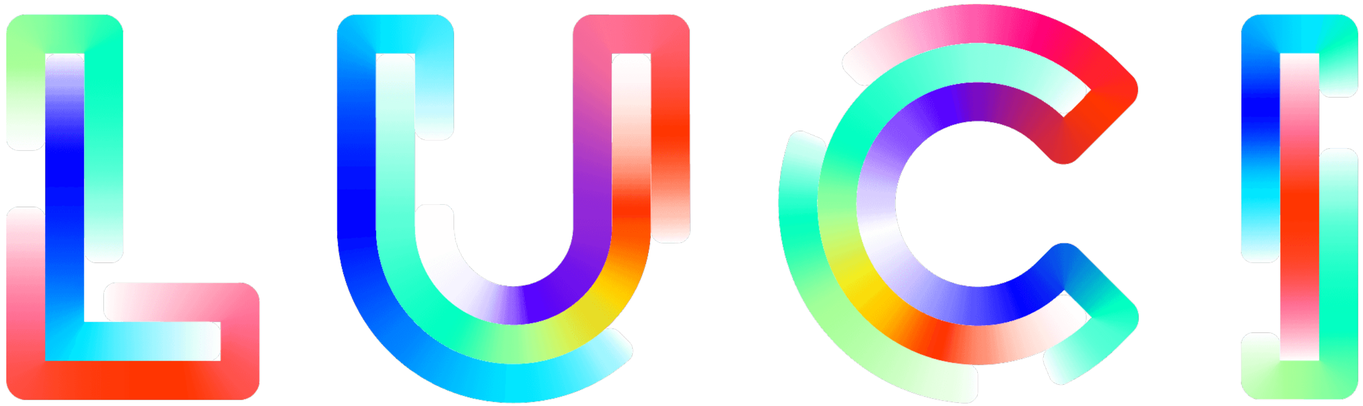

MODERN MOBILITY

Making Power Wheelchairs Smarter:

Exploring the Continuum of SMART Technology

Authored By

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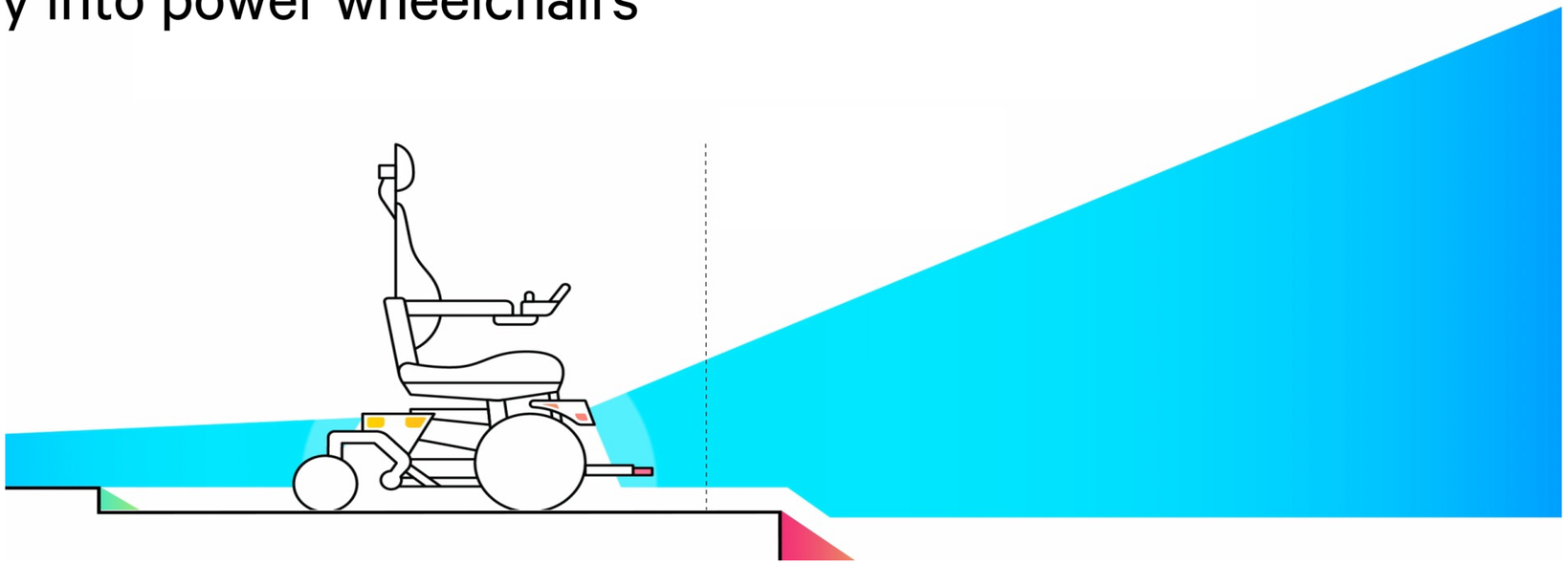
Learning Objectives

- ✓Define SMART technologies in the context of power wheelchairs
- ✓List 3 goals of power wheelchair SMART technologies
- ✓Describe 3 clinical applications of power wheelchair SMART technologies
- ✓List 3 research articles supporting the potential need for the incorporation of SMART technology into power wheelchairs



Overview for Today

The Need

The Technology

The Person

The Need

Power Wheelchair Limitations: Efficiency and Safety

Main Goal of Power Wheelchairs

Designed to provide an alternative means of moving throughout the environment for people who are unable to safely and/or efficiently **AMBULATE** or **SELF-PROPEL** an optimally configured manual wheelchair

GOAL:

Access to <u>self-generated</u> mobility!

Modes of Self-Generated Mobility

At each level, ask: Is this mobility mode functional, efficient, and safe?

- Can the person manage over 24 hr period? Can the person navigate school/ALF?

