Wheelchair Evaluation

MIT D-Lab
Comprehensive Initiative on Technology Evaluation
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COVER: A WHEELCHAIR USER TESTING OUT SKILLS ON A NEW WHEELCHAIR. PHOTO: JULIA HEYMAN

The Comprehensive Initiative on Technology Evaluation (CITE) at MIT is a program at MIT D-Lab dedicated to developing methods for product evaluation in global development. CITE is led by an interdisciplinary team and draws upon diverse expertise to evaluate products and develop an understanding of what makes products successful in emerging markets.

MIT D-Lab works with people around the world to develop and advance collaborative approaches and practical solutions to global poverty challenges. The mission is pursued through an academic program, research groups; and innovation practice.

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TABLE OF CONTENTS

LIST OF ACRONYMS

CITE - Comprehensive Initiative on Technology Evaluation
CLASP - Consolidating Logistics for Assistive Technology Supply & Provision
EMA - European Medicines Agency
FDA - Food and Drug Administration
FWM2 – Free Wheelchair Mission Generation 2 wheelchair
FWM3 – Free Wheelchair Mission Generation 3 wheelchair
HERL – Human Engineering Research Laboratories
ISO - International Organization for Standardization
ISWP - International Society of Wheelchair Providers
LDS – Latter Day Saints wheelchair
MAF Motivation Active Folding wheelchair
MRT – Motivation Rough Terrain wheelchair
PLD – Plaid wheelchair
UCP – UCP Expression wheelchair
UCPW - United Cerebral Palsy Wheels for Humanity
UGM - Universitas Gadjah Mada
RR – RoughRider wheelchair
STD – INTCO Standard wheelchair
WHO - World Health Organization
WST - Wheelchair Skills Test
WUV - Wheelchair User Voice

EXECUTIVE SUMMARY

Wheelchairs are an assistive technology that play an essential role in providing people living with disabilities the opportunity to be productive members of their society. In low-resource settings, a lack of access to well-designed, appropriate wheelchairs, with proper training and maintenance, prevent many of those living with disabilities from becoming more mobile and engaged in their communities. The MIT Comprehensive Initiative for Technology Evaluation (CITE) team conducted this research study to evaluate the design and performance of eight commonly distributed wheelchairs in low-resource settings, with the majority of this research being conducted in Bali, Indonesia with a local wheelchair distribution organization. At the time of the study, the organization was piloting a program to provide wheelchairs from several different manufacturers to their client base following a standardized protocol, allowing for direct comparisons between wheelchair types. In this study, the team used a mixed methods research approach including a series of interviews, skills test, laboratory tests, and sensors that were attached to the wheelchairs.

The results of this study highlight the complexity of the design, distribution, and usage of wheelchairs in Bali, Indonesia. During the technical testing phase of this evaluation, only one of the wheelchairs passed the International Organization for Standardization (ISO) 7176 minimum safety and performance metrics. The varying modes of failure in the chairs call attention to the difficulties in designing and manufacturing high-quality chairs that also meet a wide range of needs. This also highlights the need for more rigorous and improved testing standards. The wheelchair user skills test portion of the evaluation involved users testing their ability to complete a standard set of skills with different wheelchairs, and largely, the results show that no wheelchair is a one-size-fits-all solution with different strengths and weaknesses for the chairs. The CITE team observed low correlation between cost of wheelchair and performance of chair. Through interviews and sensor data analysis, it was observed that users had low wheelchair usage, with many users self-reporting traveling less than 500 meters/day and sensor data showing average daily distances of 77-741 meters/day, depending on the chair.

The results of this evaluation call for continued improvements in the design and provisions of wheelchairs, as well as further standards and accountability for wheelchairs. This evaluation highlights how a variety of factors including cultural context, training, user skills, and more can contribute to the adoption and impact wheelchairs shave on people living with disabilities.

SECTION 1 - INTRODUCTION

The Comprehensive Initiative on Technology Evaluation (CITE) at MIT D-Lab is the first-ever program dedicated to developing methods for product evaluation in global development. CITE is led by an interdisciplinary team at MIT and draws upon diverse expertise to evaluate products and develop a deep understanding of what makes different products successful in emerging markets. Our evaluations provide evidence for data-driven decision-making by collaborating with development workers, donors, manufacturers, suppliers, and consumers themselves.

During 2017 and 2018, CITE researchers evaluated wheelchairs for use in low-resource settings in partnership with research universities and distribution partners. While a wide range of assistive technologies exist, this study focuses on assessing manual wheelchairs through CITE's "3-S" evaluation framework: suitability, scalability, and sustainability.

The evaluation aimed to compare technical performance of eight wheelchairs, which are distributed widely in developing country contexts, using information gathered from low-cost sensor technology, wheelchair skills tests, and user surveys. The principal goal of this research and the resulting report is to provide information to donors, development agencies, non-governmental organizations, government ministries, and programs to help them make better decisions to meet wheelchair user needs, and to provide information to people with disabilities so that they can advocate on their own behalf. A secondary goal is to inform wheelchair designers and manufacturers about opportunities to improve their products in the coming years. Some of the primary research questions that CITE sought to answer during this evaluation include:

- Does the type of wheelchair a user has affect their usage?
- Do different wheelchairs allow users to perform different skills?
- Does the cost of the wheelchair correlate with its usability and performance?

The CITE team evaluated eight different wheelchairs distributed by different wheelchair providers. CITE researchers conducted mixed methods research through interviews, skills tests, and attaching data loggers to the wheelchair to monitor wheelchair usage. The majority of the testing was conducted in Bali, Indonesia. Bali was selected as the location for this research study primarily because the Coordinating Logistics for Assistive Technology Supply and Provision (CLASP) program was piloting its initiative to distribute a variety of wheelchairs from different manufacturers through one distribution organization. This model reduced potential biases from confounding factors since provision and trainings were standardized across wheelchair types, creating a favorable environment to test the technical performance of different wheelchairs.

In Indonesia, the CITE team worked closely with non-governmental organizations (NGOs) Puspadi Bali and Access Life Bali who conduct extensive work with people living with disabilities, and with a research data collection team from Universitas Gadjah Mada (UGM). Additionally, the CITE team collaborated with the non-profit United Cerebral Palsy Wheels for Humanity (UCPW) and the UCPW initiative CLASP.

Overview of CITE Methodology

The wheelchair evaluation is modeled after the CITE methodology, which consists of three core research lenses: suitability (S1), scalability (S2), and sustainability (S3). Suitability refers to the technical suitability of the product through lab-based and field-based testing of key attributes. Scalability refers to the ability for these technologies to scale, particularly examining the supply chains and distribution models for products. Sustainability refers to the organizational models that govern distribution and look at sales, trainings, and support to ensure products can continue to have impact. In order to evaluate products through these lenses, the CITE research team has developed guidelines that focus on including technical performance, ease of use, availability, affordability, demand generation and environmental impact.

Why Wheelchairs?

Wheelchairs are an assistive technology and an important precondition to enjoying human rights. Few technologies can have as transformative an impact on beneficiaries as wheelchairs. Independent mobility can allow users to engage with society in a fundamentally different way. Wheelchairs used in low-resource settings have enabled people with disabilities to attend school, travel independently, and participate in income-generating activities. However, in the international development context, people with disabilities are typically an economically and socially disadvantaged population and rely on government organizations or NGOs to provide wheelchairs. Some countries, such as Indonesia, have been actively increasing their annual spending toward wheelchair provision through the Ministry of Health, which has been shown to decrease long-term medical costs. However, since wheelchair provision relies primarily on donor funding, decisions about wheelchair provision tend to be made by NGOs and donors rather than end users. This makes it critically important to evaluate user preferences and understand the strengths and weaknesses of wheelchairs to allow decision-makers to make better purchasing and policy decisions. Poorly implemented programs to distribute wheelchairs through international aid have been largely unsuccessful in having impact, with many of the wheelchairs becoming disadopted, broken, or sold[1].

Complexity in Distribution and Provision

Effective distribution of wheelchairs to meet the needs of beneficiaries is a complex issue due to the intricacies of how product provision occurs. Many organizations that work in the sector offer a full range of services from wheelchair design to training to follow-up care. Improved wheelchair technology plays a large role in the impact and many improved wheelchair designs have been developed over the past few decades to address previously unmet needs in the marketplace. However, studies[2] [3] have shown that without proper provision models, the impact resulting from these wheelchairs is limited. In the past decade, the World Health Organization (WHO) has developed an 8-step provision model[4] to convey to distribution organizations that long-term investment in people is a higher priority than numbers of chairs distributed.

Ambiguity around Appropriate Design

A central question in the wheelchair aid industry is "Are there objectively better wheelchairs or are different chairs better for different users and different situations?" While some wheelchair organizations develop products for different use cases such as urban vs. rural users, many have a flagship product that they develop to meet the needs of the majority of their users. Furthermore, wheelchair manufacturers have different design philosophies on a spectrum ranging from "providing at

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[1] Mukherjee, Goutam, and Amalendu Samanta. "Wheelchair charity: A useless benevolence in community-based rehabilitation." *Disability and Rehabilitation,* 2005.

[2] World Health Organization, and USAID. "Joint Position Paper on the Provision of Mobility Devices in Less Resourced Settings," 2011, https://www.who.int/disabilities/publications/technology/jpp_final.pdf

[3] Maria L. Toro, et al. "The Impact of the World Health Organization 8-Steps in Wheelchair Service Provision in Wheelchair Users in a Less Resourced Setting: a Cohort Study in Indonesia." *BMC Health Services Research*, BioMed Central, 2016. bmchealthservres.biomedcentral.com/articles/10.1186/s12913-016-1268-y.

[4] World Health Organization. "Guidelines on the Provision of Manual Wheelchairs in Less Resourced Settings," 2008, https://www.who.int/disabilities/publications/technology/wheelchairguidelines/en/

scale the cheapest product that meets the most needs” to “higher-cost products that are designed to meet the varying more specific needs of users.” Since cost is highly variable in these markets, an equivalent product that costs half as much to distribute could double the impact of aid money. For example, an older user who is primarily using the wheelchair in their house with an attendant may not benefit from having a more expensive chair. However, as an assistive technology and medical device, poorly designed chairs can also pose significant risks to the users. Mechanical failures pose acute injury risk, stability issues can cause tipping, and most significantly, poor training and lack of pressure relief when using a wheelchair can cause users to develop pressure sores. Pressure sores can lead to serious complications and injury, and sometimes can be life-threatening.

Lack of Appropriate Quality Standards

In the US and Europe, wheelchairs are considered a medical device regulated by the Food and Drug Administration (FDA) or European Medicines Agency (EMA) in order to meet specific usage standards. Many of the wheelchairs designed for low-resource settings have not gone through the FDA/EMA regulatory process due to the high cost and long timeline, and, it is not required for distribution in the markets in which they are operating. Additionally, the design requirements for wheelchairs in the two markets differs significantly, particularly around cost, transportability, durability, and maintainability. However, the International Organization for Standardization (ISO) has developed standard ISO 7176 which wheelchairs must comply with in order to safely pass testing and distribution protocols. The International Society of Wheelchair Providers (ISWP) has been convening annually with the task to develop better regulatory standards for wheelchairs used in low-resources settings.

Varying Provision Models

To add to the complexity of technology design, wheelchair distribution also poses a significant challenge. Funding for wheelchairs typically comes from individual and foundational donors, aid organizations, and state and local governments. However, many distribution organizations are distributors for only a specific wheelchair manufacturer. For example, Access Life Bali is primarily a Free Wheelchair Mission wheelchair distributor. The benefits of this model are that wheelchair manufacturers can maintain a specific standard for quality for the products that they distribute. Supporting a fewer number of products for distribution means that it is easier for organizations to build expertise in training, maintaining, and supporting users on challenges related to them. However, a significant drawback for these models is that wheelchair users have limited choice in the product that they receive and that the products may not be designed or capable of fulfilling their individual needs. Initiatives such as CLASP aim to be manufacturer agnostic and match users with the wheelchair that is best suited for them. This can pose significant logistics and capacity-related challenges, as matching users with the right product is not trivial.

STUDY DESIGN

This CITE evaluation focused primarily on the "S1" or suitability. While sustainability and scalability of wheelchairs are important topics for understanding impact, the increased effort in the wheelchair aid community to provide access to a variety of wheelchairs through a consolidated effort has reduced the burden on sustainability and scalability issues and provide best practices for distribution. Furthermore, the variability within regions makes evaluating these topics challenging as different regional distributors approach sustainability and scalability in context-specific ways. As such, the primary focus for our evaluation was on the technical suitability of wheelchairs.

To evaluate the effectiveness of wheelchairs, we adopted a three-phase research plan that included both laboratory and field-testing methods. The first phase of the study involved testing the technical performance of chairs through ISO-testing protocols. These tests were conducted by the Human Engineering Research Laboratories (HERL) at the University of Pittsburgh and provided data to determine if the wheelchairs met key performance metrics.

The second phase of the study involved in-country testing in Bali, Indonesia aimed at understanding user adoption through the use of qualitative and quantitative methods. In this phase, the CITE team partnered with UCPW and Puspadi Bali to distribute 118 wheelchairs to understand user preferences as part of the Wheelchair User Voice (WUV) study. Subjects in the study participated in baseline and endline surveys concerning adoption, usage, and preliminary outcomes as well as used instrumented wheelchairs that tracked daily usage metrics over a period of several weeks.

The third phase of the study consisted of understanding user preferences and performance on wheelchairs through a side-by-side comparison of different wheelchairs using the Wheelchair Skills Test

(WST) developed by Dalhousie University. The majority of testing was conducted on-site in Bali, Indonesia with wheelchair users in partnership with Access Life Bali.

SECTION 2 - WHEELCHAIRS - AN IN-DEPTH BREAKDOWN

The wheelchairs for consideration in the CITE Evaluation are manual push-rim chairs. These wheelchairs have standard features and components that will be referred to throughout this report.

Push handle: The push handles extend backwards from the top of the backrest in order to allow an attendant to push the wheelchair.

Armrest: Armrests provide support to the wheelchair users' arms. Some of the armrests are removable for easier maneuverability in and out of the wheelchair. Armrests also can include a guard to prevent a wheelchair user's arm from contacting the rear wheel.

Push-rim: The wheels and push-rim on a wheelchair allow for users to self-propel and maneuver the wheelchair. Most of the wheelchairs in the study have wheels with treaded tires and inner tubes that can be replaced. One of the wheelchairs had tubeless rigid rubber tires instead.

Brake: A stationary brake on a manual wheelchair exerts force against the rear wheel to prevent the wheelchair from rolling. These brakes are designed to be hand-activated with minimal force. Although some wheelchairs can also have running brakes, which slow the wheelchair down when it is in motion, none of the wheelchairs in this study had that feature.

Rear wheel: The rear wheels provide contact between the wheelchair and the ground, and are composed of the hand rim, spokes, and tires. In this study, some of the wheelchairs had inflatable tires, whereas some were composed of solid rubber.

Tipping lever: The tipping lever allows an attendant to hold the push handles and push down on the lever with one foot to put the wheelchair in a wheelie position. This allows the wheelchair to more easily maneuver over curbs, thresholds, or rough terrain.

Front caster: The front caster is a smaller rigid wheel that freely rotates to allow for maneuverability. The size, number, and placement of the front caster varies significantly between wheelchairs. Larger front casters allow the wheelchair to go over obstacles more easily, but reduce the stability of the wheelchair. Increasing the distance between the caster and the rear wheels also allows for increased stability, but decreases the maneuverability of the chair.

Backrest: The backrest provides support to a wheelchair user as they may rest their back on it. The backrest is the piece of material between the upper section of the frame.

Cushion: The role of the cushion is to support the weight of the wheelchair user. Wheelchair cushions are specifically designed to accommodate people with little or no sensation in their lower extremities for long periods and distribute weight such that pressure sores are unlikely to form. Different models of wheelchairs have different types of cushions, but the majority of the wheelchairs in this evaluation use a foam support. Cheaper hospital style chairs typically do not have a foam support.

Seat: The seat is where the wheelchair user sits. An optional cushion is used to provide support. For folding wheelchairs, the seat may be made of a more flexible material whereas in non-folding wheelchairs, the seat may be made of more rigid material.

Frame: The frame is the durable structure that provides support to the seat and wheels, and connects all the components of the wheelchair.

Calf strap: The calf strap is typically a fabric strap that goes across the frame between the seat and the footrest to provide support to the calves for added stability.

Footrest: The foot support for the wheelchair is designed to rest the users' feet.

PRODUCT SELECTION

Eight different wheelchairs were selected for in-depth testing for the purpose of the evaluation. These chairs all are currently being distributed across the world through either the CLASP catalog or other mechanisms and capture much of the variation in design among commonly used wheelchairs.

UCP EXPRESSION (UCP)

The UCP Expression is a light-weight wheelchair designed by United Cerebral Palsy Wheels for Humanity. Designed for active use with high maneuverability, the UCP Expression is more similar to sports wheelchairs than standard wheelchairs. The wheelchair has removable quick-release wheels and a foldable back, allowing it to collapse down to a smaller size for transportability.

