-	-	4	1	1	3	-	-	-	2	3	3	3	4	4	-
	TV	Like	4	5	3	5	5	3	5	-	3	3	3	5	5	5	-	5	4	5	-	5	4	-	-
		Freq	3	4	3	4	5	3	3	-	1	1	2	3	4	4	1	3	2	5	5	4	1	-	1
		Ease	4	5	5	4	3	4	5	-	1	4	3	5	3	4	-	2	3	3	4	5	4	-	-
4 Do you Prop?	Yes/No		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-
	Read (book)		Y	Y	Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	-	Y	Y	-
	TV		Y	Y	-	Y	Y	Y	Y	-	-	-	Y	Y	Y	Y	-	Y	-	Y	Y	-	-	-	-
	Eat		-	-	-	-	-	-	Y	-	-	Y	-	-	-	-	-	-	Y	-	-	Y	-	Y	-
	Phone		-	-	Y	Y	-	-	-	-	-	Y	-	Y	-	-	-	Y	-	-	Y	-	Y	-	-
	Write		-	-	-	-	-	-	-	-	-	-	-	Y	-	-	Y	-	-	-	Y	-	Y	-	-
	Study		-	Y	Y	-	-	-	-	Y	-	-	-	-	-	-	Y	-	-	-	Y	-	-	-	-
	Work		-	-	-	Y	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Computer		-	-	Y	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
	Drink		-	-	-	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sew/Knit		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-
	Chilren		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Read (paper)		-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Relax		-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
	Baby		-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
	Sick		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-
	Method	Pillow	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-
		Headboard	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	-
	Satisfaction		3	3	4	4	3	5	5	4	3	5	3	2	3	3	4	2	2	2	3	2	5	4	-
5 Independence			5	5	5	4	5	1	5	5	4	5	5	5	5	5	5	5	5	5	5	4	5	5	-
		1	4	5	2	3	4	-	5	5	2	5	5	5	5	5	3	4	5	3	3	1	2	1	-
		2	2	3	5	4	3	-	2	4	4	1	2	1	2	1	4	2	4	4	4	3	5	4	-
		3	1	1	1	1	1	-	2	1	5	4	1	4	1	3	1	1	1	1	1	5	1	5	-
		4	3	4	3	2	5	-	4	3	1	2	3	3	4	4	2	3	3	2	2	4	4	2	-
		5	5	2	4	5	2	-	2	2	3	3	4	2	3	2	5	5	2	5	5	2	3	3	-

Questions			24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
1 Male/Female			-	F	M	M	F	-	M	F	F	M	F	-	M	F	F	M	F	F	F	F	M	F	M
Age			-	31	48	40	42	-	52	55	60	33	34	-	59	-	32	18	-	45	35	55	55	28	31
2 Activities:	Read	Like	3	-	3	2	-	4	3	5	5	3	3	-	5	4	5	4	2	5	5	5	4	3	4
		Freq	3	-	2	2	-	2	3	4	5	2	-	-	5	4	3	2	1	4	5	4	3	3	4
		Ease	-	-	4	4	-	3	4	4	5	2	-	-	4	3	4	3	1	3	5	3	2	3	4
	Work	Like	4	-	1	1	-	1	1	1	3	3	-	-	1	1	-	5	1	3	1	-	2	1	-
		Freq	5	-	1	1	-	1	1	1	3	2	-	-	2	2	-	4.5	1	-	1	-	2	1	-
		Ease	5	-	-	1	-	1	1	-	3	2	-	-	2	1	-	3	1	-	-	-	2	-	-
	Feed Baby	Like	-	-	1	-	3	2	1	1	1	1	1	-	-	5	4	-	-	1	5	-	-	-	-
		Freq	1	-	1	-	4	2	1	1	1	1	5	-	-	5	3	-	-	1	5	-	-	-	-
		Ease	-	-	1	-	4	2	1	-	2	1	1	-	-	4	4	-	-	1	5	-	-	-	-
	Sickness	Like	1	-	1	1	-	1	1	-	5	5	-	-	4	4	-	4	-	2	1	1	1	3	-
		Freq	2	-	1	2	-	2	2	-	5	3	-	-	2	3	-	2	-	3	3	1	2	2	-
		Ease	5	-	5	4	-	2	2	-	5	5	-	-	4	3	-	3.5	-	4	5	3	2	3	-
	Computer	Like	-	-	1	-	-	1	1	1	1	3	-	-	-	1	-	1	4	2	1	-	1	-	-
		Freq	1	-	1	-	-	2	1	1	1	3	-	-	1	1	-	1	4	2	1	-	1	-	-
		Ease	-	-	-	-	-	2	1	1	4	3	-	-	-	-	-	1	4	2	-	-	-	-	-
	Phone	Like	4	-	2	3	-	2	1	2	5	5	-	-	3	-	2	4	3	3	3	3	3	4	-
		Freq	4	-	3	2	-	2	2	2	5	5	-	-	3	-	2	2.5	3	2	3	3	4	2	-
		Ease	5	-	4	5	-	2	2	4	5	5	-	-	3	3	3	3.5	3	3	5	4	3	2	-
	Write	Like	3	-	3	2	-	1	1	1	5	1	-	-	-	4	-	2	1	2	3	-	1	-	-
		Freq	3	-	2	2	-	1	1	1	5	1	-	-	1	3	-	2	1	2	2	-	2	-	-
		Ease	3	-	2	2	-	1	1	1	4	1	-	-	-	3	-	2	1	3	3	-	3	-	-
	Eat	Like	1	-	2	5	-	1	1	1	4	3	-	-	-	2	-	2	3	2	3	3	1	-	-
		Freq	2	-	2	4	-	1	2	1	4	3	-	-	-	2	-	2	3	2	3	2	2	-	-
		Ease	1	-	2	4	-	1	2	1	4	2	-	-	-	2	-	2	3	3	3	2	3	-	-
	TV	Like	-	-	4	5	-	1	1	1	5	5	-	-	5	1	-	4	4	3	3	5	4	-	-
		Freq	1	-	2	4	-	1	1	1	5	5	-	-	4	1	-	3	4	3	1	5	5	-	-
		Ease	-	-	4	4	-	1	1	1	4	5	-	-	4	-	-	4	4	3	-	5	4	-	-
4 Do you Prop?	Yes/No		-	-	Y	Y	Y	Y	-	Y	Y	-	Y	-	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
	Read (book)		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	Y	Y	-	Y	-
	TV		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-
	Eat		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	Y	Y	-	-	-
	Phone		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	Y	-	-	Y	-
	Write		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Study		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Work		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Computer		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Drink		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sew/Knit		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-
	Chilren		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	Y	-	-	-	-
	Read (paper)		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Relax		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Baby		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sick		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Method	Pillow	-	-	Y	Y	Y	Y	-	Y	-	-	Y	-	Y	Y	Y	Y	-	Y	Y	Y	Y	Y	Y
		Headboard	-	-	N	N	N	N	-	N	-	-	N	-	N	N	N	N	-	N	N	N	N	N	N
	Satisfaction		-	-	3	3	5	3	-	3.5	-	-	1	-	3	3	3	3	-	2	3	4	3	2	3
5 Independence			-	-	4	5	5	5	-	5	-	-	1	-	5	5	5	3	4	5	5	4	5	5	5
		1	-	-	4.5	1	2	1	5	5	3.5	4.5	-	-	1	4	5	2	-	1	4	4	5	5	2
		2	-	-	2	5	4	5	1.5	3	3.5	4.5	-	-	4	2	3	4	-	5	3	1	4	2.33	4
		3	-	-	3	4	1	4	3	4	5	2	-	-	3	5	1	3	-	4	1	3	1	3	5
		4	-	-	4.5	2	3	2	4	2	1.5	2	-	-	2	3	4	1	-	2	5	5	2	2.33	3
		5	-	-	1	3	5	3	1.5	1	1.5	2	-	-	5	1	2	5	-	3	2	2	3	2.33	1