Ambula-tion

With or without an assistive device

Manual Mobility

Self-propulsion in an ‘optimally configured’ wheelchair

Power Mobility

Self-generated mobility via a consistent control method

Research Shows

The Value of Independence is Immeasurable

Greater Independence	PMD use is associated with an increased frequency of grocery shopping and going for “walks”, and an increased frequency of instrumental activities of daily living, such as going to a restaurant, posting letters, going to the bank, and visiting family and friends. *Source: Pellichero, A., et al. Relationships between Cognitive Functioning and Powered Mobility Device Use: A Scoping Review. Int. J. Environ. Res. Public Health 2021.*
Increased Brain Development	In children, PMD use contributed to the development of cognitive and play skills while increasing independence and social interactions. *Source: Pellichero, A., et al. Relationships between Cognitive Functioning and Powered Mobility Device Use: A Scoping Review. Int. J. Environ. Res. Public Health 2021.*
Promotes Self-Reliance	Independent mobility increases vocational and educational opportunities, reduces dependence on caregivers and family members, and promotes feelings of self-reliance. Reductions in functional mobility are linked with reduced participation and loss of social connections...decreases in mobility can lead to feelings of emotional loss, reduced self-esteem, isolation, stress, and fear of abandonment *Source: Simpson R, et al. .How many people would benefit from a smart wheelchair? Journal of Rehabilitation Research and Development. 2008*
It is a Human Right	According to a social justice lens, each and every individual, regardless of disability, has a fundamental right to self-directed mobility in order to fully participate in life as defined by the International Classification of Functioning, Disability and Health framework. *Source: Samuel, W, et al. Factors predicting attitudes toward self-directed mobility, Disability and Health Journal, 2018.*

Real Talk: Driving a Power Wheelchair is Challenging

Wheelchair drivers, their families, caregivers + clinicians report reluctancy to pursue power wheelchairs because:

- They worry that the driver won't be safe
- They worry that the driver will hurt someone else
- They worry that the driver will damage the environment, i.e. walls and doorframes in their home

"~40% of the users struggle to steer the standard powered wheelchair with ordinary user interfaces."

Source: Fehr L, Langbein WE, Skaar SB. Adequacy of power wheelchair control interfaces for persons with severe disabilities: a clinical survey. J Rehabil Res Dev. 2000.

Why SMART Technology?

Operating a power wheelchair is a lot like driving a car…but in MUCH more challenging environments!

What can get in the way of SAFE driving?

- **Poor Motor Control**
- **Visual Impairments**
- **Slowed Reaction time**
- **Highly Distractible Environments**

"It is RESNA' s position that age, limited vision or cognition, behavioral issues, and the ability to walk or propel a manual wheelchair short distances should not, in and of themselves, be used as discriminatory factors against providing powered mobility for children."

Source: Rosen L, et al. RESNA position on the application of power mobility devices for pediatric users. Assist Technol. 2023

Challenges from the Built Environment

Transportation

- Heavy→requires accessible transportation
- Narrow ramps
- Locking systems in vehicles

Accessibility

- Getting in and out of buildings and navigating throughout tight and/or crowded spaces→including home

Challenges from the Power Wheelchair

Inefficiency

- Maintaining a ‘straight’ path can be difficult, especially with alternative drive controls
- Caster flips can divert the chair

Tracking technologies can help but are not standard.(And not always requested!)

Safety Concerns

- The chair design cannot prevent:
  - Collisions
  - Detect and evade a drop-off
  - Tip over due to a steep angle

Reliance is solely on the driver to note and avoid potential hazards.

Safety Stats

(see Annex for more)

37.9% of wheelchair users fell at least once in the past 12 months, and 17.7% suffered a fall related injury (46.7% of fallers).

Source: Berg, et al. Wheelchair users at home: few home modifications and many injurious falls. American Journal of Piblich Health. 2002.

87% of all wheelchair users report at least one tip or fall during the last 3 years

Source: Wan-Yin Chen, et al. Wheelchair-related accidents: relationship with wheelchair-using behavior in active community wheelchair users. Archives of physical medicine and rehabilitation, 92(6):892–898, 2011.

US emergency room visits, for children ages 2-10 using mobility aids, found that 67% of injuries were related to falls from wheelchairs

Source: Alison M Barnard, et al. Pediatric mobility aid–related injuries treated in us emergency departments from 1991 to 2008. Pediatrics, 125(6):1200–1207, 2010.

Forces of impact from tip and roll accidents result in significant risk for mild to severe head injury, depending on chair position and restraint at the time of incident

Source: Brett Erickson, et al. The dynamics of electric powered wheelchair sideways tips and falls: experimental and computational analysis of impact forces and injury. Journal of NeuroEngineering and Rehabilitation, 13(1):20, 2016.

Stories from Power Wheelchair Users

Bottom Line:

When combined with SMART technology solutions, wheelchairs can provide increased independence, efficiency and safety by protecting the driver, others around them, and the environment.

The Technology

Definitions, Terminology, and Classification

What makes a mobility device SMART?

SELF-MONITORING: Sensor that can provide environmental surveillance and detect, for example, obstacles, drop-offs, or inclines.

ANALYSIS: Using the data generated by the sensors, a SMART solution analyzes this information according to the user's customized preferences.

REPORTING: This analyzed data is then interpreted and "reported" back to the user so they themselves/or in combination with their mobility device can adjust their pathway.

TECHNOLOGY: The technology includes both the hardware (the sensors on the chair!) and the software, which provides the analysis and reporting functions.