[5]**Dimensions:** 890mm length, 626mm width, 701mm height
Weight: 15.4kg
Foldable: Yes
Quick-release wheels: Yes
Stowage Dimensions: 1012mm length, 479mm width, 387mm height
Ground clearance: 103mm
Number of front casters: 2
Caster diameter: 125mm
Estimated price[6]: $263

WHIRLWIND ROUGHRIDER (RR)

The Roughrider is a wheelchair designed by Whirlwind Wheelchair International and is one of the most commonly distributed wheelchairs. It is a medium sized wheelchair designed for rugged terrain that uses standardized components to reduce cost. It has a cross-brace design to allow the wheelchair to fold for

[5] Photos taken from https://www.clasphub.org/products/adult-wheelchairs/ unless otherwise noted.
[6] Prices for all wheelchairs quoted as of December 2018.

easier transport. The roughrider also has two rubber front casters that are wider and smaller than typical off-road designs.

Dimensions: 1053mm length, 710mm width, 804mm height
Weight: 21.3kg
Foldable: Yes
Quick-release wheels: No
Stowage Dimensions: 1053mm length, 358mm width, 837mm height
Ground clearance: 74mm
Number of front casters: 2
Caster diameter: 106mm
Estimated price: $262

MOTIVATION ROUGH TERRAIN WHEELCHAIR (MRT)

Motivation Wheelchairs is an organization that provides wheelchairs and services across the world. The Rough Terrain is their iconic 3-wheel design that features a long wheelbase wheelchair with a large front caster. Built for everyday use in low-resource settings, the wheelchair is designed for increased stability, easier propulsion, and robustness.

Dimensions: 1318mm length, 667mm width, 855mm height
Weight: 23.7kg
Foldable: No
Quick-release wheels: No
Stowage Dimensions: 1104mm length, 594mm width, 488mm height
Ground clearance: 76mm
Number of front casters: 1
Caster diameter: 216mm
Estimated price: $304

MOTIVATION ACTIVE FOLDING WHEELCHAIR (MAF)

The Active Folding is a medium-sized foldable wheelchair designed by Motivation. The wheelchair is intended for active users in urban and semi-rural areas and features quick-release wheels and a foldable frame to allow for transport in vehicles. The wheelchair has a cross-frame design similar to most standard wheelchairs.

Dimensions: 970mm length, 710mm width, 820mm height
Weight: 19kg
Foldable: Yes
Quick-release wheels: Yes
Stowage Dimensions: 970mm length, 430mm width, 820mm height
Ground clearance: 13mm
Number of front casters: 2
Caster diameter: 150mm
Estimated price: $310

Latter Day Saints Charities Wheelchair (LDS)

The Latter Day Saints Charities wheelchair is an improved wheelchair that builds on the standard hospital-style wheelchair design by providing adjustability, additional reinforcement, and improved seating. The LDS wheelchair was only used in the technical testing. The LDS and INTCO Standard (STD) chair were very similar and therefore, only one chair was chosen for distribution in Indonesia and the LDS was not available for distribution through CLASP.

[7]**Dimensions:** 1080mm length, 640mm width, 800mm height
Weight: 20kg
Foldable: Yes
Quick-release wheels: No
Stowage Dimensions: 1060mm length, 320mm width, 800mm height
Ground clearance: 100mm
Number of front casters: 2
Caster diameter: 197mm
Estimated price: $110

INTCO Standard (STD)

The INTCO standard chair is a wheelchair that improves on the standard hospital-style chair by providing a better cushion for support. It is intended for adults without additional postural needs who engage in

[7] Photo taken from https://www.ldscharities.org/news/lds-charities-tests-new-wheelchair-designs

fairly low-levels of activity and has non-inflatable tires. The STD chair is distributed through CLASP and was distributed in Indonesia, while not being used in the technical testing, resulting in some data being unavailable on dimensions and clearance.

[8]**Weight:** 18-23kg
Foldable: Yes
Quick-release wheels: No
Number of front casters: 2
Caster diameter: 203mm
Estimated price: $110

FREE WHEELCHAIR MISSION GENERATION 2 WHEELCHAIR (FWM2)

The FWM2 chair is one of the most widely distributed lower-cost wheelchairs and is designed by Free Wheelchair Mission. It is a medium-sized wheelchair designed to be shipped in a flat-box and assembled on site with minimal equipment. The frame is rigid and not collapsible.

Dimensions: 1095mm length, 723mm width, 826mm height
Weight: 20.2kg
Foldable: No
Quick-release wheels: No
Stowage Dimensions: 1095mm length, 723mm width, 815mm height
Ground clearance: 170mm
Number of front casters: 2
Caster diameter: 199mm
Estimated price[9]: $80

[8] Photo taken from http://intcowheelchair.com/manual-wheelchair-9.html
[9] Photo taken from https://www.freewheelchairmission.org/our-wheelchairs/

Free Wheelchair Mission Generation 3 Wheelchair (FWM3)

The FWM3 chair is the newest chair designed by the Free Wheelchair Mission. It is similar in design to the FWM2, however it has a cross-frame that allows the chair to be folded for easier transport. Like the FWM2, it also ships in a flat-box and is designed to be assembled and fit to users on-site.

Dimensions: 1080mm length, 640mm width, 800mm height
Weight: 20kg
Foldable: Yes
Quick-release wheels: No
Stowage Dimensions: 1060mm length, 320mm width, 800mm height
Ground clearance: 146mm
Number of front casters: 2
Caster diameter: 200mm
Estimated price: $80

Section 3 - Technical Testing

The first phase of the research study involved the technical testing of the wheelchairs. To validate that wheelchair construction meets minimum safety and performance metrics, the wheelchairs were tested following the ISO 7176-1, 3, 5, 7, and 8 standards[10]. This testing was conducted by the Human Engineering Research Laboratories at the University of Pittsburgh. The overall protocol consisted of three categories of testing including safety testing, performance testing, and dimensional measurements. The safety tests measured the static stability as well as the static, impact and fatigue strengths of the chairs while the performance tests measured the brake performance. Of the eight wheelchairs tested, only the Motivation Active Folding wheelchair passed the full suite of ISO tests. Full ISO test reports are available in the appendix.

Static stability testing

Static stability testing determines the tipping angles of a wheelchair. The wheelchair is raised slowly to determine the angle at which it is no longer stable and tips in the forward or backward direction as shown in Figure 1. Wheelchair tipping determines the level of risk associated with using a wheelchair when conducting specific maneuvers such as going up or down ramps or over rugged terrain. The bigger the tipping angle, the more stable a wheelchair is determined to be. Users on a more stable wheelchair typically report feeling "safer" or more comfortable performing these complex maneuvers. Tipping and resulting falling injuries are the leading cause of injury amongst wheelchair users in the US[11].

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[10] International Organization for Standardization. *Aids and Adaptation for Moving.* https://www.iso.org/ics/11.180.10/x/

[11] Xiang, H et al. "Wheelchair related injuries treated in US emergency departments" *Injury prevention: journal of the International Society for Child and Adolescent Injury Prevention* vol. 12, 2006, pp. 8-11.

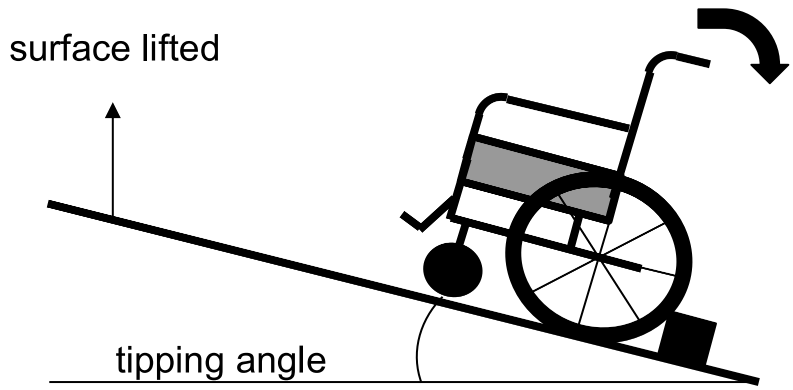


Figure 1 Static Stability Testing

Static stability is a complex issue with more experienced wheelchair users because there is an inherent tradeoff between static stability and maneuverability. Experienced wheelchair users tend to prefer wheelchairs that are less stable because they can more easily perform advanced techniques such as wheelies, which are critical to navigating terrain[12] [13]. From our interview data, decreased static stability can also make wheelchairs feel lighter for users.

Tipping angles are recorded in least- and most-stable configurations where a higher tipping angle corresponds to a higher static stability. Many wheelchairs are user-adjustable and these changes can impact the ISO ratings on static stability. A longer wheel base (distance between front and rear wheels) is a more stable configuration. Common adjustments to a wheelchair include moving the caster or moving the rear wheel such that the caster to wheel distance is increased or decreased, as shown in Figure 2.

[12] Kirby, R. Lee, et al. "The Wheelchair Skills Test: a pilot study of a new outcome measure." *Archives of Physical Medicine and Rehabilitation* vol. 83, 2002, pp.10-18.
[13] Hosseini, Shahla M., et al. "Manual wheelchair skills capacity predicts quality of life and community integration in persons with spinal cord injury." *Archives of physical medicine and rehabilitation* vol. 93, 2012, pp. 2237-2243.

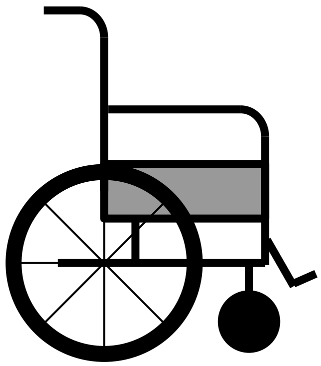


Figure 2 Stability positions in a wheelchair. Many wheelchairs have adjustable positions for the front caster and/or rear wheel which can change the stability of the chair. The image on the right has a longer wheel base (most stable). Testing occurs for both the most and least stable positions, if applicable.

The results from the static stability testing are summarized in Table 1 below.

Table 1 ISO Static Stability testing for wheelchairs. Data presented as tipping angles for wheelchairs where higher angles correspond to higher static stability. Most stable positions omitted for chairs that cannot be adjusted to change static stability.

	UCP	RR	MRT	MAF	LDS	FWM3	FWM2
Forward (most stable)	26.5°	39.1°		27.7°			
Forward (least stable)	16.9°	39.6°	40.2°	26.6°	27°	26°	26.6°
Rearward (most stable)	33.1°	17.1°		23.4°			
Rearward (least stable)	26.3°	3.5°	20.9°	14.5°	17°	20°	19.3°

Brake Performance

The brake performance test evaluates the strength of the braking system for the wheelchair and is governed by the ISO 7176-3 standard. For manual wheelchairs, the braking mechanism is applied and the wheelchair is loaded with a test dummy and placed on a flat platform. The platform is lifted at an angle until the wheelchair begins to slide and this is recorded. If the wheelchair begins to tip before sliding, a minimal upward force to prevent tipping is applied until the wheelchair slides. The test was conducted in both the uphill and downhill orientations and higher angles correspond to stronger braking systems. The results from the brake performance tests are provided in Table 2. The FWM chairs received the highest tipping angles during the testing, indicating strong braking systems. It should be noted that the brakes may have not been consistently adjusted according to manufacture settings, which could have contributed to the low values that were recorded and further testing is necessary to validate these results.

Table 2 ISO Brake Testing results. Data presented as measured angles at which slipping occurs when brakes are engaged - higher angles correspond to stronger braking systems.

	UCP	RR	MRT	MAF	LDS	FWM3	FWM2
Downhill Slide	8.1°	4.9°	1.3°	4°	4°	13°	6°
Uphill Slide	5.9°	2.7°	2.1°	3.6°	3.6°	12°	12.9°

Strength Testing

Strength testing is used to determine the wheelchair’s ability to withstand normal usage without mechanical failure and is governed by the ISO 7176-8 standard. The testing protocols are broken into three types of tests: static strength, impact strength, and fatigue strength, which correspond to different conditions. The wheelchair is subjected to forces in each of these cases and must be undamaged in order to pass.

Static strength testing

Static strength testing measures static loading on the wheelchair to ensure that individual components can withstand the forces applied to them by the wheelchair user and an attendant. Forces are applied directly to each component and gradually increased until they reach the maximum value for an individual component. Values are calculated based on either manufacturer's wheelchair claims or from expected usage values for each component. The values that each wheelchair component was tested is included in Table 3 below. Wheelchairs are considered to pass the testing protocol if there is no structural damage to the wheelchair. For certain components, typical static loading can be characterized as the following:

- *Armrests loaded in the downward direction*: Test loads will correspond to half the mass of the occupant, however this load can be increased during transfers to or from the wheelchair.
- *Footrests loaded in the downward direction:* Though most users will be unable to stand with their entire weight supported on the footrest, high loads can occur during spasms.
- *Handgrips:* Test loads are derived from attendants supporting the weight of the wheelchair and user using one handgrip, which can occur when the wheelchair and occupant are lifted up or down a curb or ramp.
- *For armrests, footrests, and push handles loaded in the upwards direction:* Attendants sometimes assist by supporting the wheelchair and occupant going up and down stairs and curbs using the armrests for increase stability.

Table 3 summarizes the results from static testing, including the forces tested for (in N) as well as whether the chair passed or failed. Blanks in the table indicate that the feature is not present on the specific wheelchair.

Table 3 Static Strength Testing Results. Table provides pass/fail values based on ISO test metrics. Numbers in the table refer to the force (in N) that the component was subjected to.

Component	**UCP**	**RR**	**MRT**	**MAF**	**LDS**	**FWM3**	**FWM2**
Armrest, downwards		Pass, 124	Pass, 187		Pass, 157	Pass, 100	Pass, 42
Footrest, downwards	Pass, 108	Pass, 45	Pass, 211	Pass, 167	Pass, 16	Pass, 26	Pass, 75
Tipping levers					Pass,		

					114		
Handgrips	Pass, 61	Fail[14], 96	Pass, 88	Pass, 157	Pass, 130		
Armrest, upwards		Pass, 156	Pass, 113		Pass, 150	Pass, 99	Pass, 46
Footrest, upwards	Pass, 50	Pass, 170	Pass, 112	Pass, 115	Pass, 143	Pass, 45	Pass, 30
Push handles, upwards	Pass, 40	Pass, 98	Pass, 110	Pass, 50	Pass, 110	Pass, 90	Pass, 84

FATIGUE TESTING

**Figure 3 Double drum testing apparatus with FWM2 wheelchair being tested.
The chair is loaded with a test dummy and cycled for 200K revolutions or until failure occurs.**

[14] Handgrip slid off handle. Part was replaced and testing continued.

Fatigue testing is used to determine the longevity of the wheelchair and ensure that it can have a reasonable use-life, and consists of a multi-drum test where the wheelchair is rolled on cylindrical drums (as shown in Figure 3) and a curb drop test where a wheelchair is repeatedly dropped. Wheelchairs are loaded with a test dummy and rolled on a multi-drum system at a speed of 1 m/s for a minimum of 200,000 cycles or higher if the manufacturer claims that the wheelchair exceeds minimum requirements. The ISO 7176-8 multi-drum system test simulates transport across uneven and rough paths typical to what would be found in the US or Europe. ISWP is actively working on determining more appropriate conditions and developing a better standard to evaluate wheelchairs for use in low-resource settings. If a wheelchair passed the multi-drum test, it was subjected to the drop test where the loaded was raised to a height of 50mm and dropped until 6,666 drop cycles were completed. Table 4 summarizes the results from the drop tests as well as the drum test results too. It is important to note that when a wheelchair fails the drum test, it is not subjected to the drop test. Failure modes and pictures are documented in the appendix.

Table 4 Drop Test Results.

	UCP	**RR**	**MRT**	**MAF**	**LDS**	**FWM3**	**FWM2**
Double-drum Test	Fail	Pass	Fail	Pass	Fail	Fail	Fail
Cycles completed	82,454	200,000	183,359	200,000	<200K[15]	22,625	130,457
Failure Mode	Caster		Frame		Frame	Frame	Tire, Frame
Drop Test		Pass, 6,666		Pass, 6,666			

[15] Failure noticed after test completion, therefore the number of cycles is unknown.

IMPACT TESTING

Each wheelchair was additionally tested for performance against impact. The purpose of impact testing is to determine whether the wheelchair will be able to survive normal wear and tear and the corresponding drops, impacts, and forces associated with that. In order to pass the impact testing component, wheelchairs are determined if there is any structural damage to the components and all parts continue to be functional (including free rotation of casters and wheels). The wheelchair hand-rim, backrest, and casters were tested against a fixed impact using a weighted pendulum and rated pass or fail. Additionally, the entire wheelchair was subjected to lateral and longitudinal impacts and rated pass or fail. All of the wheelchairs passed the impact testing portion of the testing standards.

SECTION 4 - WHEELCHAIR USER VOICE PROJECT

The second phase of the study aimed at understanding the adoption and usage of wheelchairs through survey tools and sensor-based data collection. In order to carry out this study, the research team participated in the Wheelchair User Voice project, a large collaboration led by UCPW in collaboration with Puspadi Bali, UGM, and CITE. This project occurred throughout 2017 and involved distributing five (RoughRider, Motivation Rough Terrain, Motivation Active Folding, UCP Expression, and the Standard wheelchair) of the wheelchairs included in this CITE study to 118 Puspadi Bali clients. The goal of this project was to measure usage and preliminary outcomes an appropriate wheelchair has on wheelchair users. Wheelchair users were interviewed at a baseline and endline time point, and had data loggers attached to their wheelchairs. Select data relevant to the CITE study goals of looking at product usage and performance were drawn from the wider data set and analyzed.