Questions			Participant																	
			47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
1 Male/Female			M	M	F	F	M	M	M	F	-	M	M	F	F	M	F	F	F	M
Age			39	37	-	47	50	33	54	40	-	21	38	27	38	34	36	28	31	35
2 Activities:	Read	Like	5	5	4	5	5	4	4	4	4	4	5	5	4	4	4	5	5	5
		Freq	3	1	1	4	5	3	4	3	4	3	4	5	3	3	5	5	3	5
		Ease	3	2	2	4	3	2	4	3	3	3	3	5	4	5	4	4	4	5
	Work	Like	-	1	1	3	3	3	1	1	3	3	2	5	1	2	4	2	1	-
		Freq	-	1	1	3	3	4	2	1	4	2	2	3	2	2	3	2	1	1
		Ease	-	1	1	3	2	1	3	-	3	2	3	3	1	5	4	1	1	-
	Feed Baby	Like	-	-	4	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
		Freq	-	-	3	-	-	-	-	1	-	-	1	-	-	-	-	-	-	1
		Ease	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sickness	Like	1	1	1	1	3	1	1	1	1	1	1	5	1	1	1	1	2	5
		Freq	2	2	2	4	3	2	2	1	1	2	1	3	2	2	1	1	2	2
		Ease	5	3	3	4	4	3	4	2	2	3	-	5	4	5	5	4	5	5
	Computer	Like	-	1	1	-	-	4	1	4	3	-	1	5	2	3	-	2	1	-
		Freq	-	1	1	-	1	4	1	5	4	-	1	3	2	2	-	2	1	1
		Ease	-	3	2	-	-	1	-	4	3	-	-	3	2	4	-	1	3	-
	Phone	Like	-	5	4	4	3	4	3	5	4	4	1	5	5	4	4	4	4	-
		Freq	-	4	3	4	3	4	2	5	3	4	1	5	4	3	3	4	4	1
		Ease	-	5	5	4	4	2	4	3	4	4	-	5	4	5	5	4	5	-
	Write	Like	-	1	1	3	1	3	1	2	3	3	1	5	3	3	-	3	3	-
		Freq	-	1	1	3	2	3	1	2	3	2	1	5	1	2	-	1	4	1
		Ease	-	3	3	3	1	2	-	2	3	2	-	4	2	5	-	2	1	-
	Eat	Like	2	1	1	2	1	4	3	1	2	2	1	5	1	2	5	4	1	-
		Freq	2	1	1	2	1	4	3	1	3	2	1	4	1	2	4	4	1	1
		Ease	2	1	1	3	1	2	3	3	2	2	-	3	3	5	5	4	5	-
	TV	Like	5	1	1	1	3	2	4	3	4	5	4	1	4	3	-	3	3	-
		Freq	3	1	1	1	2	2	4	1	2	4	3	1	1	1	-	2	1	1
		Ease	3	1	1	3	2	2	4	3	4	2	3	5	3	5	-	4	5	-
4 Do you Prop?	Yes/No		Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
	Read (book)		Y	Y	Y	-	Y	Y	-	Y	Y	Y	Y	-	Y	Y	Y	Y	Y	-
	TV		Y	-	-	-	Y	-	-	-	-	Y	Y	-	-	-	-	Y	Y	-
	Eat		Y	-	-	Y	-	-	-	-	-	Y	-	-	-	-	-	Y	-	-
	Phone		-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	Y	-
	Write		-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
	Study		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Work		-	-	-	Y	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
	Computer		-	-	-	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-
	Drink		-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-
	Sew/Knit		-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-
	Chilren		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Read (paper)		-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
	Relax		-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
	Baby		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sick		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Method	Pillow	Y	Y	Y	Y	Y	Y	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-
		Headboard	N	N	N	N	N	N	-	N	N	N	N	N	N	N	N	N	N	-
	Satisfaction		1.5	5	5	2.5	1	2	-	3	3	2	3	3	3	5	5	3	3	-
5 Independence			5	3	4	4	5	1	5	5	4	2	5	5	4	3	5	3	5	5
		1	5	1	1	-	5	2	4	1.5	1	4	2	5	5	5	1	4	4.5	3
		2	3	4	4	-	2	4	3	4	2	3	4	2	3	3	2	3	1.5	4
		3	1	5	5	-	1	1	2	1.5	5	2	1	3	1	4	4	1	3	1
		4	2	3	3	-	3	3	5	3	4	1	4	4	2	1.5	5	2	4.5	2
		5	4	2	2	-	4	5	1	5	3	5	4	1	4	1.5	3	5	1.5	5

Questions			65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82
1 Male/Female			F	-	M	F	M	F	F	F	F	F	F	F	M	F	M	F	M	F
Age			31	-	49	45	43	31	29	59	33	24	48	36	40	-	-	56	57	-
2 Activities:	Read	Like	5	5	5	5	-	-	5	5	5	1	5	5	3	5	4	4	3	2
		Freq	5	5	5	5	-	-	3	3	5	1	4	5	2	3	3	4	3	2
		Ease	3	3	2	5	-	-	3	5	4	-	4	3	3	2	2	4	4	2
	Work	Like	3	-	3	3	-	-	-	3	-	-	1	-	4	-	1	-	1	1
		Freq	2	-	3	3	-	-	-	1	-	-	1	-	4	-	-	1	1	-
		Ease	1	-	2	3	-	-	-	5	-	-	1	-	1	-	-	-	-	-
	Feed Baby	Like	-	-	1	1	-	-	-	5	-	-	-	-	-	-	-	-	-	-
		Freq	-	-	1	1	-	-	-	1	-	-	-	-	-	-	1	-	-	-
		Ease	-	-	1	1	-	-	-	5	-	-	-	-	-	-	-	-	-	-
	Sickness	Like	4	-	2	3	1	1	5	5	5	3	-	1	-	-	-	1	1	-
		Freq	3	-	2	1	1	2	3	2	1	3	-	1	-	1	-	2	1	-
		Ease	3	-	2	3	1	5	5	5	5	5	-	1	-	5	-	3	3	-
	Computer	Like	3	-	1	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-
		Freq	3	-	1	1	-	-	-	1	-	-	-	-	-	-	1	1	1	-
		Ease	2	-	1	1	-	-	-	5	-	-	-	-	-	-	-	-	-	-
	Phone	Like	4	-	2	3	1	3	5	5	5	4	2	4	4	5	-	3	3	2
		Freq	4	-	2	3	1	2	3	4	2	4	2	4	4	3	2	2	4	2
		Ease	4	-	2	3	5	4	4	5	5	3	3	3	4	4	3	4	4	2
	Write	Like	3	-	1	1	-	-	3	3	-	3	1	4	3	2	-	1	2	2
		Freq	2	-	1	1	-	-	2	1	-	2	1	4	2	1	1	2	2	2
		Ease	2	-	1	1	-	-	2	5	-	4	2	2	2	1	-	3	3	2
	Eat	Like	-	-	3	4	-	-	2	5	2	2	3	4	4	1	-	3	3	2
		Freq	-	-	3	3	-	-	2	4	1	2	2	4	4	1	2	3	2	2
		Ease	-	-	3	2	-	-	2	5	4	3	2	2	3	1	2	4	3	2
	TV	Like	-	-	3	3	-	-	5	-	5	5	4	3	4	-	3	4	2	2
		Freq	-	-	3	2	-	-	5	-	5	5	3	4	5	-	3	4	3	2
		Ease	-	-	3	2	-	-	5	-	4	3	3	3	3	-	3	4	4	2
4 Do you Prop?	Yes/No		Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y
	Read (book)		Y	Y	Y	Y	-	-	Y	Y	Y	-	Y	Y	-	Y	Y	Y	Y	-
	TV		-	-	-	-	-	-	-	Y	Y	Y	Y	-	-	-	Y	Y	Y	-
	Eat		-	-	Y	Y	-	-	-	-	-	-	Y	Y	-	Y	Y	-	-	-
	Phone		-	-	-	-	-	-	-	Y	-	Y	-	-	-	-	-	-	-	-
	Write		Y	-	-	-	-	-	Y	-	-	-	-	Y	-	-	-	-	-	-
	Study		-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
	Work		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Computer		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Drink		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sew/Knit		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Chilren		Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Read (paper)		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y
	Relax		-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-
	Baby		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sick		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Method	Pillow	Y	Y	Y	Y	-	-	Y	Y	Y	Y	Y	Y	-	Y	Y	Y	Y	Y
		Headboard	N	N	N	N	-	-	N	N	N	N	N	N	-	N	N	N	N	N
	Satisfaction		4	2	4	3	-	-	3	3	3	3	3	3	-	1	2	3	3	3
5 Independence			5	5	5	5	3	4	3	5	5	4	5	5	5	5	5	5	5	5
		1	5	5	5	5	-	5	5	3.25	4	3	5	4	5	2	3	4	5	1
		2	2	2	2	2	-	1	3	2	3	2	1.5	3	3	4	4	3	1	5
		3	3	3	1	1	-	3	1	3.25	1	1	3	1	1	1	1	2.5	2.5	4
		4	1	4	4	4	-	4	4	3.25	2	4	4	5	4	3	3	2.5	4	3
		5	4	1	3	3	-	2	2	3.25	5	5	1.5	2	2	5	4	3	2.5	2

		No.	Avg Rating	%	Std Dev	Respondents	Percentage
Total Number	82						
Female	46	Male	29				
Max Age	60	Min Age	17	Avg Age 37.8		68	82.9
Read	Like		4.22		0.95	76	92.7
	Freq		3.49		1.17	76	92.7
	Ease		3.50		1.01	74	90.2
Work	Like		2.21		1.18	57	69.5
	Freq		2.04		1.13	58	70.7
	Ease		2.42		1.32	48	58.5
Feed Baby	Like		2.32		1.73	19	23.2
	Freq		1.92		1.55	26	31.7
	Ease		2.35		1.54	17	20.7
Sick	Like		2.41		1.70	63	76.8
	Freq		2.19		1.02	67	81.7
	Ease		3.84		1.14	65	79.3
Computer	Like		1.92		1.16	36	43.9
	Freq		1.67		1.06	46	56.1
	Ease		2.50		1.25	30	36.6
Phone	Like		3.49		1.18	69	84.1
	Freq		3.03		1.13	73	89.0
	Ease		3.95		1.01	70	85.4
Write	Like		2.42		1.15	53	64.6
	Freq		2.07		1.11	58	70.7
	Ease		2.40		1.11	52	63.4
Eat	Like		2.51		1.30	59	72.0
	Freq		2.35		1.11	63	76.8
	Ease		2.74		1.18	58	70.7
TV	Like		3.57		1.35	61	74.4
	Freq		2.77		1.48	66	80.5
	Ease		3.40		1.20	60	73.2
Propers		70		85.37		76	92.68
Read (book)		50		60.98		50	60.98
TV		27		32.93		27	32.93
Eat		18		21.95		18	21.95
Phone		14		17.07		14	17.07
Write		9		10.98		9	10.98
Study		6		7.32		6	7.32
Work		4		4.88		4	4.88
Computer		4		4.88		4	4.88
Drink		3		3.66		3	3.66
Sew/Knit		3		3.66		3	3.66
Chilren		3		3.66		3	3.66
Read (paper)		3		3.66		3	3.66
Relax		3		3.66		3	3.66
Baby		1		1.22		1	1.22
Sick		1		1.22		1	1.22
Pillow		69		84.15		69	84.15
Headboard		0		0.00		69	84.15
Satisfaction		3.11			1.01	69	84.1
Independence		4.48			0.99	75	91.5
Method Of Adjustability	1	3.56			1.51	73	89.0
	2	3.01			1.15	73	89.0
	3	2.35			1.48	73	89.0
	4	3.07			1.10	73	89.0
	5	3.01			1.37	73	89.0

