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Cost-Savings and Economic Benefits due to the Assistive Robotic Manipulator (ARM)

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Abstract—**Besides the social and personal benefits of a rehabilitation robot, the direct cost-savings and other (indirect) economic benefits, or effectiveness, are of major importance to party who pays for (or reimburses) the rehabilitation robot. This paper gives an overview of these cost-savings and, on a larger scale, economic benefits of the Assistive Robotic Manipulator (ARM) rehabilitation robot.**

I. Introduction

NUMEROUS user evaluations and studies [1-8] have shown the social and personal benefits of rehabilitation robots, and of the ARM in particular. These benefits include, improved independence (of the user, as well as of spouse, and relatives etc.), improved quality-of-life, increased self-esteem and increased participation in society.

In most countries, especially in Europe, assistive aids, such as a rehabilitation robot, are not paid by its day-to-day user, but reimbursed by a third party, e.g. the user's health insurance company or the governmental social or health insurance system. Although these third party payers are aiming at the improved quality-of-life of their clients, they are foremost (if not only) interested in the cost effectiveness of an aid they (are about to) reimburse [9]. This is especially the case for high-tech aids like a rehabilitation robot. In the Netherlands, the cost effectiveness of the ARM has been proven by several studies, as will be shown in this paper. Unfortunately in every country, in which the ARM is introduced, (governmental) organizations again ask for this proof of cost-effectiveness, instead of adopting the results from the Netherlands. This question, and not issues related to the technology itself, impedes the swift introduction of the ARM in every new country.

The cost effectiveness is usually defined as the degree of cost-savings which can be reached by the procurement of the rehabilitation robot on the total cost of care of the user. The total cost of care includes the cost of labor of personal assistance, as well as, the cost of technical aids, which the robot under consideration could replace. In other words, because the user can carry out tasks independently using his rehabilitation robot, and without the help of assistance, labor costs can be saved on professional assistance. And because a rehabilitation robot has the same (or comparable) functionality as a (set of) technical aids to carry out *Activities of Daily Life* (ADL), like a feeding device, a page turner, and domotics to remotely control, lights, doors, curtains, windows, TV, etc. cost can be saved on these devices.

Besides these *direct* economic benefits, the procurement of a rehabilitation robot can also save costs at a larger economic scale. These *indirect* economic benefits include, for example, savings on unemployment compensation, because the user can work (again), or start their own business, using his rehabilitation robot. The direct (cost-savings) and indirect economic benefits of a rehabilitation robot are discussed, in the remainder of this paper, based on studies and calculations of the Assistive Robotic Manipulator (ARM), also known as "Manus". Therefore, the ARM is introduced in section II. Next, the direct economic benefits (cost-savings) are quantified. The indirect economic benefits are discussed qualitatively in section IV.

II. Assistive Robotic Manipulator (ARM)

The ARM [10], assists disabled people having very limited or non-existent hand and/or arm function (see Fig. 1). The typical ARM user may suffer from Duchenne, Muscular Dystrophy (MD), Multiple Sclerosis (MS), Cerebral Palsy, Rheumatism, or spinal-cord lesions.

Fig. 1. Wheelchair mounted rehabilitation robot ARM

The ARM is mounted on a wheelchair, and allows a variety of ADL tasks to be carried out in the home, at work, and outdoors. These tasks include drinking from a glass, removing an item from a desk, scratching ones head, discarding an item in a trash receptacle, handling a floppy disk, or

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posting a letter. The ARM can be operated using a wide range of input devices that include, but are not limited to, a keypad (sixteen-buttons in a 4x4 grid), or a joystick (e.g. the joystick of the wheelchair). Additionally, a headband or spectacle mounted laser pointer, or other specially adapted device can be devised and constructed to function by the use of a non-disabled body part, such as the chin. Table 1 lists some technical characteristics of the ARM. Today, more than 225 ARMs are operational world wide. Since the commercial introduction of the Manus, and later of the ARM, the rehabilitation robots have proven to be safe, efficient, and highly appreciated assistive devices.

TABLE I
CHARACTERISTICS AND PROTERTIES OF THE ARM

Property	Value
Degrees of freedom	6 + gripper + lift (8 in total)
Reach	80 cm + 25 cm (lift, optional)
Weight	13 to 18 kg depending on options
Max. payload	Up to 2 kg
Gripper	2 fingers with 4-point grasping
Gripper force	20N
Repeatability	±1.5 mm
Max. velocity	9.9 cm/s (max. joint vel. 30°/s)
Safety features	Slip-couplings, limited velocity, limited acceleration and limited gripper force
Power supply	24VDC@1A cont., 3A peak (wheelchair batt.)
Input devices	Joystick, keypad, switches, UniScanner, EasyRider, etc.
Display	5x7 LED matrix, with buzzer
Control modes:	Carthesian & joint
ROI	1 to 2 years (see section III.A.2)

III. COST-SAVINGS (DIRECT ECONOMIC BENEFITS)

A. Cost-savings on professional assistance

The savings on labor costs of professional assistance depends on the reduced hours of required professional assistance, due to the use of the rehabilitation robot, and the hourly rate of the assistance. In 1998 and 1999, two user studies have been carried out. Both studies identified the daily use of the ARM. The second study also calculated the cost-savings on professional assistance.

1) Quality-of-life and ARM usage investigation

In 1999, the Dutch *Council of Health Care Insurance* (CvZ) commissioned the Dutch *Institute for Rehabilitation Research* (iRV) to carry out a study to analyze the target user-group, and the cost-effectiveness and indication criteria of the ARM [3,11]. Part of the study was to determine the effect of the ARM on the independence of specific ARM users, and their perception of the changes to their quality of life. The study compared the activities of 13 long term (>4 years) ARM users, to 21 non-ARM users having a comparable level of impairment. The activities of both groups were analyzed with respect to individual levels of independence, required assistance, perceived quality of life, and more. The observations included eating, drinking, self-care activities like washing and brushing teeth, removing objects from the floor or out of a cupboard, feeding pets, and operating typical devices such as a VCR. Statistical evaluation showed that 10% of the users applied the ARM for more than 4 hours per day, 30% for 2 to 2.5 hours per day, and 60% for less than 2 hours per day, or about 2 hours per day on average. It was noted that ARM users carried out about 40% more ADL-tasks themselves, than did the non-ARM users. In addition, ARM users required about 30% less assistance to carry out those tasks, indicating greater independence. For the ARM users, assistance was mainly required to prepare the specific task, like uncorking a bottle of wine, while pouring and drinking the wine was then carried out by the users themselves. Moreover, ARM users reported an increased feeling of independence and autonomy, which led to a higher level of satisfaction and pride when they accomplished these activities unassisted. Although these benefits of the ARM can not be expressed in terms of money, they are of course of great value.

Remarks: During the investigation ARM users were entitled to 24/7 professional assistance and were not forced to use the ARM. Therefore it is expected that the ARM would (or had to) be used more when the availability of assistance would have been reduced. In addition, the users had the availability of numerous additional technical aids (see Table III), and their homes are furnished with a high degree of home automation. It is therefore likely that an ARM user which lacks these additional aids will (need to) use the ARM for more than the reported 2 hours per day. In addition, expenses on additional ADL aids could be saved.

TABLE II
AVERAGED TIMES (IN HOURS PER DAY) PROVIDED BY ADL ASSISTANT WITH AND WITHOUT THE USE OF AN ARM.

	Without ARM			With ARM			Difference		
	min	avg	max	min	avg	max	min	avg	max
Assistance	2.9	3.7	5.8	1.4	2.8	4.8	0.7	1.2	1.8
ARM usage	-	-	-	0.6	1.5	3.7	0.6	1.5	3.7

2) ARM usage and cost-savings investigation

In 1998, almost parallel to the iRV-study, the Siza Dorp Group, started an independent user study [12]. The main focus of this study was to quantify the net cost-savings on labor-costs of ADL caregivers, due to the reduced ADL assistance required by ARM users. Eight non-ARM users ranging in age from 21 to 37 were selected and were provided with an ARM and trained how to use it. Next, one-week observations of users took place at 3-month intervals, comprising a total of 4 weeks in 12 months. During these observations, the amount and duration of ARM usage, as well as the amount and duration of ADL assistance was recorded (See Table II).

A wide variation in ARM usage, and ADL-assistance required, was noted. This variation was attributed to the cognitive and physical capabilities of each user, and included any lack of desire to use the ARM. Results show that, due to the use of the ARM, at least 0.7 to 1.8 hours "per day" can be saved on the labor-costs of ADL caregivers. Assuming an average hourly rate of €28, for ADL-assistance , this results in individual savings of €7,154 to €18,396 per year per user. A target group study [9] showed that, in the Netherlands, (pop. 16 million) yearly about 80 handicapped qualify for an ARM-.i.e. 0.005‰ of the population. This implies country-wide savings of €0.57M to €1.47M annually. Extrapolating these numbers to a European scale (pop. 400M) implies annual cost savings of €14M to €37M.

Remarks: It can be argued that the measured reduction of 0.7 to 1.8 hours per day on ADL-assistance is conservative for the following reasons. The group of ARM users that were tested has the availability of additional aids, as well as a high degree of home automation. It is therefore likely that an ARM user lacking these additional aids will save more on assistance than the reported 0.7 to 1.8 hours per day. Unfortunately, this study does not report which, or how cognitive and physical limitations impede the use of the ARM. Also, the individual desire and level of determination to use the ARM are important factors governing the degree of ADL-assistance required. It is reasonable to expect that, in the future, once a user has the availability of an ARM, he/she must use the ARM for at least a certain number of hours each day to gain the cost benefit.

The cost for a standard ARM is about €25,000, excluding local sales tax, wheelchair modification and training. Then, with the estimated savings on ADL assistance of 2 to 3 hours per day, this implies a return on investment of about 1 to 1½ years.

B. *Cost-savings of alternative technical aids*

Numerous ADL technical aids exist to carry out a single (or a few) ADL-tasks. These devices are referred to as *task-restricted* aids [6]. Table III gives an overview of such devices and their corresponding cost.

TABLE III
COST OF TASK-RESTRICTED ADL AIDS

Purpose	Example(s)	Cost (€)
Feeding	Handy [13], MySpoon [14], Neater Eater [15], Winsford Feeder [16]	3950 to 7000
Page turner	GEWA BLV-6 [17], Turny [17]	3300
Office assistant or workstation	AFMaster [20]	53000
Door opener	Dorma [18], Besam [19]	1000 to 2000
Curtain opener	Harrison [21]	700 to 1000
Domotics	Homeservant [22], Gewa Prog ||| [17]	1000 to 22000

As the ARM is a versatile multi-purpose rehabilitation robot, designed to be used for almost any task, in an unstructured environment [6], it can replace several, if not all, task-restricted ADL-aids listed in table III. Hence, investing in an ARM saves the cost of task-restricted ADL-aids. It should be noted however, that task-restricted aids are optimized for their specific task. Therefore, in most cases, these devices are more efficient–i.e. more quickly, when carrying out their specific task, than a rehabilitation robot. On the other hand, the ARM is a mobile, wheelchair mounted, rehabilitation robot, whereas task-restricted ADL-aids are stationary. So, using the ARM, tasks can be carried at any location, without the need to invest in multiple task-restricted aids at several locations.

IV. INDIRECT ECONOMIC BENEFITS

The indirect economic benefits of a mobile, multi-purpose rehabilitation robot, and of the ARM in particular, arise when:

a. the professional ADL assistance is optimized,
b. users move to a cheaper residence,
c. users (or e.g. their spouse) start to work (again),

and are discussed qualitatively in the following.

A. *Optimized professional ADL-assistance*

ARM users can manage themselves over a considerable amount of time without assistance. Therefore, the supply of professional ADL assistance, which remains, can be optimized. That is, assistive and preparatory tasks of the professional could be clustered. For example, in the morning, after the user has been assisted to get out of bed, wash and to get dressed, the ADL-assistant could prepare tasks to be completed by the ARM user himself later that day. These preparatory activities could for example be the preparation of drinks (e.g. uncorking a wine bottle), the preparation of food (e.g. unpacking a pizza from its carton box and place it on a plate in the microwave), and setting out medicine. Hence, the ADL-assistant does not need to attend the user repeatedly during the day to carry out just a single small preparatory task.

B. *Cheaper residence*

Many potential ARM users life in communities with 24/7 professional assistance available. In addition, several high-level (and therefore costly) services and facilities, such as state subsidized hairdresser, gardener, store, restaurant and technical service, are available in these communities. An example of such a community is *Het Dorp* ("the village") in Arnhem, the Netherlands [22]. Having the availability of an ARM, users do no longer depend on all these services and facilities. Most ARM users have therefore moved from these communities to residences (private homes) with a low, or moderate level of services and facilities. Currently, about 10 (5%) of the ARM users in the Netherlands still live in communities with services and facilities and about 170 (95%) in homes with low or moderate service level: about 80 users (45%) live at home with their parents, and about 90 users (50%) live independently.

C. *Employment*

As the ARM is a multi-purpose rehabilitation robot it can carry out occupational tasks. Therefore some ARM users are employed, and earn their own income. Most ARM users, who are employed, carry out office tasks, such as, answering telephones, handling mail and operating computers, printers and scanners, see figure 2.

Fig. 2. Carrying out occupational tasks using an ARM. Photo courtesy of FTB, Volmarstein/Wetter, Germany [25].

A good example of a company hiring ARM users is *Nezzo Print & Copy Shop* [23] in Druten, the Netherlands. A few ARM users have even started their own business. These companies (also) offer office services. An example is the company *Apolo* [24], specialized in the development of websites. The economic benefits of working users of rehabilitation robots is obvious. Unfortunately, reliable information on the number of employed ARM users is lacking. From the 13 ARM users in the 1999 study of the iRV (see section III.A.1) 4 users were employed. And 2 users attended a school or college and 7 were unemployed. Unfortunately, this group of 13 ARM users is too small to calculate a reliable prediction of ARM users who could be employed. Further study and analysis of a larger group is therefore required.

Besides professional assistants, frequently the spouse, relatives or friends are providing ADL-assistance to the ARM user. Due to the increased independence of the ARM user, these individuals have the opportunity to work outdoors or start or complete their education.

Unfortunately the single individual savings, and as a result also country wide and Europe-wide savings, due to indirect economic benefits, are difficult to quantify.

V. CONCLUSION

An ARM not only increases the quality-of-life of its users, but also saves costs of labor of professional ADL-assistants, ranging from about €7000 up to €18000 per year. On a European scale annual cost savings range from €14M to €37M.

In addition, the cost of task-restricted aids, ranging from about €1000 up to €53000 per device can be saved, because the ARM is a very versatile device. Besides these direct economic benefits, the indirect benefits, such as cheaper residence of the ARM users and the employment of ARM users, contributes to the return-on-investment on a larger economic scale.

Future work will include more detailed measurements and calculations of direct, as well as indirect economic benefits of the ARM, based on a large(r) group of ARM users.

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