SMART in the Context Power Wheelchairs

*A Smart Wheelchair is integrated or retrofitted self-monitoring technology for a power wheelchair that provides enhanced, independent **mobility** to a wheelchair user, can collect and report **user health and wellness data** and provides **connectivity** to integrate with the connected world.*

-Michelle L. Lange, OTR/L, ABDA, ATP/SMS

SMART WHEELCHAIR (SWC) CONTINUUM

SWC Level 0	SWC Level 1	SWC Level 2	SWC Level 3	SWC Level 4	SWC Level 5
Warning Systems	Driver Assistance	Advanced Driver Assistance	Conditional Automation	Highly Autonomous System	Fully Autonomous System
No Automation/ Intervention	Single function assisted navigation	Multiple function assisted navigation	Autonomously navigate through a specific process/under specific conditions	The wheelchair is fully autonomous for an entire trip in specific environments	The wheelchair can navigate without human input in all environments

SMART WHEELCHAIR (SWC) CONTINUUM

SWC Level	Name	Definition	Human Role	Functional Example	Product Feature Example	Product Example
Human driver monitors the driving environment						
0	**Warning Systems**: no automation/ intervention	A warning system that monitors, and alerts, or provides additional feedback to the driver of potential hazards but does not affect user drive inputs. The system does NOT intervene but relies solely on the driver	Operator-the user is always in complete control.	The system does NOT intervene- reliance is solely on the driver to respond appropriately/timely to the warning given	Sensors that warn driver of potential collisions or other hazards	**Braze Mobility:** collision warning systems (auditory, visual, and haptic warnings) **ASL:** 404 Four Sensor Alert & 405 Two Sensor Alert, collision warning system, (auditory) **LUCI**: Incline/tip warning (auditory)
					Backup camera gives visual display of potential collisions or other hazards prior to driving in reverse	**Cheelcare:** Aware A1 / A2 / A3 backup Cameras **Tadibrothers:** backup camera **Quantum Rehab:** backup camera

✓ Human driver monitors the driving environment

Let's Talk Sensors

- Variety of sensors…but each type has its strengths and weaknesses!
- Examples:
  - Stereo Vision Cameras
  - Radar
  - Ultrasonic
  - LIDAR

Warning Systems: No Automation

Adaptive Switch Labs

- ✓Photo-electric switches in a 2 or 4 switch array, provides auditory feedback when approaching an obstacle
- ✓Can be programmed to ‘alert’ between 4-21” from obstacle (user reaction time)
- ✓Driver must hear and modify driving based on warning
- ✓Does **not** detect drop-offs

Close Up View

Warning Systems: No Automation

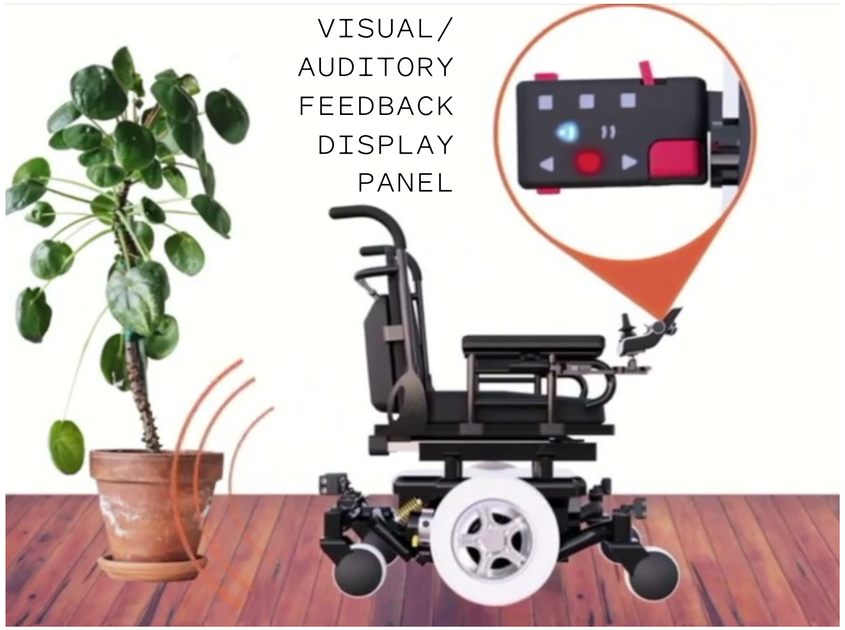
Braze™ MOBILITY

- ✓Ultrasonic blind spot sensors: mounted at user's preferred location on PWC
- ✓Feedback choice of visual, auditory, and/or vibration (up to 3 pads)
- ✓Most robust model, Sentina, provides 180 degrees horizontal/rearview and 50 degrees vertical coverage
- ✓Can add additional blind spot coverage via Echo Head (up to 3)
- ✓Does **not** detect drop-offs or soft material