Appendix E Bed Adjustability User Trial

Participant			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Total	32				
Sex			M	F	F	M	M	M	M	M	M	M	M	M	M	F	M	M	M	M	M	M	M	M	M	M	F	M	F	F	F	F	F	F	Male	22	Female	10		
Height			184.5	169	168	191	178	178	179	178	183	193	170	180	179.5	168	167.5	169	169.5	174.5	177	180	189	178	164	178	-	166	155	179	165	169	159	160	Avg Height	174.1	mm			
Weight			85	56	66	116	103	98	73	80	81.5	98	57	110	78	81	79	71	72	67	84	75	70	79	61	65	-	59	55	59	64	60	63	49	Avg Weight	74.7	kg			
Group			I	C	E	L+	K	K	E	H	I	L+	D	K+	H	I	G	D	D	E	H	H	F	H	D	E	B	D	A	F	E	C	F	B						
Activites																																								
Read	Flat	Rating	3	7	6	5	6	2.5	7	5	6	5	8	4	2	9	7	2	7	5	8	5	8	8	4	6	3	5	0	8	5	6.5	7	4	Avg	5.4	SD	2.14		
	Angle	Angle Back (mm)	36	46.5	26	43	29	46.5	46.5	14.5	43	40	36	39	41	40	45	46.5	20	46.5	46.5	45	46.5	28.5	33	46.5	28.5	18	46.5	24	19	22.5	28	11						
		Angle Back (Deg)	39.6	55.4	27.4	49.6	30.9	55.4	55.4	14.9	49.6	45.1	39.6	43.7	46.5	45.1	52.8	55.4	20.7	55.4	55.4	52.8	55.4	30.3	35.7	55.4	30.3	18.6	55.4	25.1	19.7	23.5	29.7	11.2	Avg	42.2				
		Extra Back Angle	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	10	25	0	0	0	0	25	0	0	0	0	0	0	0	0						
		Angle Back Total	39.6	55.4	27.4	49.6	30.9	55.4	65.4	14.9	49.6	45.1	39.6	43.7	46.5	45.1	52.8	55.4	20.7	65.4	80.4	52.8	55.4	30.3	35.7	80.4	30.3	18.6	55.4	25.1	19.7	23.5	29.7	11.2						
		Angle Back Avg	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2						
		Angle Leg (mm)	0	9	5	17.5	4	5.5	0	0	13	3	9	0	0	0	11.5	7	0	0	0	13	17.5	11	0	17.5	0	0	0	4	13.5	6	0	10						
		Angle Leg (Deg)	0.0	17.5	9.6	35.7	7.7	10.6	0.0	0.0	25.7	5.7	17.5	0.0	0.0	0.0	22.5	13.5	0.0	0.0	0.0	25.7	35.7	21.5	0.0	35.7	0.0	0.0	0.0	7.7	26.7	11.5	0.0	19.5	Avg	4.7				
		Extra Leg Angle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
		Angle Leg Total	0.0	17.5	9.6	35.7	7.7	10.6	0.0	0.0	25.7	5.7	17.5	0.0	0.0	0.0	22.5	13.5	0.0	0.0	0.0	25.7	35.7	21.5	0.0	35.7	0.0	0.0	0.0	7.7	26.7	11.5	0.0	19.5						
		Angle Leg Avg	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7						
		Rating	9	9	9	8	9	8	8	8	8	9	8	9	5.5	10	9	10	8	9	8	9	9	9	9	4	9	8	8	10	8	9	9	8.5	Avg	8.5	SD	1.17		
		Rating Diff	6	2	3	3	3	5.5	1	3	2	4	0	5	3.5	1	2	8	1	4	0	4	1	1	5	-2	6	3	8	2	3	2.5	2	4.5	Avg	3.0	SD	2.24	t-Test	1.28E-08
TV	Flat	Rating	5	2	3	4	7	3	6	7	5	5	7	7	3	9	4	3	8	7	6	6	5	9	5.5	4	7	2	5	7	4	2	6	6	Avg	5.3	SD	1.95		
	Angle	Angle Back (mm)	27.5	46.5	28	46.5	12	25	46.5	18	20.5	32.5	21.5	40.5	37.5	12	46.5	23	29	5	46.5	46.5	46.5	38	46.5	40	5	25.5	46.5	30	20	43	12	25						
		Angle Back (Deg)	29.1	55.4	29.7	55.4	12.3	26.3	55.4	18.6	21.3	35.1	22.4	45.8	41.6	12.3	55.4	24.0	30.9	5.1	55.4	55.4	55.4	42.3	55.4	45.1	5.1	26.8	55.4	32.1	20.7	49.6	12.3	26.3	Avg	36.4				
		Extra Back Angle	0	10	0	15	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	6	0	0	0	0						
		Angle Back Total	29.1	65.4	29.7	70.4	12.3	26.3	60.4	18.6	21.3	35.1	22.4	45.8	41.6	12.3	55.4	24.0	30.9	5.1	55.4	55.4	70.4	42.3	55.4	45.1	5.1	26.8	55.4	38.1	20.7	49.6	12.3	26.3						
		Angle Back Avg	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4						
		Angle Leg (mm)	10	7	5	17.5	0	4.5	8	11.5	8.5	3	4	0	8	0	0	0	0	17.5	12	17.5	17.5	11.5	0	9	0	0	17.5	6	10	5	4	11						
		Angle Leg (Deg)	19.5	13.5	9.6	35.7	0.0	8.6	15.5	22.5	16.5	5.7	7.7	0.0	15.5	0.0	0.0	0.0	0.0	35.7	23.6	35.7	35.7	22.5	0.0	17.5	0.0	0.0	35.7	11.5	19.5	9.6	7.7	21.5	Avg	13.9				
		Extra Leg Angle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
		Angle Leg Total	19.5	13.5	9.6	35.7	0.0	8.6	15.5	22.5	16.5	5.7	7.7	0.0	15.5	0.0	0.0	0.0	0.0	35.7	23.6	35.7	35.7	22.5	0.0	17.5	0.0	0.0	35.7	11.5	19.5	9.6	7.7	21.5						
		Angle Leg Avg	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9						
		Rating	9	8	8	8	8	9	8	9	8.5	9	9	10	7.5	10	8	10	9	10	7	9	7	9.5	10	8	10	7	10	9	8	9	9	7.5	Avg	8.7	SD	0.97		
		Rating Diff	4	6	5	4	1	6	2	2	3.5	4	2	3	4.5	1	4	7	1	3	1	3	2	0.5	4.5	4	3	5	5	2	4	7	3	1.5	Avg	3.4	SD	1.77	t-Test	4.69E-12
Work	Flat	Rating	3	4	2	5	6	2	4	2	2	6	9	5	3	9	2	1	6	6	7	4	3	9	4	5	4	1	5	7	2	4.5	6	3	Avg	4.4	SD	2.25		
	Angle	Angle Back (mm)	43	46.5	46.5	46.5	33	46.5	46.5	30	46.5	40	46.5	32	46.5	28.5	46.5	33.5	16	46.5	46.5	46.5	46.5	46.5	46.5	46.5	41.5	25.5	46.5	44	43.5	44	46.5	25						
		Angle Back (Deg)	49.6	55.4	55.4	55.4	35.7	55.4	55.4	32.1	55.4	45.1	55.4	34.5	55.4	30.3	55.4	36.4	16.5	55.4	55.4	55.4	55.4	55.4	55.4	55.4	47.3	26.8	55.4	51.1	50.3	51.1	55.4	26.3	Avg	51.1				
		Extra Back Angle	0	20	10	15	0	0	5	0	0	0	10	0	0	0	0	0	0	10	0	0	0	10	0	25	0	0	0	0	0	0	0	0						
		Angle Back Total	49.6	75.4	65.4	70.4	35.7	55.4	60.4	32.1	55.4	45.1	65.4	34.5	55.4	30.3	55.4	36.4	16.5	65.4	55.4	55.4	55.4	65.4	55.4	80.4	47.3	26.8	55.4	51.1	50.3	51.1	55.4	26.3						
		Angle Back Avg	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1	51.1						
		Angle Leg (mm)	14.5	14	2	17.5	0	0	17.5	0	13	3	7.5	0	5	14	0	0	14	0	17.5	11	7	17.5	0	17.5	0	0	0	7	14	13.5	11	10						
		Angle Leg (Deg)	28.9	27.8	3.8	35.7	0.0	0.0	35.7	0.0	25.7	5.7	14.5	0.0	9.6	27.8	0.0	0.0	27.8	0.0	35.7	21.5	13.5	35.7	0.0	35.7	0.0	0.0	0.0	13.5	27.8	26.7	21.5	19.5	Avg	15.8				
		Extra Leg Angle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0						
		Angle Leg Total	28.9	27.8	3.8	35.7	0.0	0.0	35.7	0.0	25.7	5.7	14.5	0.0	9.6	27.8	0.0	0.0	27.8	0.0	45.7	21.5	13.5	35.7	0.0	35.7	0.0	0.0	0.0	13.5	27.8	26.7	21.5	19.5						
		Angle Leg Avg	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8						
		Rating	8	8	8	8	8	7	7	9	7	9	8	9	7	9	8	8	7	8	7.5	8	7	9.5	7	7	10	8	9	9	9	8	5	7	Avg	7.9	SD	1.01		
		Rating Diff	5	4	6	3	2	5	3	7	5	3	-1	4	4	0	6	7	1	2	0.5	4	4	0.5	3	2	6	7	4	2	7	3.5	-1	4	Avg	3.5	SD	2.29	t-Test	8.70E-10
Phone	Flat	Rating	4	6	2	7.5	4	3	8	1	2	5	7	8	2.5	9	4	1	8	6	5	9	7	7	6	7	5	5	7	6	4	4	8.5	8	Avg	5.5	SD	2.32		
	Angle	Angle Back (mm)	26.5	46	20	0	27.5	37	24	13	46.5	40	46.5	28	41	23.5	29	19	17	35	0	0	0	26.5	23	0	20	20	0	30	5	43.5	16	20						
		Angle Back (Deg)	28.0	54.5	20.7	0.0	29.1	40.9	25.1	13.3	55.4	45.1	55.4	29.7	46.5	24.6	30.9	19.7	17.5	38.3	0.0	0.0	0.0	28.0	24.0	0.0	20.7	20.7	0.0	32.1	5.1	50.3	16.5	20.7	Avg	24.8				
