Rehabilitation engineering as the crow flies*

PART IV—CRITERIA AND CONSTRAINTS

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In Parts I and II of this series we discussed the way in which a biomechanics clinic team can be formed and the kind of information the rehabilitation engineer should seek as an aid to defining problems and solving them. In Part III we offered a “framework” for problem-solving which can be used to pace development of solutions and help facilitate communications between team members and various teams. We will discuss now the criteria and constraints which determine the nature of the “products” of rehabilitation engineering.

Criteria = factors used in evaluating various designs which are proposed.

Constraints = factors which form boundaries or limits to possible designs.

The criteria define the goals or ideals you have in mind and the constraints limit the degree to which the goals can be achieved. If your goal is to go to London, the methods of transportation possible place limits on your plans. The constraints will never allow for the perfection desired, but when the criteria are broken down into parts and valued, the optimum possibilities will emerge and necessary compromises be anticipated.

As an example, let us consider a real patient for whom we developed a set of statements on criteria and constraints. She is a person who spends most of her time lying on a plinth, and who is lifted many times a day for the performance of various functions. The biomechanics clinic team suggested that her life could be improved through rehabilitation engineering on the basis of information provided by various team members and others associated with the patient.

For this person, the problem was stated as to increase her comfort.

This was the most general statement we could think of. It was our intention to leave this statement in as open a form as possible so that the direction of enquiry or the solution selected would not be inhibited by the initial statement. Starting at this point, we developed the following set of statements on criteria and constraints (Table 1).

Note that we see the objective in terms of the patient rather than in terms of some mechanical contrivance! And this will be the point of entry to all problem-solving which is related to a particular patient’s well-being. (If the solution sought were to benefit an institution or a professional group for example, then the focus would be on that.) The aim now is to build up a mental image or environment within team members as they act and interact around the problem in such a way that criteria which are increasingly explicit and which encompass the original general statement are developed. Thus, to improve comfort becomes to improve:

- **Functional comfort** = comforts essential for life
- **Physical comfort** = comforts which make life easier
- **Psychological comfort** = comforts related to the quality of life

We are seeing comfort (almost feeling it!) in terms of what is essential, what is facilitating, and what adds quality to the person’s life. Consider the first sort of comfort. For the

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TABLE 1

Problem: To improve the comfort of the disabled person Ms............................... 82

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Criteria (relevant factors used for evaluating the design)

Types of comfort:  
- Functional comfort = Comforts essential for life
- Physical comfort = Comforts which make life easier
- Psychological comfort = Comforts related to the quality of life

Functional comfort criteria

1. Protection from environment—safety
2. Optimum feeding capacity
3. Optimum body-product management
4. Optimum capacity to communicate
5. Psychological factors optimally handled
6. Dependent factors optimally handled
7. Optimum management of sleeping

Physical comfort criteria

1. Ability to shift position
2. Ability to assume most comfortable position
3. Access to physical environment
4. Protection from environment
5. Optimum control of movement, location
6. Optimum use of senses (vision, hearing, etc.)
7. Optimum pressure distribution
8. Optimum use of body power
9. Ability to control heat flow
10. Optimum capacity for hygiene
11. Optimum garment design
12. Dependent functions optimally handled

Psychological comfort criteria

1. Ability to be private
2. Psychological protection
3. Access to dynamic sensations
4. Ability to influence design
5. Optimized cosmesis (colour, shape, etc.)
6. Optimized capacity to communicate
7. Access to communication devices
8. Creativity facilitated
9. Access to information
10. Opportunity to contribute
11. Access to psychological environment
12. Dependent functions optimally handled

Constraints (limitations on design)

Types of constraints:

- Patient = Those essential for survival
- Physical environment = The material world
- Social environment = The community and its institutions
- Technological = Skills, facilities, techniques, materials, etc.

Patient

1. Vital functions
   - Pulmonary function
   - Cardiac status
   - Vascular status
   - Neurological status
   - Metabolism
   - Elimination—bowels, bladder, etc.
   - Susceptibility to disease

2. Feeding
   - Frequency
   - Quantity
   - Quality
   - Duration
   - Periodicity
   - Aids

3. Sleeping
   - When

Physical environment

1. Heat transfer
   - Heat transfer coefficients
   - Thermal resistance
   - Environmental temperature & humidity

2. Spatial factors
   - Door sizes
   - Hall widths
   - Floor plans
   - Transport system used
     - Car doors
     - Trunk size
     - Seating arrangements
     - Access arrangements
   - Stairs, steps, curbs
   - Elevators
   - Bathroom arrangements
   - Boundaries, inside, outside
   - Ground surface characteristics

Social environment

1. Staff limits
   - Times available
   - Number
   - Location
   - Strength
   - Skills
   - Acceptance
   - Turnover rate
   - Shift changes
   - Frequency of contact