METHODS

The team collected the data through interviews with wheelchair users who were clients of Puspadi Bali in Indonesia. A baseline interview was conducted when receiving the new study wheelchair and an endline interview was conducted 3-6 months later. The interview included both quantitative questions and open-ended qualitative questions. The close-ended responses were entered into tablets using Kobo Toolkit, a survey software. The interview was also recorded and the qualitative questions were transcribed and translated into English. The recordings were also used to cross-check the data entered through the survey software.

The interview protocol was comprised of questions from a variety of existing tools including an adapted version of the Most Significant Change Method, the International Society of Wheelchair Professionals (ISWP) Minimum Data Set, the Wheelchair Skills Test, the Quebec User Tool, the Poverty Probability Index for Indonesia, and the CHART Tool.

RESULTS

120 Puspadi Bali clients were included in the study, however, nine user's data were omitted due to a variety of quality control reasons. The final count for the wheelchairs included in the WUV study can be seen in Table 5. Almost all of the participants included in this study were existing wheelchair users, had

an average age of 40, and the majority of wheelchair users were diagnosed with polio (52%) or a spinal cord injury (18.7%).

Table 5 Sample Size for WUV study

Wheelchair	Total Users
Motivation Active Folding (MAF)	24
Motivation Rough Terrain (MRT)	19
RoughRider (RR)	26
Standard (STD)	25
UCP Expression (UCP)	17

Wheelchair Usage

Data included in this report was collected during the endline survey, where participants were reporting on the past 3-6 months of their wheelchair usage. The majority of wheelchair users reported using their wheelchair everyday (see Figure 4). RR wheelchair users reported the highest usage with 92% of users reporting daily usage while MRT users reported the lowest usage with only 42% of users reporting daily usage over the 3-6 month period.

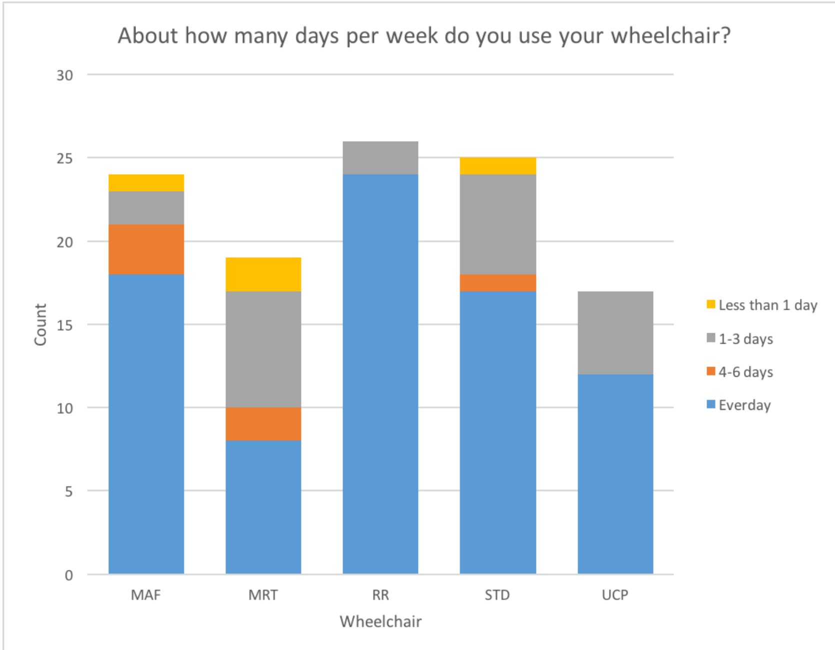


Figure 4 Weekly Wheelchair Usage

Although many users reported high days per week use, many of the users reported low hour per day usage (see Figure 5). Again, RR users reported the highest usage for hours per day with 50% of riders using it more than eight hours a day. UCP users reported the lowest hours per day usage with only 29% of users riding the wheelchair more than eight hours a day and 53% of users riding the chair either 1-3 or less than one hour a day. For the MAF (37.5%), the MRT (47.3%), the STD (48%) wheelchairs, a significant portion of the users also spent between 1-3 or less than 1 hour per day using their wheelchair.

During the study, therapists prescribed wheelchairs to clients based on their needs and product availability. This is a potential source of bias in the study design as clients' needs may influence their usage and activity. It is a challenge to discern if a product influenced usage or if the clients' usage played a deterministic role in which wheelchair was prescribed to them. However, our results show that the STD wheelchair users had a high amount of activity compared to the UCP and MRT wheelchairs, which are typically prescribed to more active users.

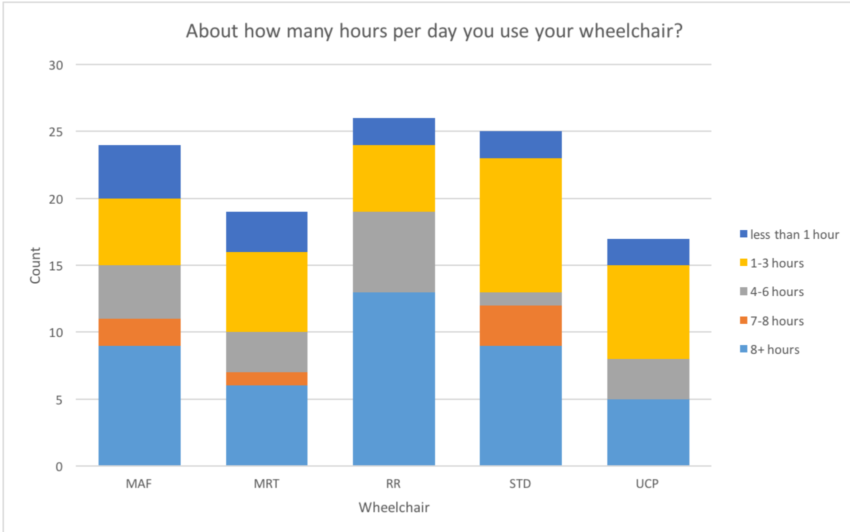


Figure 5 Daily Wheelchair Usage

Regardless of wheelchair type, wheelchair users reported traveling short distances in their wheelchairs (see Figure 6). The majority of wheelchair users (MAF-87.5%, MRT-72.2%, RR-65.3%, STD-80%, and UCP-82.4%) reported traveling less than 500 meters in a day. This was mostly consistent with the data collected from the data loggers, which showed short distances traveled daily. In further understanding these usage characterizations, societal contexts are essential to understand. Many users stated that they suffered from social stigma and would not leave their home compound, which could be supporting reasons for their low distances traveled per day. Additionally, the Balinese terrain and multi-level home structure provided logistical challenges to movement in a wheelchair.

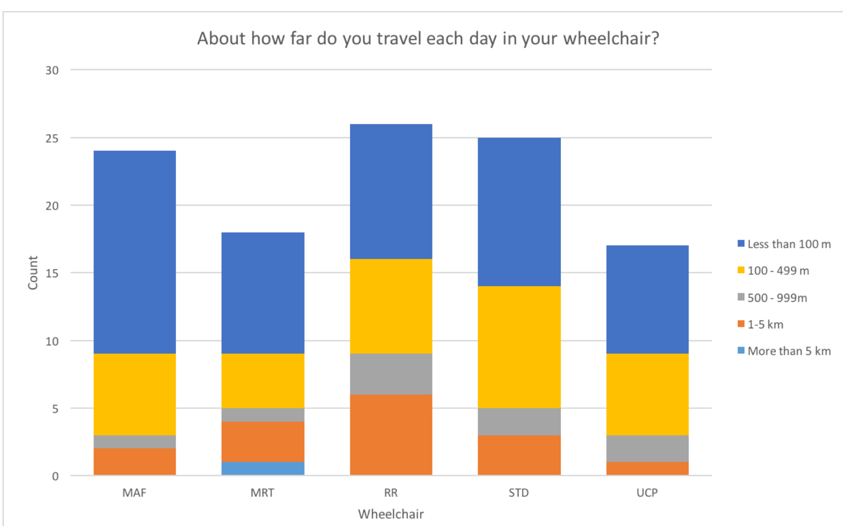


Figure 6 Daily Distance Traveled

Users reported high levels of satisfaction with the wheelchairs. When asked to rank their level of satisfaction with the wheelchair on a scale of 1-5 (1-not satisfied, 5-very satisfied), the MAF received an average score of 3.96, the UCP received an average 4, the STD received an average score of 4.18, the MRT received an average score of 4.21, and the RR received an average score of 4.38.

SECTION 5: DATA LOGGERS

The second phase of the study aimed to understand the adoption and usage of wheelchairs. The wheelchair aid industry has varying accounts of the impacts of distributed wheelchairs on beneficiaries. In our initial scoping interviews, some distribution organizations claimed their client engagement led them to believe that primary benefit derived from wheelchairs is mobility within households and cheaper wheelchairs are a more cost-effective solution to maximize impact. Other experts claimed that their experiences showed that wheelchair users travel significant distances and that cheaper wheelchairs may not meet their needs. While many of these differences may be attributable to regional and cultural variation between populations, there was consensus among the organizations that collecting more data on in-country wheelchair usage would provide significant value to the field and the overall understanding of how to maximize impact on beneficiaries.

To understand the functional differences between wheelchairs, we decided that a priority area to study was to understand how wheelchair usage varied between users and between products. In order to characterize these usage metrics, we developed two separate wheelchair data loggers, a basic data logger and an advanced data logger. The basic data logger was designed to understand how often a wheelchair was being used. This data would provide a comparison between different products and provide insights into how wheelchair design affected user mobility. The advanced data logger was designed to measure the forces and loading on a typical wheelchair. This data logger would provide insights into the types of terrains that wheelchairs were used in low-resource settings toward designing better laboratory tests to predict the in-country performance of wheelchairs.

BASIC DATA LOGGER

The basic data logger was designed to collect usage metrics from various wheelchair designs and record them over an extended period. As demonstrated by other researchers[16] [17], the data logger was designed to be attached to the spokes of a wheel and counted wheelchair rotations. In order to ensure accurate

[16]Tolerico, Michelle L., et al. "Assessing mobility characteristics and activity levels of manual wheelchair users." *Journal of Rehabilitation Research & Development* vol. 44, no. 4, 2007, pp. 561-572.

[17] Sonenblum, Sharon Eve, et al. "Validation of an accelerometer-based method to measure the use of manual wheelchairs." *Medical engineering & physics* vol. 34 no. 6, 2012, pp. 781-786.

data collection using low-power sensors, the device measured rotations using 3-axis accelerometer and bout lengths using a real-time clock. This data could be processed to determine speed, bout length, number of bouts, and distance traveled. Prototype basic data loggers were developed for testing at MIT, and were designed and implemented by Sensen Inc.[18]

METHODS

Wheel rotation was measured through a zero-crossings algorithm that counted whether the x-axis or y-axis signal went from positive to negative. Forward vs backward rotation was determined by the previous zero-crossing. A debouncing algorithm was adapted to ensure that bumps, braking, and rocking would not trigger an erroneous value in the algorithm.

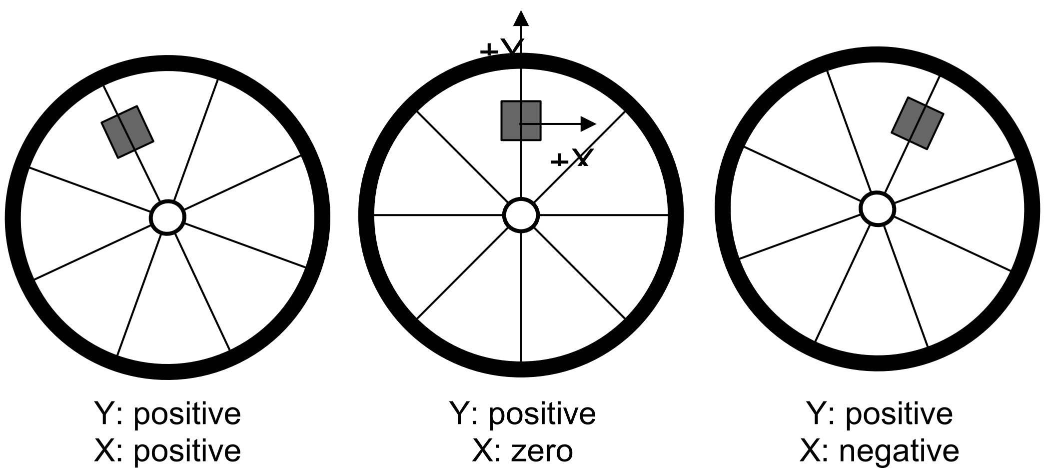


Figure 7 Rotational detection for wheelchair wheel. The 3-axis accelerometer on the wheel was used to detect rotation by measuring the number of zero-crossings.

Table 6 Crossing detection algorithm to determine directionality.

Previous Crossing	Current Crossing	Rotational direction
+X	+Y	backward
+X	-Y	forward

[18] www.sensen.co

-X	-Y	backward
-X	+Y	forward
+Y	+X	forward
+Y	-X	backward
-Y	-X	forward
-Y	+X	backward

The data logger was designed to run in low-power mode for the majority of the usage. A low-magnitude acceleration would wake up the data logger and place it in active sampling mode. Start time, number of positive rotations and number of negative rotations were measured over the usage period. A 10-second period of inactivity was set to determine inactivity and the device would record bout length and return to low-power sleep mode. The data logger was designed to be connected to the cellular network and send data to a secure server once a week. A functional diagram for the device operation is shown in Figure 8.

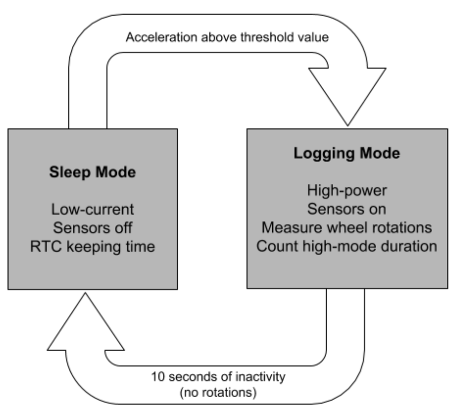
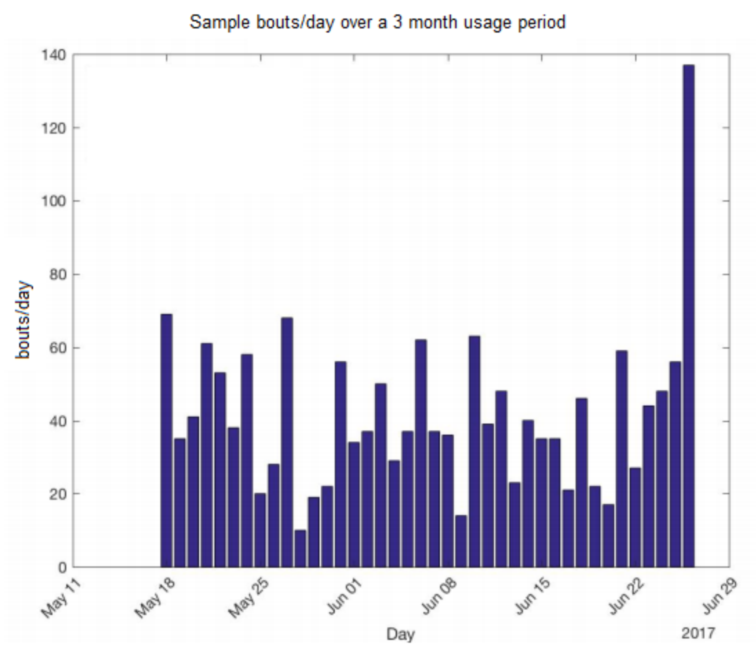


Figure 8 Data logger firmware design.

Processing the recorded data and combining it with information about the wheel size for the wheelchair allows us to determine the following metrics for usage: average number of daily bouts, average distance traveled per bout, average speed during the bout, and average distance traveled per day. Example processed data plotted against time is shown in Figure 9. These metrics have been shown to have a strong correlation with positive health impacts on users where higher bout length corresponds to more active usage[19] and can be used to compare between the various wheelchair types. This data can be further compared to values found in literature for typical usage in the United States and Europe.



[19] Sonenblum, Sharon Eve, Stephen Sprigle, and Ricardo A. Lopez. "Manual wheelchair use: bouts of mobility in everyday life." *Rehabilitation research and practice* vol. 2012, 2012.

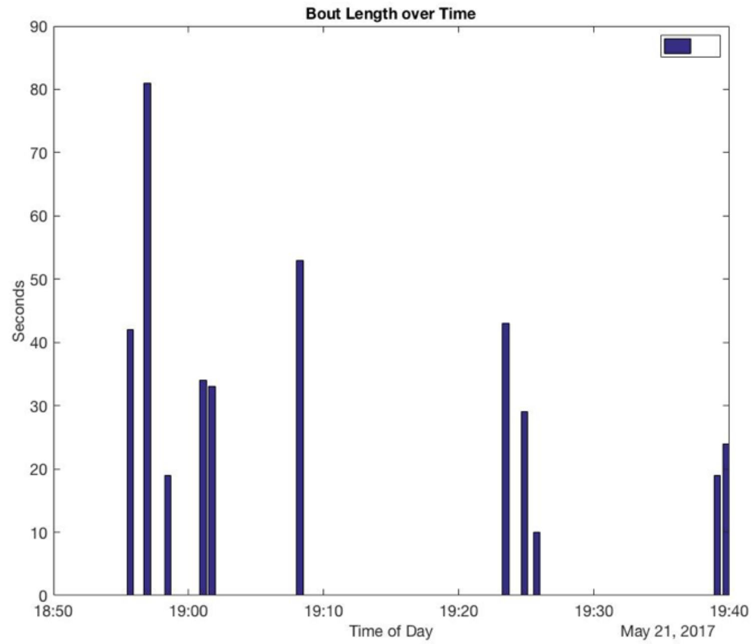


Figure 9 Sample plotted data from a data logger attached to a RoughRider.

