

Measuring Economic Benefits of Built Environment Accessibility Technologies for People with Disabilities

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Abstract. Given the challenges of wayfinding in large indoor built environments, especially for persons with disabilities (PWDs), a new class of accessible technologies called built environment accessible technologies (BEAT) are being developed. Such technologies are envisioned to help achieve product and opportunity parity for PWDs. The impact and adoption of these BEATs depends largely on clear and quantifiable (tangible and intangible) economic benefits accrued to the end-users and stakeholders. This paper describes the results of a survey conducted to measure potential benefits in terms of quality of life and quality of work life (work productivity) by increased accessibility provisions within built environments as it relates to navigation for PWDs and those without disabilities. Results of this work indicate that BEATs have the greatest potential to improve mobility and exploratory activities for people with disabilities, exploratory activities for people without disabilities, and improve job security for everyone.

Keywords. Assistive & Accessible Technology, Built environment, Indoor navigation, Economic Benefits, People with Disabilities

1. Introduction

Technological advances in areas such as, but not limited to, artificial intelligence, digitalization, automation, robotics, biometrics and big data have led to major cultural changes that transformed how people live and work, with impacts on quality of life and labor markets. Benefits accrued to the general population have not necessarily been realized by under-represented populations, which include persons with disabilities (PWDs). One area where PWDs have been historically disadvantaged is efficient access within and around built environments due to fixed and time-varying barriers, improper wayfinding signage, or the inability to access wayfinding information.

The level of accessibility in built environments in most communities meets minimum requirements at best [1]. To enable PWDs to fully participate in society, a holistic change is needed in common-use spaces. These changes will enable people of

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all ages and abilities to participate equally in social and economic life while creating healthy and socially sustainable communities. Accessible spaces reduce barriers to using services and amenities, increase the range of regular activities persons can conduct independently, and enhance user's health and well-being through increased opportunities of physical activity-levels. From a macroeconomic perspective, as of 2021, only 31.4% of working age Americans (aged 16 to 64) with disabilities were employed vs. 72.5% of Americans without disabilities [2]. Enabling environments can be instrumental for the integration of PWDs in workforces and increased productivity. The gross domestic product (GDP) could increase up to \$25 billion for each 1% improvement in PWD employment statistics [3]. Globally, in developing countries, 80% to 90% of PWDs of working age are unemployed, whereas in industrialized countries the figure is between 50% and 70%. In most developed countries, the official unemployment rate for persons with disabilities of working age is at least twice that for those who have no disability [4].

To achieve product and opportunity parity for people with disabilities (PWDs) in the context of indoor mapping and navigation, Built Environment Accessibility Technologies (BEATs) are being developed. The impact and adoption of these BEATs depends largely on clear and quantifiable (tangible and intangible) economic benefits accrued to the end-users and stakeholders. *This paper describes and evaluates an economic survey developed to measure potential benefits in terms of quality of life and quality of work life (work productivity) by increased accessibility provisions within built environments as it relates to navigation and wayfinding for PWDs.* Envisioned users of BEATs include those with visual or mobility impairments (blind, low vision, wheelchair users, cane users, etc.), cognitive, hearing impairments, older adults as well as other categories of PWDs including the general population with planning and navigation assistance needs.

2. Built Environment Accessibility Technology (BEAT) System Description

This work is motivated by a specific BEAT system called MABLE (Mapping for Accessible Built Environments) under development by the authors. This BEAT consists of two components: a) digital accessibility maps for indoor environments with an interface for assessing, planning, and navigating within them based on the affordances and capabilities of the user, and b) an indoor navigation system within MABLE called CityGuide that uses information from created digital maps to provide fine-grained, customized, turn-by-turn navigation within or across indoor and outdoor spaces. The various applications of the MABLE BEAT system include emergency management, remote assistance, transit, wayfinding, tourism [5] in large indoor public spaces such as shopping centers, convention centers, stadiums, airports, hospitals and private or access controlled indoor spaces such as company campuses, commercial multi-story buildings. While the creation of the MABLE BEAT system is motivated to benefit PWDs, general population is expected to greatly benefit based on the applications and their needs. An example of the application of the system is illustrated in Fig 1. An objective to reach the destination using the shortest path (dotted lines) may not always be feasible due to temporary obstacles, thus the system provides the safest path (green line) although a longer path, to navigate to the destination.

The intent of developing BEATs is clearly to benefit PWDs in navigating unfamiliar places. However, an important criterion for BEATs to be widely adopted is the consideration of economic benefits, which can be measured as cost-savings or return in

investments. This paper sets out to determine the economic value of adopting a potential BEAT for PWDs and is applicable to the entire class, not limited to just a specific BEAT like MABLE.