SENTINA ULTRASONIC SENSOR UNIT

ECHO HEAD

VIBRATORY PAD

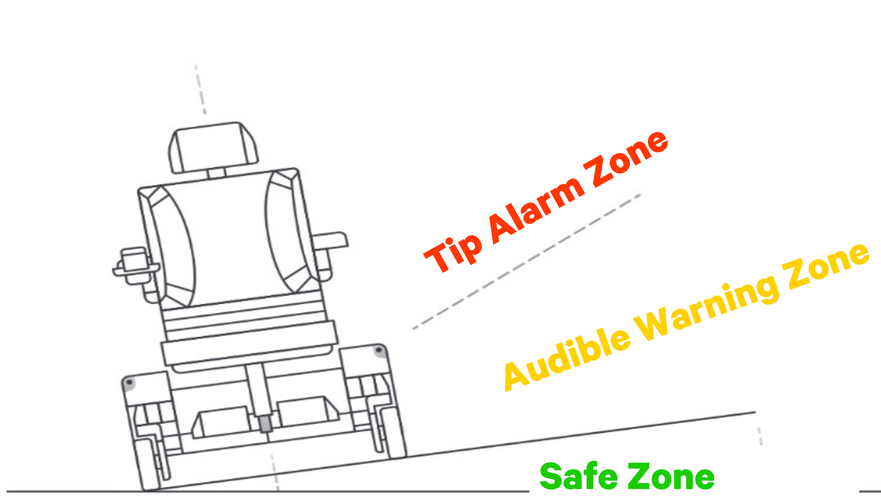


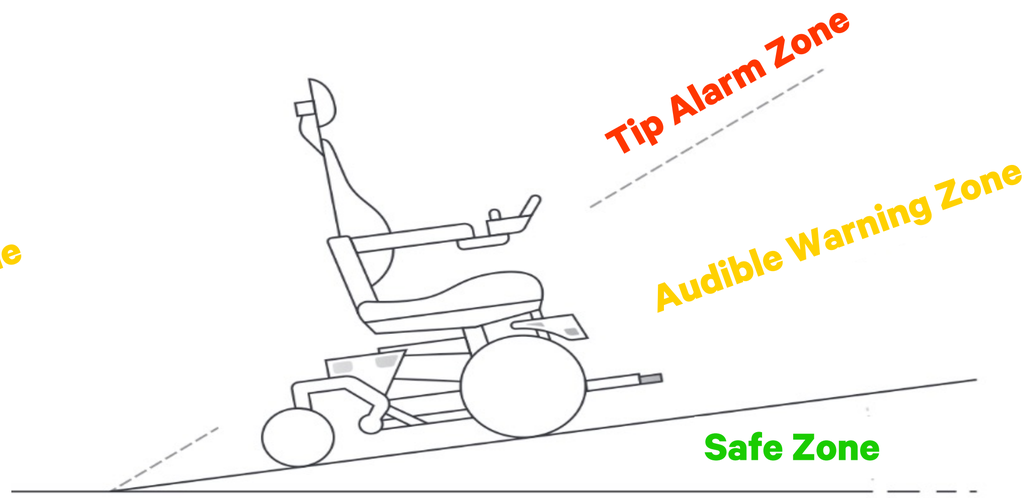
Braze Mobility

Warning Systems: No Automation

LUCI : Incline/tip warning

✓Audible alert when LUCI detects the chair is driving at an unsafe angle where the chair is at risk for tipping over





Warning Systems: No Automation

Backup Cameras

“Last week, I received the Quantum® wheelchair backup camera. I honestly didn’t know what to expect, but in the first few days of having it, I’m pleasantly surprised. I don’t enjoy backing up my Quantum Rehab Wheelchair, but I’m finding now that I do it a lot because I officially have eyes in the back of my head! What’s your superpower?”

“Having the power wheelchair backup camera has given me peace of mind, saved my walls and other people’s toes! I have a service dog that I use both at home and in public. With the backup camera, I can safely find his paws and not accidentally hurt him. I’m sure he appreciates that!”

Source: https://life.quantumrehab.com/2020/12/20/many-ways-my-wheelchair-backup-camera-helps-me

SMART WHEELCHAIR (SWC) CONTINUUM

	Human driver and automated driving system monitor the driving environment					
1	**Driver Assistance:** Single function assisted navigation (Speed or Steering)	An active system that can make adjustments to inputs for only one function (e.g., either speed or steering) to assist with navigation. The system DOES intervene.	Collaborator-the user is in control with assistance from the system	Driver controls all driving options except for emergency stops in response to detected collisions or other hazards	Sensors that warn driver of potential collisions or other hazards and the system stops the wheelchair if the driver does not respond appropriately	**NA**
				Increases driving efficiency by reducing compensatory movement, for example driving on a side slope.	Tracking technology: reduces joystick movements or switch activations and reduces time to move between locations	**Quantum Rehab:** Accu-Trac **Invacare:** G-Trac **Permobil:** ESP **Sunrise Medical**: SureTrac **AMYLIOR:** Smart-Track

✓ Level 1: Human driver and automated driving system monitors the driving environment

Driver Assistance: Emergency Stop

permobil

Remote Stop

ASL

Remote Emergency Stop Switch

Driver Assistance: Tracking Technology

- ✓ Increased efficiency! Reduces joystick movement/switch activations required to get from Point A to Point B
- ✓ Optional (meaning it can be denied) and is often not ordered/approved for clients who can benefit

permobil	Enhanced Steering Performance (ESP)
INVACARE	G-Trac
SUNRISE MEDICAL	SureTrac
AMYLIOR	Smart-Track
QUANTUM REHAB	Accu-Trac

SMART WHEELCHAIR (SWC) CONTINUUM

SWC Level	Name	Definition	Human Role	Functional Example	Product Feature Example	Product Example
Human driver and automated driving system monitor the driving environment, cont.						
2	**Advanced Driver Assistance:** Multiple function assisted navigation. (Speed and Steering)	An active system that can make both speed and steering adjustments simultaneously to the driver's inputs to assist with navigation. The system DOES intervene.	Cooperator- The user-monitors and engages while the system can adjust inputs.	Driver can steer. System will avoid collisions, drop-offs, and/or tipping by Simultaneously controlling speed and direction	Driver can continue driving, but not in the direction of a hazard. System imposes a restriction in travel that can be overridden	**LUCI:** Navigation assistance/collision avoidance, Drop-off protection
				Driver can control speed. System will automatically slow, as needed	Driver can increase speed, but system will slow in response to environment, such as walking in a crowd	**LUCI:** Crowd confidence and dynamic slowing

✓ Level 1: Human driver and automated driving system monitors the driving environment

Advanced Driver Assistance

LUCI : Fusion Sensors offer a 360-degree view of the driving environment detecting obstacles AND drop-offs