		Extra Back Angle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
		Angle Back Total	28.0	54.5	20.7	0.0	29.1	40.9	25.1	13.3	55.4	45.1	55.4	29.7	46.5	24.6	30.9	19.7	17.5	38.3	0.0	0.0	0.0	28.0	24.0	0.0	20.7	20.7	0.0	32.1	5.1	50.3	16.5	20.7						
		Angle Back Avg	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8						
		Angle Leg (mm)	0	10.5	7.5	0	0	4	0	9	11	3	2	7.5	5	0	0	0	8	14	17.5	0	0	17.5	0	0	0	0	0	0	8	13	1	10						
		Angle Leg (Deg)	0.0	20.5	14.5	0.0	0.0	7.7	0.0	17.5	21.5	5.7	3.8	14.5	9.6	0.0	0.0	0.0	15.5	27.8	35.7	0.0	0.0	35.7	0.0	0.0	0.0	0.0	0.0	0.0	15.5	25.7	1.9	19.5	Avg	9.1				
		Extra Leg Angle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
		Angle Leg Total	0.0	20.5	14.5	0.0	0.0	7.7	0.0	17.5	21.5	5.7	3.8	14.5	9.6	0.0	0.0	0.0	15.5	27.8	35.7	0.0	0.0	35.7	0.0	0.0	0.0	0.0	0.0	0.0	15.5	25.7	1.9	19.5						
		Angle Leg Avg	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1						
		Rating	8	8	7.5	7.5	8	7	8.5	8	8	9	8	9	6	10	4	7	9	10	6	9	7	10	8	7	8.5	7	7	9	9	8.5	9	8.5	Avg	8.0	SD	1.28		
		Rating Diff	4	2	5.5	0	4	4	0.5	7	6	4	1	1	3.5	1	0	6	1	4	1	0	0	3	2	0	3.5	2	0	3	5	4.5	0.5	0.5	Avg	2.5	SD	2.12	t-Test	2.07E-07
Computer	Flat	Rating	3	5	2	2	6	1	4.5	0	5	0	7	3	2.5	8	1	0	5	6	7	6	7	9	4	5	7	3	0	-	1	4	6.5	5	Avg	4.0	SD	2.61		
	Angle	Angle Back (mm)	36.5	46.5	46.5	46.5	46.5	46.5	46.5	30	46.5	34.5	46.5	46.5	38	46.5	46.5	33.5	36.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5	23	46.5	-	43.5	44	46.5	44.5						
		Angle Back (Deg)	40.2	55.4	55.4	55.4	55.4	55.4	55.4	32.1	55.4	37.6	55.4	55.4	42.3	55.4	55.4	36.4	40.2	55.4	55.4	55.4	55.4	55.4	55.4	55.4	55.4	24.0	55.4	-	50.3	51.1	55.4	52.0	Avg	53.0				
		Extra Back Angle	0	15	10	15	0	0	10	0	15	0	10	0	0	0	0	0	0	10	15	15	0	0	0	10	0	0	0	-	0	0	0	0						
		Angle Back Total	40.2	70.4	65.4	70.4	55.4	55.4	65.4	32.1	70.4	37.6	65.4	55.4	42.3	55.4	55.4	36.4	40.2	65.4	70.4	70.4	55.4	55.4	55.4	65.4	55.4	24.0	55.4	-	50.3	51.1	55.4	52.0						
		Angle Back Avg	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	53.0	-	53.0	53.0	53.0	53.0						
		Angle Leg (mm)	10.5	0	0	8	0	0	17.5	8	0	0	14	17.5	9.5	0	0	10	8	0	9.5	12	17.5	17.5	0	17.5	0	0	0	-	0	14	0	10						
		Angle Leg (Deg)	20.5	0.0	0.0	15.5	0.0	0.0	35.7	15.5	0.0	0.0	27.8	35.7	18.5	0.0	0.0	19.5	15.5	0.0	18.5	23.6	35.7	35.7	0.0	35.7	0.0	0.0	0.0	-	0.0	27.8	0.0	19.5	Avg	12.5				
		Extra Leg Angle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0						
		Angle Leg Total	20.5	0.0	0.0	15.5	0.0	0.0	35.7	15.5	0.0	0.0	27.8	35.7	18.5	0.0	0.0	19.5	15.5	0.0	18.5	23.6	35.7	35.7	0.0	35.7	0.0	0.0	0.0	-	0.0	27.8	0.0	19.5						
		Angle Leg Avg	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	-	12.5	12.5	12.5	12.5						
		Rating	9	6	5	8	8	7	8	8	6	9	8	8	7	10	9	8	8	9	8.5	9	9	10	7	8	6	6	8	-	8	8	8	8.5	Avg	7.9	SD	1.19		
		Rating Diff	6	1	3	6	2	6	3.5	8	1	9	1	5	4.5	2	8	8	3	3	1.5	3	2	1	3	3	-1	3	8	-	7	4	1.5	3.5	Avg	3.9	SD	2.61	t-Test	3.39E-09
Eat	Flat	Rating	5	5	1	5	6	1	6	0	6	6	7	5	2.5	9.5	5	0	6	6	3	6	7	7	4	6	5	4	3	6	1	2	4.5	2	Avg	4.5	SD	2.30		
	Angle	Angle Back (mm)	46.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5	40	46.5	45	46.5	35.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5	30	46.5	36	36.5	44	34	32						
		Angle Back (Deg)	55.4	55.4	55.4	55.4	55.4	55.4	55.4	55.4	55.4	55.4	55.4	55.4	45.1	55.4	52.8	55.4	38.9	55.4	55.4	55.4	55.4	55.4	55.4	55.4	55.4	32.1	55.4	39.6	40.2	51.1	37.0	34.5	Avg	59.2				
		Extra Back Angle	10	10	15	15	0	0	25	0	15	10	10	10	0	25	0	10	0	20	0	15	0	25	0	25	10	0	0	0	0	0	0	0						
		Angle Back Total	65.4	65.4	70.4	70.4	55.4	55.4	80.4	55.4	70.4	65.4	65.4	65.4	45.1	80.4	52.8	65.4	38.9	75.4	55.4	70.4	55.4	80.4	55.4	80.4	65.4	32.1	55.4	39.6	40.2	51.1	37.0	34.5						
		Angle Back Avg	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2	59.2						
		Angle Leg (mm)	0	0	0	1	0	0	0	4	0	5	1	0	0	0	0	0	9	0	0	12	0	7	0	0	0	0	0	5	8.5	14	0	10						
		Angle Leg (Deg)	0.0	0.0	0.0	1.9	0.0	0.0	0.0	7.7	0.0	9.6	1.9	0.0	0.0	0.0	0.0	0.0	17.5	0.0	0.0	23.6	0.0	13.5	0.0	0.0	0.0	0.0	0.0	9.6	16.5	27.8	0.0	19.5	Avg	4.7				
		Extra Leg Angle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
		Angle Leg Total	0.0	0.0	0.0	1.9	0.0	0.0	0.0	7.7	0.0	9.6	1.9	0.0	0.0	0.0	0.0	0.0	17.5	0.0	0.0	23.6	0.0	13.5	0.0	0.0	0.0	0.0	0.0	9.6	16.5	27.8	0.0	19.5						
		Angle Leg Avg	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7						
		Rating	8	6	5	6	7	7	3	8	6	5	6	7	6.5	8.5	8	6	9	8	7	9	4	6	8	4	7	7	7	9	7	6	8.5	9	Avg	6.8	SD	1.54		
		Rating Diff	3	1	4	1	1	6	-3	8	0	-1	-1	2	4	-1	3	6	3	2	4	3	-3	-1	4	-2	2	3	4	3	6	4	4	7	Avg	2.4	SD	2.83	t-Test	4.33E-05
General Questions																																								
Control device ease of use			6	10	7	10	8	9	8	8	5	7	10	10	8	10	9	7	9	7	6.5	7	8	9	9	9	9	5	10	10	5	8	6	9	Avg	8.08	SD	1.59		
Control device understanding			9	8	9	10	9	10	8	9	5	8	10	10	8	10	9	7	10	9	6	7	8	10	9	8	10	9	10	10	5	8	8	9	Avg	8.59	SD	1.41		
Force required to operate control			-	10	9	10	9	9	8	9	7	9	10	10	9	10	9	9	8	6	8	10	6	10	10	10	10	7	8	10	7	6	10	10	Avg	8.81	SD	1.35		
Each of reaching the control			5	-	3	10	6	6	8	8	5	9	10	10	5	9	6	3	7	6	9	4	4	6	7	-	4	6	7	8	8	4	4.5	8	Avg	6.52	SD	2.11		
Ease of obtaining desired angles			7	10	8	10	9	7	9	8	8	9	10	8	7	10	10	8	10	7	7.5	5	5	9	10	9	10	8	10	9	9	7	8	7	Avg	8.39	SD	1.42		
Speed			4	8	8	10	7	8	7	7	8	9	10	8	7	10	9	8	8	9	7.5	10	5	7	9	7	5	8	8	8	8	6	10	8	Avg	7.86	SD	1.48		
Smoothness			8	10	8	10	9	9	9	8	9	10	10	10	7	10	10	7	10	9	8	10	8	10	10	9	10	7	10	10	10	8	6.5	9.5	Avg	9.03	SD	1.13		
Noise			-	10	10	10	9	10	9	10	9	9	10	10	7	10	10	9	10	9	9	10	10	10	10	6	10	10	8	10	10	6	9	7.5	Avg	9.24	SD	1.18		
How at ease they felt at using the bed			8	10	8	10	9	9	8	9	8	9	10	10	9	10	9	8	10	9	9	8	9	10	8	10	10	8	10	10	9	8	7.5	8.5	Avg	9.00	SD	0.85		
Safety			9	10	7	10	7	8	8	8	5	9	10	10	8	10	10	6	9	-	7.5	7	8	10	10	-	10	10	8	10	10	3	8	6	Avg	8.38	SD	1.78		
Robustness			7	10	7	10	8	8	8	8	6	7	10	10	-	10	9	7	10	-	-	-	8	10	9	-	10	7	8	10	10	7	9	6	Avg	8.48	SD	1.40		
Firmness			-	10	7	10	8	8	8	8	6	9	10	10	8	-	10	10	7	9	-	8	8	10	9	8	10	7	10	10	10	-	6.5	6	Avg	8.59	SD	1.37		
Appearance			6	-	7	10	6	8	8	7	5	6	10	10	-	5	9	2	9	-	-	10	5	9	9	6	-	8	10	10	5	5	5	6	Avg	7.26	SD	2.19		

