Test methods to determine propulsion work while maneuvering manual wheelchairs

A need exists to better distinguish the performance of manual wheelchairs during maneuvers in straight and turning trajectories

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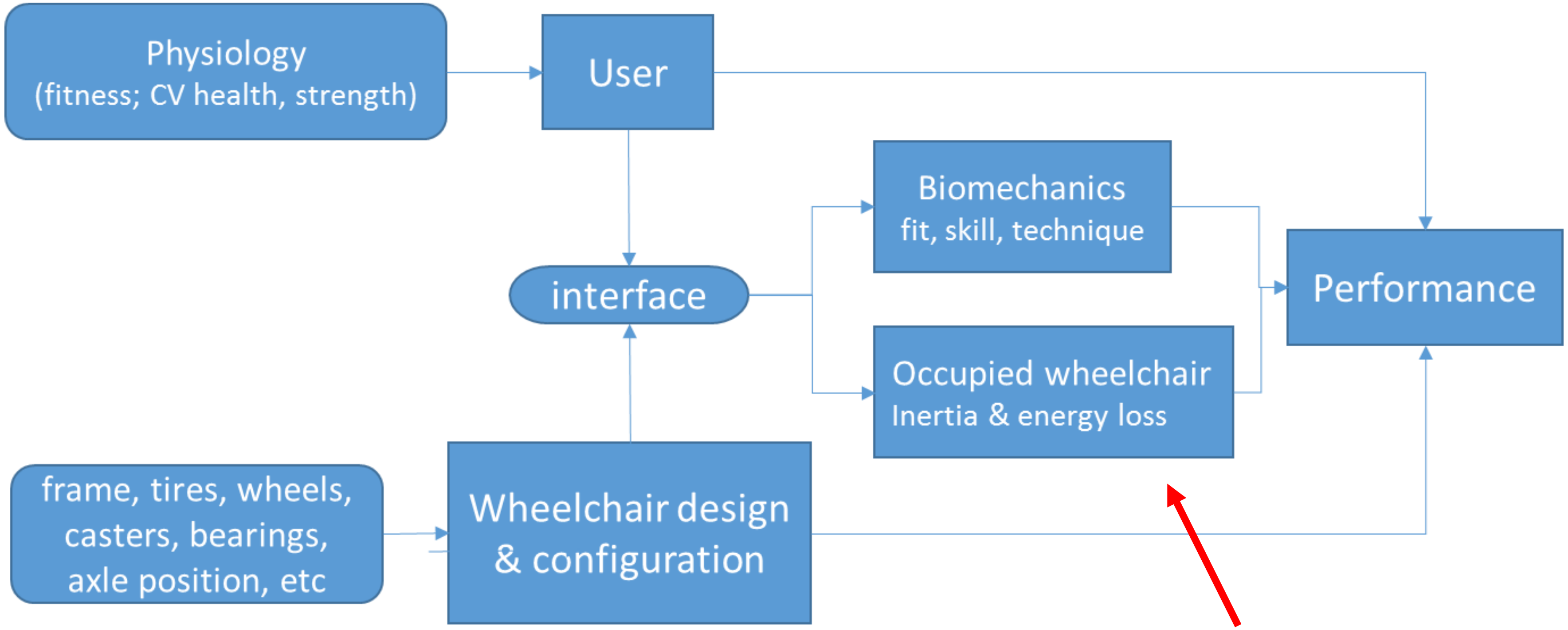
Study of manual wheelchairs as mechanical systems

- Propelling a wheelchair involves imparting propulsion torque to change the wheelchairs momentum
  - Embodied by changes in both speed and direction
- While propulsion biomechanics dominates research, one cannot ignore the study of the mechanical system
  - Wheelchair design and configuration impacts inertia and energy loss, both of which impact propulsion effort
  - A poor mechanical system requires greater effort regardless of user biomechanics
- Component testing (i.e. wheels and casters) can be used to characterize performance as a means to improve prescription and design
- Systems level testing can be used to define the overall importance of the components for a various maneuvers
  - The maneuvering ‘task’ dictates the propulsion effort
- To date, most wheelchair testing is focused on a single direction…straight trajectory
  - This ignores influences of turning resistance and yaw inertia
  - People cannot go straight forward all the time

Maneuvering manual wheelchairs



Physiology
(fitness; CV health, strength)

User

interface

Biomechanics
fit, skill, technique

Occupied wheelchair
Inertia & energy loss

Performance

frame, tires, wheels, casters, bearings, axle position, etc

Wheelchair design & configuration

Developing a technique to test manual wheelchairs

- Characterize the propulsion work in straight and turning trajectories
- Compatible with use of different rolling surfaces
  - Tile and low pile carpet used in current tests
- Capable of utilizing multiple & realistic loads on the wheels
  - Current tests based upon % drive wheel loading of 60%, 70%, & 80%
- Able to evaluate wheelchair systems with myriad configurations
  - Presented data focuses
    - drive wheels, casters and weight distribution
    - 3 canonical maneuvers
    - Carpet and tile
- Meets requisite repeatability and reproducibility