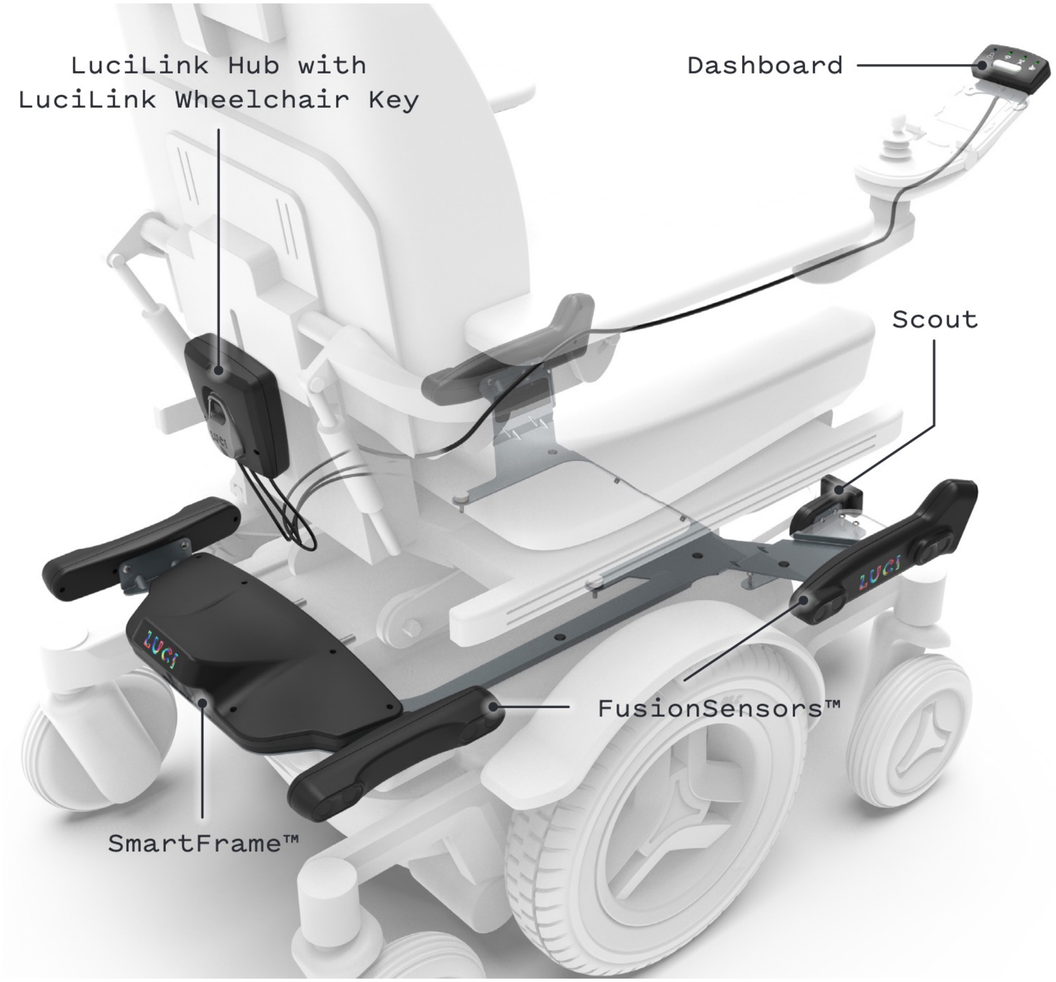
- Light Blue represents coverage by stereo vision cameras and infrared
- Purple represents radar coverage
- Green represents ultrasonic coverage

Advanced Driver Assistance

LUCI : Steering + Speed:

- Sensors will slow the chair as it approaches an obstacle giving the driver an opportunity to self correct/make a course deviation

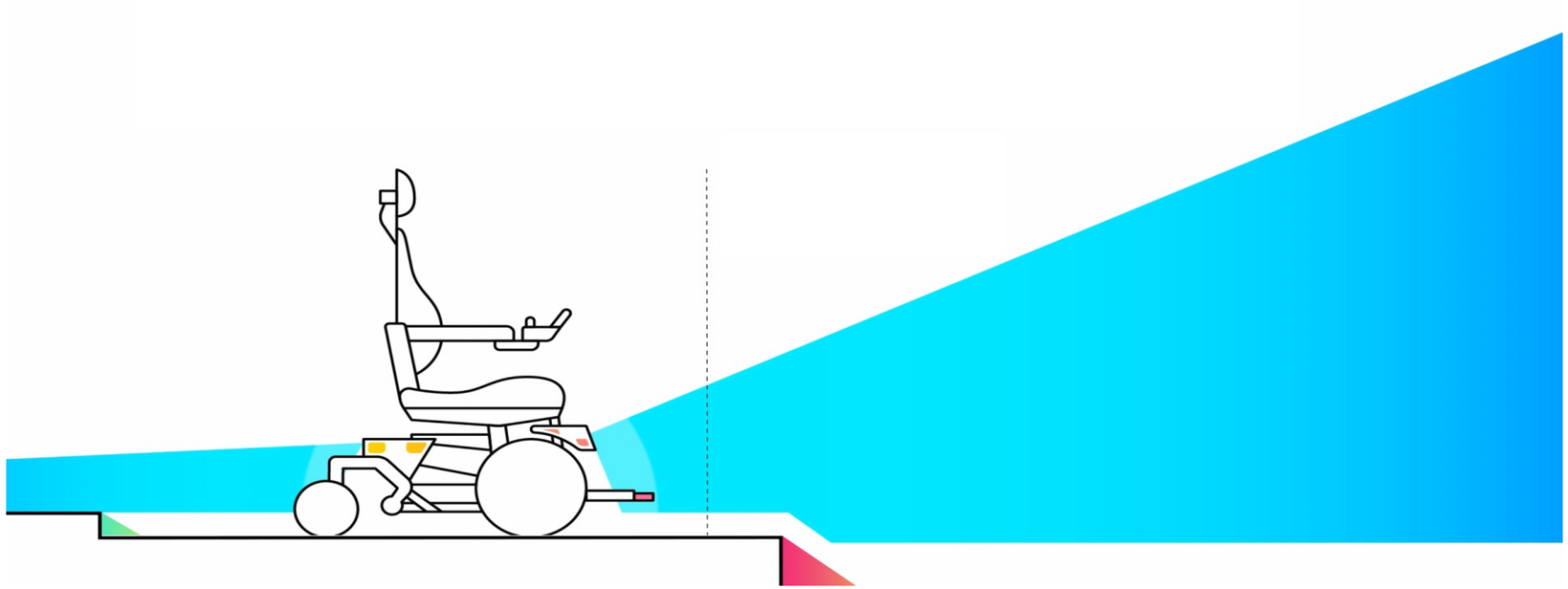
- If the driver does not respond (keeps the same input) or is not able to respond in time, LUCI will intervene and stop the chair