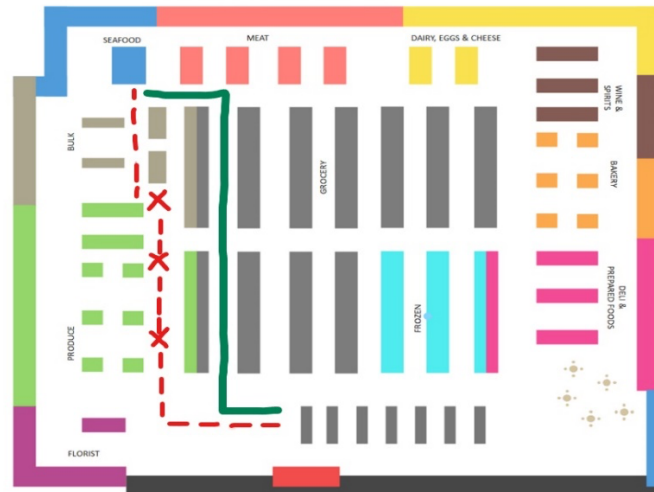


Figure 1. System Application at a supermarket. Photo credit:edrawsoft.com

3. Measuring Economic Benefits

3.1. Objective

The objective of the survey is to evaluate and analyze the economic benefits of adopting accessible and assistive technologies for indoor navigation in built environments in terms of improvements in quality of life and in quality of work.

3.2. Design of Survey

The survey is an adaptation of commonly used survey instruments adopted for measuring health states such as EQ-5D-5L developed by the EuroQoL Group and some others-Health Utilities Index Mark 3 scale (HUI3), SF-6D etc. This questionnaire evaluates not just Quality of Life but also Quality of Work Life, addressing factors that affect productivity at work. It follows the construct to calculate Quality Adjusted Life Years (QALY) which 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], [7], [8], [9]. The survey is designed to have two parts, one to measure the *current* health state (quality of life) and work productivity (work life), and two to measure *potential changes* to health states and work life based on adopting BEATs. Both parts of the instrument are constructed with identical 10 questions, where five questions relate to general health and the next five relate to work life. All questions are provided with 5 levels of answer choices, 1 always being the best state and 5 always being the worst state. The structure is similar to that of EQ-5D-5L in which 5 questions focus on quality of life, and the 5 different answer choices mimic the main concepts of the EQ instrument. The flow of the survey is designed to skip work productivity (or work life) questions for

respondents who are not working. Fig 2 provides a schema of the questionnaire. As in [10], the survey instrument is used to generate useful insights into adopting BEATs in improving overall changes in quality of life and work life.

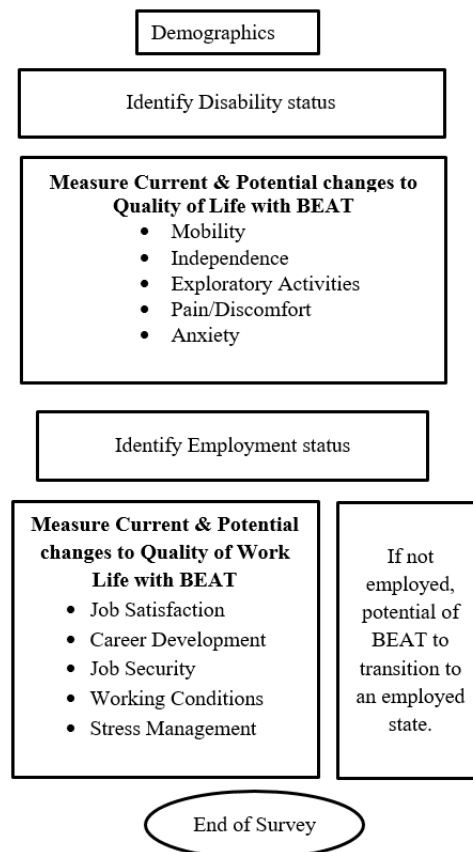


Figure 2. Design of the survey instrument.

3.3. Data Collection

Envisioned users of the system include those with visual or mobility impairments (blind, low vision, wheelchair users, walker users, etc.), cognitive, hearing impairments, older adults as well as other categories of PWDs including the general population with planning and navigation assistance needs.

This study is approved by Kansas State University (KSU) IRB protocol# 10616. Using Qualtrics through KSU, the survey was sent to a) students representing a savvy group comfortable with technology mostly with no disability, and b) individuals known to have a disability (disability types mentioned above) through prior interactions in research studies (who were also encouraged to pass it on to others they know or their care givers). Both groups could have varying employment status, ranging from working full-time, part-time, or not working at all. The survey was sent in May 2023 and participants were given the option of being entered into a drawing to win a gift card. A description of the BEAT system being developed was provided in the survey so that

survey takers could make an informed choice. A total of 40 responses were collected and these were split as results for those with a disability and those without a disability.