Systems testing

Assessing the work required to maneuver manual wheelchairs using over-ground maneuvers

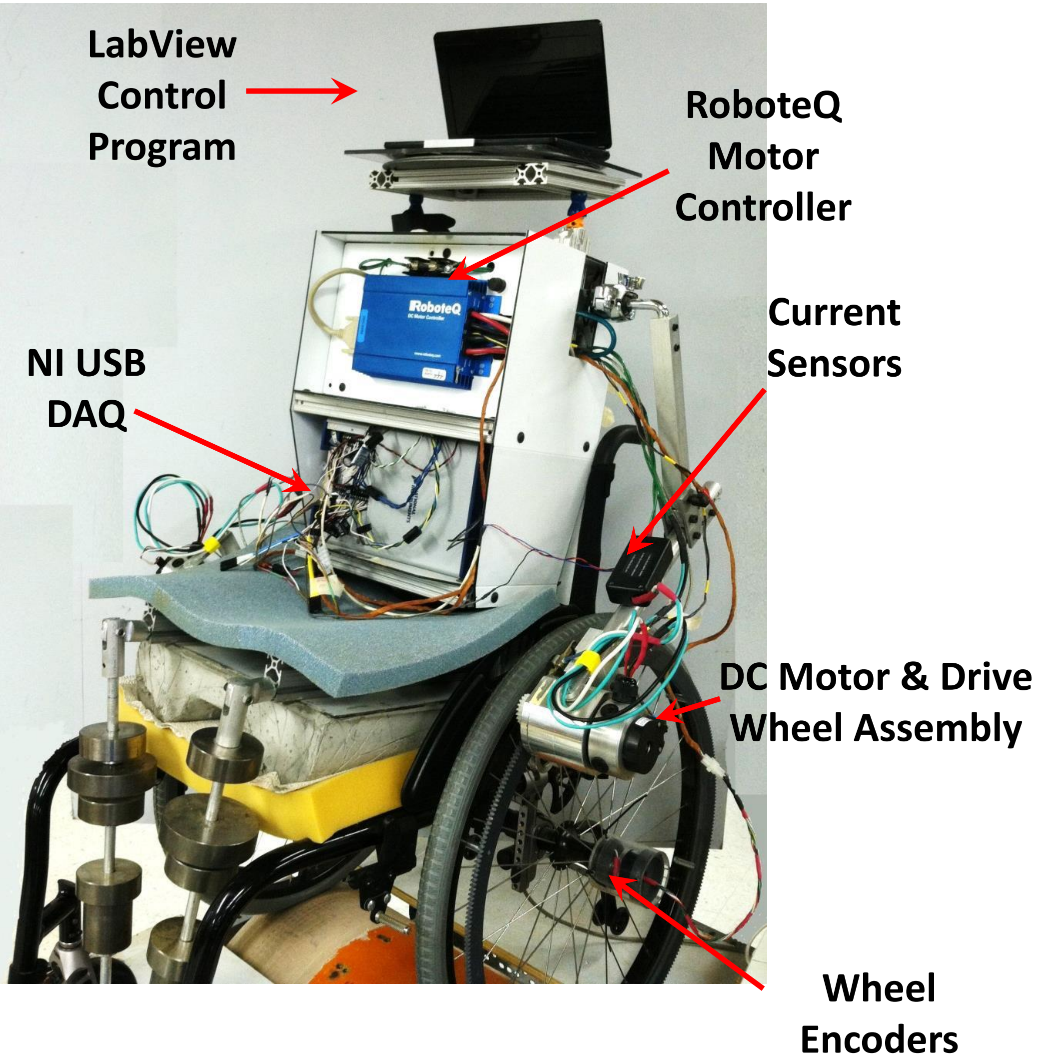
Goes beyond asking the question: “Does a difference exist?”
Offers the capability of answering “When does a difference present?”

$$W_{in} = KE + E_{loss}$$

(inertial) *(resistive)*

System mass (rectilinear inertia)
Yaw inertia
Rotational inertia

Drive wheel scrub & roll resistance
Caster scrub & rolling resistance
Bearings
Frame vibration
Suspension & damping
etc



Mass distribution matches body segment parameters
100 kg

Casters

Vary in diameter, width and hardness of wheel material




Component	Diameter	Tire Width
6 x 1” Pneumatic	**15.1 cm (5.9”)	2.79 cm (1.10”)
5 x 1.5” Soft Roll (SR)	**12.6 cm (5.0”)	3.56 cm (1.40”)