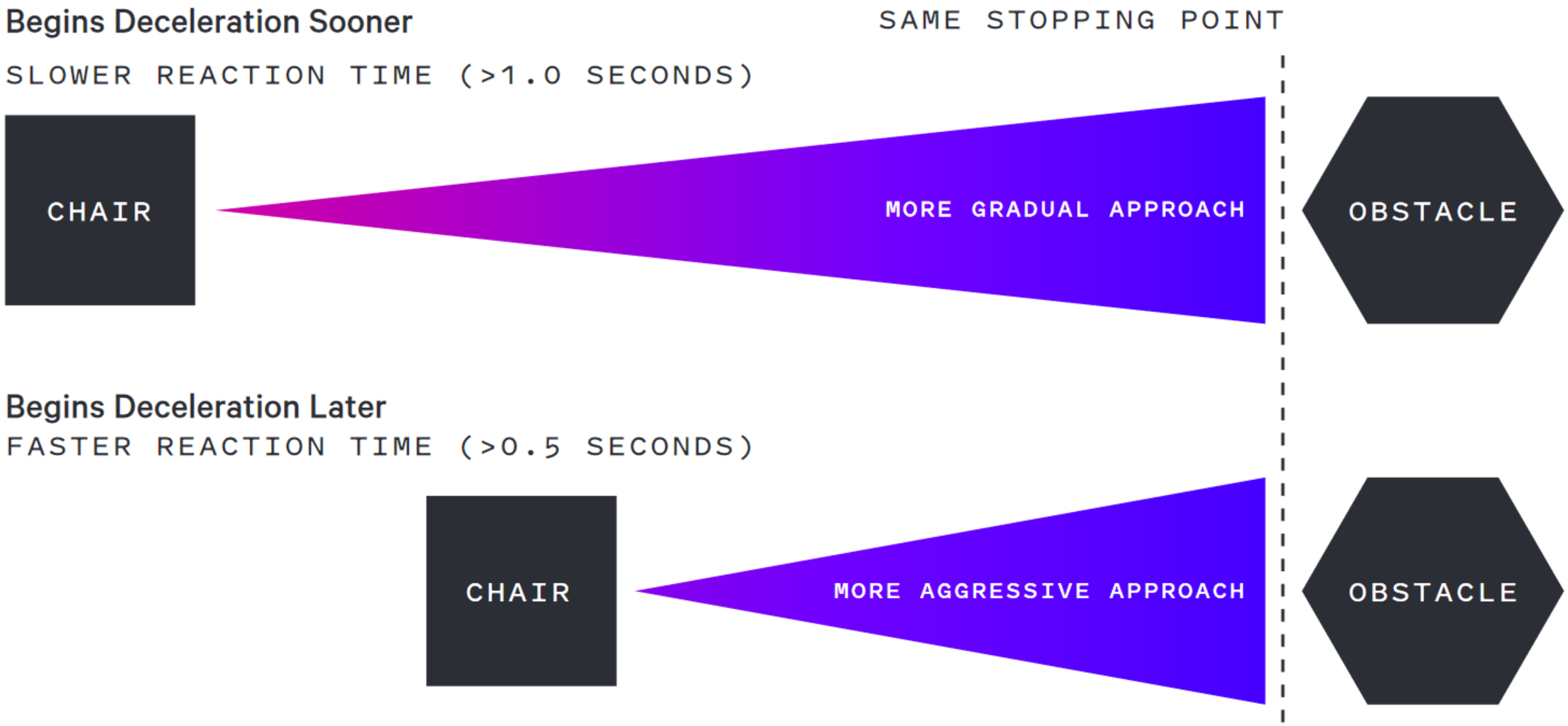
Advanced Driver Assistance

LUCI : Drop-off Detection

- If LUCI's FusionSensors detect an unsafe **drop off,** speed will automatically slow and then stop, if needed, to prevent dropping off a curb or the edge of a ramp



REACTION TIME FEATURE



Advanced Driver Assistance

LUCI : Crowd Confidence

SMART WHEELCHAIR (SWC) CONTINUUM

	Automated driving system monitors the driving environment					
3	**Conditional Automation:** Autonomously navigate through a specific process and adapt under specific conditions.	An active system that makes limited, fully automated actions in response to the user inputs. The system DOES intervene.	Initiator/Supervisor- Users must be ready to drive when autonomous features are not engaged.	Ability to navigate to a destination. The driver can initiate and stop movement, as desired, but stopping is not required	System follows a preprogrammed 'map' or tape on the floor and modifies driving in response to sensor feedback	**Smile Smart System (SSS):** driver initiates and stops movement with switch **LUCI:** RampAssist™

Conditional Automation

SMILE Smart System

- ✓ Driver initiates and stops movement with switch
- ✓ The PWC follows a tape track that can be used indoors and/or outdoors
- ✓ Sensors prevent collision (anti-collision sensors)
- ✓ Line following can be used as a safe pathway from which to develop switch access skills and joystick use over time, gently adapting settings as personal abilities evolve

Conditional Automation

Conditional Automation

LUCI : RampAssist™

- Sensors follow TAGS on the ramp to maintain specific path
- Driver must give continual input telling the system to continue following the tags, if the driver releases the JS/drive input, the chair stops
- Driver can stop at any time
- All other features of LUCI remain active during Ramp Assist, i.e. drop-off protection