Results

The basic data loggers were attached to a variety of wheelchairs through the WUV study in partnership with UCPW in Bali in 2017. In addition to the five wheelchairs being distributed to Puspadi clients, data loggers were attached to PLD wheelchairs to serve as a comparison group. Wheelchair data loggers were attached to 133 wheelchairs and a two- to four-week period of usage data was collected and analyzed from 91 participants using six different wheelchair models. Due to various challenges with the cellular connectivity, data logger battery life suffered and data was not collected for a portion of the wheelchair users. The list of wheelchair types and number of data points is shown in Table 7 below.

Table 7 Sample size for data loggers.

	RR	MRT	MAF	STD	UCP	PLD
Sample Size	14	15	12	15	16	19

For each wheelchair type, the mean daily bouts, mean bout length, mean speed, and mean distance were calculated. To generate mean distance, individual distance traveled was calculated for each bout by multiplying wheel rotations by the wheel circumference, assuming a 26” wheel for each chair. Speeds were calculated for each bout by dividing distance by bout length and averaged for each user. The resulting data is shown in Table 8. The PLD chairs had significantly less usage compared to improved wheelchairs, both in terms of average daily bouts and aggregate distance traveled. This group of users was significantly older (an average age of 57.4 compared to 40.4 for the Puspadi group) which could contribute to decreased mobility and usage. Additionally, users did not use the larger MRT chair as frequently, but traveled longer distances on average when they used it. One potential reason the STD chair could have had such high usage was that many of the wheelchair users mentioned this wheelchair is comfortable and felt familiar. Users also tended to travel at similar speeds of 0.4 mph on average. The average daily distance data aligns decently well with the self-reported distance traveled data that was collected in the questionnaire, where a majority of the participants reported traveling less than 500 meters a day.

Table 8 Key usage metrics from analyzed data logger data for each chair.

	MAF	PLD	RR	MRT	STD	UCP
Average Daily Bouts	63.6	11.72	46.66	27.28	68.97	60.88
Average Bout Length (s)	30.76	26.92	27.97	34.75	29.83	31.6
Average Speed (m/s)	0.16	0.13	0.15	0.21	0.19	0.2
Average Distance (m)	9.44	6.49	6.96	12.82	9.69	10.95
Average Daily Distance (m)	325	77	400	381	715	741

ADVANCED DATA LOGGER

The advanced data logger was designed to collect high-resolution data on forces and loading applied to wheelchairs during typical usage in low-resource settings. This was an exploratory phase of the project. Additionally, the data loggers measured the presence or absence of both the rider and wheelchair attendant to determine the degree of independence of the wheelchair user. The goal of developing these sensors was to explore if a methodology could be built for characterizing the types of terrain that wheelchairs typically encounter and understanding whether different wheelchairs encourage mobility over different terrains in actual usage, for example, how significantly having a more rugged wheelchair contributes to a user traversing more rugged terrain. The results from these measurements can also be compared to values from typical testing standards to assess the effectiveness of ISO standards in evaluating wheelchairs developed for low-resource settings.

Methods

The advanced data logger consisted of a system of sensors that were sampling multiple times a second (at 20Hz) while the wheelchair was in motion. To measure forces and loading, two 3-axis accelerometers were attached to the frame near a front caster of the wheelchair and the rear wheel axle. The accelerometer resolution was set to measure accelerations of up to 16G in each direction and were responsible for measuring the instantaneous loading. Additionally, a 9 degrees-of-freedom IMU (3-axis accelerometer, 3-axis gyroscope, 3-axis magnetometer) was attached to the frame under the seat support to measure forces felt by the rider and the orientation of the wheelchair. To detect whether a rider or wheelchair attendant was present, two proximity IR sensors were attached to the push handle. To achieve low-power consumption, the advanced data logger, like the basic data logger, was placed in sleep mode for the majority of the time and awakened for a sampling interval based on a low-amplitude acceleration event.

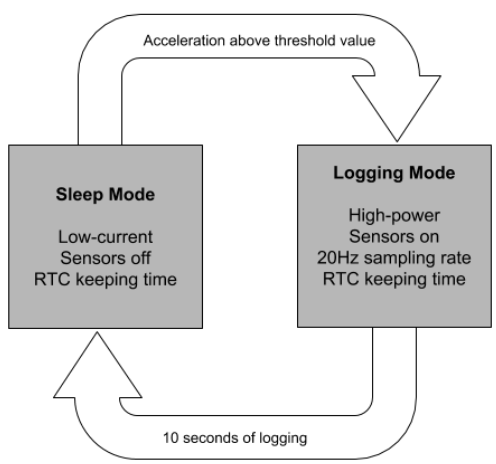


Figure 10 Advanced Data logger Firmware Design

Results

The advanced data loggers were attached to several FWM wheelchairs in partnership with Free Wheelchair Mission and Access Life Bali. Only FWM wheelchairs were included because Access Life Bali only distributed FWM chairs and were responsible for subject recruitment. Data was collected from eight different wheelchairs that consisted of FWM2 and FWM3 chairs. High-resolution data can be used to understand loading profiles from the wheelchair, which correspond to forces and loading experienced by the chair in-use, as shown in Figure 10. This raw data can be used to understand the intensity of different bouts and loading intensity at the wheelchair-level or bout-level to determine the usage scenarios, as shown in Figure 11.

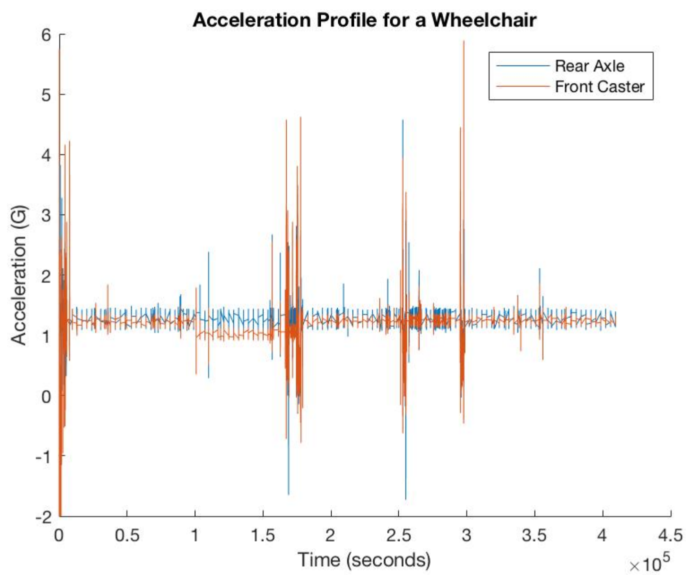


Figure 11 Plot of the acceleration profile for an example wheelchair used for one week.

In general, larger amplitude accelerations (>2G) correspond to riding over more rugged terrain or drops of the wheelchair. Based on the acceleration analysis, it can be seen that the majority of usage for these wheelchairs is low-loading use corresponding to smooth terrain (<1G). The distribution for all wheelchairs is plotted in Figure 12, showing the distribution of loadings that were <1G, between 1G-2G, and >2G.

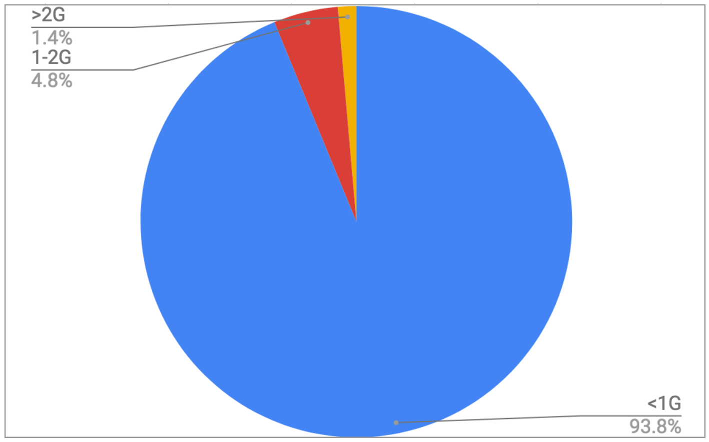


Figure 12 Distribution of accelerations for wheelchairs. Usage is dominated by low-impact usage

Section 6 - Track Testing

The third phase of the study design was to understand user performance on different wheelchairs. To this effect, throughout 2018, the CITE research team conducted skills testing in Bali, Indonesia in partnership with Access Life Bali. The main goal of the skills testing was to identify how the studies' wheelchairs performed across a representative set of skills during wheelchair riding. Additionally, secondary goals of the test were to compare how the wheelchairs performed to a PLD wheelchair as well as to compare how the lower cost wheelchairs performed to the higher cost wheelchairs.

Methodology

The CITE team used a modified version of the Wheelchair Skills Test[20] version 4.3.3, developed by Dalhousie University. The wheelchair skills test was selected as it is a validated and refined tool that is a standard in the wheelchair field. Most of the modifications to the skills test included omitting the advanced skills as many of the wheelchair riders we piloted with in Bali were unable to perform these and there were limitations due to the selected environment or available equipment.

The fully administered skills test in this CITE study can be found in the appendix. Examples of skills the participants were asked to perform include: roll forward and backward 10 meters, maneuver sideways, or ascend/descend a slight/steep incline. Users were observed and received a mark from 0-2 depending on their ease of completing the task (0-could not perform task, 1-perform task with difficulty, 2- perform task with ease).

After the skills test was completed, a short interview was conducted asking users about their self-perceived level of difficulty (1-very difficult, 5-very easy) completing some of the skills. Additionally, other administered questions included topics such as wheelchair comfort and satisfaction. Overall, the skills testing took around one to one and a half hour(s) for wheelchair participants to complete.

For the testing in Bali, Indonesia, a small convenience sample approach was used and a total of 26 wheelchair users were included. Access Life Bali was a value partner in this track testing, especially by

[20] Kirby RL, Smith C, Parker K, McAllister M, Boyce J, Rushton PW, Routhier F, Best KL, MacKenzie D Mortenson B, Brandt A. "The Wheelchair Skills Program Manual." 2015. www.wheelchairskillsprogram.ca

helping to recruit participants. Access Life Bali is a Free Wheelchair Mission chair distributor, so the majority of users included in the test were Free Wheelchair Mission users. An average demographic profile was developed as shown in Table 9.

Table 9 Average Demographics of Wheelchair Users (n = 26)

Average Age of Wheelchair Users	37
Gender of respondents:	
Male	15
Female	11
New or existing wheelchair user:	
New	8
Existing	17
Disability diagnosis	
Polio	10
Spinal Cord Injury	3
Cancer	2
Osteogenesis Imperfecta	2
Other	8

Wheelchair users were asked to perform the set of selected skills on a hospital wheelchair as well as a combination of two to five of the sample wheelchairs. Wheelchairs were selected randomly for each participant, and the order the participants tested the wheelchairs in was randomized in order to reduce bias in the test. Additionally, wheelchair users were given some time to get acquainted with the different wheelchairs that were being tested. Some users indicated being unable or unwilling to test certain wheelchairs and special considerations of a participant’s comfort or mobility were taken into consideration when deemed appropriate. Each chair was tested a minimum of five times and the sample counts for each wheelchair are shown below in Table 10.

Table 10 Sample Counts for Wheelchair Tests.

Wheelchair	Number of tests
PLD	18

FWM3	11
UCP	11
FWM2	8
MAF	8
RR	8
MRT	6
STD	5

RESULTS

The wheelchair skills test overall score is calculated with the following formula:

Total WST score = Sum of individual scores/ (number of possible skills-number of not possible skills - number of testing error scores) *100%

Below in Figure 13, the average score for the tests for each wheelchair is recorded. All of the wheelchairs averaged higher total scores than the PLD chair, with the RR and MRT scoring the highest. The rest of this section will dive deeper into the differences observed between the wheelchairs for selected skills.

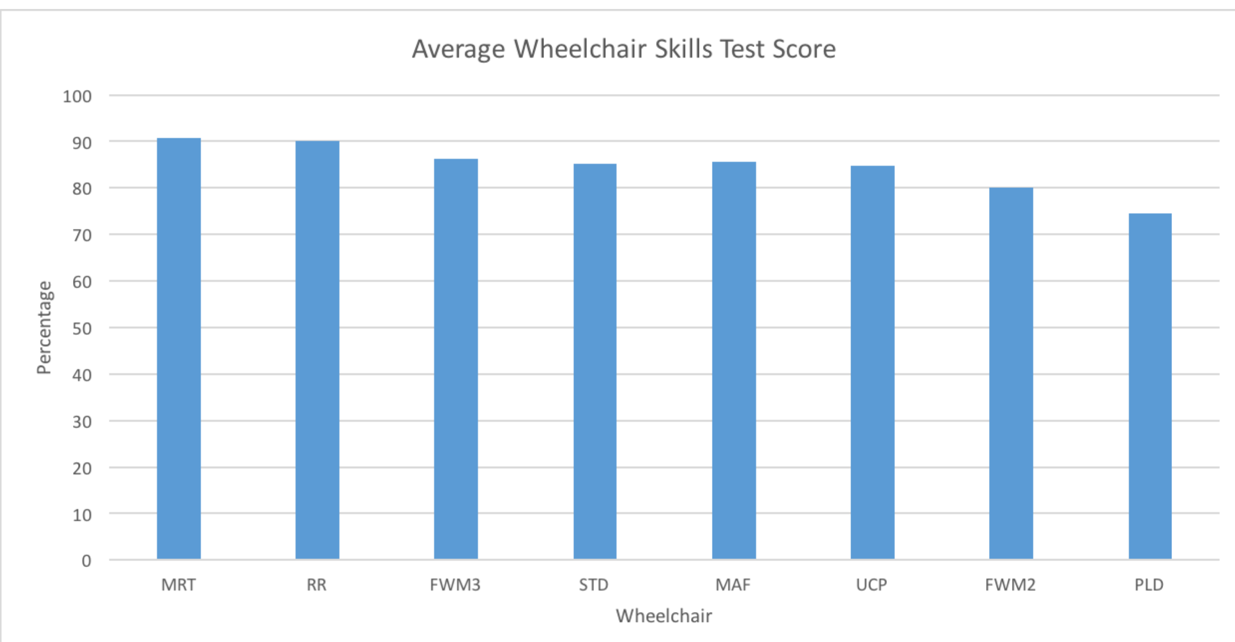


Figure 13 Average wheelchair skills test scores

Basic Skills

Based on the wheelchair skills test, most of the participants were able to complete the basic skills with ease regardless of which wheelchair was being tested. Differences in wheelchairs were more observable as the skills became more difficult. Averaging over all the wheelchairs, all of the basic skills had average scores of 1.8 or higher, with maneuvering sideways (1.80) and turning while moving backward (1.82) being the most challenging basic skills to complete, as seen in Figure 15.

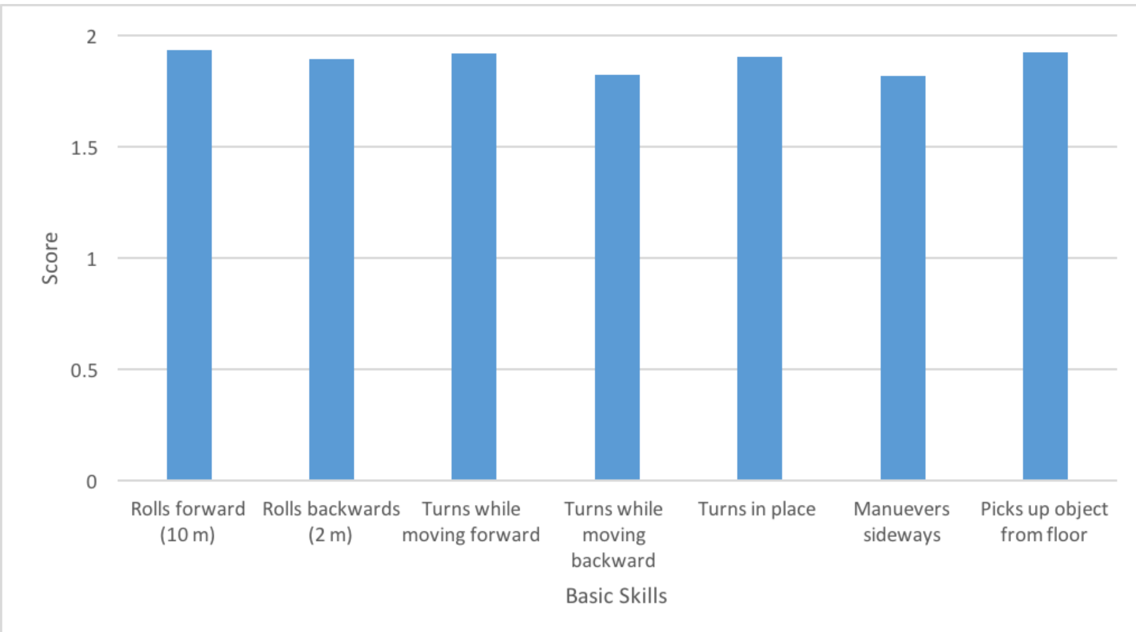


Figure 14 Basic Skills Average Scores across all wheelchairs

Interestingly, during the questionnaire, participants indicated that the plaid wheelchair was significantly more difficult to roll forward in (Figure 15) compared to the study wheelchairs. Wheelchair participants completed the skill with an average score of 1.89 indicating that most participants were able to complete the skill with ease, but that the plaid chair could require more effort.