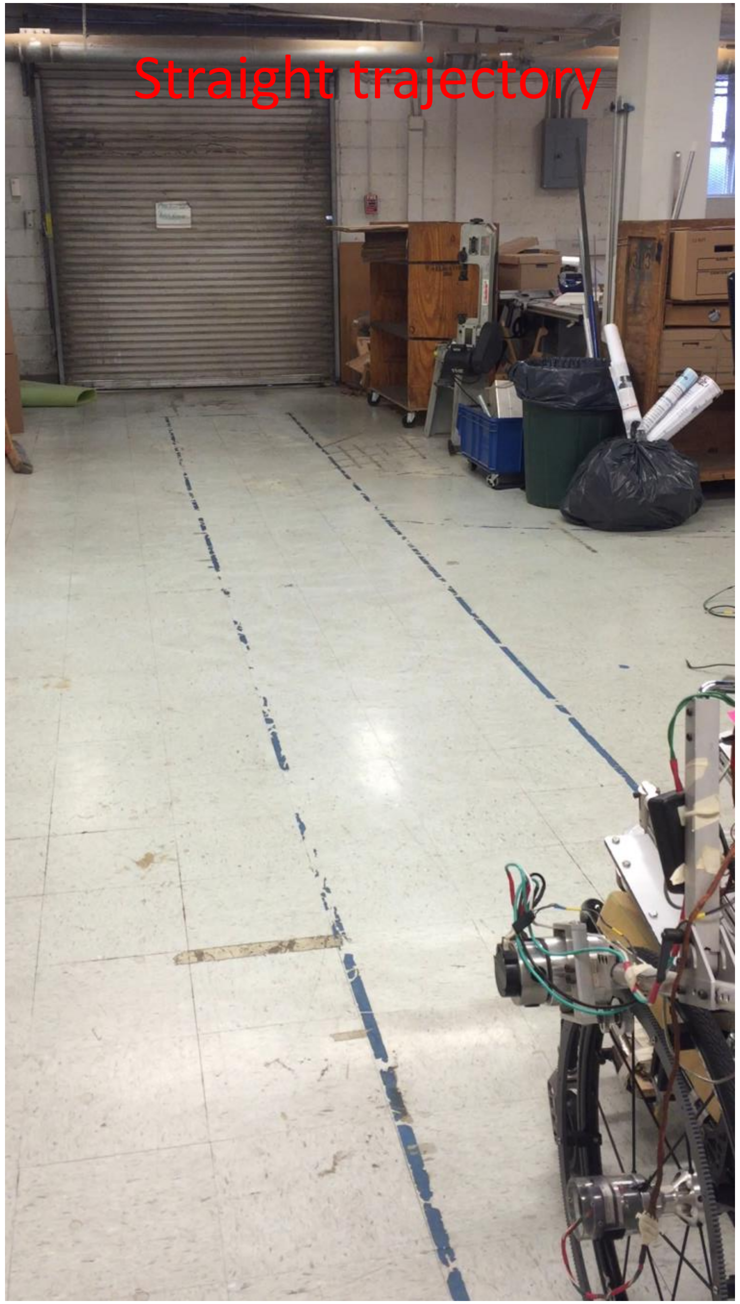

Component	Diameter	Tire Width
5 x 1” Primo	**12.4 cm (4.9”)	2.43 cm (0.96”)
4 x 1.5” Frog Legs	**10.6 cm (4.2”)	3.60 cm (1.42”)

Drive Wheels

Component	Diameter	Tire Width
24 x 1” Solid Mag	61 cm (24”)	2.75 cm (1.08”)
24 x 1-3/8” Spoked Pneumatic	61 cm (24”)	3.28 cm (1.29”)

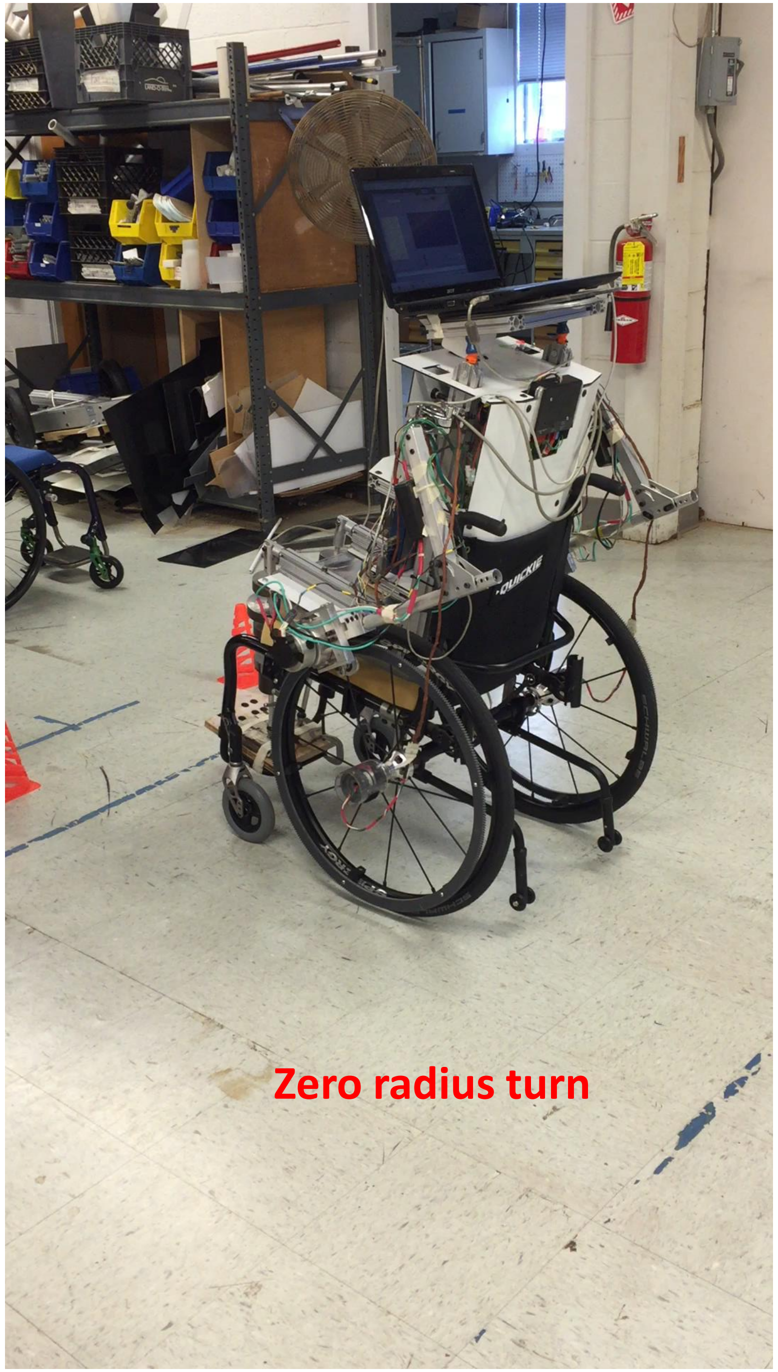
Component	Diameter	Tire Width
24 x 1” Spinegy	61 cm (24”)	2.65 cm (1.04”)