The 2019 American Community Survey published by the US Census Bureau determined 12.7% of the US population has disabilities. The disability population has 71.2% individuals above the age of 65 years and 25.9% are employed as shown in Table 1. US national statistics for persons with disabilities on age, gender, race, employment provide a benchmark to compare the results of the survey.

People with disabilities constitute 22% of the sample, with types of disabilities identified as vision, mobility and cognitive. Majority of the respondents are below the age of 35 years (68%), male (62%), and represent whites (73%). 78% are employed with almost equal distribution between part-time and full-time employment status. Those who are not employed indicated an even split in the potential of BEATs to be helpful in transitioning to an employed state. Table 1 summarizes the background characteristics of the sample.

Table 1. Demographics

Characteristic	Survey Count (%)	US PWD %
Age		
Less than 21 years	10 (27%)	6.3%
21-35 years	15 (41%)	6.7%
36-45 years	4 (11%)	12.4%
46-55 years	3 (8%)	
56-65 years	3 (8%)	
Above 65 years	2 (5%)	71.2%
Gender		
Male	23 (62%)	12.6%
Female	13 (35%)	12.8%
Non-Binary	1 (3%)	
Race		
Asian	7 (19%)	7.2%
White	27 (73%)	13.2%
Hispanic	3 (8%)	9.1%
Disability		
No	29 (78%)	87.3%
Yes	8 (22%)	12.7%
	Vision-5, Mobility-3, Cognitive-1	Vision-2.3%, Mobility-6.9%, Cognitive-5.2%
Employment		
No	8 (22%)	70.3%
Yes	29 (78%)	25.9%
	Full-time-13, Part-time-16	

3.4. Results

Quality of life is measured using five dimensions: mobility, independence, exploratory activities, pain/discomfort, and anxiety/depression. Quality of work life is defined by job satisfaction, career development, job security, working conditions and stress management at work. The levels range from 1 to 5 where 1 is the best always for any dimension considered. Table 2 provides a comparison of ratings or levels for each dimensions pre and post adoption of a BEAT for people with disabilities and without.

Levels 2 to 5 represent some problems with the dimensions considered such as lower mobility, independence to not mobile or independent at all (rating 5), i.e., not ideal cases. Comparing level 1 (perfect health state and work-life) across dimensions, BEATs are expected to improve both quality of life and work life across all dimensions. For example, row corresponding to level 1 of Table 2 can be interpreted as: the disability community survey takers imply before a BEAT adoption they do not have excellent mobility, are not fully independent, are not able to fully explore activities beyond their routine, are not super comfortable in unknown indoor environments, and two indicated they are never anxious or stressed. After a BEAT adoption, three from the disability group feel mobility is at its best, feel independent, are fully able to explore, are comfortable and two indicate anxiety is removed. Similarly, for the people without disabilities group, 14 indicate their mobility is excellent with a BEAT as opposed to 10 without a BEAT.

Weighted average benefits are determined pre- and post-BEAT for each dimension by multiplying the levels and pre/post values and dividing by sum of all levels. The cardinality of the levels results in a lower post weighted average, which indicates benefits are accrued with a BEAT. Percentage increase in weighted average benefits with BEAT are pronounced in quality of life over quality of work-life. The disability group indicates they benefit the most with mobility using a BEAT (rank #1), the non-disability group benefit the most in exploratory activities, and a BEAT does well in affording job security in the work-life realm.

Table 2: Measuring Weighted Average Benefits: pre- and post-BEAT adoption.

	Quality of Life for People with Disability									
	Mobility		Independence		Exploratory Activities		Pain/Discomfort		Anxiety/Depression	
	pre-	post	pre-	post	pre-	post	pre-	post	pre-	post
1	0	3	0	3	0	2	0	1	2	2
2	1	3	1	3	1	4	2	4	1	4
3	4	1	4	2	4	1	3	1	2	2
4	2	0	1	0	1	0	1	1	1	0
5	1	0	1	0	2	0	1	0	2	0
N/A	0	0	0	0	0	0	1	1	0	0
Total	8	7	7	8	8	7	8	8	8	8
Weighted Average Benefits	1.8	0.8	1.5	1	1.9	0.9	1.5	1.1	1.6	1.1
%increase in Weighted Average Benefits	-56		-35		-54		-27		-33	
Ranking of Weighted Average Benefits	#1		#3		#2		#5		#4	