Conditional Automation

SMART WHEELCHAIR (SWC) CONTINUUM

SWC Level	Name	Definition	Human Role	Functional Example	Product Feature Example	Product Example
4	**Highly Autonomous System:** The wheelchair is fully autonomous for an entire trip in specific environments.	An active system where driver input is unnecessary in specific environments and situations.	Occupant in specific environments-no human interaction needed	Ability to navigate to a destination while deciding an optimal process for negotiating obstacles and terrain. The system controls all features in specific environments	The system controls all features in specific environments	**NA**
5	**Fully Autonomous System:** The wheelchair can navigate without a human in all environments.	An active system where driver input is not required.	Occupant in all environments -no human interaction needed	Autonomous in all environments -The system controls all features, everywhere, at all times, in all conditions.	The system controls all features	**NA**

Highly/Fully Autonomous System

Nothing currently available on the market!

In part, these levels of automation are extremely difficult to execute from a technical standpoint.

From a user perspective, removing their involvement/autonomy/independent decision making would be a consideration...

Connectivity

A SMART wheelchair also means the ability to integrate to the connected world

Connectivity: BT to other devices

All Complex Rehab power wheelchairs offer Bluetooth (BT) that allows switch access or mouse emulation to external devices, i.e computer, tablet, smartphone, SGD

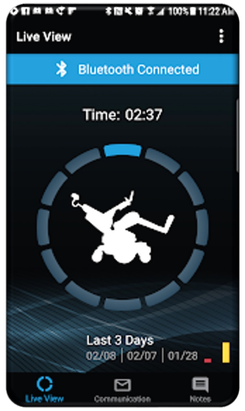
- ✓ Invacare: LiNX
- ✓ Permobil: R-net
- ✓ Quickie: R-net
- ✓ Quantum: Q-Logic
- ✓ AmyLior: R-net
- ✓ Merits: R-net

Connectivity: BT to Monitoring Apps

permobil

MyPermobil

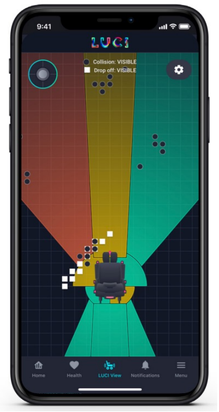
- Real-time battery status, distance traveled, seating activity
- Integrated map with GPS location
- Voice Assistant (e.g. Alexa)
- Fleet Management



SUNRISE MEDICAL

Switch-It

- Monitors time spent in various seating positions + alerts when time for position change
- Share with care team to create individualized pressure relief programs



LUCI®

MyLUCI App

- View collisions, drop-offs avoided
- View live sensor feedback with LUCIView™
- Manage health and seating alerts
- Invite caregivers, share data, trigger event notifications
- Voice Assistant (e.g. Alexa)
- Driver location (using GPS)
- Battery usage

Connectivity: Health and Wellness

MyLUCI App:

- Apple Health and Google Fit compatible heart rate monitoring
- Heart rate tracking and notification of elevated heart rate sent to care team

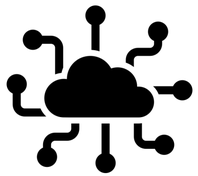
Connectivity: WiFi

LUCI:

✓ Over-the-air updates are pushed automatically- LUCI updates overnight to the latest software version

- New product features added via software update, i.e. RampAssist™

✓ Tech support can “see” what LUCI “sees” to assist with troubleshooting.



Permobil:

✓QuickConfig

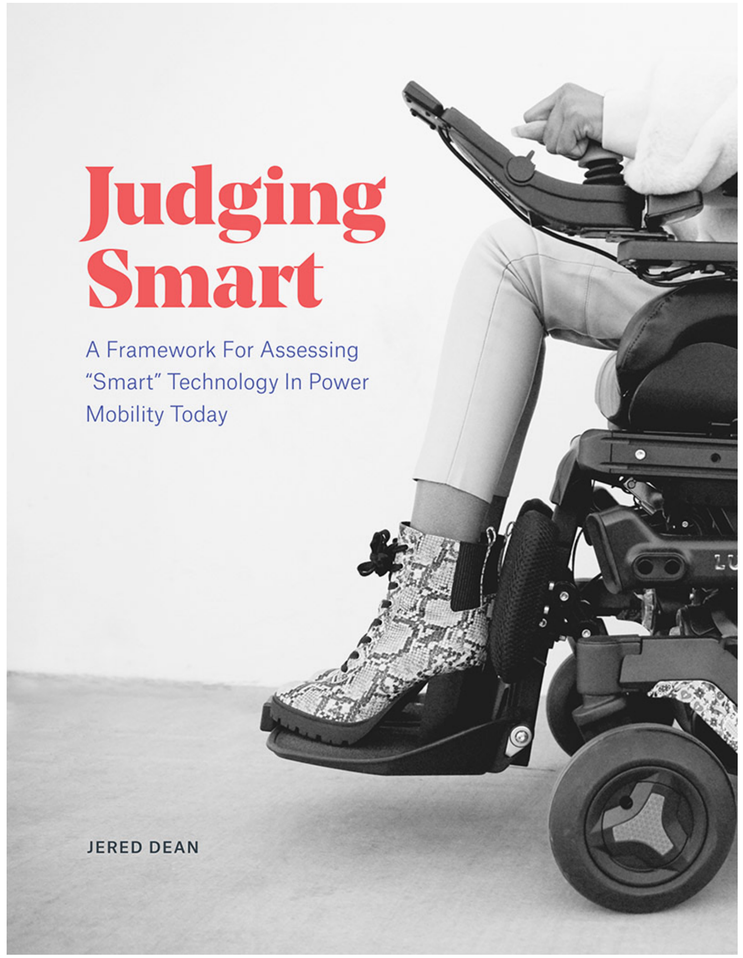
- Allows programming and customization of the chair, i.e. memory seating positions, standing sequence, drive profiles

Judging Smart White Paper

- White paper designed around questions that users should be asking of their assistive technology

- This has also been adapted into a downloadable slide deck, perfect for clinicians/ATPs/users wanting to boost their language and understanding of SMART Assistive Tech.