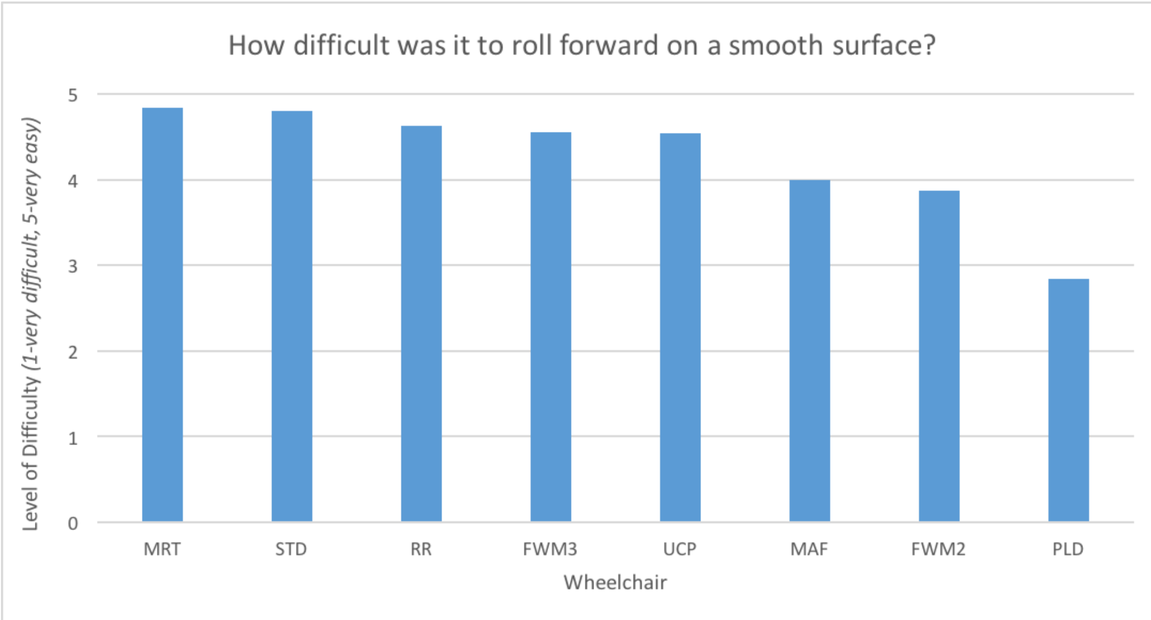


Figure 15 Self-reported difficulty of rolling forward on a smooth surface.

New wheelchair users are defined as participants that could participate in the skills testing but do not currently own and use a wheelchair whereas existing users were defined as participants that currently own and use a wheelchair. Comparing new and existing wheelchair users, new wheelchair users scored lower on passing with ease in all the basic skills as seen in Figure 16. This result was expected.

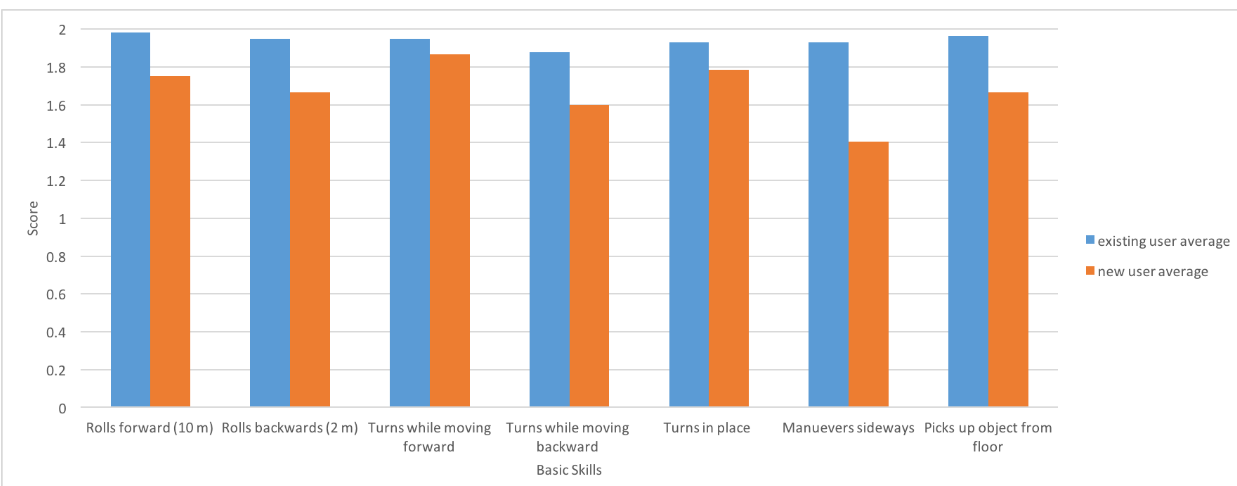


Figure 16 New vs Existing User Performance

INTERMEDIATE SKILLS

The intermediate skills proved to have the most granularity for observing differences in completing tasks in the different wheelchairs included in the study. Complementing the skills test with the interview allowed for insight into potential reasons for the increased difficulty or easiness of completing certain skills.

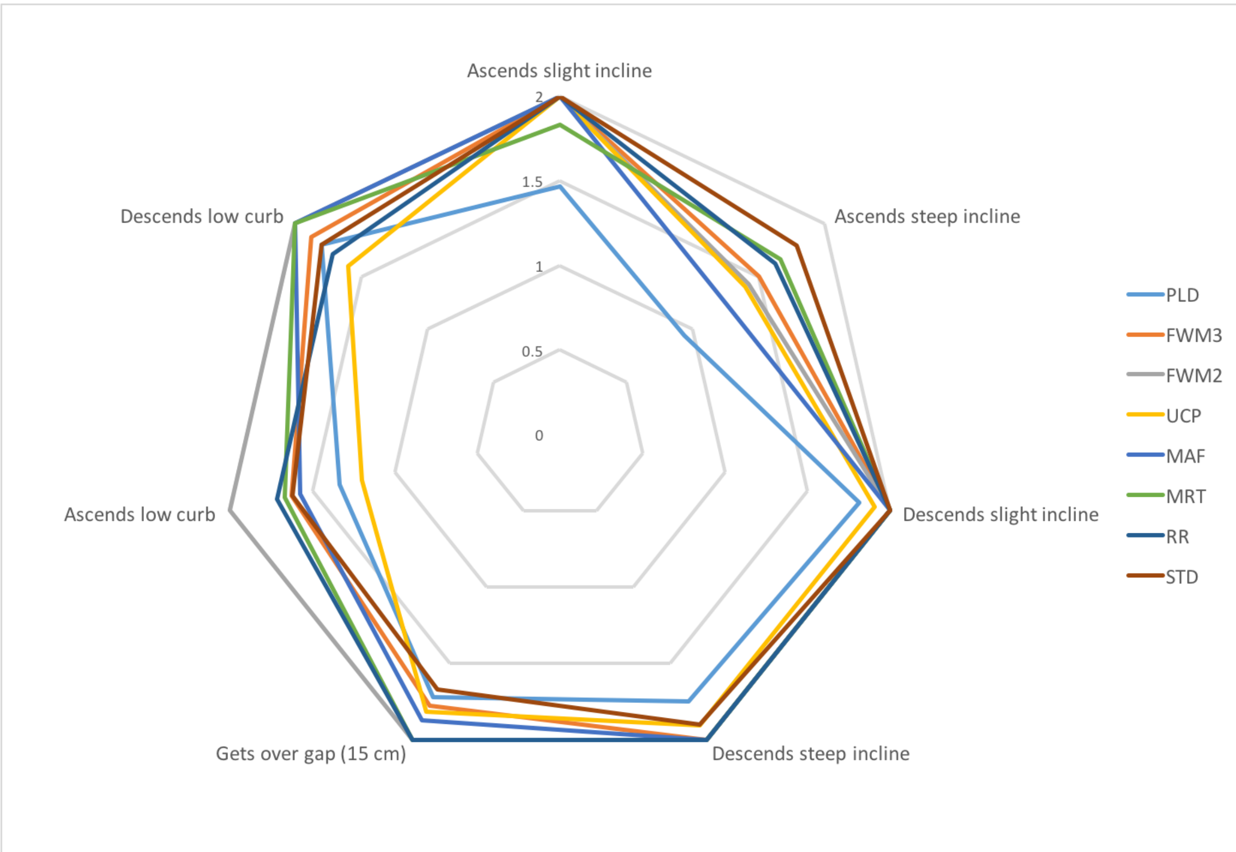


Figure 17 Intermediate Skills Results for Each Wheelchair

Figure 17 shows the average score users received on the intermediate skills in the different wheelchairs. The PLD wheelchair consistently averaged one of the lowest scores across the set of intermediate skills. During the interview, the majority of users cited that the high armrests made the PLD chair difficult to maneuver while trying more difficult tasks as well as the chair being too uncomfortable.

Most users were able to ascend and descend a slight incline with ease regardless of which wheelchair was being ridden. When ascending a steep incline, the RR scored lower than the other chairs, with users citing heaviness and likeliness to tip on the incline as the main reasons. Additionally, in the technical testing phase, the RR had the lowest rearward stability, which translates into a higher likelihood to tip to the rear, supporting this observation.

The MRT averaged a 1.67 for ascending the steep incline, with users noting the large front wheel of the MRT assisting with ascending the steep incline because of the weight balance. The RR and MRT averaged 1.71 and 1.67 respectively on the ascending the small curb and a 2 for both chairs for getting over a 15 cm gap, which supports the idea of a rugged design of being able to maneuver easily over uneven surfaces. This is also supported by some of the technical testing previously mentioned in the report where the RR and MRT recorded high forward stability.

An interesting observation is that the FWM2 and FWM3 averaged similar scores to the other wheelchairs, despite the lower cost of these wheelchairs. Users noted that the chair felt comfortable and safe when trying the skills and liked its low weight. This is an encouraging finding given its low price; however, there are other factors to consider such as the longevity and the maintenance of the chair.

Additionally, many of the results were as expected; for example, the MRT and RR scored high on ascending a hill and are designed to more easily ascend a hill. However, some of the results were more surprising, such as the STD scoring. The majority of the advanced skills were omitted as they were too challenging for users to perform. Only one user was able to perform a stationary wheelie, and so the skill was adapted to ask user to try to pop their front casters off the ground.

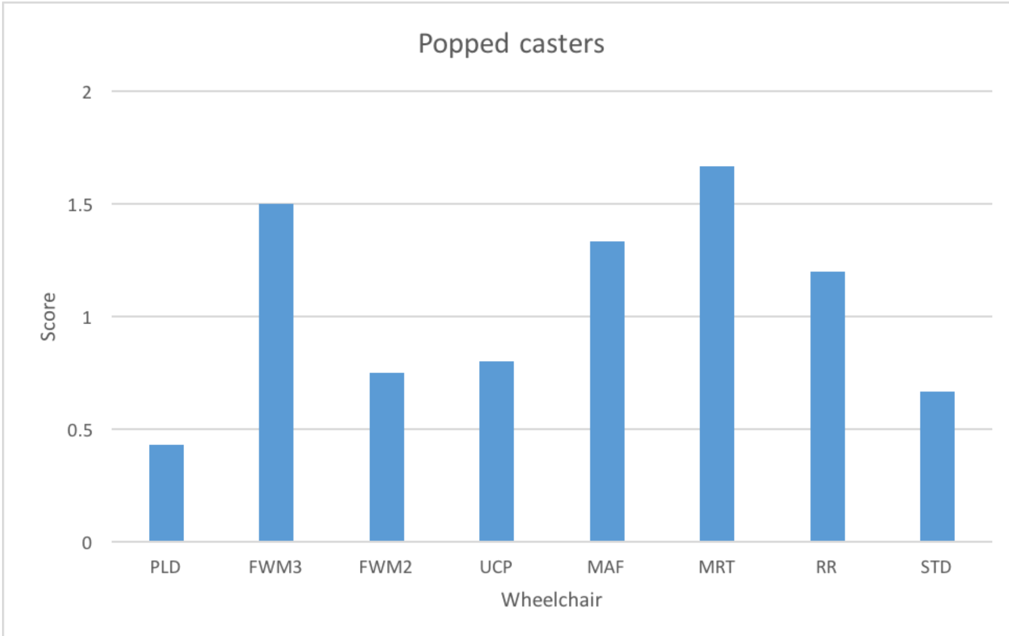


Figure 18 Average scores for popping front casters for wheelchairs

As seen in Figure 18, popping the front casters off the ground proved to be a challenging task and show differences between the wheelchairs. All wheelchairs averaged higher scores than the PLD chair with the FWM3 and MRT being the easiest for users to perform the task.

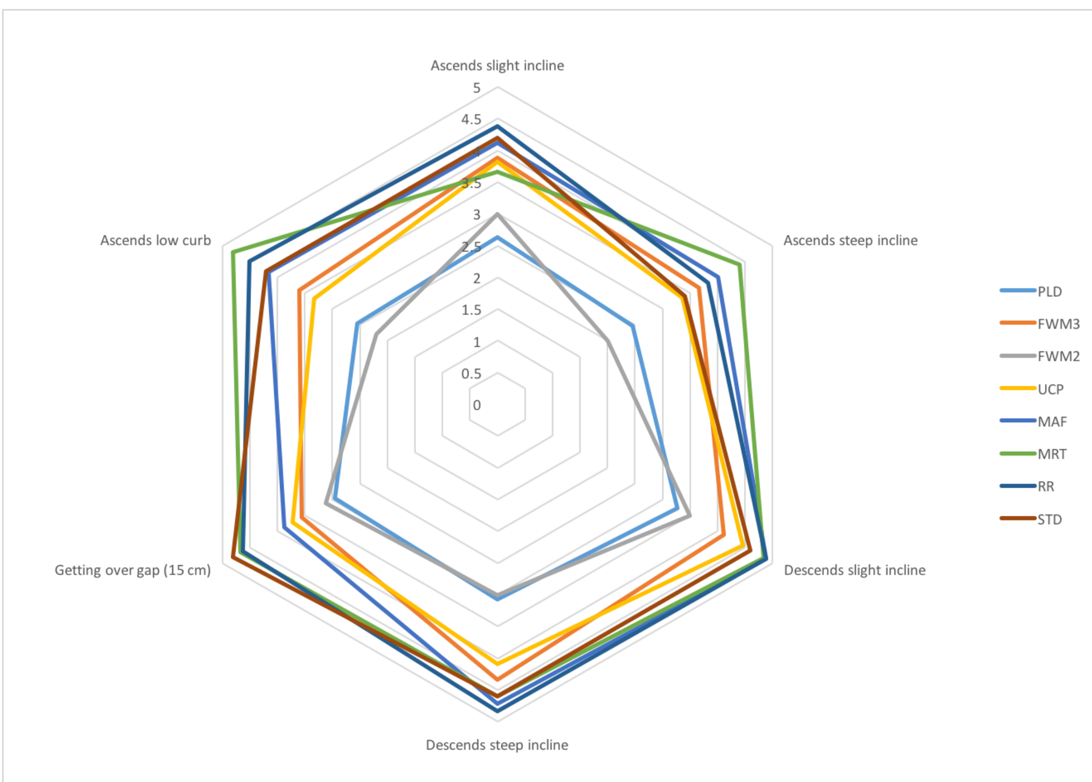


Figure 19 Self-reported difficulty of intermediate skills.

Figure 19 shows the average scores users reported in terms of difficulty for completing a certain skill for the different wheelchairs. Users were asked how difficult it was to complete the skills, and the PLD and FWM2 significantly averaged as the most difficult chairs to complete the intermediate skills in. The MRT and RR consistently scored the highest for ease of completing the skills, which for most part aligns with the wheelchair skills test observations.

SECTION 7 - LIMITATIONS

Throughout the different phases of the study, there were a variety of limitations of the approach and different logistical barriers.

During the ISO testing conducted HERL, each of the wheelchairs was only tested once. This could have led to bias results or abnormal results and can be further replicated to validate or update results. The technical testing team did not have access to a user manual and wheelchair specification sheet during the process, which would have been helpful during the wheelchair setup. Additionally, during the brake performance testing, the brakes were not adjusted according to manufacture settings, which could have contributed to the low values that were recorded in this section of testing.

The WUV project (section four of this report) had a variety of constraints during implementation. During the interviews, there was a lack of responses from some of the users, with many users having trouble understanding certain questions or finding it challenging to answer some of the open-ended questions. CITE deems that some of the questions were asked inconsistently and it appeared that questions were being asked in a leading manner, and therefore these questions were omitted from the data analysis for this report. Additionally, the wheelchairs were distributed over two different periods and some of the users received their new wheelchair long before the beginning of the study, which could have introduced recall bias or created uneven periods to compare.

Due to organizational differences with regards to goals for the study and the approach to the work, the CITE team made a decision to discontinue its work on the Wheelchair User Voice project. In the beginning of 2018, the CITE team collaborated with Access Life Bali to finish the track testing phase of the project. Because of this restructure, the CITE team found a new sample of wheelchair users for the track testing. The sample size is rather small and many of the users were Free Wheelchair Mission users, which could have induced bias into the sample when testing wheelchairs on the wheelchair skills test. Ideally, wheelchair users could be familiar with each of the wheelchairs before testing, however, this was not possible to achieve due to logistical constraints. Additionally, many of the users had limited mobility to self-propel so they could not do many of the advanced skills. In future testing, the CITE team recommends working with more active users to be able to see more granularity in the track testing results.

