ON THE APPLICATION OF MODERN MAINTENANCE TECHNIQUES TO AIDS FOR THE HANDICAPPED

R. Elmgard and B. Klasson

Summary

Successful technical aids for the handicapped play primary roles in the life of the user by creating interdependence. The man-aid-system represents a level of rehabilitation. If the aid is not operationally functional when desired, the degree of rehabilitation is forfieted.

The function of the technical aid must be properly maintained in order to have a sufficient degree of availability.

The basic maintenance relationship is:

$A = f\ (R_{reliability}, R_{maintainability}, R_{supportability})$

A = the probability of availability.

Modern maintenance techniques serve as instruments to optimize the function of the aid to the lowest cost and to select the proper components for the construction of the aid.

The total cost when using the device is the sum of the purchase cost and the cost of maintaining and operating the device. High demends on the reliability result in high purchase cost, but also result in low cost of using and maintaining the device. The reliability representing minimum total cost can be calculated.

The measure of the reliability is the "mean time between failure" (MTBF). The probability that the equipment will function during a certain period t is given by the expession

$R_{(t)} = e^{-\frac{t}{m}}$, *where* m = *MTBF*

All equipment has a so-called "running-in period", during which the failure rate is higher than during the normal "using phase", which is followed by the "wear-out phase" when the failure rate again increases.

As the availability of the device is a matter of design and organization these elements can be considered and optimized in advance to achieve the expected results.

The introduction of more advanced technology into rehabilitation may fail unless appropriate maintenance techniques are applied. Certain difficulties may arise because of the uniqueness of the criteria to be fulfilled.

A more generalized approach would be to maintain and evaluate the total rehabilitation level of the patient with his technical aid.

Not long time ago a simple hook was the most advanced and best functional device that would be given to the hand amputee. Today a great number of splithooks and hands are available, some hands are powered by electric or pneumatic motors, controlled by different

systems utilizing myoelectric or biomechanical control sites. For the leg amputee a simple pylon was available. Today many kinds of artificial legs with various swing phase controls, locking mechanisms, and other more or less advanced pieces of engineering are available and used. Where in formed days a handicapped person had to be carried or was riding on various primitive devices, he is now using light and strong wheelchairs, many of them electrically powered and many of them capable of reaching considerable speed and able to move about in heavy terrain.

Many of the devices, like electric and pneumatic arm prostheses, are still in the early state of development, and their functional contributions may not yet be so very important. There is a gradual development phase though, where the first experience promising that the device in fact moves stimulates further analysis of the functional requirements and in turn futher development devices to meet the new functional requirement. Many technical aids for the handicapped are however undoubtedly playing an important role in the life of their users as an important tool for different activities.

As soon as the technical aid has demonstrated its capacity to play a role in the life of the handicapped person and has been accepted by this person, it is most important that the technical aid be available when called upon. In this context it should be noted that it is the function of the technical aid that must be available, not only that the aid is physically present.

If the handicapped person is able to perform a task by means of a technical aid, and this way of performing the task represents the best and easiest way to preform it, and has been accepted by the user, a level of performance or a level of rehabilitaion has been established. If now the technical aid is not available when it is supposed to be used, this level of rehabilitation is lost. If this happens often, or maybe only one or two times in critical situations, the user will lose confidence of his aid, and the level of rehabilitation that the aid was a part of has been forfeited. Maybe not only this level has been forfeited but it is also possible that the patient's general attitutde to rehabilitation and to technical aids has been changed in a negative sense.

Unlimited availability of technical devices is however not possible. It is necessary to learn to live together with a limited

availability, as well it is necessary to learn to live with the handicap. It is however possible to optimize the availability. Techniques for this optimization has been established and are used and well documented in industrial production, armed force administration, communication, etc. The laws and the logistics are general; only the criteria vary according to the demands of availability. It may therefore be reasonable to discuss the general principles, and then comment of the application in the field of rehabilitation.

The Basic "Maintenance Relationship"

When dealing with maintenance problems one often meet terms such as availability, reliability, maintainability ect. This terms are well defined and related to each others as expressed by basic "maintenance relationship".

$A_{op} = P_{MTBF} \times P_{MTTR} \times P_{US}$ where

A_{op} = availability or systems availability, which is the probability that a stated percentage of missions of a certain time duration will not have any failure in any mission which cannot, through maintainability and/or supportability be restored to service in a time equal to or less than a given time constant t.

P_{MTBF} = reliability, which is the probability of the device performing its purpose adequately for the period of time intended under the operating conditions encountered.

P_{MTTR} = maintainability, which is the probability that the device will be restored to operational effectivness within a given period of time when the maintenance action is performed in accordance with prescribed procedures.

P_{US} = supportability, which is the probability of a maintenance action present when needed.

From these definitions it is obvious that the terms P_{MTBF} and P_{MTTR} are related to the technical characteristics of the equipment, while P_{US} is related to the maintenance handling of the equipment. The mean time between failure to be expected from an equipment depends upon the quality of the components and designed elements

for certain environments and conditions. Maintainability is related to the way the designer has prepared the equipment for easy operation, testing, and maintenance. Supportability, however, is a purely organizational factor involving maintenance personnel and their level of skill, maintenance documentation, spare parts, spare units, tools, maintenance equipments and transportation facilities.

The formula visualizes the well-known fact, that a poor device can be kept alive with frequent maintenance and repair efforts, while high quality equipment demands less support. The formula, thus, allows several solutions in order to achieve a required availability. Selecting the best solution is a metter of optimizing, where usually a good balance between material reqirements and support is preferred. The object of the optimizing is always to achieve lowest possible cost for a given availability and under the operational conditions stated for the equipment. It may, however, be that the cheapest alternative cannot always be chosen, for instance when psychological and other specific factors have to be taken into consideration. The patient and aid must be seen as a unit system.

As the components of the basic formula represent costs, the total cost to be paid for the availability is the sum of the purchase cost and the maintenance and the operation costs. The costs can be plotted as a function of reliability as seen from Figure 1.

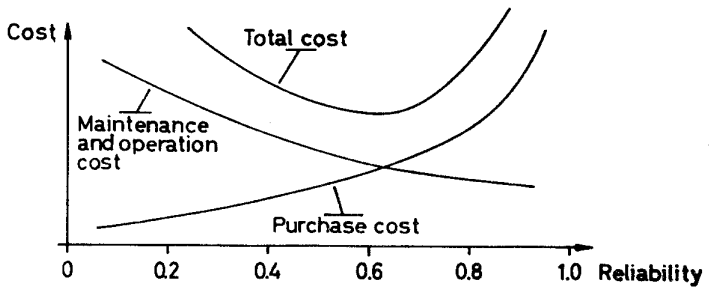

Fig. 1. Costs as function of realibility.

The diagram shows that the purchase cost will increase very much with increasing reliability while the cost of using and maintaining the equipment will be lower at increasing reliability-level of the equipment. This is important to remember when selecting the proper components. One measure of reliability is "meantime between fail-

ures", MTBF, which mathematically can be shown as

$R_{(t)} = e^{-\frac{t}{m}}$ where $R_{(t)}$ is the probability that the equipmant will function during the period t,
m is the meantime between failure and
e is the base of the natural logarithm.

The Bath Tub Curve

When optimizing a system for a certain period of time it is important to know the behaviour of the equipment during its lifetime.

The equipment has always a "running-in period" during which time the failure intensity is higher than during normal use (operation). After this "running-in period" the "normal phase" is reached, during which time the failure intensity in general would be kept at a stable level. After this time the "wear-out period" occurs, indicated by a higher failure rate. This behaviour is shown in the so-called "bath tub" diagram (Fig. 2).

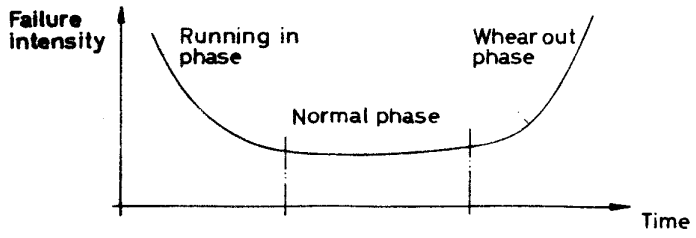

Fig. 2. The bath tub curve.

Summary of Basic Aspects

From what precedes, it will be understood that generally speaking the availability depends on a constructional portion (for the appropriate environment selected material, components etc.), and an organizational portion (the maintenance organization, "service stations" etc.). With knowledge of applied maintenance technique the designer will not only be able to create a good product for the user, but he also will have the best possibilities to consider a matched maintenance organization for the repair and maintenance work which has to be established.

Applications in Rehabilitation

Modern maintenance technique have not been applied in rehabilitation to any significant extent. It is the authors view that if more advanced technology is introduced in rehabilitation, adequate maintenance principles also have to be introduced. Otherwise the advanced technology cannot be utilized to a full extent.

The first "must" is then to find a method to classify components so that components of equal quality can be selected in order to avoid "bottle necks" in the system. It is a well-known fact that the designer of advanced systems is very conservative in his choise of components. The designer is prepared to take the risk that the system does not work properly and that it has to be modified. He is not prepared to take the risk that components in his system do not work, so he only chooses well documanted components where he also can rely upon other qualified users' experience.

In the development of advanced prostheses and similar aids there is no sufficient armentarium of components available, which means that components have to be designed. Also these unique components have to be designed for the expected operational conditions, e.g. to adequate lifetime, and with adequate resistence against humidity, temperature etc. and also with adequate reproduceability of its performance data.

In our work we have seen that the supportability, e.g. the possibilities to maintain the rehabilitation aid in limbfitting shops and similar organizations is not sufficient for complicated technical aids. Of course the maintenance system has to be tailored to the aid. This is not necessarily as difficult as it seems to be. The obvious solution is to work at different service levels, where the total system is checked in one organization, where also the failures is identified, and the failing components may be exchanged, while the repair of the components is done at another service level, e.g. by the manufacturer of the component or by a specialized organization.

A critical point, however, is the identification of the requirements of availability in the field of rehabilitation. In rehabilitation this is not always a pure economical question. It involves psychological aspects. If a patient cannot trust his equipment under all conditions, he may very well reject it totally. This

is important not only for normal use of technical aids, but also in the early development phase. Many devices and inventions have probably not had a real opportunity to show their possibilities, because a major or minor failure occurred during an early state of the testing which distorted the relation between the patient and the device, and thus spoiled the development.

We have also observed that some patients do not accept a maintenance programme concerning "a part of his body". To some extent this can probably be overcome by information, but in some cases it may be more difficult.

Unfortunately different systems for social care affect the question of availability. As stated above high availability has to be paid for. Then the level of ambition of rehabilitation depends on the availability to be specified. It is important that the owner of the device also is responsible for the maintenance of it. If the prosthesis is owned by a hospital, a national authority, or by a patient, this very hospital etc. should also be responsible for the maintenance. Otherwise it may be that a very expensive device owned by the goverment is forfieted because the patient does not follow up and pay for the maintenance in this respect.

Modern maintenance technique means a system, involving all the three components of the basic formula, and the responsibility for running this system should not be split up.

In rehabilitation it may be noted, that the results that have been achieved are valid only when new levels of rehabilitation have been established. The device to be used by the patient is of no interest unless it is accepted and used by the patient on long term bases. If something goes wrong, this may be due to failures of the device, but it may also be due to medical, human and environmental factors. Then the technical aid is only a part in the rehabilitation, and it is the authors' view that modern maintenance techniques, at least as far as supportability is concerned, should cover not only the technical aid but the whole system involving the patient and the enviroment. This would probaly not necessarily lead to more total work for the clinical system, but it leads to a better understanding and organization of the follow up.

Conclusion

It is the authors' opinion that modern maintenance techniques have to be applied in rehabilitation. We cannot give a general for-

mula telling how this should be done. We would only like to state that qualified methods and techniques have been established in other fields of material handling and give an overview of these methods. Our comments about factors to be considered in rehabilitation serve only the purpose of initiating further discissions on the subject.