2. Other persons
   - Who
   - Frequency of contact
   - Where
   - Skills
   - Duration of contact

3. Responsible agents
   - Medical

Technological

1. Time
   - Design
   - Fact-finding
   - Fabrication
   - Prototype testing
   - Experimenting
   - Follow-up
   - Maintenance (long term)

2. Costs
   - Time
   - Materials, components
   - Environmental changes
   - Operators

3. Safety
   - Chemical stability
   - Fire resistance
   - Structural safety factor
   - Electrical safety
How well she sleeps
(c) Duration
(d) Where
(e) Positions during

4. Sensory factors
(a) Range of vision
(b) Hearing
(c) Touch
(d) Kīnesthesia
(e) Taste
(f) Smell
(g) Balance
(h) Rate of response
(i) Intensity of response
(j) Appropriateness of response

5. Heat transfer
(a) Body area
(b) Temperature distribution
   on her body
(c) Variations with time

6. Hygiene
(a) Frequency of cleaning
(b) Method of cleaning
(c) Her response to it
(d) Who assists
(e) Where it is done
(f) When it is done

7. Psychological
(a) Cosmesis, body image
(b) Self-help capacity
(c) Self-help inclination
(d) Frustration tolerance
(e) Fears
(f) Desires

8. Biomechanical factors
(a) Weight distribution
(b) Body dimensions
(c) Ranges of movements
(d) Forces generated
(e) Power developed
(f) Rate of movements
(g) Reaction time
(h) Duration of actions
(i) Intensity of actions
(j) Appropriateness of actions

(j) Furniture dimensions
   (i) Home
   (ii) Institutional
   (iii) Community

(b) Parental
(c) Community (legal, financial)
(d) Others, family, etc.

(e) Mechanical safety—pilchuck, stability
(f) Locking of wheels

3. Safety
(a) Protection from weather acceptance
   (i) Position
   (ii) Shape
   (iii) Odour
(b) Acceptance by her

5. Communications
(a) Where
(b) When
(c) Methods
(d) Ability to get information
(e) Limits of speed, quality, quantity
(f) With whom

5. Cosmesis
(a) Institution, community
   (i) Position
   (ii) Shape
   (iii) Odour
(b) Acceptance by her

5. Hygiene
(a) Protection from weather
(b) Protection from impacts

4. Size
(a) Maximums of
   (i) Surfaces
   (ii) Lengths
   (iii) Volumes
(b) Minimums of
   (i) Surfaces
   (ii) Lengths
   (iii) Volumes
(c) Dimensional ratios

6. Safety
(a) Impacts
(b) Psychological
(c) Other

4. Sensory factors
(a) Range of vision
(b) Hearing
(c) Touch
(d) Kīnesthesia
(e) Taste
(f) Smell
(g) Balance
(h) Rate of response
(i) Intensity of response
(j) Appropriateness of response

6. Safety
(a) Impacts
(b) Psychological
(c) Other

6. Manufacturing
(a) Degree of complexity allowable
(b) Maintenance limits
(c) Life expectancy of device
(d) Market
(e) Distribution system
person to be functionally comfortable she needs to be able to do a number of things. For example, she must be able to communicate. She must be able to regulate or adjust to the environment. She must be able to participate favourably in her social environment.

Imagine the impact on engineers who start to focus this closely on the individuals who will be the recipients of their services. How much better it is to investigate in this way than to plunge in, plaster already dripping wet and tools ready. If we continue to investigate only a single facet of comfort, such as functional comfort, a number of criteria emerge.

(1) The patient is to be protected from the environment—indoors? outdoors? fair weather or foul? in public places? etc. (Remember, if psychological comforts are a serious consideration, you may expand her environment, facing her with new hazards.)

(2) Optimum feeding of the patient—design anticipates health-promoting foods, foods that are attractive, and not just easy to feed.

(3) Optimum handling of body wastes—saliva, urine, faeces, sweat.

(4) Optimum organization of communication to ensure improved capacity to survive. (Risks are sometimes taken which are unwarranted unless such risks are off-set by important gains.)

(5) Optimum handling of psychological factors—the patient should not be so disturbed by the process of living as to expose her to the risks which are life-threatening, for example, suicide.

(6) Optimum approach to dependent functions—the patient will not face risks such as being dropped, gouged, etc.

(7) Optimum management of rest, sleep and relaxation—avoidance of hazards such as smothering or falling.