Maneuvers



Straight trajectory

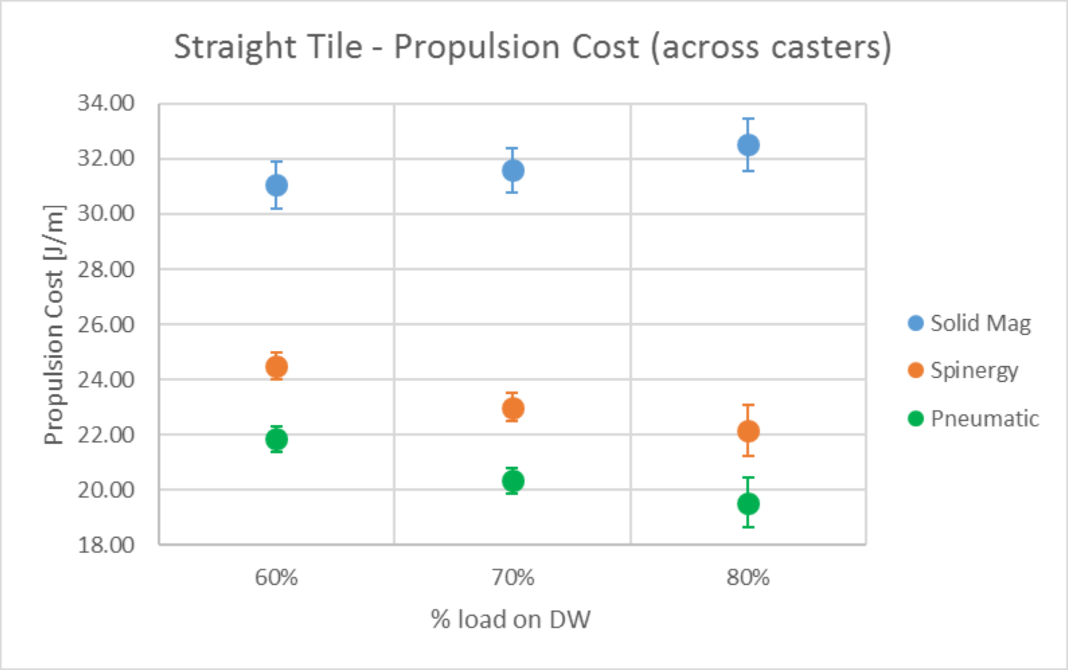
Fixed wheel turn

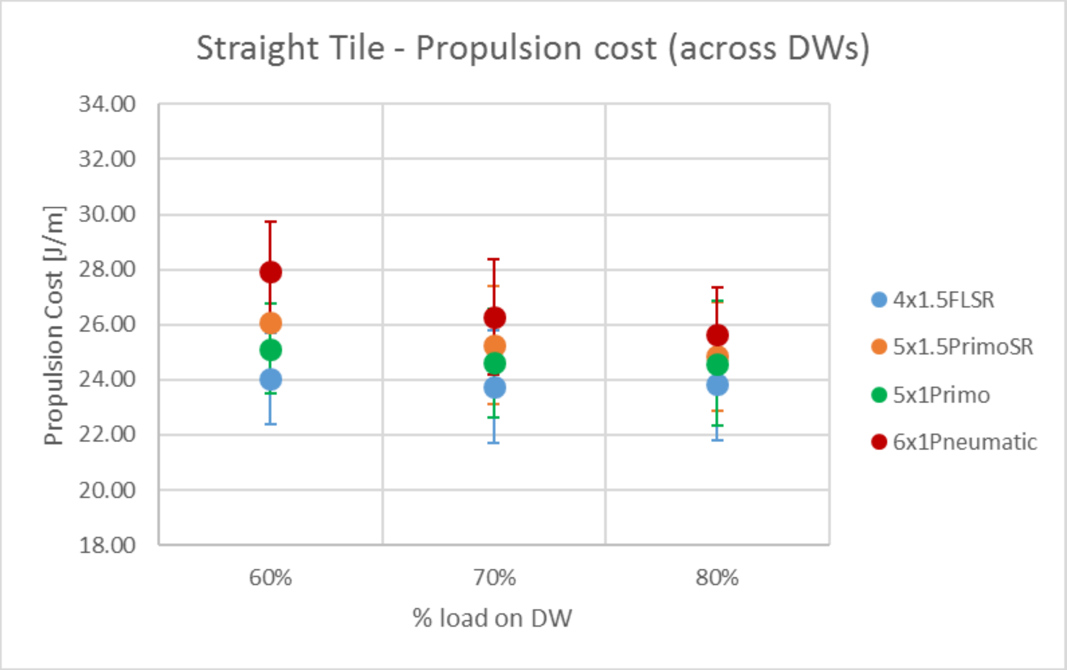


Zero radius turn

Propulsion cost on tile- straight trajectory

Straight Trajectory- rolling only





Cost decreases with increased DW load with Spinergy and Pneumatic tires

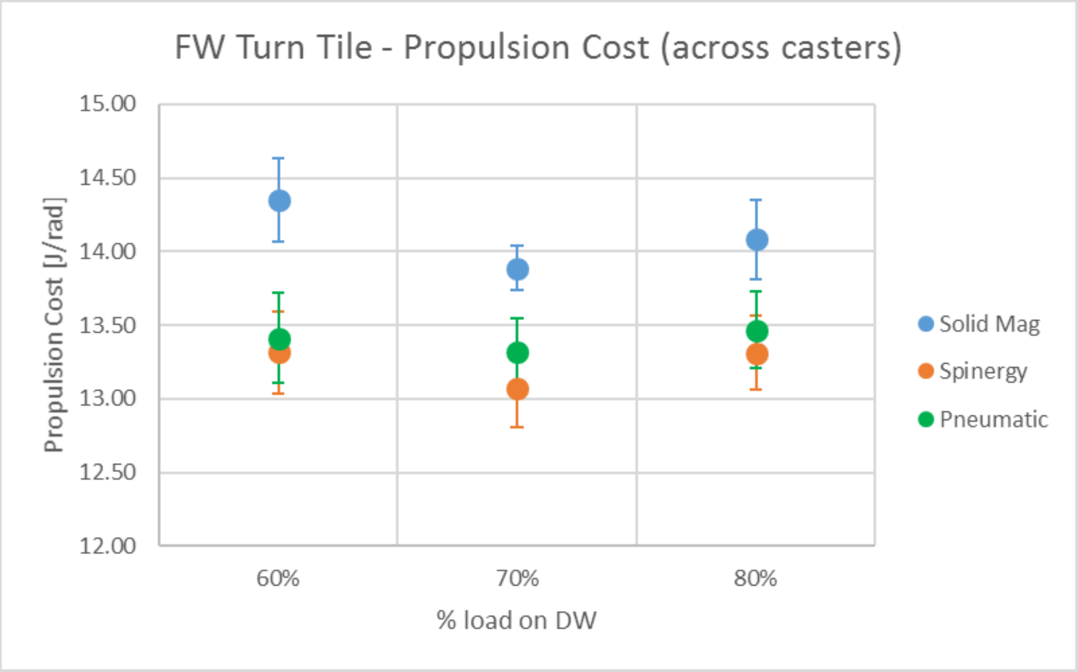
Greater difference when casters are loaded more
At 80% DW load, casters differ by 7 ½% vs 16%

Propulsion cost on tile- fixed wheel turn

<u>Fixed wheel turn:</u>

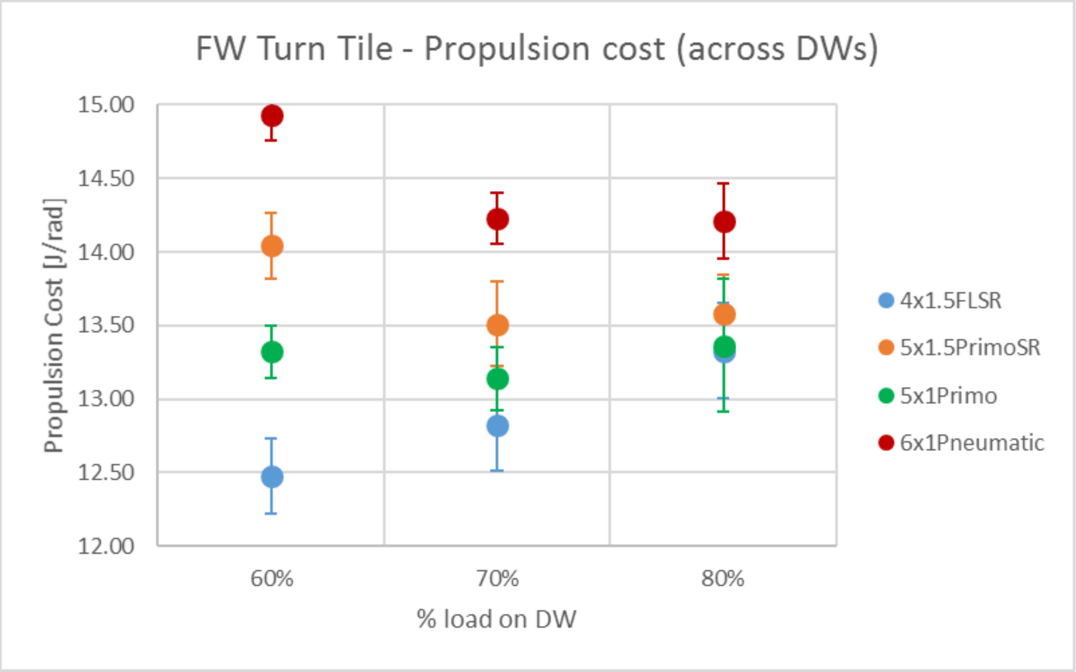
DWs: combination of rolling and scrub

Casters: rolling only



Interesting response: slight dip in Cost at 70% DW load

Cost reflects both inertial and energy loss influences



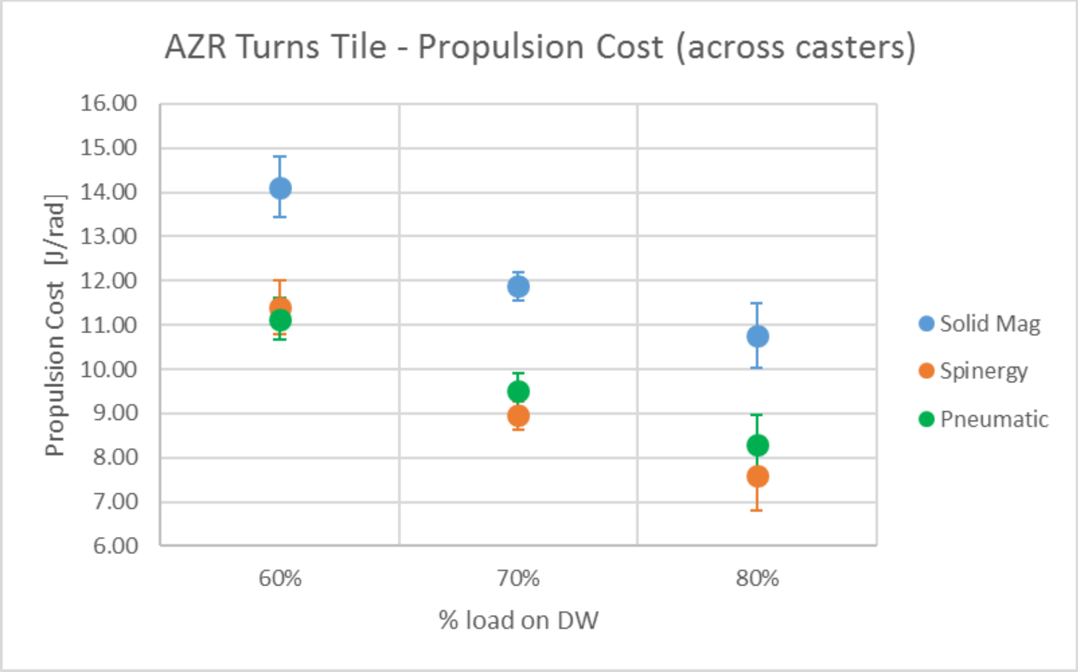
More separation in Cost at higher caster loading

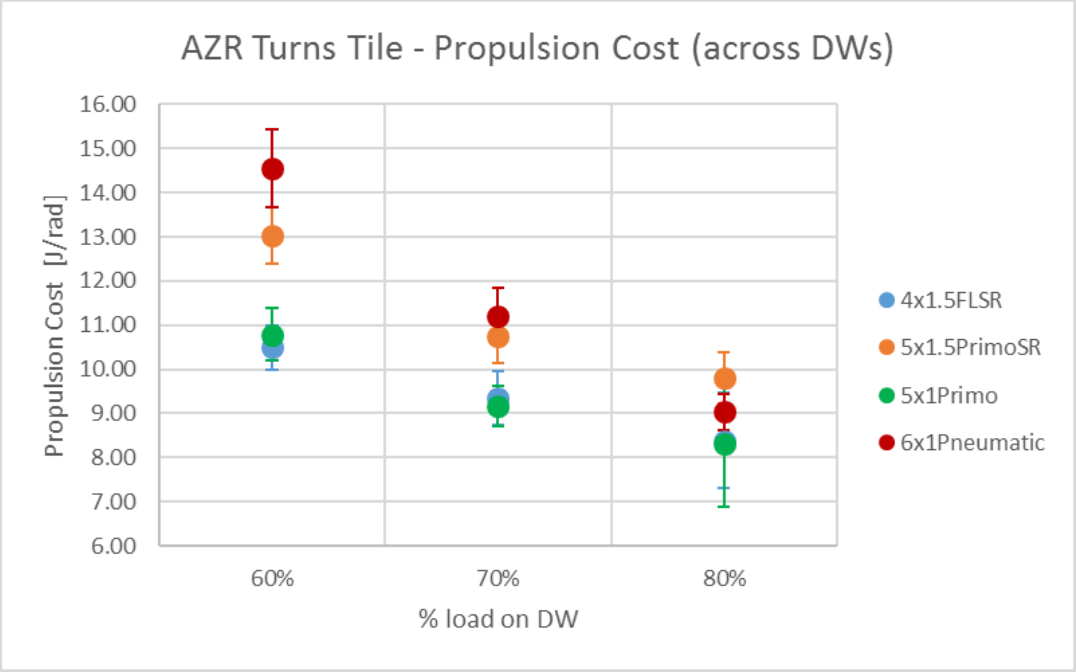
20% vs 7%

Alternating Zero radius turns on tile

Drive wheels: scrub
Casters: scrub and rolling

Maneuver has high energy loss but low inertial work



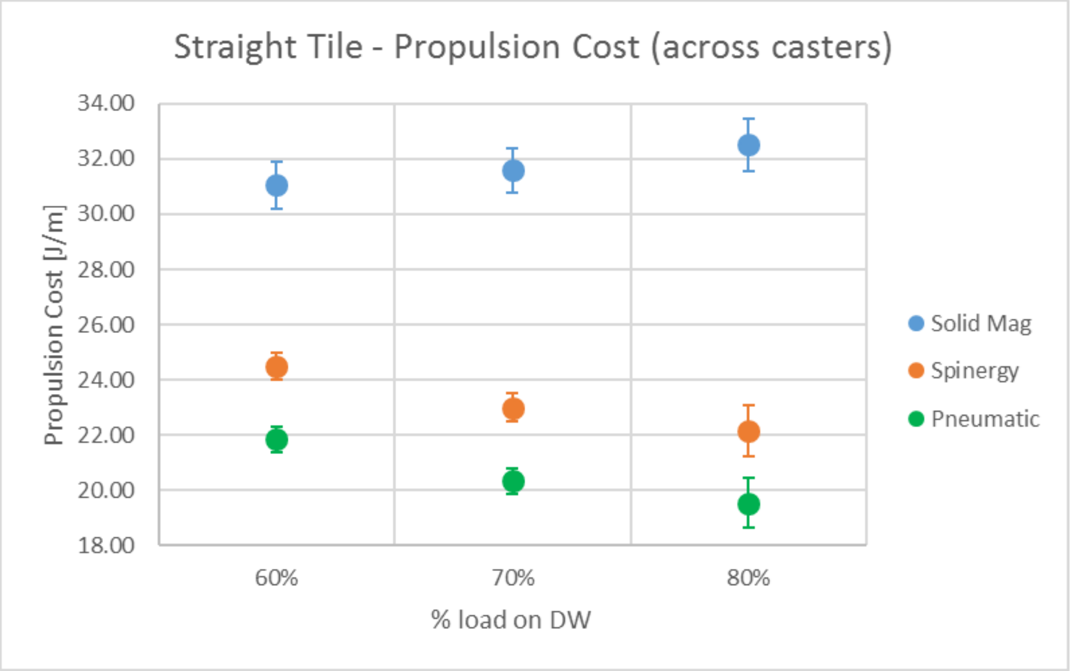


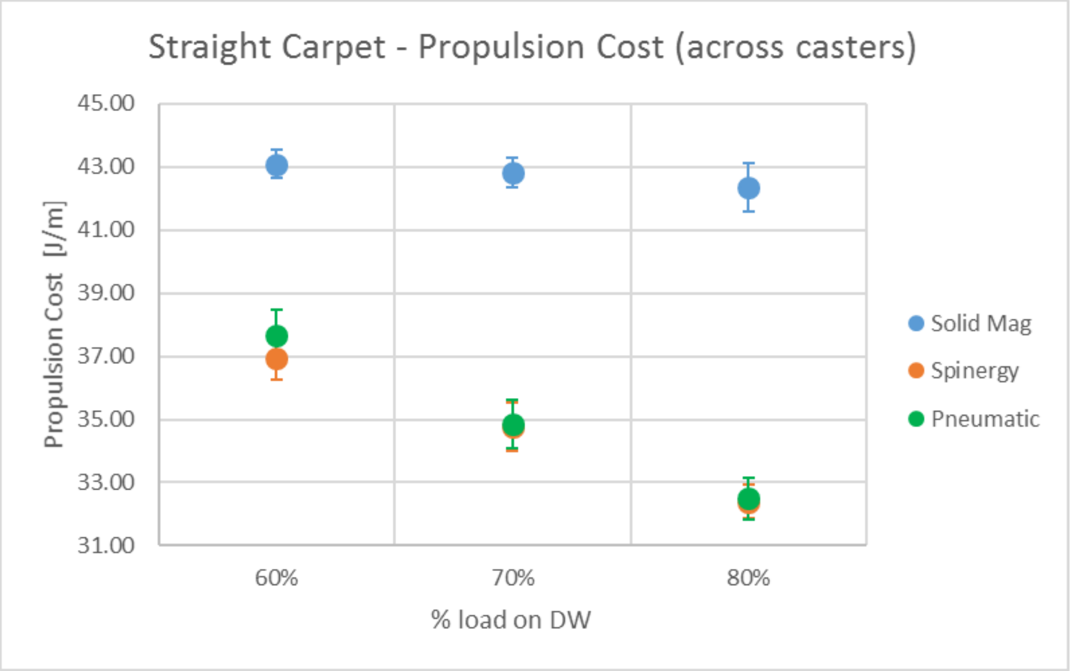
Decreasing Cost with increasing DW load

Propulsion cost of drive wheels on tile and carpet
Straight trajectory

Propulsion cost on carpet is 50% greater than on tile

Solid mag performs poorly on both surfaces



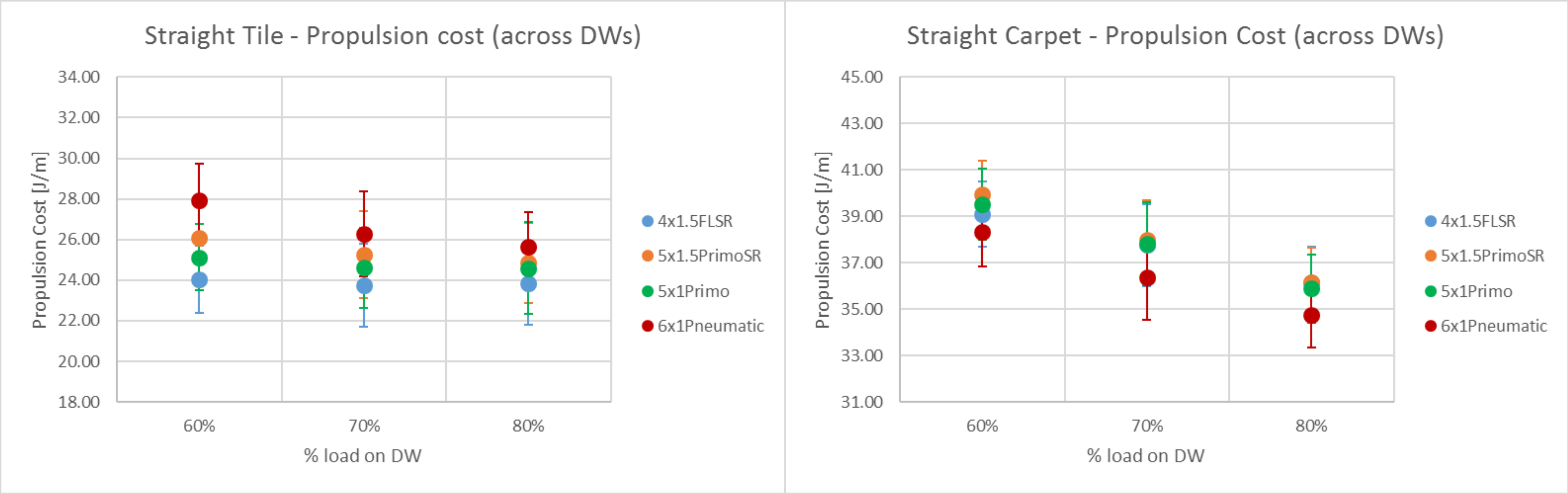


High loss surface eliminates differences between Spinergy & Pneumatic

Propulsion cost of casters on tile vs carpet - straight trajectory

Propulsion cost on carpet is 50% greater than on tile

Less separation of caster influence on carpet



6” pneumatic caster has lowest cost on carpet but highest cost on tile

Research & Clinical Implications

- Impossible to assess Propulsion cost of configuration using human operators
    - Consider the myriad configurations
        - 3 maneuvers X 2 surfaces X 3 DW loads X 3 DWs X 4 casters
    - Consider the sensitivity
- Results can be used to inform human subject testing
    - Only way to assess ‘meaningfulness’
    - Allows focus on configurations with differences
- Propulsion cost varies with maneuver
    - This is true for all assessments of work
    - Highlights need to consider propulsion ‘task’
        - Best to include changes in momentum: speed and direction
            - With constant speed and direction, only assessing some energy loss parameters, not inertial influences
- Casters influence on Cost lessens with greater DW load
    - Should definitely attend to caster selection as %DW load approaches 60%
- Difference in Std Pneumatic and Spinergy DWs is <1% across maneuvers and surfaces
- 4” Frog Leg casters are surprisingly good
    - Given their small diameter