The basic and advanced data loggers encountered limitations when deployed in the field. The basic data loggers were programmed to send data over the cellular network, and due to connectivity issues, this was largely unsuccessful. This drained the battery, leading to shorter than expected battery life and smaller/incomplete datasets. Additionally, for the advanced data loggers, further data analysis and testing would need to be conducted to properly discern terrain types.

The majority of the study occurred in Bali, Indonesia, which has its own cultural, societal, and environmental norms. One stark structural observation was that buildings have a large step, often greater than 12 inches, to enter into the building, which presents a challenge for wheelchair user and can prevent independence. These norms may differ from other settings, and we believe these findings are location specific. More testing would be necessary to make any generalizations.

SECTION 8 - CONCLUSION

The overall results of this study highlight that wheelchair distribution is a complex issue and that the local context for distribution plays a large role in the determining the adoption and impact that these technologies could have on users.

In the Indonesian context, cultural norms and architectural practices may limit the usage of wheelchairs. As discussed earlier, social stigma around disabilities significantly reduce outside interactions between wheelchair users and the community. We find that while many wheelchairs are used daily, users have a low-bout count and travel fairly short distances which coincides with on-site observations. Furthermore, we also find that smaller, lighter chairs may be more appropriate for this context and that bulkier chairs such as the hospital-chair and the MRT had significantly fewer daily bouts. The overall acceleration profiles for forces and loading also seem to suggest that users may not often travel outside their home compounds, and the usage is dominated by low-intensity bouts.

From a technical design perspective, the performance of chairs on the ISO 7176 standards was surprising and we found that most of the wheelchairs tested did not pass the minimum ISO standard requirements for wheelchairs. Of the eight tested chairs, only the MAF chair passed the whole suite of testing standards, with the majority of chairs failing the fatigue testing component. The differing failures between the wheelchairs, with some of the chairs having repairable damage such as tire wall failures and other chairs having irreparable damage such as weld failure, speak to the variety in the quality between chairs. This also speaks to the challenges of designing and manufacturing chairs that can be used in a wide range of settings and remote places where preferences and challenges can vary greatly.

Additionally, such a high failure rate brings up the need for improved standards for this context. The ISO standards are designed for wheelchairs distributed throughout the US and Europe and therefore may not be an accurate measure of the diverse needs, preferences, and local infrastructure wheelchair users may experience in low-resource settings. Even within a country, the wide range in accessibility and conditions presents challenges in determining appropriate guidelines and standards for wheelchairs.

The wheelchair skills test portion of the study highlighted some of the differences in the chairs in terms of user experience. The CITE team observed that wheelchairs have different strengths and weaknesses based on their design- it was clear that no wheelchair was better at every skill than others. Interestingly, many of the findings in the skills testing were supported by the earlier technical testing. All of the wheelchairs included in the study scored higher than the hospital plaid chair demonstrating the importance of appropriately designed technology. The MRT and RR consistently scored high across the many sections of the testing; however, their bulkiness was often discussed. Additionally, there was low correlation between the cost of the wheelchair and the skills test score. Throughout the skills test, the need for more in-depth training for wheelchair users was apparent as many of the users were unable to complete more advanced skills.

Throughout the CITE wheelchair evaluation it was evident that there would be no one-size-fits-all solution with a clear winning technology design. User skills and training as well as local infrastructure and cultural context contribute to the adoption, impact, and outcomes the different wheelchairs may have on users. There is a need to invest in further research and design of these technologies and implement further accountability and standards for the wheelchairs.

ACKNOWLEDGMENTS

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Sensen

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United Cerebral Palsy Wheels for Humanity

Universitas Gadjah Mada

Puspadi Bali

APPENDIX

Wheelchair Skills Test

#	Individual Skill	Capacity Score (0-2)
1	Rolls forward short distance	
2	Rolls backwards short distance	
3	Turns in place	
4	Turns while moving forwards	
5	Turns while moving backwards	
6	Maneuvers sideways	
7	Picks objects from floor	
8	Avoids moving obstacle	
9	Ascends slight incline	
10	Descends slight incline	
11	Ascends steep incline	
12	Descends steep incline	
13	Rolls across side-slope	
14	Rolls on soft surface	
15	Gets over threshold	
16	Gets over gap	
17	Ascends low curb	
18	Descends low curb	
19	Performs stationary wheelie	

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OVERVIEW OF TEST RESULTS
Standard testing with ISO 7176 sections 1, 3, 5, 7, and 8 was successfully carried out on the UCP Expression Wheelchair model. Below is an overview of the test results.
UCP Expression

Safety Tests:

ISO 7176 Section 1: Static Stability……………………………….. **Forward (least stable) 16.9°**
……………………………………………………………………. **Rearward (least stable) 26.3°**
ISO 7176 Section 8: Static, Impact and Fatigue………………………………………… **FAILED Performance**

Tests:

ISO 7176 Section 3: Brake Performance………………………………….. **Downhill Slide at 8.1°**
…………………………………………………………………………………… **Uphill Slide at 5.9° Dimensional**

Measurements:

ISO 7176 Section 5: Maximum Overall Dimensions…………………………………….. **(see pg.7)**
ISO 7176 Section 7: Seating Dimensions…………………………………………………. **(see pg.8)**

TESTING METHODS
Wheelchair Set Up
The test wheelchairs were supplied by CITE at MIT for testing by the International Society for Wheelchair Professionals.
Dummy load: 100 kg (220 lb)
Position of all the Adjustable Parts: Foot support Seat support position Back support angle Driving tires Push handles
Methods
All tests were performed using one product sample according to the procedures specified in ISO 7176 Sections 1, 3, 5, 7, and 8. The test values disclosed represent values based upon testing a single sample of the wheelchair model. These values represent the maximum performance without failure as tested on a new wheelchair. The performance that a wheelchair rider would obtain from a specific wheelchair may vary, depending upon environmental conditions and personal wheelchair riding habits.
Testing Overview
Standard testing with ISO 7176 Sections 1,3,5, and 7 was successfully carried out. The test wheelchair successfully passed the minimum testing requirements with the ISO static/impact strength tests but failed during multi-drum test. During the static and impact testing, the footrest moved up/down in the clamp setting. This occurred when both the upward and downward forces where applied. After each movement occurred, the footrest position was reset, and the clamp was tightened. Testing was continued. During the multi-drum testing, the stem bolt of the right caster fractured at 82,454 cycles. The failure was noted, and testing ceased.

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ISO 7176-01: Determination of Static Stability

Stability Direction		Tipping Angle			
		Least Stable		Most Stable	
Forward	Front Wheels Locked	**9.3**	-	**9.5**	-
	Front Wheels Unlocked	**9.2**	16.9	**9.4**	26.5
Rearward	Rear Wheels Locked	**10.3**	25	**10.5**	26.5
	Rear Wheels Unlocked	**10.2**	26.3	**10.4**	33.1
	Anti-tip Devices *	**11.2**	-	**11.3**	-
Sideways	Left	**12.1**	22.5	**12.2**	26.6
	Right	**12.1**	21.8	**12.2**	22
* "Least Stable" and "Most Stable" refer to the positioning of the anti-tip devices. (See 11.2.3 and 11.3.2					

ISO 7176-03: Determination of Effectiveness of Brakes

<table>
<tr><th>Brake Type</th><th colspan="2">Method of Operation</th><th>Operating Force Needed</th></tr>
<tr><td>Lever</td><td colspan="2">Hand</td><td>Varies</td></tr>
<tr><th>Direction of Chair</th><th>Tipping Angle</th><th colspan="2">Type of Movement</th></tr>
<tr><td>Downhill</td><td>8.1</td><td colspan="2">Slide</td></tr>
<tr><td>Uphill</td><td>5.9</td><td colspan="2">Slide</td></tr>
</table>

ISO 7176-05: Determination of Overall Dimensions, Mass and Turning Space

Section	Test		Value	Units
8.2	Full Overall Length		890	mm
8.3	Overall Width		626	mm
8.4	Handgrip Height		701	mm
8.5	Stowage Length		1012	mm
8.6	Stowage Width		479	mm
8.7	Stowage Height		387	mm
8.8	Rising		-	mm
8.9	Total Mass		15.4	kg
8.10	Mass of Heaviest Part		11.8	kg
8.11	Pivot Width		1434	mm
8.12	Reversing Width		1155	mm
8.13	Turning Diameter		1143	mm
8.14	Ground Clearance		103	mm
8.15	Required Width of Angled Corridor		799	mm
8.16	Required Doorway Entry Depth		1031	mm
8.17	Required Corridor Width for Side Opening	Entering:	809	mm
		Exiting:	874	mm

ISO 7176-07: Method of Measurement of Seating and Wheel Dimensions

	Dimension Description	Fixed or Minimum Value	Maximum if relevant	Number of Increments	Units
1	**Seat Plane Angle**	7.5			°
2	**Effective Seat Depth**	329	432	10	mm
3	**Seat Width**	330			mm
4	**Effective Seat Width**	366			mm
5	**Seat Surface Height at Front Edge**	439			mm
6	**Backrest Angle**	5	57	7	°
7	**Backrest Height**	307			mm
8	**Backrest Width**	295			mm
9	**Headrest in Front of Backrest**	-			mm
10	**Headrest Height Above Seat**	-			mm
11	**Footrest to Seat**	319			mm
12	**Footrest Clearance**	103			mm
13	**Footrest Length**	198			mm
14	**Footrest to Leg Angle**	65			°
15	**Leg to Seat Surface Angle**	107.5			°
16	**Armrest Height**	-			mm
17	**Front of Armrest to Backrest**	-			mm
18	**Armrest Length**	-			mm
19	**Armrest Width**	-			mm
20	**Armrest Angle**	-			°
21	**Distance Between Armrests**	-			mm
22	**Front Location of Armrest Structure**	-			mm
23	**Hand Rim Diameter**	532			mm
24	**Propelling Wheel Diameter**	610			mm
25	**Horizontal Location of Wheel Axle**	40	126	6	mm
26	**Vertical Location of Wheel Axle**	96	137	3	mm
27	**Caster Wheel Diameter**	125			mm

ISO 7176-08: Determination of Static, Impact, and Fatigue Strengths

	Static	Force Applied	Pass/Fail
8.4	Armrest resistance to downward forces	N/A	-
8.5	Footrest resistance to downward forces	108	Pass*
8.6	Tipping Levers	N/A	-
8.7	Handgrips	61	Pass
8.8	Armrest resistance to upward forces	N/A	-
8.9	Footrest resistance to upward forces	50	Pass*
8.10	Push handles resistance to upward load	40	Pass
	Impact		**Pass/Fail**
9.3	Backrest resistance to impact		Pass
9.4	Handrim resistance to impact		Pass
9.5	Casters resistance to impact		Pass
9.6	Footrest resistance to impact		
9.6.3	Lateral impact		Pass
9.6.4	Longitudinal impact		Pass
	Front structure resistance to impact		
9.7.2	Frontal impact		N/A
9.7.3	Offset impact		N/A
	Fatigue	**Cycles**	**Pass/Fail**
10.4	Two-drum Test	82,454	Fail
10.4.3	Preliminary Current Measurement		
10.5	Curb Drop Test	--	--

Failure Pictures:

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OVERVIEW OF TEST RESULTS
Standard testing with ISO 7176 sections 1, 3, 5, 7, and 8 was successfully carried out on the Whirlwind Roughrider Wheelchair model. Below is an overview of the test results.
Whirlwind Roughrider

Safety Tests:

ISO 7176 Section 1: Static Stability……………………………..… **Rearward (most stable) 17.1°**
…………………………………………………………..………… **Rearward (least stable) 3.5°**
ISO 7176 Section 8: Static, Impact and Fatigue…..……………………………………..… **FAILED Performance**

Tests:

ISO 7176 Section 3: Brake Performance………………………………….. **Downhill Slide at 4.9°**
……………..……………………………………………………..…………… **Uphill Slide at 2.7° Dimensional**

Measurements:

ISO 7176 Section 5: Maximum Overall Dimensions……………………………..……… **(see pg.6)**
ISO 7176 Section 7: Seating Dimensions……………….…………………………….……. **(see pg.7)**

TESTING METHODS
Wheelchair Set Up
The test wheelchairs were supplied by CITE at MIT for testing by the International Society for Wheelchair Professionals.
Dummy load: 100 kg (220 lb)
Position of all the Adjustable Parts: Foot support Seat support position Back support angle Driving tires Push handles
Methods
All tests were performed using one product sample according to the procedures specified in ISO 7176 Sections 1, 3, 5, 7, and 8. The test values disclosed represent values based upon testing a single sample of the wheelchair model. These values represent the maximum performance without failure as tested on a new wheelchair. The performance that a wheelchair rider would obtain from a specific wheelchair may vary, depending upon environmental conditions and personal wheelchair riding habits.
Testing Overview
Standard testing with ISO 7176 Sections 1,3,5,7, and 8 was successfully carried out. The test wheelchair failed the minimum testing requirements with the ISO static/impact strength tests. It successfully passed the multi-drum and curb drop tests. During static and impact testing, the rubber handgrip completely came off the handle when the force was applied. The handgrip was put back on and further testing was continued.

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ISO 7176-01: Determination of Static Stability

Stability Direction		Tipping Angle			
		Least Stable		Most Stable	
Forward	Front Wheels Locked	**9.3**	39.6	**9.5**	40.2
	Front Wheels Unlocked	**9.2**	38.4	**9.4**	39.1
Rearward	Rear Wheels Locked	**10.3**	1.7	**10.5**	13.4
	Rear Wheels Unlocked	**10.2**	3.5	**10.4**	17.1
	Anti-tip Devices *	**11.2**	-	**11.3**	-
Sideways	Left	**12.1**	30.4	**12.2**	-
	Right	**12.1**	22.5	**12.2**	-
* "Least Stable" and "Most Stable" refer to the positioning of the anti-tip devices. (See 11.2.3 and 11.3.2					

ISO 7176-03: Determination of Effectiveness of Brakes

Brake Type	Method of Operation		Operating Force Needed
Lever	Hand		Varies
Direction of Chair	**Tipping Angle**	**Type of Movement**	
Downhill	4.9	Slide	
Uphill	2.7	Slide	

ISO 7176-05: Determination of Overall Dimensions, Mass and Turning Space

Section	Test		Value	Units
8.2	Full Overall Length		1053	mm
8.3	Overall Width		710	mm
8.4	Handgrip Height		804	mm
8.5	Stowage Length		1053	mm
8.6	Stowage Width		358	mm
8.7	Stowage Height		837	mm
8.8	Rising		-	mm
8.9	Total Mass		21.3	kg
8.10	Mass of Heaviest Part		-	kg
8.11	Pivot Width		1596	mm
8.12	Reversing Width		1366	mm
8.13	Turning Diameter		1216	mm
8.14	Ground Clearance		74	mm
8.15	Required Width of Angled Corridor		890	mm
8.16	Required Doorway Entry Depth		1198	mm
8.17	Required Corridor Width for Side Opening	Entering:	1011	mm
		Exiting:	1167	mm

ISO 7176-07: Method of Measurement of Seating and Wheel Dimensions

	Dimension Description	Fixed or Minimum Value	Maximum if relevant	Number of Increments	Units
1	**Seat Plane Angle**	12			°
2	**Effective Seat Depth**	437			mm
3	**Seat Width**	428			mm
4	**Effective Seat Width**	424			mm
5	**Seat Surface Height at Front Edge**	506			mm
6	**Backrest Angle**	12			°
7	**Backrest Height**	429			mm
8	**Backrest Width**	444			mm
9	**Headrest in Front of Backrest**	-			mm
10	**Headrest Height Above Seat**	-			mm
11	**Footrest to Seat**	303			mm
12	**Footrest Clearance**	74	212	∞	mm
13	**Footrest Length**	236			mm
14	**Footrest to Leg Angle**	94			°
15	**Leg to Seat Surface Angle**	94			°
16	**Armrest Height**	-			mm
17	**Front of Armrest to Backrest**	-			mm
18	**Armrest Length**	-			mm
19	**Armrest Width**	-			mm
20	**Armrest Angle**	-			°
21	**Distance Between Armrests**	-			mm
22	**Front Location of Armrest Structure**	-			mm
23	**Hand Rim Diameter**	477			mm
24	**Propelling Wheel Diameter**	597			mm
25	**Horizontal Location of Wheel Axle**	6	80	5	mm
26	**Vertical Location of Wheel Axle**	128			mm
27	**Caster Wheel Diameter**	106			mm

ISO 7176-08: Determination of Static, Impact, and Fatigue Strengths

	Static	Force Applied	Pass/Fail
8.4	Armrest resistance to downward forces	124	Pass
8.5	Footrest resistance to downward forces	45	Pass
8.6	Tipping Levers	-	-
8.7	Handgrips	96	Fail*
8.8	Armrest resistance to upward forces	156	Pass
8.9	Footrest resistance to upward forces	170	Pass
8.10	Push handles resistance to upward load	98	Pass
	Impact		**Pass/Fail**
9.3	Backrest resistance to impact		Pass
9.4	Handrim resistance to impact		Pass
9.5	Casters resistance to impact		Pass
9.6	Footrest resistance to impact		
9.6.3	Lateral impact		Pass
9.6.4	Longitudinal impact		Pass
	Front structure resistance to impact		
9.7.2	Frontal impact		-
9.7.3	Offset impact		-
	Fatigue	**Cycles**	**Pass/Fail**
10.4	Two-drum Test	200K	Pass
10.4.3	Preliminary Current Measurement		
10.5	Curb Drop Test	6,666	Pass

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OVERVIEW OF TEST RESULTS
Standard testing with ISO 7176 sections 1, 3, 5, 7, and 8 was successfully carried out on the Motivation Rough Terrain Chair model. Below is an overview of the test results.
Motivation Rough Terrain

Safety Tests:

ISO 7176 Section 1: Static Stability……………………………………. **Forward (unlocked) 40.2°**
…………………………………………………………………………. **Rearward (unlocked) 20.9°**
ISO 7176 Section 8: Static, Impact and Fatigue……………………………………………. **FAILED Performance**

Tests:

ISO 7176 Section 3: Brake Performance……………………………………. **Downhill Slide at 1.3°**
……………………………………………………………………………………… **Uphill Slide at 2.1° Dimensional**

Measurements:

ISO 7176 Section 5: Maximum Overall Dimensions……………………………………… **(see pg.6)**
ISO 7176 Section 7: Seating Dimensions……………………………………………… **(see pg.7)**

TESTING METHODS
Wheelchair Set Up
The test wheelchairs were supplied by CITE at MIT for testing by the International Society for Wheelchair Professionals.
Dummy load: 100 kg (220 lb)
Position of all the Adjustable Parts: Foot support Seat support position Back support angle Driving tires Push handles
Methods
All tests were performed using one product sample according to the procedures specified in ISO 7176 Sections 1, 3, 5, 7, and 8. The test values disclosed represent values based upon testing a single sample of the wheelchair model. These values represent the maximum performance without failure as tested on a new wheelchair. The performance that a wheelchair rider would obtain from a specific wheelchair may vary, depending upon environmental conditions and personal wheelchair riding habits.
Testing Overview
Standard testing with ISO 7176 Sections 1,3,5,7, and 8 was carried out. The test wheelchair passed the minimum testing requirements with the ISO static/impact strength tests but failed on the multi-drum test. During multi-drum testing, the axle bolt of a propelling wheel fractured at 183,359 cycles. This fractured caused a break in the frame in the welding connection to the back frame and the middle support frame. Testing was ceased following this event.