You might be able to add criteria to the lists provided in the table developed for the example case. A good technique is to imagine yourself in comparable circumstances. Imagine the sort of environment you would choose to be in, or require for optimum survival from the functional, physical and psychological view-points. Such criteria as "the ability to shift position" lead to quite different views of how devices such as orthoses should be designed. We see "back braces" which are such straight jackets that the motions needed or desirable are inhibited—even after "cure" is complete. For the case in question, you will see that we identified over 30 "comfort" criteria. You will also notice that the qualifying words "optimized" or "access to" are governed by limits. Thus, such criteria as "optimized cosmesis" (the feel, sound, shape, colour, and motions which harmonize with the recipient and environment) or the "ability to be private" (meaning the capacity to choose private conditions) are bound by essential realities. These constitute the constraints.

In generating the lists of constraints, we identified four main groups which would affect the degree to which we could reach toward any ideal goal established by the assembled criteria. We saw some which related strictly to the patient. Others related to the physical environment, the social environment, and finally, the technological limits.

Considering the conditions within which the patient now lives, one can be committed at least to improving the conditions for this patient. The gap between the ideal and the end result constitutes the compromise necessary or accepted. That there will be compromise for the example patient is clearly indicated by the extent of the constraints generated. Some are more important than others, some permit little or no compromise. To live at all means that vital functions must continue—breathing, circulation, sensing, digesting food, eliminating wastes, conquering infection. These are inside-the-body operations which can be affected by design. Other constraints are imposed by the need to live—eating, sleeping, sensing, heat transfer, hygiene, psychological factors, biomechanical factors—such as skin resistance to force-motion. These constraints are of high importance.

As soon as you start considering such constraints as the patient imposes, others which relate to the physical environment come into focus. A support surface imposes forces, allows
movements, restricts circulation, inhibits heat flow, collects moisture, etc. The size of a door, an elevator, a curb, the presence of steps confines you in your design approach. The wheels of a dune buggy are not the same as the wheels of a baby carriage.

When the person ventures out, the social environment impinges; whether "out" is into the corridor or onto the street. Such factors as how strong or willing a helper is; the degree to which people around contribute to the psychological well-being of the patient; who the person is, family, friend, volunteer, assistant; how well informed these people are; the speed, extent and quality of communications; community acceptance; her acceptance of those in the community; the safety of the person in the social environment, all affect design. An old person's balance requires consideration from the bus driver and fellow passengers or even assurance of a seat. A dribbling person is better served with a paper napkin than embarrassing stares. A humane social environment is one in which the means are made available by which the imbalance between the able and the disabled can be redressed. How nearly this is optimal affects design.

Even when there is ample good will and money is available, there can be limits of skills, limits of other means. The technological constraints are a final hurdle imposing compromise. Fact-finding, designing, fabricating and testing take time. Maintenance is required no matter how well you design, especially initially. An operator may be needed. Would it be better to by-pass the machine and use a person directly? Will there be enough demand to make design worthwhile? Can it, will it be made, by whom, where, in what sort of facility?

Finally, all the information must be sought, sifted and ordered into useful form constituted as criteria and constraints. The information will be based on the observations, expert opinion, recorded information and personal preferences of those involved (patient, family, doctor, helpers). This takes time. In this case we interviewed therapists, nurses, the dietitian, other engineers, doctors, the social workers, the parent, the teachers and a psychologist. Such an extravagant enquiry may not be needed often, but in this case, exposure to the various opinions and pieces of information led us to a radical change of view as we assembled the constraints and criteria. We came to understand the problem in terms not only of lifting, but also in terms of mobility and communications within the context of a changed environment. This experience raised regrets for previous impulsive enterprises which could have been better prepared and which might never have been attempted at all had the criteria and constraints been laid out. Alternatively, definition of the criteria and constraints centred on this person has led to worthwhile solutions to problems of mobility, and developments are underway to design a lifting system—so designed as to form modules for an environment more suitable to this sort of patient. We recommend that people working to apply engineering to rehabilitation problems make up such criteria lists. The criteria can be rated with respect to particular designs so that they can be "scored", perhaps on a 0–10 scale. The total score of a particular design can be used to rate it in relative terms with other designs or compare it to the ideal which the criteria represent.

Summary

When engineers function in a biomechanics clinic team, collecting information for the definition and solution of problems, and developing solutions in a logical pattern, then establishment of criteria by which to judge actions and results at various stages are essential. In our procedures, we make the most general statement we can which will indicate the goal we have for the patient or the type of patient being considered. Based on this, we proceed with a breakdown of the goal into increasingly explicit statements keeping the objective in focus. Eventually, with the criteria we need in order to decide "yes or no" to any aspect of the solution developing, we consider the constraints. These we see as imposed by the life-requirements of the patient, the effects of the physical environment, the limitations imposed by the social environment, and the limits of available technology, including the skills of the designers, the manufacturing capabilities and the distribution system with which the designers must cope. When a "checklist" of requirements and limits has been established, the "critical eye" watches over the rehabilitation engineer as he in effect watches over himself!