Download both at:
www.luci.com/smart/



The Person

Clinical Applications

Clinical Applications: Accessibility

- Maneuvering around tight spaces is very difficult
  - Examples:
    - up a ramp to get into a van
    - within a van to line up with tie downs or a locking system
    - a crowded hallway at school or an assisted living facility
    - airport
    - grocery store

Clinical Applications: Accessibility

Clinical Applications: Obstacles

- To avoid obstacles, the driver must see them
  - Hard to see areas: behind and low
- Also need to gauge distance and respond in a timely manner
- These are often very difficult for our PWC users

Clinical Applications: Distractions

- We all get distracted…squirrel!
- Most of us have bumped into something walking and talking or looking down at our phone, but the consequences are more severe when in a PWC

Clinical Applications: Motor, Visual, and Cognitive Requirements

- Motor limitations may limit driving precision and reaction time
- Visual limitations may make driving more difficult, specifically lack of acuity and visual spatial concerns (i.e. depth perception), visual field cut
- Visual field neglect or inattention
- Cognitive limitations may lead to a reduced understanding of the implications of certain driving maneuvers, such as driving off of a curb or colliding with an obstacle
- **Many clients have more than one area of involvement**

“The envelope of who is going to be able to safely operate a wheelchair in a whole variety of environments just opened right up”

JEAN MINKEL, PT/ATP
SENIOR VICE PRESIDENT
INDEPENDENCE CARE SYSTEMS
NEW YORK, NY

Clinical Applications: Summary

- So, who can benefit from Smart Wheelchair technologies?
  - Anyone who is not driving efficiently and safely, to their full potential
  - A client who has been deemed unsafe to drive a PWC and is currently in a dependent situation, i.e. tilt-in-space
  - A client who requires assistance/intermittent assistance with management of a MWC or a PWC

NOTE: Important to match client needs with specific product parameters

- There is no one product that meets everyone's needs, that is why understanding the continuum is important

Questions?

LUCI Contact Information

- Lindsey Sharpe, PT, DPT, ATP: Regional Director of Clinical Education
  - Email: lindsey@luci.com

ANNEX

More Safety Stats

Medical bills incurred in wheelchair-related falls, including rehabilitation, are often between $25,000-$75,000.

Source: Gavin-Dreschnack, et al. (2005). Wheelchair-related Falls: Current Evidence and Directions for Improved Quality Care. Journal of Nursing Care Quality

87% of all wheelchair users report at least one tip or fall during the last 3 yearsSource:

Source: Wan-Yin Chen, et al. Wheelchair-related accidents: relationship with wheelchair-using behavior in active community wheelchair users. Archives of physical medicine and rehabilitation, 92(6):892–898, 2011.

US emergency room visits, for children ages 2-10 using mobility aids, found that 67% of injuries were related to falls from wheelchairs.

Source: Alison M Barnard, et al. Pediatric mobility aid–related injuries treated in us emergency departments from 1991 to 2008. Pediatrics, 125(6):1200–1207, 2010.

Forces of impact from tip and roll accidents result in significant risk for mild to severe head injury, depending on chair position and restraint at the time of incident.

Source: Brett Erickson, et al. The dynamics of electric powered wheelchair sideways tips and falls: experimental and computational analysis of impact forces and injury. Journal of NeuroEngineering and Rehabilitation, 13(1):20, 2016.

- For a person who relies on a wheelchair for mobility, a wheelchair tip or a fall can impact morbidity and mortality. A tip or fall can also affect function, activity, independence, and quality of life. If the tip or fall results in a serious injury, such as a fracture, an extended hospital stay, or an extended bed rest, the inevitable loss of strength due to immobilization can occur.

- Three different studies have estimated the yearly incidence of serious wheelchair related accidents (fractures, concussions, dislocations, amputations, and serious head and spinal injuries) in 3 different populations as 3.2%, 5%, and 17.7%.

Source: Gavin-Dreschnack, et al. (2005). Wheelchair-related Falls: Current Evidence and Directions for Improved Quality Care. Journal of Nursing Care

- In the United States, an estimated yearly average of 36,559 nonfatal, wheelchair related accidents occur that require emergency department attention.

- The majority of injuries sustained in wheelchair-related incidents are the result of tips and falls.

Source: Kirby RL, et al. Wheelchair-related accidents caused by tips and falls among noninstitutionalized users of manually propelled wheelchairs in Nova Scotia. Am J Phys Med Rehabil. 1994;73(5):319– 330.

Tips and falls were identified in one study as the most common form of accidents, resulting in fractures (45.5%), lacerations (22.3%), and contusions/abrasions (20.1%).

Source: Kirby RL, Coughlan SG, Christie M. Could changes in the wheelchair delivery system improve safety? CMAJ. 1995;153(11):1585–1591

The impact of adverse events includes healthcare utilization, cost, and patient-perceived consequences (eg, prolonged bed rest, activity restrictions, and other factors that could affect quality of life). *Source: Gavin-Dreschnack, et al. (2005). Wheelchair-related Falls: Current Evidence and Directions for Improved Quality Care. Journal of Nursing Care Quality*

Over half of the accidents, reported in a 10-year period, result from drivers impacting a stationary object or encountering environmental hazards like uneven terrain.

Source: Anna Carlsson and Jörgen Lundälv. Acute injuries resulting from accidents involving powered mobility devices (pmds)—development and outcomes of pmd-related accidents in sweden. Traffic Injury Prevention, 20(5):484–491, 2019.