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ISO 7176-01: Determination of Static Stability

Stability Direction		Tipping Angle			
		Least Stable		Most Stable	
Forward	Front Wheels Locked	**9.3**	-	**9.5**	-
	Front Wheels Unlocked	**9.2**	40.2	**9.4**	-
Rearward	Rear Wheels Locked	**10.3**	18.7	**10.5**	-
	Rear Wheels Unlocked	**10.2**	20.9	**10.4**	-
	Anti-tip Devices *	**11.2**	-	**11.3**	-
Sideways	Left	**12.1**	19	**12.2**	-
	Right	**12.1**	18.1	**12.2**	-

* "Least Stable" and "Most Stable" refer to the positioning of the anti-tip devices. (See 11.2.3 and 11.3.2

ISO 7176-03: Determination of Effectiveness of Brakes

Brake Type	Method of Operation		Operating Force Needed
Lever	Hand		Varies
Direction of Chair	**Tipping Angle**	**Type of Movement**	
Downhill	1.3	Roll	
Uphill	2.1	Roll	

ISO 7176-05: Determination of Overall Dimensions, Mass and Turning Space

Section	Test		Value	Units
8.2	**Full Overall Length**		1318	mm
8.3	**Overall Width**		667	mm
8.4	**Handgrip Height**		855	mm
8.5	**Stowage Length**		1104	mm
8.6	**Stowage Width**		594	mm
8.7	**Stowage Height**		488	mm
8.8	**Rising**		-	mm
8.9	**Total Mass**		23.7	kg
8.10	**Mass of Heaviest Part**		15.8	kg
8.11	**Pivot Width**		1736	mm
8.12	**Reversing Width**		1368	mm
8.13	**Turning Diameter**		1427	mm
8.14	**Ground Clearance**		76	mm
8.15	**Required Width of Angled Corridor**		888	mm
8.16	**Required Doorway Entry Depth**		1197	mm
8.17	**Required Corridor Width for Side Opening**	**Entering:**	987	mm
		Exiting:	1120	mm

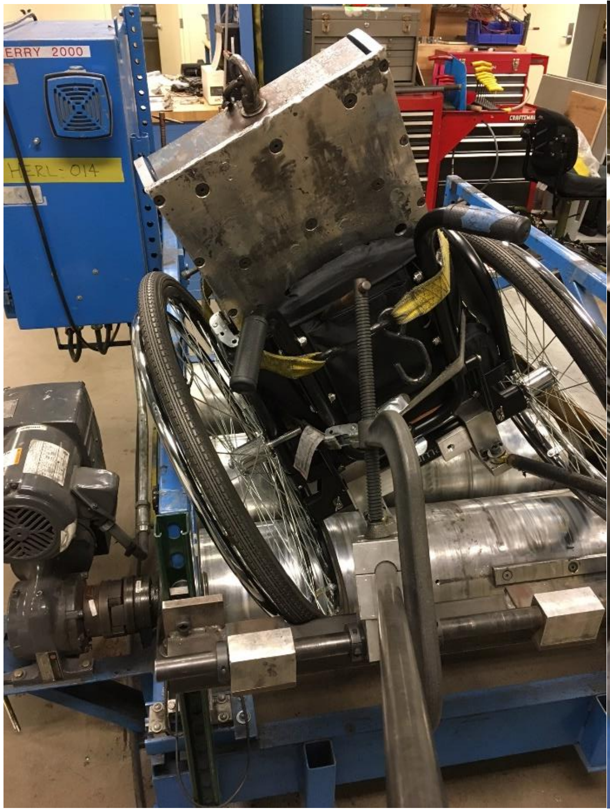
ISO 7176-07: Method of Measurement of Seating and Wheel Dimensions

	Dimension Description	Fixed or Minimum Value	Maximum if relevant	Number of Increments	Units
1	**Seat Plane Angle**	7			°
2	**Effective Seat Depth**	384			mm
3	**Seat Width**	399			mm
4	**Effective Seat Width**	434			mm
5	**Seat Surface Height at Front Edge**	541			mm
6	**Backrest Angle**	8.5			°
7	**Backrest Height**	311			mm
8	**Backrest Width**	365			mm
9	**Headrest in Front of Backrest**	-			mm
10	**Headrest Height Above Seat**	-			mm
11	**Footrest to Seat**	472			mm
12	**Footrest Clearance**	67			mm
13	**Footrest Length**	229			mm
14	**Footrest to Leg Angle**	112			°
15	**Leg to Seat Surface Angle**	113			°
16	**Armrest Height**	160			mm
17	**Front of Armrest to Backrest**	259			mm
18	**Armrest Length**	345			mm
19	**Armrest Width**	210			mm
20	**Armrest Angle**	7.5			°
21	**Distance Between Armrests**	407			mm
22	**Front Location of Armrest Structure**	278			mm
23	**Hand Rim Diameter**	585			mm
24	**Propelling Wheel Diameter**	662			mm
25	**Horizontal Location of Wheel Axle**	34			mm
26	**Vertical Location of Wheel Axle**	113			mm
27	**Caster Wheel Diameter**	216			mm

ISO 7176-08: Determination of Static, Impact, and Fatigue Strengths

	Static	Force Applied	Pass/Fail
8.4	Armrest resistance to downward forces	187	Pass
8.5	Footrest resistance to downward forces	211	Pass
8.6	Tipping Levers	-	-
8.7	Handgrips	88	Pass
8.8	Armrest resistance to upward forces	113	Pass
8.9	Footrest resistance to upward forces	112	Pass
8.10	Push handles resistance to upward load	110	Pass
	Impact		Pass/Fail
9.3	Backrest resistance to impact		Pass
9.4	Handrim resistance to impact		Pass
9.5	Casters resistance to impact		Pass
9.6	Footrest resistance to impact		
9.6.3	Lateral impact		Pass
9.6.4	Longitudinal impact		Pass
	Front structure resistance to impact		
9.7.2	Frontal impact		-
9.7.3	Offset impact		-
	Fatigue	Cycles	Pass/Fail
10.4	Two-drum Test	183,359	Fail*
10.4.3	Preliminary Current Measurement		
10.5	Curb Drop Test	-	-

Failure Pictures:



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OVERVIEW OF TEST RESULTS
Standard testing with ISO 7176 sections 1, 3, 5, 7, and 8 was successfully carried out on the Motivation Active Folding Chair model. Below is an overview of the test results.
Motivation Active Folding Chair

Safety Tests:

ISO 7176 Section 1: Static Stability…………………………………… **Forward (unlocked) 26.6°**

……………………………………………………………………….. **Rearward (unlocked) 14.5°**

ISO 7176 Section 8: Static, Impact and Fatigue…………………………………………….. **PASSED Performance**

Tests:

ISO 7176 Section 3: Brake Performance…………………………………….. **Downhill Slide at 4°**

…………………………………………………………………………….…… **Uphill Slide at 3.6° Dimensional**

Measurements:

ISO 7176 Section 5: Maximum Overall Dimensions……………………………………… **(see pg.6)**

ISO 7176 Section 7: Seating Dimensions…………………………………………………. **(see pg.7)**

TESTING METHODS
Wheelchair Set Up
The test wheelchairs were supplied by CITE at MIT for testing by the International Society for Wheelchair Professionals.
Dummy load: 100 kg (220 lb)
Position of all the Adjustable Parts: Foot support Seat support position Back support angle Driving tires Push handles
Methods
All tests were performed using one product sample according to the procedures specified in ISO 7176 Sections 1, 3, 5, 7, and 8. The test values disclosed represent values based upon testing a single sample of the wheelchair model. These values represent the maximum performance without failure as tested on a new wheelchair. The performance that a wheelchair rider would obtain from a specific wheelchair may vary, depending upon environmental conditions and personal wheelchair riding habits.
Testing Overview
Standard testing with ISO 7176 Sections 1,3,5,7, and 8 was successfully carried out. The test wheelchair successfully passed the minimum testing requirements with the ISO multi-drum and curb drop tests. During the multi-drum testing, the right axle bolt for the rear wheel was found loose with the nut off. The nut was replaced, and testing was resumed. The wheelchair went on to further complete the multi-drum and curb drop testing.

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ISO 7176-01: Determination of Static Stability

Stability Direction		Tipping Angle			
		Least Stable		Most Stable	
Forward	Front Wheels Locked	**9.3**	-	**9.5**	-
	Front Wheels Unlocked	**9.2**	26.6	**9.4**	27.7
Rearward	Rear Wheels Locked	**10.3**	10.8	**10.5**	17.1
	Rear Wheels Unlocked	**10.2**	14.5	**10.4**	23.4
	Anti-tip Devices *	**11.2**	-	**11.3**	-
Sideways	Left	**12.1**	27.4	**12.2**	-
	Right	**12.1**	25.2	**12.2**	-

* "Least Stable" and "Most Stable" refer to the positioning of the anti-tip devices. (See 11.2.3 and 11.3.2

ISO 7176-03: Determination of Effectiveness of Brakes

Brake Type	**Method of Operation**	**Operation Force Needed**
Lever	Hand	Varies
Direction of Chair	**Tipping Angle**	**Type of Movement**
Downhill	3.2	roll
Uphill	5	roll

ISO 7176-05: Determination of Overall Dimensions, Mass and Turning Space

Section	Test		Value	Units
8.2	Full Overall Length		970	mm
8.3	Overall Width		710	mm
8.4	Handgrip Height		820	mm
8.5	Stowage Length		970	mm
8.6	Stowage Width		430	mm
8.7	Stowage Height		820	mm
8.8	Rising		-	mm
8.9	Total Mass		19	kg
8.10	Mass of Heaviest Part		11	kg
8.11	Pivot Width		1650	mm
8.12	Reversing Width		-	mm
8.13	Turning Diameter		1150	mm
8.14	Ground Clearance		13	mm
8.15	Required Width of Angled Corridor		900	mm
8.16	Required Doorway Entry Depth		1250	mm
8.17	Required Corridor Width for Side Opening	Entering:	1000	mm
		Exiting:	1050	mm

ISO 7176-07: Method of Measurement of Seating and Wheel Dimensions

	Dimension Description	Fixed or Minimum Value	Maximum if relevant	Number of Increments	Units
1	**Seat Plane Angle**	13			°
2	**Effective Seat Depth**	370			mm
3	**Seat Width**	460			mm
4	**Effective Seat Width**	500			mm
5	**Seat Surface Height at Front Edge**	450			mm
6	**Backrest Angle**	15			°
7	**Backrest Height**	360			mm
8	**Backrest Width**	460			mm
9	**Headrest in Front of Backrest**	-			mm
10	**Headrest Height Above Seat**	-			mm
11	**Footrest to Seat**	350			mm
12	**Footrest Clearance**	120			mm
13	**Footrest Length**	145			mm
14	**Footrest to Leg Angle**	89			°
15	**Leg to Seat Surface Angle**	83			°
16	**Armrest Height**	-			mm
17	**Front of Armrest to Backrest**	-			mm
18	**Armrest Length**	-			mm
19	**Armrest Width**	-			mm
20	**Armrest Angle**	-			°
21	**Distance Between Armrests**	-			mm
22	**Front Location of Armrest Structure**	-			mm
23	**Hand Rim Diameter**	580			mm
24	**Propelling Wheel Diameter**	660			mm
25	**Horizontal Location of Wheel Axle**	20			mm
26	**Vertical Location of Wheel Axle**	60			mm
27	**Caster Wheel Diameter**	150			mm

ISO 7176-08: Determination of Static, Impact, and Fatigue Strengths

	Static	Force Applied	Pass/Fail
8.4	Armrest resistance to downward forces	-	-
8.5	Footrest resistance to downward forces	167	Pass
8.6	Tipping Levers	-	-
8.7	Handgrips	157	Pass
8.8	Armrest resistance to upward forces	-	-
8.9	Footrest resistance to upward forces	115	Pass
8.10	Push handles resistance to upward load	50	Pass
	Impact		**Pass/Fail**
9.3	Backrest resistance to impact		Pass
9.4	Handrim resistance to impact		Pass
9.5	Casters resistance to impact		Pass
9.6	Footrest resistance to impact		
9.6.3	Lateral impact		Pass
9.6.4	Longitudinal impact		Pass
	Front structure resistance to impact		
9.7.2	Frontal impact		-
9.7.3	Offset impact		-
	Fatigue	**Cycles**	**Pass/Fail**
10.4	Two-drum Test	200k	Pass
10.4.3	Preliminary Current Measurement		
10.5	Curb Drop Test	6666	Pass

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OVERVIEW OF TEST RESULTS
Standard testing with ISO 7176 sections 1, 3, 5, 7, and 8 was successfully carried out on the LDS Standard Wheelchair model. Below is an overview of the test results.
LDS Standard Chair

Safety Tests:

ISO 7176 Section 1: Static Stability ……..…………………………. **Forward (unlocked) 26.6°**

……………………………………………………………………. **Rearward (unlocked) 19.3°**

ISO 7176 Section 8: Static, Impact and Fatigue…………………………………………. **FAILED Performance**

Tests:

ISO 7176 Section 3: Brake Performance…………………………………………. **Downhill Slide at 4°**

……………………………………………………………………………. **Uphill Slide at 3.6° Dimensional**

Measurements:

ISO 7176 Section 5: Maximum Overall Dimensions…………………………………………. **(see pg.6)**

ISO 7176 Section 7: Seating Dimensions…………………………………………………. **(see pg.7)**

TESTING METHODS
Wheelchair Set Up
The test wheelchairs were supplied by CITE at MIT for testing by the International Society for Wheelchair Professionals.
Dummy load: 100 kg (220 lb)
Position of all the Adjustable Parts: Foot support Seat support position Back support angle Driving tires Push handles
Methods
All tests were performed using one product sample according to the procedures specified in ISO 7176 Sections 1, 3, 5, 7, and 8. The test values disclosed represent values based upon testing a single sample of the wheelchair model. These values represent the maximum performance without failure as tested on a new wheelchair. The performance that a wheelchair rider would obtain from a specific wheelchair may vary, depending upon environmental conditions and personal wheelchair riding habits.
Testing Overview
Standard testing with ISO 7176 Sections 1,3,5,7, and 8 was carried out. The test wheelchair failed the minimum testing requirements with the ISO static/impact strength tests and the multi-drum test. During static and impact testing, the footrest pedals moved positions within the clamp when the force was applied. This was the case for both the upward and downward resistances. The pedal was returned to its original location and testing was continued. During the multi-drum testing, a fracture in the front seat support frame was noted. The failure was observed after completion of the multi-drum test, therefore, the number of cycles to failure is unknown. Testing was ceased, and the chair did not continue to curb drop testing.