Appendix F Function Structures

Rough Structure:

User:

- Uncomfortable
- Wants to move into position suitable for a certain activity
- Wants to lie down

→ User performs action to adjust bed section(s) → Particular section(s) of the bed adjusts → User reaches desired position

Refined Structure:

- Users motivation:
  - Uncomfortable
  - Wants to move into position suitable for a certain activity
  - Wants to lie down
- Actuator stores power:
  - Electricity
  - Air
    - Compressed
    - Pumped
  - Personal weight
  - Personal energy
- User input:
  - Electrical signal:

    User presses a button → Electrical Signal sent to Actuator
  - Pneumatic Valve:

    User depresses valve → Air is released and Actuator moves
  - Lever:

    User pulls/pushes lever → Mechanism Actuated
  - Button release:

    User presses a button → Mechanism unlocked to move freely

- Bed Section Adjusts:
    - Actuator moves
    - Mechanism moves under manual actuation
    - Movement controlled by body movements and actuator
- Outcome:
    - User moved to desired position

Total Structures:

1. Electrically powered

User:
- Uncomfortable
- Wants to move into position suitable for a certain activity
- Wants to lie down

→ User presses a button (↓ Electricity) → Electrical Signal sent to Actuator → Actuator moves (↓ Electricity) → User reaches desired position

2.Air powered

User:
- Uncomfortable
- Wants to move into position suitable for a certain activity
- Wants to lie down

→ User depresses valve (↓ Compressed Air) → Air is released and Actuator moves → User reaches desired position

3.Personal weight powered

User:
- Uncomfortable
- Wants to move into position suitable for a certain activity
- Wants to lie down

→ User pulls/pushes lever (↓ Human Effort) → Mechanism Actuated → User moved to desired position

4.Personal energy powered

User:
- Uncomfortable
- Wants to move into position suitable for a certain activity
- Wants to lie down

→ User presses a button → Mechanism unlocked to move freely → Mechanism moved (↓ Human Effort) → User reaches desired position

Appendix G QFD

This section gives a summary of the steps that were taken in the QFD procedure and the results that were obtained.

1) Identify customer requirements in terms of product attributes.
   a) Adjusted Position:
      - Head/Neck support
      - Back adjustment
      - Leg Adjustment
      - Arm support
      - Lumbar support
      - Bedside table reach
   b) Control:
      - Ease of use
      - Understanding
      - Force required to operate
      - Ease of reaching the control
      - Ease of obtaining angle
      - Ease of loosing remote
      - Ease of using remote in dark
      - Length of cord
      - No cord
      - Control Holder
      - Fixed control
      - Auto lower button
      - Programmable positions
      - Hardiness of control
   c) Operation:
      - Speed
      - Is the speed adjustable?
      - Smoothness
      - Noise
      - How at ease they felt
      - Safety
      - Robustness
   d) Mattress:
      - Does it move around?
      - Mattress bunching
   e) Situations:
      - 1 up, 1 down
      - Double bed
      - Cost appeal
   f) Extras:
      - Built in light
      - Accessories socket
      - Massage
      - Support Surface
   g) Activities:
      - Reading
      - Television watching
      - Working
      - Phoning
      - Computing
      - Eating

2) Determine the relative importance of the attributes:

3) Evaluate the attributes of competing products:

- Distribute 500 points around the customer requirements to determine the relative importance
- Rate the benchmarks from 0-10
- Table G-1 shows the evaluation of a normal bed and the Dico Adjustable bed.

Table G-1 Evaluation of the attributes of a standard bed and the Dico Adjustable bed

		Weighting	Benchmarks	
			Standard Bed	Dico Adj. Bed
Adjustability	Head/Neck support	17	0	4.0
	Back adjustment	35	0	5.0
	Leg Adjustment	35	0	6.0
	Arm support	10	0	3.0
	Lumbar support	10	0	3.0
	Bedside table reach	10	0	4.0
Control	Ease of use	6	0	8.1
	Understanding	5	0	8.6
	Force required to operate	8	0	8.8
	Each of reaching the control	21	0	6.5
	Ease of obtaining desired angles	21	0	8.4
	Ease of loosing remote	2	0	2.0
	Ease of using remote in dark	2	0	3.0
	Length of cord	5	0	3.0
	No cord	9	0	0.0
	Control Holder	12	0	3.0
	Fixed control	8	0	0.0
	Auto lower button	16	0	0.0
	Programmable positions	10	0	0.0
	Hardiness of control	21	0	7.0
Operation	Speed	12	0	7.9
	Is the speed adjustable?	4	0	0.0
	Smoothness	12	0	9.0
	Noise	12	10	9.2
	Do they feel at ease?	15	10	9.0
	Safety	20	10	8.4
	Robustness	12	10	8.5

Situations	1 person up, 1 down?	6	0	8.0
	A double bed?	5	10	7.0
	Does mattress move around?	5	10	5.0
	Mattress bunches	6	10	5.0
	Cost appeal	5	10	3.0
Extras	Built in light	4	0	0.0
	Accessories socket	3	0	0.0
	Massage	2	0	0.0
	Support Surface	5	0	0.0
Activities	Reading	28	5.5	8.5
	Television watching	23	5.3	8.7
	Working	15	4.4	7.9
	Phoning	22	5.5	8.0
	Computing	13	4.0	7.9
	Eating	16	4.5	6.8

4) Draw a matrix of product attributes against engineering characteristics.
   - Table G-2 shows the table that was produced.

Table G-2 Engineering characteristics required for each of the requirements

	Customer Requirement	**Engineering Characteristic**	**Units**
Adjustability	Head/Neck support	Head/Neck Max Angle	^{o}
		Head/Neck Max Velocity	ms^{-1}
	Back adjustment	Back Max Angle	^{o}
		Back Max Velocity	ms^{-1}
	Leg Adjustment	Leg Max Angle	^{o}
		Leg Max Velocity	ms^{-1}
	Arm support	Force taken off arm	N
	Lumbar support	Force taken off lumbar support	N
	Bedside table reach	Distance from Wall to top bed end	mm
Control	Ease of use	Button Force	N
		Adjustment Inertia	m^{4}
	Understanding		Scale
	Force required to operate	Button Force	N
	Each of reaching the control	Distance to storage position	mm
	Ease of obtaining desired angles	Minimum adjustment	^{o}
	Ease of loosing remote	Volume of remote	cm^{3}
		Top Area of Remote	cm^{2}
	Ease of using remote in dark	Control button protrusion	mm
Co ntr ol	Length of cord	Cord length	mm

	No cord		Y/N
	Control Holder		Y/N
	Fixed control		Y/N
	Auto lower button		Y/N
	Programmable positions		Y/N
	Hardiness of control	Remote impact resistance	N (#)
Operation	Speed	All velocities	ms^{-1}
		Movement delay	s
	Is the speed adjustable?	Speed Range	ms^{-1}
	Smoothness		Scale
	Noise	Noise level	db (#)
	Do they feel at ease?		Scale
	Safety	Length of dangerous jamming area	mm
		Collapsing Force	N (#)
	Robustness	Collapsing Force	N (#)
Situations	1 person up, 1 down?		Scale
	How does it handle a double bed?		Scale
	Does mattress move around?	Force to move mattress	N
		Distance of mattress slip	mm
	Mattress bunches	Height mattress bunches	mm
	Cost appeal		Scale
Extras	Built in light		Y/N
	Accessories socket		Y/N
	Massage		Y/N
	Support Surface		Scale
Activities	Reading	Head/Neck Max Angle	^{o}
		Back Max Angle	^{o}
		Leg Max Angle	^{o}
	Television watching	Head/Neck Max Angle	^{o}
	Working	Head/Neck Max Angle	^{o}
	Phoning	Back Max Angle	^{o}
	Computing	Head/Neck Max Angle	^{o}
		Back Max Angle	^{o}
	Eating	Head/Neck Max Angle	^{o}
		Back Max Angle	^{o}

The remaining steps involve the creation of the QFD chart which is shown in Figure 5-6.

5) Identify the relationships between engineering characteristics and product attributes.

6) Identify any relevant interactions between engineering characteristics.

7) Set target figures to be achieved for the engineering characteristics.

Appendix H PDS

Table H-1 The PDS document issued on 10/10/2001

Design Mobel		Requirements List Adjustable Bed Mechanism	Issued on 10/10/2001
Changed	**D/W**	**Requirements**	
		Frame Sizes:	
5/6/01	D	2050x1530mm	
5/6/01	D	2050x1630mm	
5/6/01	D	2050x1730mm	
5/6/01	D	2050x1830mm	
		Weight:	
	W	Low as possible for freights and assembly reasons	
		Depth of Collapsed Bed:	
	D	<128mm	
		Forces:	
	D	Max weight of user = 130kg	
	D	Shock loading from someone jumping on bed	
	D	No Deformation under loads	
		Energy:	
	W	Avoid electricity or magnetic distortion	
	W	Any other power source available.	
		Material:	
	W	Alloy for structural support	
	W	Recyclable plastics for brackets	
10/6/01	W	Steel for mechanism parts	
		Control	
	W	Rapid adjustment over large distance	
	W	Fine adjustment	
	W	Reset button	
	W	Stored positions	
		Operation:	
	D	In situ adjustment	
	D	Silent	
	D	Smooth controlled movement, not jerky	
	D	Intuitive controls for user, control icon based	
		Safety:	
	D	Watch areas where people could catch hands between the frames	

	D	Control system: Safe and away from problem areas
	D	Stability
	D	Movement limit. No chance of bed flicking up and hitting user
	D	Likely degree of abuse should be considered
	D	Definitive operating instructions must be prepared
	D	Labelling should give adequate warnings.
19/3/01	D	Length of dangerous jamming area max: 3500mm
		Ergonomics:
	D	Initial user trial and questionnaires will form basis of ergonomic decisions
	D	Articulation points based on the initial load profile research: Divisions of 330mm slat zones.
		Assembly:
	W	Possible for the user to assemble unit to prevent high freight cost
	W	Separate top and bottom half mechanism options
		Production:
	W	Utilise pre-existing techniques of manufacture than developmental ones
		Preferred production methods:
	W	Alloy or plastic extrusion
	W	Injection moulding
	W	High pressure die-casting
		Shipping and Packing:
	D	Primarily air freight, allow for sea freight. Thus allow for temperature changes.
	D	Card based, to protect mechanism and frame
		Maintenance:
	W	No maintenance over 10 year operational time frame
	D	Wear should relate to the 10 year timeframe
	W	Easily removable maintainable parts
		Recycling:
	D	The product should utilise materials which are either recyclable or low impact
		Costs:
	D	Maximum permissible manufacturing costs = $300 per side
	D	Cost of tooling: $60-80,000
		Aesthetics, Appearance and Finish:
	D	Product should use existing product appearance as a basis to ensure consistency

	W	Semantically the product should take into account the nature of the bedroom. It should appear safe and robust to give the impression of durability
	D	Simple appearance
	D	Colour and finish of the parts will largely be determined in the basic system design
26/4/01	D	Do not have holes on the outside of the frame
		Product Life Span:
	D	10 years before replacement or maintenance
		Market Constraints:
	D	Electrical power supply
	D	Power Active Near user
		Quantity:
	W	1000 units in the first year
	W	Up to 5000 in 5 years
		Schedules:
	D	End of date development for working prototype: 12/2001
	D	In production date: 8/2002
		Target Customer:
	W	Age: 25-45
	W	Weight: 60-90kg
	W	Height: 1600-1910mm
		Operating Environment:
	D	Designed to be used in the home bedroom
	D	Temperature range: -10-50 ^{o}C
	D	Affect of humidity on parts
19/3/01		**Adjustability:**
19/3/01	W	Head/Neck support section max angle: >20^{o}
29/10/01	W	Back support section max angle: >75^{o}
19/3/01	W	Leg support section max angle: 36^{o}
19/3/01	D	Minimum Adjustment: 3mm
29/10/01		All velocities 0.044ms^{-1}
19/3/01		**Control Device:**
19/3/01	D	Button Force: 3/10
19/3/01	W	Distance of remote to bed centre max: ½ width
19/3/01	W	Volume of Remote: >160cm^{3}
19/3/01	W	Front Area of Remote: >70cm^{2}
19/3/01	D	Button Protrusion min: 2.5mm
19/3/01	D	Remote cord length max: 2200mm
19/3/01	D	Remote Toughness: 8/10

19/3/01		**Mechanism:**
19/3/01	D	Movement Delay: 0.5s
19/3/01	W	Speed Range: $0.05ms^{-1}$
19/3/01	D	Noise Level: 2/10 (Dico = 4)
19/3/01		**Structure:**
19/3/01	D	Inertia: 5/10 (Dico = 6)
19/3/01	D	Collapsing Force: 8/10 (Dico = 6)
19/3/01		**Mattress:**
19/3/01	W	Force to move mattress: 8/10 (Dico = 5)
19/3/01	D	Distance of Mattress Slip: 10mm
19/3/01	D	Mattress Bunching Height: 10mm

	Replaces issue of 10/6/2000	

Appendix I Morphological Matrix Method

This section shows the steps that were taken in the morphological chart process for generating concept alternatives.

1. List the features or functions that are essential to the product:
   - Top Adjustment
   - Leg Adjustment
   - Mechanism
   - Power
   - Integration
   - Other Features

   Other:
   - Safety
   - Smooth, Silent Operation
   - In situ, easy to use Control

2. For each features or function list the means by which it might be achieved:

- Top Adjustment:
  - None
  - Head
  - Back
  - Head/Back
  - Contour
- Leg Adjustment:
  - None
  - Leg
  - Leg Bent Parallel
  - Leg Bent Not Parallel
  - Contour
- Mechanism:
  - Linkages
  - Pulleys and wires
  - Pneumatic Cylinders
  - Dynamic
  - Manual hinges
  - Pivoting Sections
  - Screw drive
  - Scissors Mechanism
  - Circular/linear gear
  - Cams
- Power:
  - Electric
  - Gas Strut
  - Pneumatic
  - Air Bladder
  - Personal Weight
  - Manual move
- Integration:
  - Fully assembled frame
  - Separate 1/3 2/3 frame
  - Assemble onto bed frame
- Other Features:
  - Built in lamps
  - Foldaway armrests
  - Slide back mechanism

3. Draw up a chart containing all the possible sub-solutions (Table I-1):

Table I-1 List of all the possible means to achieve each of the features and functions

Feature	Means										
Top Adj.	None	Head	Back	Head /Back							
Leg Adj.	None	Leg Straight	Leg Bent P	Leg Bent NP							
Mechanism	None	Circular /linear gear	Pivot Lever Arm	Pneumatics	Dynamic	Manual	Pulleys/ Wires	Screw Drive	Scissors	Linkages	Cams
Actuation	None	Electric	Personal Weight	Comp Air	Air Bladder	Manual move					
Integration	Full Frame	Separate 1/3 2/3 frame	Some Asm	All Asm							
Accessories	None	Built in lamps	Foldaway armrests	Slide back							

Notes: Asm = Assembly

4. Identify feasible combinations of sub-solutions (Table I-2):

Table I-2 Morphological list of feasible solutions for each of the features and functions

No.	Description	Top Adj	LegAdj	Mechanism	Power	Integration	Features
0.1	Normal Bed	None	None	None	None	Full	None
0.2	Dico Bed	Back	Leg Bent P	Pivot Arm	Electric	Full	None
1.1	Air Simple 1	Back	Leg Straight	None	Air Bladder	Full	None
1.2	Air Simple 2	Back	Leg Straight	None	Air Bladder	1/3 & 2/3	None
1.3	Air Mid 1	Back	Leg Bent P	None	Air Bladder	Full	None
1.4	Air Mid 2	Back	Leg Bent P	None	Air Bladder	1/3 & 2/3	None
1.5	Air Mid Asm	Back	Leg Bent P	None	Air Bladder	All	None
1.6	Air Duluxe 1	Back /Head	Leg Bent NP	None	Air Bladder	Full	None
1.7	Air Duluxe 2	Back /Head	Leg Bent NP	None	Air Bladder	1/3 & 2/3	None
1.8	Air Duluxe Asm	Back /Head	Leg Bent NP	None	Air Bladder	All	None
2.1	Cam Elec Simple 1	Back	Leg Straight	Cam	Electric	Full	None
2.2	Cam Elec Simple 2	Back	Leg Straight	Cam	Electric	1/3 & 2/3	None
2.3	Cam Elec Mid 1	Back	Leg Bent P	Cam	Electric	Full	None
2.4	Cam Elec Mid 2	Back	Leg Bent P	Cam	Electric	1/3 & 2/3	None
2.5	Cam Elec Mid Asm	Back	Leg Bent P	Cam	Electric	All	None
2.6	Cam Elec Duluxe 1	Back /Head	Leg Bent NP	Cam	Electric	Full	None
2.7	Cam Elec Duluxe 2	Back /Head	Leg Bent NP	Cam	Electric	1/3 & 2/3	None
2.8	Cam Elec Duluxe Asm	Back /Head	Leg Bent NP	Cam	Electric	All	None
3.1	Cam Man Simple 1	Back	Leg Straight	Cam	Manual	Full	None

3.2	Cam Man Simple 2	Back	Leg Straight	Cam	Manual	1/3 & 2/3	None
3.3	Cam Man Mid 1	Back	Leg Bent P	Cam	Manual	Full	None
3.4	Cam Man Mid 2	Back	Leg Bent P	Cam	Manual	1/3 & 2/3	None
3.5	Cam Man Mid Asm	Back	Leg Bent P	Cam	Manual	All	None
3.6	Cam Man Duluxe 1	Back /Head	Leg Bent NP	Cam	Manual	Full	None
3.7	Cam Man Duluxe 2	Back /Head	Leg Bent NP	Cam	Manual	1/3 & 2/3	None
3.8	Cam Man Duluxe Asm	Back /Head	Leg Bent NP	Cam	Manual	All	None
4.1	Linkages Man Simple 1	Back	Leg Straight	Linkages	Manual	Full	None
4.2	Linkages Man Simple 2	Back	Leg Straight	Linkages	Manual	1/3 & 2/3	None
4.3	Linkages Man Mid 1	Back	Leg Bent P	Linkages	Manual	Full	None
4.4	Linkages Man Mid 2	Back	Leg Bent P	Linkages	Manual	1/3 & 2/3	None
4.5	Linkages Man Mid Asm	Back	Leg Bent P	Linkages	Manual	All	None
4.6	Linkages Man Duluxe 1	Back /Head	Leg Bent NP	Linkages	Manual	Full	None
4.7	Linkages Man Duluxe 2	Back /Head	Leg Bent NP	Linkages	Manual	1/3 & 2/3	None
4.8	Linkages Man Duluxe Asm	Back /Head	Leg Bent NP	Linkages	Manual	All	None
5.1	Scissor Man Simple 1	Back	Leg Straight	Scissor	Manual	Full	None
5.2	Scissor Man Simple 2	Back	Leg Straight	Scissor	Manual	1/3 & 2/3	None
5.3	Scissor Man Mid 1	Back	Leg Bent P	Scissor	Manual	Full	None
5.4	Scissor Man Mid 2	Back	Leg Bent P	Scissor	Manual	1/3 & 2/3	None
5.5	Scissor Man Mid Asm	Back	Leg Bent P	Scissor	Manual	All	None
5.6	Scissor Man Duluxe 1	Back /Head	Leg Bent NP	Scissor	Manual	Full	None
5.7	Scissor Man Duluxe 2	Back /Head	Leg Bent NP	Scissor	Manual	1/3 & 2/3	None

5.8	Scissor Man Duluxe Asm	Back /Head	Leg Bent NP	Scissor	Manual	All	None
6.1	Screw Elc Simple 1	Back	Leg Straight	Screw	Electric	Full	None
6.2	Screw Elc Simple 2	Back	Leg Straight	Screw	Electric	1/3 & 2/3	None
6.3	Screw Elc Mid 1	Back	Leg Bent P	Screw	Electric	Full	None
6.4	Screw Elc Mid 2	Back	Leg Bent P	Screw	Electric	1/3 & 2/3	None
6.5	Screw Elc Mid Asm	Back	Leg Bent P	Screw	Electric	All	None
6.6	Screw Elc Duluxe 1	Back /Head	Leg Bent NP	Screw	Electric	Full	None
6.7	Screw Elc Duluxe 2	Back /Head	Leg Bent NP	Screw	Electric	1/3 & 2/3	None
6.8	Screw Elc Duluxe Asm	Back /Head	Leg Bent NP	Screw	Electric	All	None
7.1	Pulley/Wire Elc Simple 1	Back	Leg Straight	Pulley /Wire	Electric	Full	None
7.2	Pulley/Wire Elc Simple 2	Back	Leg Straight	Pulley /Wire	Electric	1/3 & 2/3	None
7.3	Pulley/Wire Elc Mid 1	Back	Leg Bent P	Pulley /Wire	Electric	Full	None
7.4	Pulley/Wire Elc Mid 2	Back	Leg Bent P	Pulley /Wire	Electric	1/3 & 2/3	None
7.5	Pulley/Wire Elc Mid Asm	Back	Leg Bent P	Pulley /Wire	Electric	All	None
7.6	Pulley/Wire Elc Duluxe 1	Back /Head	Leg Bent NP	Pulley /Wire	Electric	Full	None
7.7	Pulley/Wire Elc Duluxe 2	Back /Head	Leg Bent NP	Pulley /Wire	Electric	1/3 & 2/3	None
7.8	Pulley/Wire Elc Duluxe Asm	Back /Head	Leg Bent NP	Pulley /Wire	Electric	All	None
8.1	Pulley/Wire Man Simple 1	Back	Leg Straight	Pulley /Wire	Manual	Full	None
8.2	Pulley/Wire Man Simple 2	Back	Leg Straight	Pulley /Wire	Manual	1/3 & 2/3	None
8.3	Pulley/Wire Man Mid 1	Back	Leg Bent P	Pulley /Wire	Manual	Full	None
8.4	Pulley/Wire Man Mid 2	Back	Leg Bent P	Pulley /Wire	Manual	1/3 & 2/3	None
8.5	Pulley/Wire Man Mid Asm	Back	Leg Bent P	Pulley /Wire	Manual	All	None

8.6	Pulley/Wire Man Duluxe 1	Back /Head	Leg Bent NP	Pulley /Wire	Manual	Full	None
8.7	Pulley/Wire Man Duluxe 2	Back /Head	Leg Bent NP	Pulley /Wire	Manual	1/3 & 2/3	None
8.8	Pulley/Wire Man Duluxe Asm	Back /Head	Leg Bent NP	Pulley /Wire	Manual	All	None
9.1	Circ/Lin Elec Simple 1	Back	Leg Straight	Circ /Lin	Electric	Full	None
9.2	Circ/Lin Elec Simple 2	Back	Leg Straight	Circ /Lin	Electric	1/3 & 2/3	None
9.3	Circ/Lin Elec Mid 1	Back	Leg Bent P	Circ /Lin	Electric	Full	None
9.4	Circ/Lin Elec Mid 2	Back	Leg Bent P	Circ /Lin	Electric	1/3 & 2/3	None
9.5	Circ/Lin Elec Mid Asm	Back	Leg Bent P	Circ /Lin	Electric	All	None
9.6	Circ/Lin Elec Duluxe 1	Back /Head	Leg Bent NP	Circ /Lin	Electric	Full	None
9.7	Circ/Lin Elec Duluxe 2	Back /Head	Leg Bent NP	Circ /Lin	Electric	1/3 & 2/3	None
9.8	Circ/Lin Elec Duluxe Asm	Back /Head	Leg Bent NP	Circ /Lin	Electric	All	None
10.1	Dynamic Simple 1	Back	Leg Straight	Dynamic	P Weight	Full	None
10.2	Dynamic Simple 2	Back	Leg Straight	Dynamic	P Weight	1/3 & 2/3	None
10.3	Dynamic Mid 1	Back	Leg Bent P	Dynamic	P Weight	Full	None
10.4	Dynamic Mid 2	Back	Leg Bent P	Dynamic	P Weight	1/3 & 2/3	None
10.5	Dynamic Mid Asm	Back	Leg Bent P	Dynamic	P Weight	All	None
10.6	Dynamic Duluxe 1	Back /Head	Leg Bent NP	Dynamic	P Weight	Full	None
10.7	Dynamic Duluxe 2	Back /Head	Leg Bent NP	Dynamic	P Weight	1/3 & 2/3	None
10.8	Dynamic Duluxe Asm	Back /Head	Leg Bent NP	Dynamic	P Weight	All	None
11.1	Manual Simple 1	Back	Leg Straight	Manual	Manual	Full	None
11.2	Manual Simple 2	Back	Leg Straight	Manual	Manual	1/3 & 2/3	None
11.3	Manual Mid 1	Back	Leg Bent P	Manual	Manual	Full	None

11.4	Manual Mid 2	Back	Leg Bent P	Manual	Manual	1/3 & 2/3	None
11.5	Manual Mid Asm	Back	Leg Bent P	Manual	Manual	All	None
11.6	Manual Duluxe 1	Back /Head	Leg Bent NP	Manual	Manual	Full	None
11.7	Manual Duluxe 2	Back /Head	Leg Bent NP	Manual	Manual	1/3 & 2/3	None
11.8	Manual Duluxe Asm	Back /Head	Leg Bent NP	Manual	Manual	All	None
12.1	Pivot Arm Simple 1	Back	Leg Straight	Pivot Arm	Electric	Full	None
12.2	Pivot Arm Simple 2	Back	Leg Straight	Pivot Arm	Electric	1/3 & 2/3	None
12.3	Pivot Arm Mid 1	Back	Leg Bent P	Pivot Arm	Electric	Full	None
12.4	Pivot Arm Mid 2	Back	Leg Bent P	Pivot Arm	Electric	1/3 & 2/3	None
12.5	Pivot Arm Mid Asm	Back	Leg Bent P	Pivot Arm	Electric	All	None
12.6	Pivot Arm Duluxe 1	Back /Head	Leg Bent NP	Pivot Arm	Electric	Full	Slide Back
12.7	Pivot Arm Duluxe 2	Back /Head	Leg Bent NP	Pivot Arm	Electric	1/3 & 2/3	Slide Back
12.8	Pivot Arm Duluxe Asm	Back /Head	Leg Bent NP	Pivot Arm	Electric	All	Slide Back
13.1	Pneumatic Simple 1	Back	Leg Straight	Pneumatic	Comp Air	Full	None
13.2	Pneumatic Simple 2	Back	Leg Straight	Pneumatic	Comp Air	1/3 & 2/3	None
13.3	Pneumatic Mid 1	Back	Leg Bent P	Pneumatic	Comp Air	Full	None
13.4	Pneumatic Mid 2	Back	Leg Bent P	Pneumatic	Comp Air	1/3 & 2/3	None
13.5	Pneumatic Mid Asm	Back	Leg Bent P	Pneumatic	Comp Air	All	None
13.6	Pneumatic Duluxe 1	Back /Head	Leg Bent NP	Pneumatic	Comp Air	Full	Slide Back
13.7	Pneumatic Duluxe 2	Back /Head	Leg Bent NP	Pneumatic	Comp Air	1/3 & 2/3	Slide Back
13.8	Pneumatic Duluxe Asm	Back /Head	Leg Bent NP	Pneumatic	Comp Air	All	Slide Back

Appendix J Evaluating Alternatives

The following is a list of the steps taken to evaluate the concepts using the weighted objectives techniques:

1. List the design objectives: Table J-1

Table J-1 Design objectives

Integration into bed frame	(A)
Assembly:	
Easy assembly by customer	(B)
As much assembly by customer as possible	(C)
Form:	
Simple and aesthetically pleasing to the eye	(D)
Adequate adjustability for activities	(E)
Minimum of parts	(F)
Energy source issues	(G)
Innovative	(H)
Safety	(I)
Production/Manufacturing:	
Cheap	(J)
Availability of parts	(K)
Materials	(L)
Operation:	
Smooth	(M)
In situ adjustment	(N)
Shipping Issues (size)	(O)
Maintenance:	
Easy Maintenance	(P)
No Maintenance Required	(Q)

2. Rank-order the list of objectives: see Table J-2

Table J-2 Scores for each of the objectives.

Score	Objective
0	A
1	D
2	E
4	N
5	H
6	J
7	I
8	C
9	M
10	K,O
11	B,F,G
13	L,Q
15	P

3. Assign relative weights to the objectives: see Table J-3

Table J-3 Objectives ranked in order and given weightings

Objective	Weightings
A	13.50
D	12.00
E	11.00
N	10.00
H	9.50
J	8.00
I	7.00
C	6.75
M	5.00
O	4.50
K	4.00
G	3.50
B	2.00
F	1.50
Q	1.00
L	0.50
P	0.25
Total	100

4. Establish performance parameters or utility scores for each of the objectives: see Table J-4.

Table J-4 The performance parameters for each of the objectives

Objective	Performance Parameters
A	Ease of Integration
D	Simplicity and Aesthetics of form
E	Level of Adjustability
N	Ease of adjusting from the bed
H	Level of innovation
J	Costs involved with manufacture
I	Level of safety
C	Percentage of assembly by the customer
M	Smoothness of operation
O	Size of packaging
K	Availability of parts
G	Energy Impact on Occupant
B	Ease of assembly by customer
F	Number of parts
Q	Level of Maintenance required
L	Commonality of materials
P	Ease of maintenance

5. Calculate and compare the utility values of the alternative designs: The summary results of this process are shown in Table 6-3.

Appendix K Prototype User Trial

	Participant			Pre-Quest				
Participant	Sex	Height	Weight	Robust	Simple	Friendly	Appeal	Interest
1	F	161	72	5	4	4	5	5
2	F	168	120	5	5	5	4	4
3	F	168	87	4	5	5	3	4
4	M	182	107	4	4	4	5	5
5	M	190	104	4	4	3	3	5
6	M	178	73	4	5	4	2	3
9	M	187	83	5	5	5	4	5
11	F	161.5	64	4	5	5	3	3
12	F	160	77	5	4	5	3	5
13	F	166	58	4	3	4	4	4
14	M	176.5	98	4	4	4	3	4
15	M	186	83	4	5	4	3	4
16	M	190	80	5	4	4	3	4
17	M	186	100	5	5	5	5	5
18	F	164	61	4	5	5	4	4
19	M	183	84	4	5	5	4	5
20	M	186	122	4	4	4	5	5
21	F	160	100	5	5	5	5	5
22	F	168	67	3	3	4	4	3
Total	0.0	174.8	86.3	4.32	4.42	4.42	3.79	4.32
SD				0.58	0.69	0.61	0.92	0.75

	Post Qn																						
	Adj					Control										Operation						Mattress	
Participant	1	2	3	4	5	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	1	2
1	3	5	5	5	4	5	5	5	5	2	1	5	5	4	5	5	5	5	5	5	4	4	4
2	4	5	5	5	4	5	5	5	5	2	4	4	4	4	5	5	5	4	5	5	5	5	4
3	2	4	4	5	4	5	5	5	5	2	3	2	3	3	5	5	5	4	5	5	5	5	4
4	4	5	5	3	2	5	5	5	5	1	2	5	4	4	2	5	5	2	5	5	5	4	5
5	5	3	5	4	4	4	3	3	4	2	3	4	4	4	5	5	4	3	5	5	5	4	4
6	3	3	4	4	4	5	5	4	4	3	4	4	5	5	5	4	4	4	4	5	5	3	3
9	4	5	5	5	2	5	5	5	5	3	3	4	3	4	5	5	5	5	5	5	5	5	5
11	3	5	3	4	3	5	5	4	5	3	5	5	3	5	5	5	5	4	5	5	5	5	5
12	3	3	3	3	3	5	5	4	5	5	4	5	4	5	5	5	5	5	5	5	5	5	5
13	5	5	5	4	4	5	5	5	4	1	2	5	5	5	3	5	5	5	5	5	5	5	4
14	2	4	4	4	3	5	5	5	4	2	2	5	4	4	4	5	5	4	4	4	5	5	5
15	4	4	5	2	5	5	5	5	5	1	2	5	5	4	5	5	5	2	5	5	5	5	4
16	4	4	4	3	2	5	5	5	5	2	2	5	3	4	3	5	5	4	5	5	5	5	4
17	4	5	5	5	2	5	5	5	5	3	3	5	5	5	5	5	5	5	5	5	5	5	5
18	1	5	3	5	2	5	5	5	5	4	5	5	5	5	5	4	5	5	5	5	5	5	5
19	4.5	4.5	5	4.5	4	5	5	5	4	2	3	5	5	4	5	5	5	3	5	5	5	5	5
20	4	4	5	4	5	5	5	5	5	4	4	5	4	4	5	4	5	4	5	5	5	5	5
21	5	5	5	5	3	5	5	5	5	2	4	5	5	5	5	5	5	4	5	5	5	5	5
22	4	3	4	3	4	4	4	4	4	4	4	3	4	4	5	4	4	3.5	5	4	4	4	5
Total	3.61	4.29	4.42	4.08	3.37	4.89	4.84	4.68	4.68	2.53	3.16	4.53	4.21	4.32	4.58	4.79	4.84	3.97	4.89	4.89	4.89	4.68	4.53
SD	1.09	0.80	0.77	0.92	1.01	0.32	0.50	0.58	0.48	1.12	1.12	0.84	0.79	0.58	0.90	0.42	0.37	0.95	0.32	0.32	0.32	0.58	0.61