	Quality of Life for People with No Disability									
	Mobility		Independence		Exploratory Activities		Pain/Discomfort		Anxiety/Depression	
	pre-	post	pre-	post	pre-	post	pre-	post	pre-	post
1	10	14	9	14	10	5	10	12	8	13
2	5	2	7	3	3	6	5	4	8	2
3	9	3	6	2	8	2	5	2	3	3
4	1	3	2	1	3	2	2	2	2	2
5	1	0	1	0	2	0	2	0	4	1
N/A	0	3	0	4	0	4	2	5	1	4
Total	26	25	25	24	26	19	26	25	26	25
Weighted Average Benefits	3.7	2.6	3.6	2	4.1	2.1	3.5	2.3	4.1	2.6
%increase in Weighted Average Benefits	-30		-44		-50		-36		-36	
Ranking of Weighted Average Benefits	#4		#2		#1		#3		#3	

	Quality of Work Life									
	Job Satisfaction		Career Development		Job Security		Working Conditions		Stress Management	
	pre-	post	pre-	post	pre-	post	pre-	post	pre-	post
1	9	11	6	6	7	7	9	12	7	8
2	6	4	9	9	4	5	6	4	6	6
3	8	6	6	3	4	4	7	2	8	6
4	2	1	0	2	2	3	2	2	4	3
5	1	2	2	1	4	0	1	2	1	1
N/A	0	2	3	5	4	7	0	0	0	2
Total	26	26	26	26	25	26	25	22	26	26
Weighted Average Benefits	3.9	3.4	3.5	3.1	3.7	2.7	3.7	2.9	4.3	3.7
%increase in Weighted Average Benefits	-12		-12		-25		-20		-14	
Ranking of Weighted Average Benefits	#4		#4		#1		#2		#3	

4. Discussion

There are many assistive technologies already developed, tested and adopted by people with disabilities. For example, people who are blind can easily navigate using a \$35 cane. Familiarity of space and routine activities provide comfort and stability in accomplishing tasks and goals. However, when it comes to navigating unknown large indoor spaces, a system needs to be in place to provide people with disabilities the same access as that of people without disabilities. A BEAT called MABLE is proposed to level the playing field across disabilities for navigational needs and even enhance the quality of life and work-life for people without disabilities. A survey designed to measure economic benefits with a BEAT in terms of certain dimensions of health translating to quality of life and other dimensions related to work, shows that BEATs do have the scope to benefit both people with and without disabilities. Benefits can magnify based on economies of scale and scope, where economies of scale relates to a large user base while scope relates to various uses of the system. BEATs promise to satisfy on both the counts based on the design and its applicability.

The survey results affirm improvements in quality of life and work-life with BEATs for people with and without disabilities. However, results can be more nuanced, intuitive and accurate with a sample more heavily tilted towards people with disabilities. The current results are dominated by people without disabilities. The legitimacy of the results are preserved because a necessary condition of BEAT adoption is increased benefits to people without disabilities while the sufficient condition is benefits to people with disabilities.

Some interesting and perhaps unexpected findings are the ranking of dimensions that affect the groups. For example, it might be expected that a BEAT would alleviate anxiety considerably for people with disabilities. New large indoor spaces can be disorienting, stressful and quite challenging, thereby triggering anxiety. Based on this reasoning, the weighted average benefit of using a BEAT should rank anxiety at the top. However, the results suggest improvements in mobility and exploratory activities with a BEAT are proportionally even greater than other dimensions. The reasoning could be that they believe if technical challenges are solved, the corresponding anxiety afforded by the challenges could be absolved. The other reasoning to explain this result could be that people with disabilities attribute stress and anxiety to multiple factors that transcend navigating an unknown space. In the same vein, employed people with disability or without have an array of challenges related to work-life, that marginal benefits afforded by BEAT can be very low. This would explain the impact of BEATs being more pronounced in improving quality of life over work-life.

Adoption of BEATs requires an analysis of both benefits and costs of establishing the system. This paper focuses on measuring benefits. Costs can be easily determined and will be relegated to future work. There are other directions that can be explored such as calculating Quality Adjusted Life-Years (QALY) based on the foundations of this work. QALY can be further used to determine incremental cost-effectiveness ratio when two different technologies need to be compared and evaluated.

5. Conclusion

The results of this paper show that BEATs will be instrumental in affording people with and without disabilities greater mobility, independence in locating amenities, ability to

explore activities in new spaces, relieve discomfort and anxiety to collectively improve their quality of life. In the work-space, BEATs can improve satisfaction with jobs by helping meet some of the demands of mobility, helping with career advancement by enabling new opportunities, improving job security, and providing accessibility to amenities, while alleviating stress related to workplace commute and travel. While benefits are more pronounced with Quality of life over Quality of Work-Life, BEATs have been identified to be helpful in transitioning to an employed state for those who are currently not employed. As the system develops, further iterations of the study will be helpful in attesting to the benefits of BEATs.

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