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Director, ISWP		

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ISO 7176-01: Determination of Static Stability

Stability Direction		Tipping Angle			
		Least Stable		Most Stable	
Forward	**Front Wheels Locked**	**9.3**	27	**9.5**	-
	Front Wheels Unlocked	**9.2**	27	**9.4**	-
Rearward	**Rear Wheels Locked**	**10.3**	14	**10.5**	-
	Rear Wheels Unlocked	**10.2**	17	**10.4**	-
	Anti-tip Devices *	**11.2**	-	**11.3**	-
Sideways	**Left**	**12.1**	21	**12.2**	-
	Right	**12.1**	23	**12.2**	-
* "Least Stable" and "Most Stable" refer to the positioning of the anti-tip devices. (See 11.2.3 and 11.3.2					

ISO 7176-03: Determination of Effectiveness of Brakes

Brake Type	Method of Operation		Operating Force Needed
Lever	Hand		Varies
Direction of Chair	**Tipping Angle**	**Type of Movement**	
Downhill	4	Slide	
Uphill	3.6	Slide	

ISO 7176-05: Determination of Overall Dimensions, Mass and Turning Space

Section	Test		Value	Units
8.2	Full Overall Length		1020	mm
8.3	Overall Width		640	mm
8.4	Handgrip Height		900	mm
8.5	Stowage Length		790	mm
8.6	Stowage Width		310	mm
8.7	Stowage Height		830	mm
8.8	Rising		-	mm
8.9	Total Mass		17	kg
8.10	Mass of Heaviest Part		16	kg
8.11	Pivot Width		1530	mm
8.12	Reversing Width		-	mm
8.13	Turning Diameter		1230	mm
8.14	Ground Clearance		100	mm
8.15	Required Width of Angled Corridor		1100	mm
8.16	Required Doorway Entry Depth		1100	mm
8.17	Required Corridor Width for Side Opening	Entering:	1000	mm
		Exiting:	1050	mm

ISO 7176-07: Method of Measurement of Seating and Wheel Dimensions

	Dimension Description	Fixed or Minimum Value	Maximum if relevant	Number of Increments	Units
1	**Seat Plane Angle**	3			°
2	**Effective Seat Depth**	437			mm
3	**Seat Width**	434			mm
4	**Effective Seat Width**	483			mm
5	**Seat Surface Height at Front Edge**	503			mm
6	**Backrest Angle**	12			°
7	**Backrest Height**	414			mm
8	**Backrest Width**	108			mm
9	**Headrest in Front of Backrest**	-			mm
10	**Headrest Height Above Seat**	-			mm
11	**Footrest to Seat**	349			mm
12	**Footrest Clearance**	145			mm
13	**Footrest Length**	157			mm
14	**Footrest to Leg Angle**	95			°
15	**Leg to Seat Surface Angle**	112			°
16	**Armrest Height**	256			mm
17	**Front of Armrest to Backrest**	249			mm
18	**Armrest Length**	242			mm
19	**Armrest Width**	47			mm
20	**Armrest Angle**	5			°
21	**Distance Between Armrests**	457			mm
22	**Front Location of Armrest Structure**	283			mm
23	**Hand Rim Diameter**	507			mm
24	**Propelling Wheel Diameter**	589			mm
25	**Horizontal Location of Wheel Axle**	12			mm
26	**Vertical Location of Wheel Axle**	159			mm
27	**Caster Wheel Diameter**	197			mm

ISO 7176-08: Determination of Static, Impact, and Fatigue Strengths

	Static	Force Applied	Pass/Fail
8.4	Armrest resistance to downward forces	157	Pass
8.5	Footrest resistance to downward forces	16	Pass*
8.6	Tipping Levers	114	Pass
8.7	Handgrips	130	Pass
8.8	Armrest resistance to upward forces	150	Pass
8.9	Footrest resistance to upward forces	143	Pass*
8.10	Push handles resistance to upward load	110	Pass
	Impact		Pass/Fail
9.3	Backrest resistance to impact		Pass
9.4	Handrim resistance to impact		Pass
9.5	Casters resistance to impact		Pass
9.6	Footrest resistance to impact		
9.6.3	Lateral impact		Pass
9.6.4	Longitudinal impact		Pass
	Front structure resistance to impact		
9.7.2	Frontal impact		-
9.7.3	Offset impact		-
	Fatigue	Cycles	Pass/Fail
10.4	Two-drum Test	200k	Fail
10.4.3	Preliminary Current Measurement	-	-
10.5	Curb Drop Test	-	-

Failure Pictures:

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OVERVIEW OF TEST RESULTS
Standard testing with ISO 7176 sections 1, 3, 5, 7, and 8 was successfully carried on the Free Wheelchair Mission Gen. 3 model. Below is an overview of the test results.
Free Wheelchair Mission Gen 3

Safety Tests:

ISO 7176 Section 1: Static Stability…………………………………….. **Forward (unlocked) 26°**

……………………………………………………………………. **Rearward (unlocked) 20°**

ISO 7176 Section 8: Static, Impact and Fatigue…………………………………..…**FAILED Performance**

Tests:

ISO 7176 Section 3: Brake Performance………………………………… **Downhill Slide @ 13°**

………………………………………………………………………….… **Uphill Slide @ 12° Dimensional**

Measurements:

ISO 7176 Section 5: Maximum Overall Dimensions…………………………………….***(see pg.6)***

ISO 7176 Section 7: Seating Dimensions……………..………………….…………..…***(see pg.7)***

TESTING METHODS
Wheelchair Set Up
The test wheelchairs were supplied by CITE at MIT for testing by the International Society for Wheelchair Professionals.
Dummy load: 100 kg (220 lb)
Position of all the Adjustable Parts: Foot support Seat support position Back support angle Driving tires Push handles
Methods
All tests were performed using one product sample according to the procedures specified in ISO 7176 Sections 1, 3, 5, 7, and 8. The test values disclosed represent values based upon testing a single sample of the wheelchair model. These values represent the maximum performance without failure as tested on a new wheelchair. The performance that a wheelchair rider would obtain from a specific wheelchair may vary, depending upon environmental conditions and personal wheelchair riding habits.
Testing Overview
Standard testing with ISO 7176 Sections 1,3,5,7, and 8 was successfully carried out. The test wheelchair did not pass the minimum testing requirements with the ISO static/impact strength tests and the multi-drum test. During static and impact testing, the footrest pedal popped out of its angle setting. The pedal was returned to the center setting and testing was continued. During the multi-drum testing, a crack in the welding connecting the caster hub to the chair frame occurred at 22,625 cycles. The testing was ceased and the chair did not continue to the curb drop for testing.

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ISO 7176-01: Determination of Static Stability

Stability Direction		Tipping Angle			
		Least Stable		Most Stable	
Forward	Front Wheels Locked	9.3	27°	9.5	-
	Front Wheels Unlocked	9.2	26°	9.4	-
Rearward	Rear Wheels Locked	10.3	17°	10.5	-
	Rear Wheels Unlocked	10.2	20°	10.4	-
	Anti-tip Devices *	11.2	-	11.3	-
Sideways	Left	12.1	25°	12.2	-
	Right	12.1	25°	12.2	-

* "Least Stable" and "Most Stable" refer to the positioning of the anti-tip devices. (See 11.2.3 and 11.3.2

ISO 7176-03: Determination of Effectiveness of Brakes

Brake Type	Method of Operation		Operating Force Needed
Lever	Hand		Varies
Direction of Chair	**Tipping Angle**	**Type of Movement**	
Downhill	13°	Slide	
Uphill	12°	Slide	

ISO 7176-05: Determination of Overall Dimensions, Mass and Turning Space

Section	Test		Value	Units
8.2	Full Overall Length		1080	mm
8.3	Overall Width		640	mm
8.4	Handgrip Height		800	mm
8.5	Stowage Length		1060	mm
8.6	Stowage Width		320	mm
8.7	Stowage Height		800	mm
8.8	Rising		-	mm
8.9	Total Mass		20	kg
8.10	Mass of Heaviest Part		8	kg
8.11	Pivot Width		750	mm
8.12	Reversing Width		-	mm
8.13	Turning Diameter		400	mm
8.14	Ground Clearance		170	mm
8.15	Required Width of Angled Corridor		900	mm
8.16	Required Doorway Entry Depth		1500	mm
8.17	Required Corridor Width for Side Opening	Entering:	1100	mm
		Exiting:	1135	mm

ISO 7176-07: Method of Measurement of Seating and Wheel Dimensions

	Dimension Description	Fixed or Minimum Value	Maximum if relevant	Number of Increments	Units
1	**Seat Plane Angle**	12.4			°
2	**Effective Seat Depth**	410			mm
3	**Seat Width**	390			mm
4	**Effective Seat Width**	440			mm
5	**Seat Surface Height at Front Edge**	560			mm
6	**Backrest Angle**	20			°
7	**Backrest Height**	820			mm
8	**Backrest Width**	370			mm
9	**Headrest in Front of Backrest**	-			mm
10	**Headrest Height Above Seat**	-			mm
11	**Footrest to Seat**	520			mm
12	**Footrest Clearance**	90			mm
13	**Footrest Length**	130			mm
14	**Footrest to Leg Angle**	30			°
15	**Leg to Seat Surface Angle**	61			°
16	**Armrest Height**	-			mm
17	**Front of Armrest to Backrest**	-			mm
18	**Armrest Length**	-			mm
19	**Armrest Width**	-			mm
20	**Armrest Angle**	-			°
21	**Distance Between Armrests**	-			mm
22	**Front Location of Armrest Structure**	-			mm
23	**Hand Rim Diameter**	480			mm
24	**Propelling Wheel Diameter**	640			mm
25	**Horizontal Location of Wheel Axle**	0			mm
26	**Vertical Location of Wheel Axle**	180			mm
27	**Caster Wheel Diameter**	200			mm

ISO 7176-08: Determination of Static, Impact, and Fatigue Strengths

	Static	Force Applied	Pass/Fail
8.4	Armrest resistance to downward forces	100	Pass
8.5	Footrest resistance to downward forces	26	Pass*
8.6	Tipping Levers	-	-
8.7	Handgrips	-	-
8.8	Armrest resistance to upward forces	99	Pass
8.9	Footrest resistance to upward forces	45	Pass
8.10	Push handles resistance to upward load	90	Pass
	Impact		Pass/Fail
9.3	Backrest resistance to impact		Pass
9.4	Handrim resistance to impact		Pass
9.5	Casters resistance to impact		Pass
9.6	Footrest resistance to impact		
9.6.3	Lateral impact		Pass
9.6.4	Longitudinal impact		Pass
	Front structure resistance to impact		
9.7.2	Frontal impact		-
9.7.3	Offset impact		-
	Fatigue	Cycles	Pass/Fail
10.4	Two-drum Test	22,625	Fail
10.4.3	Preliminary Current Measurement		
10.5	Curb Drop Test	-	-

Failure Pictures:

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OVERVIEW OF TEST RESULTS
Standard testing with ISO 7176 sections 1, 3, 5, 7, and 8 was successfully carried out on the Free Wheelchair Mission Gen 2 model. Below is an Overview of the test results.
Free Wheelchair Mission Gen 2

Safety Tests:

ISO 7176 Section 1: Static Stability…………………………………. **Forward (unlocked) 26.6°**

…………………………………………………………………..……… **Rearward (unlocked) 19.3°**

ISO 7176 Section 8: Static, Impact and Fatigue…………………………………….…….. FAILED

Performance Tests:

ISO 7176 Section 3: Brake Performance……………………………………. **Downhill Slide @ 6°**

……………………………………………………………………….…… **Uphill Slide @ 12.9° Dimensional**

Measurements:

ISO 7176 Section 5: Maximum Overall Dimensions…………………………………..…. ***(see pg.7)***

ISO 7176 Section 7: Seating Dimensions……………….………………………….......... ***(see pg.8)***

TESTING METHODS
Wheelchair Set Up
The test wheelchairs were supplied by CITE at MIT for testing by the International Society for Wheelchair Professionals.
Dummy load: 100 kg (220 lb)
Position of all the Adjustable Parts: Foot support Seat support position Back support angle Driving tires Push handles
Methods
All tests were performed using one product sample according to the procedures specified in ISO 7176 Sections 1, 3, 5, 7, and 8. The test values disclosed represent values based upon testing a single sample of the wheelchair model. These values represent the maximum performance without failure as tested on a new wheelchair. The performance that a wheelchair rider would obtain from a specific wheelchair may vary, depending upon environmental conditions and personal wheelchair riding habits.
Testing Overview
Standard testing with ISO 7176 Sections 1,3,5,7, and 8 was successfully carried out. The test wheelchair successfully passed the minimum testing requirements with the ISO static/impact strength tests and multi- drum and curb drop tests. During the multi-drum test, the left foot pedal bolt fractured, and 3 flat tires occurred. The bolt that secures the foot pedal to the height setting fractured at 59,703 cycles. The bolt was not replaced, and testing was continued without the foot pedal. Both rear tires went flat during testing: the right, once and the left, twice. The left rear tire was the first flat tire at 105,344 cycles. The tire was removed and fixed allowing for testing to be continued. At 105,697 cycles, the left rear tire was found flat again. This tire was replaced, and the testing resumed. At 130,457 cycles, the right rear tire was found flat. The cause of failure was determined to be due to cracking present in the rubber of the tire. These cracks look to be from the wear of the tires during testing. After this failure, the chair was taken off the multi-drum and testing was ceased.

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Reviewers	Signature	Date
Testing Coordinator		
Director, ISWP		

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ISO 7176-01: Determination of Static Stability

Stability Direction		Tipping Angle			
		Least Stable		Most Stable	
Forward	Front Wheels Locked	**9.3**	27°	**9.5**	-
	Front Wheels Unlocked	**9.2**	26.6	**9.4**	-
Rearward	Rear Wheels Locked	**10.3**	19.4	**10.5**	-
	Rear Wheels Unlocked	**10.2**	19.3	**10.4**	-
	Anti-tip Devices *	**11.2**	-	**11.3**	-
Sideways	Left	**12.1**	24.8	**12.2**	-
	Right	**12.1**	25.5	**12.2**	-

* "Least Stable" and "Most Stable" refer to the positioning of the anti-tip devices. (See 11.2.3 and 11.3.2)

ISO 7176-03: Determination of Effectiveness of Brakes

Brake Type	Method of Operation		Operating Force Needed
Lever	Hand		Varies
Direction of Chair	**Tipping Angle**	**Type of Movement**	
Downhill	6	Slide	
Uphill	12.9	Slide	

ISO 7176-05: Determination of Overall Dimensions, Mass and Turning Space

Section	Test		Value	Units
8.2	Full Overall Length		1095	mm
8.3	Overall Width		723	mm
8.4	Handgrip Height		826	mm
8.5	Stowage Length		1095	mm
8.6	Stowage Width		723	mm
8.7	Stowage Height		815	mm
8.8	Rising		-	mm
8.9	Total Mass		20.2	kg
8.10	Mass of Heaviest Part		19.4	kg
8.11	Pivot Width		1702	mm
8.12	Reversing Width		1291	mm
8.13	Turning Diameter		1309	mm
8.14	Ground Clearance		146	mm
8.15	Required Width of Angled Corridor		940	mm
8.16	Required Doorway Entry Depth		1141	mm
8.17	Required Corridor Width for Side Opening	Entering:	961	mm
		Exiting:	1128	mm

ISO 7176-07: Method of Measurement of Seating and Wheel Dimensions

	Dimension Description	Fixed or Minimum Value	Maximum if relevant	Number of Increments	Units
1	**Seat Plane Angle**	11			°
2	**Effective Seat Depth**	457			mm
3	**Seat Width**	441			mm
4	**Effective Seat Width**	414			mm
5	**Seat Surface Height at Front Edge**	549			mm
6	**Backrest Angle**	12			°
7	**Backrest Height**	382			mm
8	**Backrest Width**	417			mm
9	**Headrest in Front of Backrest**	-			mm
10	**Headrest Height Above Seat**	-			mm
11	**Footrest to Seat**	306	482	8	mm
12	**Footrest Clearance**	87	254	8	mm
13	**Footrest Length**	130			mm
14	**Footrest to Leg Angle**	56	124	7	°
15	**Leg to Seat Surface Angle**	109			°
16	**Armrest Height**	184			mm
17	**Front of Armrest to Backrest**	196			mm
18	**Armrest Length**	190			mm
19	**Armrest Width**	25			mm
20	**Armrest Angle**	305			°
21	**Distance Between Armrests**	414			mm
22	**Front Location of Armrest Structure**	196			mm
23	**Hand Rim Diameter**	491			mm
24	**Propelling Wheel Diameter**	653			mm
25	**Horizontal Location of Wheel Axle**	28			mm
26	**Vertical Location of Wheel Axle**	99			mm
27	**Caster Wheel Diameter**	199			mm

ISO 7176-08: Determination of Static, Impact, and Fatigue Strengths

	Static	Force Applied	Pass/Fail
8.4	Armrest resistance to downward forces	42	Pass
8.5	Footrest resistance to downward forces	75	Pass*
8.6	Tipping Levers	-	-
8.7	Handgrips	-	-
8.8	Armrest resistance to upward forces	46	Pass
8.9	Footrest resistance to upward forces	30	Pass
8.10	Push handles resistance to upward load	84	Pass
	Impact		Pass/Fail
9.3	Backrest resistance to impact		Pass
9.4	Handrim resistance to impact		Pass
9.5	Casters resistance to impact		Pass
9.6	Footrest resistance to impact		
9.6.3	Lateral impact		Pass
9.6.4	Longitudinal impact		Pass
	Front structure resistance to impact		
9.7.2	Frontal impact		-
9.7.3	Offset impact		-
	Fatigue	Cycles	Pass/Fail
10.4	Two-drum Test	130,457	Fail
10.4.3	Preliminary Current Measurement		
10.5	Curb Drop Test	-	-

Failure Pictures: