Assessment of Economic Value of Assistive Technologies Through Quality-Adjusted Work-Life Years (QAWLY)

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Abstract. Assistive technologies (ATs) are commonly used to improve the quality of life of persons with disabilities. While their utility to a person is usually clear, their cost-effectiveness or economic value is often unclear. There are no tools for specifically assessing the cost-effectiveness of an AT. Such cost effectiveness analysis is often important in workplace contexts where an employer or other agencies are responsible for providing accommodations. In this paper a tool called Quality-Adjusted Work-Life Years (QAWLY) is introduced to measure how cost-effectiveness of AT can be assessed including considerations of extended work-life and improved quality/productivity at work. Case studies are presented that showcase how QAWLY can be used to provide economic data points to be used for decision making involving AT.

Keywords: Assistive technology · Economic value · Work

1 Introduction

Technological advances in health and social care have led to a plethora of assistive technologies (AT) that enable people with impairments or disabilities to ameliorate their impact to varying extents. There is an increasing awareness that there are many barriers, physical or otherwise, that impede opportunities for work, education, and participation by people with disabilities. Technology has tremendous potential for removing accessibility barriers. For example, mapping and localization systems deployed in public spaces support orientation and wayfinding, or to identify safe paths to traverse for wheelchair users [1–3].

Often ATs are developed with the claim of having the potential to improve the quality of life for people with disabilities [4, 5]. However, an important criteria for AT to be adopted is the consideration of its cost-effectiveness. This paper sets out to determine how one goes about answering such questions. We are interested in determining the economic value of adopting a potential AT for a person with a disability.

Potential tools/metrics for such assessment can be based on prior related work. Quality-Adjusted Life Years (QALY) is a well-known measure that attempts to show the extent to which a particular treatment or system extends life and improves the quality of life at the same time [6–8]. It is a tool aimed at incorporating all the essential

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dimensions of health, ability, and length of life. It combines the effects of health interventions on morbidity (quality of life) and mortality (quantity of life) into a single index. QALY has been largely used by insurance providers to weigh the benefits of a drug or medical treatment for patients [8–10]. It has, however, come under a lot of criticism for its use for assessing disability and related quality of life [10].

Another potential tool for assessing cost effectiveness of AT is the disability-adjusted life year (DALY), which is a measure of overall disease burden, expressed as the number of years lost due to ill-health, disability or early death [11]. It was developed in the 1990s as a way of comparing the overall health and life expectancy in different countries. DALYs are calculated by combining measures of life expectancy as well as the adjusted quality of life during a burdensome disease or disability for a population. DALYs are related to the quality-adjusted life year (QALY) measure; however QALYs only measure the benefit with and without medical intervention and therefore do not measure the total burden. Also, QALYs tend to be an individual measure, and not a societal measure. Both DALYs and QALYs are forms of HALYs or health-adjusted life years. HALYs, including DALYs and QALYs, are especially useful in guiding the allocation of health resources as they provide a common numerator, allowing for the expression of utility in terms of dollar/DALY, or dollar/QALY [12].

To measure how the technology extends work-life and improves the quality of work at the same time for people with disabilities, we introduce in this paper an adaptation to QALY called QAWLY where QAWLY considers work-life instead of length of life.[1] This measure then follows the same process as QALY in determining the impact of technological adoptions on work morbidity and work mortality for people with disabilities. Specifically, this paper determines the value and impact of ATs for people with disabilities for workplaces and shows through case studies how QAWLY could be applied for common AT categories.

2 Introduction to QALY Computation

To calculate QALY, it is necessary to determine by how much not being in health impacts a person's quality of life. QALY's do this by assigning a number between 0 and 1, called a health utility, to the various conditions a person's health could be in. A 0 would represent the lowest possible quality of life, while a 1 would represent the highest possible quality of life. Health utilities are typically derived from surveys, which attempt to determine how much survey participants would prefer to be in one health state as compared to another. Health states do not correspond directly to specific disabilities- they instead represent the degree of impairment a person has in specific, limited categories of functioning (such as mobility, ability to perform tasks, etc.). However, most disabilities share some or all characteristics of a health state.

The steps to compute QALY starts with determining how having a disability impacts a person. This can be accomplished with the help of a survey. There are a number of

[1] QAWLY is an adaptation of QALY instead of DALY despite the similarities in the focus on disability because DALY measures the overall burden of the disease on the population as a whole, while QALY allows for determining the impact of AT on individuals.

survey instruments adopted for measuring the health utility, namely EQ-5D-3L developed by the EuroQol Group, the 8-item Health Utilities Index Mark 3 scale (HUI3), and the 6-item SF-6D scale developed from SF-36 [13]. The most common questionnaire is EQ-5D-3L, where three levels of severity are assigned to five dimensions of quality of life, namely, mobility, self-care, usual activities, pain/discomfort, and anxiety/depression. Similarly, HUI3 considers eight attributes of 5 to 6 levels. Other questionnaires to evaluate at-work disability and productivity loss are the Work Limitations Questionnaire (WLQ-25) [14] and Workplace Activity Limitation Scale (WALS).

After determining the health utility, the decimal is multiplied by the number of years (quantity of life) that the intervention is expected to cover. The quantity can be the number of years by which the system extends work-life, i.e., the number of years a person expects to use the system over their lifetime in being able to work effectively.

More formally, a person who is expected to benefit from a health intervention through an increase in health utility of u_1 to u_2 and a lifespan change from t_1 to t_2 is said to have gained $(u_2t_2 - u_1t_1)$ QALYs. This concept is illustrated in Fig. 1.

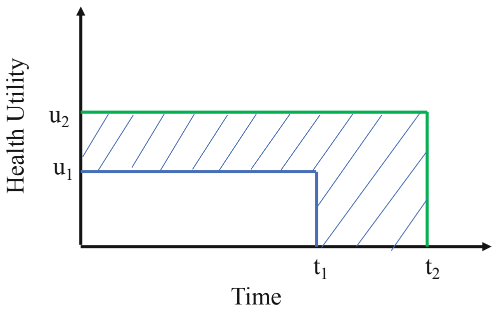

Fig. 1. QALY illustration

If the cost of an intervention is c, a cost effectiveness ratio (CER) is computed as

$$\text{CER} = \frac{c}{(u_2t_2 - u_1t_1)} \tag{1}$$

An intervention with a lower CER is considered to be a more cost effective intervention. This implies lower costs and/or higher utility is desirable. CERs have also been used with thresholds with interventions approved only when below a set threshold. In the past, the National Institute of Health and Clinical Excellence (NICE) in the UK has used pound 20,000–30,000 as a CER threshold.

Another related metric used with QALY is that of incremental cost effective ratio (ICER), it is useful if comparing two interventions. It is the incremental costs per number of QALYs gained and can be expressed as:

$$\text{ICER} = \frac{c_2 - c_1}{u_2t_2 - u_1t_1} \tag{2}$$

where c_2 and c_1 are the respective costs of the two interventions.

3 Adaptation of QALY to QAWLY

This section takes the existing theory on QALY and modifies to QAWLY. This adaptation helps determine the impact of AT in extending work-life and improving the quality of work. A major modification needed is to introduce the concept of work-life (the number of years a person wishes to stay in the workforce) as opposed to lifespan. Intuitively, a long-term investment on AT may not be cost effective if a person's work-life is expected to be much shorter than the useful-life of the AT. With this adaptation, we modify the lifespan based expression for time t used previously to the expression, $t(i) = \min(t, \mathit{worklife}(i))$, where $\mathit{worklife}(i)$ is the number of years left for a person i to be able to work till a widely accepted retirement age, as measured for a person with no disabilities from the population. If R is denoted this retirement age, then $\mathit{worklife}(i) = \max(R - \mathit{age}(i), 0)$ where $\mathit{age}(i)$ is the age of a person.

Consider an existing AT, say A, with a utility score u_A and another improved AT under consideration called B with a utility score u_B. Assume that A has a useful life of $t_A(i)$ for a person i going forward and B will have a useful life of $t_B(i)$. The QALYs gained by switching to B is then $u_B t_B(i) - u_A t_A(i)$. Consider that the total cost to acquire AT A and B are c_A and c_B. The incremental cost effectiveness ratio (ICER) then is the ratio $(c_B - c_A)/(u_B t_B(i) - u_A t_A(i))$. ATs with smaller values of ICER are considered more cost-effective than those with larger values. If an AT is being considered over a status quo with no AT, $c_A = 0$. The values of u_A and $t_A(i)$ could be the current utility for person i without an AT and $t_A(i) = t_B(i)$ because we are interested in comparing over the same time-frame as AT B. This gives a cost effectiveness ratio (CER) of any AT to be $c/(\Delta u t(i))$ where c is the cost of the AT, Δu is the change in utility (or impact) by the adoption of this AT and $t(i)$ is the useful-life of the AT (capped by work-life) over which it is assumed to provide a constant utility to the user. This assumption has been common in prior work too such as [6]. If utility is likely to change, then this can be construed as the average utility over this period.

Next we show a few examples of how QAWLY can be used in practice. The first step involves benchmarking with existing AT followed by incorporation of work-life.

Rollator: The rollator (also called a walker) is a commonly used mobility aid. It costs in the range \$50–400 depending on construction quality and features. Its lifetime typically ranges from 3–5 years. In the study [6], the EQ-5D-3L instrument[2] showed a change in utility of about 0.05. Utilizing values from these ranges, the CER value with rollators can be computed (shown in Table 1) as 1000.

Hearing Aids: A hearing aid is also a common AT used to improve hearing capabilities. Cost of a pair of hearing aids (for both ears) typically ranges from \$2000 to as much as \$8000 depending on features, quality, and additional services provided with them. Lifespan of these aids is typically 3–7 years. In the study [6], a change of utility of 0.186 was determined using the HUI3 instrument (HUI3 is considered better than

[2] The best-case scenario would be to use modified WLQ-25 or WALS survey instrument generated values of health utility in the context of AT adoption. However, published utility estimates with AT adoption are only available using EQ-5D-3L instrument.

Table 1. CER benchmarking using known parameters from [6]

AT	Cost ($) C	Change in utility Δu	AT useful-life (years) t	CER
Rollator	200	0.05	4	1000
Hearing aid	2500	0.186	5	2688

EQ-5D-3L for capturing sensory impairments). Using values from these ranges, a CER of 2688 can be computed as shown in Table 1.

These two case studies with utility weights computed previously provide for an effective benchmark to compare with other AT products.

Now assume that the two ATs of Rollator and Hearing Aids were being used by persons for work scenarios and are supported by their employers as accommodations. Table 2 shows the CER computations for workers with three different ages: 60, 63, 67 in a country with a typical retirement age of 66.

Table 2. CER computations for varying work-life

AT	Cost ($) c	Change in utility Δu	AT useful-life (years) t	Work-life	CER
Rollator (age 60)	200	0.05	4	4	1000
Rollator (age 63)	200	0.05	4	3	1334
Rollator (age 67)	200	0.05	4	0	∞
Hearing aid (age 60)	2500	0.186	5	5	2688
Hearing aid (age 63)	2500	0.186	5	3	4480
Hearing aid (age 67)	2500	0.186	5	0	∞

These results show that when ATs are supported with a work-life shorter than the useful-life or lifespan of the device, the CERs increase to signify that the investment may not be as sound as compared to a younger person, unless the AT can be reused by someone else. These case studies also show the impact of maintenance of the AT can have on CERs; each year of life added to an AT is significant, especially for those ATs that have a small useful-life to begin with.

4 General Principles of Applying QAWLY

To simply exposition in general terms, we introduce the notion of cost per work-life year c_{wy} for any AT. This is simply, $c/worklife(i)$. For any AT to be cost-effective, the necessary condition for c_{wy} can be expressed as:

$$c_{wy} \leq \gamma_{CER} \Delta u \qquad (3)$$

where γ_{CER} is the maximum CER that is deemed acceptable for that class of AT. For example, using c_{wy} results from Tables 1 and 2, for Rollators, or perhaps any mobility device, γ_{CER} could be in the range of 1000–1500 whereas AT for hearing challenges or in general sensory impairments could have a γ_{CER} in the range 2500–5000.

Intuitively, the condition above provides a price ceiling for an ATs adoption given cost-effectiveness of prior AT from which γ_{CER} is derived. A larger benefit in utility to the end-user allows for greater annual costs that may be acceptable to the end-user or those who support them (such as insurance and employers) that can be used for investment in research and development to develop the AT.

An alternate consideration in the design of AT is to look at how much benefits it must provide, for it to be under serious consideration. This can be answered by the condition for Δu expressed as: $\Delta u \geq c_{wy}/\gamma_{CER}$, with $0 \leq c_{wy} \leq \gamma_{CER}$.

Case studies with different ATs (computations shown in Table 3) are described next to show how the above theory of QAWLY can be used. To keep the exposition simple, it is assumed in all cases that work-life of the potential user is greater than the useful-life of the AT. When this is not true, the below calculations should adjust the number of years the AT will be used in computing annual costs.

Screen Reader: The JAWS screen reader costs \$90/year. If a γ_{CER} of \$2500 is used (CER for sensory impairment from Table 1), the potential increase in utility comes out to 0.036. This indicates that the JAWS screen reader is cost effective as long it provides capabilities that result in at least a utility weight increase of about 4%.

Smartphone App: Apps can range from free to up to \$100 a year. For a free smartphone app we pick the SeeingAI app that allows blind individuals to recognize objects using a camera. With a γ_{CER} of \$2500 (or any value for that matter), such an app is always cost-effective. The Seeing Eye GPS, an app that provides wayfinding information specific to blind individuals, costs \$72 a year. Using the same γ_{CER}, this app can be considered cost-effective with a utility increase of 0.029 or about 3%.

Ergonomic Chair: The Herman Miller Mirra costs \$1000 and comes with a 12-year warranty, for an annual cost of \$83.33. Assuming it is for a user who will work longer than 12 years, using a γ_{CER} or 1000 from Table 1 for a mobility impairment AT, the minimum utility increase needed is 0.0834. An ergonomic chair therefore is considered effective as long it results in a utility increase of about 8%.

Wheelchair Ramps: Average wheelchair ramps for homes and small businesses (mostly individual use) cost around \$2000 with a 10-year warranty, although there is a wide range in terms of where they are used and construction materials, length and height. With an average annual cost of \$200 with a γ_{CER} of 1000, the minimum utility increase needed is 0.20 or 20%.

Wheelchair Ramps (Shared Use): Sturdy ramps built on a permanent basis for use by many individuals cost around \$7500. These can last 20 or more years without much maintenance. If 5 employees at a workplace use a ramp, the annual cost is \$75. With a

γ_{CER} of 1000, the minimum utility increase needed per person is 0.075. The same ramp with only one user would have needed a utility increase of 0.375. Thus, ATs with more number of users can be cost effective even if upfront costs are greater due to improved quality or scale needed.

Wayfinding Infrastructure (Shared Use): Recent apps for indoor navigation and wayfinding such as NavCog [1], GuideBeacon [2, 3] complementing outdoor GPS-based apps require infrastructure modifications such as the embedding of wireless devices called beacons typically at a density of about 10 per 1000 sq. ft. A five-story office building with 5000 sq. ft every floor will require 250 beacons. Addition beacons at entrances, stairways, and emergency exit locations may require another 50 beacons. Each beacon can cost around $25 and should last around 10 years with $5 in battery replacements over this life, requiring a cost of $9000 just for the beacon hardware. Assuming another $11,000 in cost for R & D and app development totaling $20,000 in costs resulting in an annual cost of $2000/year. Assuming 50 users use such a system (for example an employer of blind individuals at a manufacturing site), with a γ_{CER} of 2500, a minimum utility increase of 0.016 per person. If only one user uses this system, a utility increase of at least 0.8 would be needed. Such AT with large infrastructure costs need amortization of costs over a large number of users to be cost effective. If such a large user base exists, the minimum utility increase needed is quite minimal.

Table 3. Computing utility increases for AT adoption

AT	Annual cost ($) c_{wy}	Assumed minimum CER threshold γ_{CER}	Minimum utility increase (Δu) necessary for adoption
Screen reader	90	2500	0.036
App – seeing AI	0	2500	0
App – seeing eye GPS	72	2500	0.029
Ergonomic chair	83.34	1000	0.0834
Ramp (individual use)	200	1000	0.20
Ramp (shared use)	75	1000	0.075
Wayfinding (shared use)	40	2500	0.016

5 Limitations and Future Work

This work's primary contribution has been in connecting health utility and the concept of work-life as it applies to AT to assess cost effectiveness. Most health utility capturing instruments include various aspects of life, not just the work component. Thus, a better characterization of cost-effectiveness of AT for work should use instruments specific to work. The WALS (specifically for those with Rheumatoid Arthritis) and the WLQ-25 are potential options that need to be considered in future with the QAWLY model developed in this work to provide a more accurate picture. Because those instruments were not developed to be used in assessing ATs, they may need to be modified. This work has also been limited by being able to use only two ATs (and their associated utility values) for benchmarking CERs, with only one for mobility impairments and one for sensory impairments. Benchmark CER scores would have more confidence if more ATs could be added to Table 1. Computation of minimum utility benefits needed for a specific AT are more accurate for individual use ATs as there is less uncertainty about the number of potential users. For shared use AT such as ramps and navigation infrastructure, judging the number of potential users adds uncertainty and the best approach would be to work with a range of maximum and minimum likely users using past data. Given these limitations, QAWLY as introduced in this paper, is still a work in progress and much future work needs to be done in terms of designing instruments to assess utility weights for work, and deploying these instruments widely to gather statistics from individuals with a wide range of disabilities.

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