DESIGN OF MOBILITY ATTACHMENT

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Abstract

Currently most mobility impaired people (disabled & aged) who use wheelchairs are limited in their mobility to internal built environments. There are now some powered wheelchairs and scooter type vehicles for external use, but as the mobility impaired are often unable to move from one chair to another they are of limited use.

Mobility in Internal Environments require precise control (which is best achieved by hand power), rigidity (un-sprung), low wheel base, low mass (lightness) and clean non-marking wheels. All manual wheelchairs share these attributes.

Mobility in External Environments requires external power (as ranges are long and motion continuous) motion control, suspension, and pneumatic wheels (for greater comfort). There are also hygiene problems associated with wheel contamination that make such vehicles unsuitable for internal use.

Given the contradictory nature of the requirements designs optimized for one environment will be unsuitable for the other. Complete mobility for the mobility impaired necessitates switching wheelchairs for each of the two environments.

In any environment, the basic functional requirements of the wheelchair would be to provide mobility and comfort. This paper will not discuss the issues of comfort related to rehabilitative postural seating as it is another subject altogether. The paper will instead focus its attention on mobility issues and analyze in detail the different requirements for internal and external environments in terms of stability, manoeuvrability, safety, ergonomics of operation and issues related to mobility impairment. It will point out how the requirements for optimal performance in both environments are sometimes similar and at others contradictory, and illustrate, with examples, how they are reconciled in the design solution.

Figure 1 Design Requirements

The design requirements for internal and external environments are different and sometimes contradictory hence there are no successful general purpose designs that perform well in both environments.

Mobility in Internal Environments require precise control (which is best achieved by hand power), rigidity (un-sprung), low wheel base, low mass (lightness) and clean non-marking wheels. All manual wheelchairs share these attributes.

Mobility in External Environments requires external power (as ranges are long and motion continuous) motion control, suspension, and pneumatic wheels (for greater comfort). There are also hygiene problems associated with wheel contamination that make such vehicles unsuitable for internal use.

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The issues of multi-criteria design is discussed in detail and the method of resolving such issues is proposed using this way of solving mobility problem for mobility impaired.
Introduction

The wheelchair is an important intermediary between the user, his environment and his tasks. The design of the chair reflects the functional requirements for different users, different environments and different tasks. In addressing the mobility of the user, one has to consider both the indoor environment and the outdoor environment. The indoor environment is characterised by tight spaces, smooth flooring and obstacles. Thus, small controlled movement is required under such conditions. The outdoor environment, however, is characterised by open spaces, uneven terrain, ramps, kerbs and long range movement. Such conditions are a strain on manual propulsion. Both environments exert different functional requirements for the wheelchair, some similar, some contradictory. However, there is no single satisfactory design solution to address the two simultaneously as yet.

Presently, users often have 2 wheelchairs, one for indoor use (usually a manual wheelchair) and one for outdoor use (usually an outdoor wheelchair). The shifting between chairs is a cumbersome process and is potentially dangerous for the mobility impaired.

“A blend of the two types could be the ideal strategy for your mobility. It is an approach that does not waste your energy or overuse your body.”


Wheelchairs are designed to solve a certain part of mobility needs and they can be roughly classified under 4 different typologies.

1. Self-propelled Wheelchair (manual wheelchair)
2. Power Wheelchair (electric wheelchair)
3. Hybrid Power Assist Wheelchair
4. Scooter

The Self-propelled Wheelchair is excellent for indoor use because of its functional performance whereas the Scooter type is excellent for outdoor long distance travelling. Power Wheelchairs are usually prescribed for patients who are less able; and in most cases patients who are not able to propel themselves. The Electric Power Wheelchair is also heavy and cumbersome which pose many mobility problems. These include difficulty in vehicular transport due to its weight and size and also decrease in manoeuvrability in a closed space.

The Power Assist Wheelchair type tries to address the need for power assistance for less able users to achieve long range mobility and indoor closed space manoeuvrability. However, the attachments designed thus far are not ideal. The difficulty to independently attach and detach the attachments poses a problem for the users.

The ideal wheelchair system should have the advantages of both the self-propelled wheelchair in the indoor environment and the advantages of scooters in the outdoor environment.

The design of wheelchairs varies according to tasks and environmental needs. The difference in the environments of indoor and outdoor wheelchairs results in different design specifications for the wheelchair. Most of the wheelchair designs are primarily for a specific environment and task and they do not perform as well in others. As the problem is largely unsolved by prior art, the paper seeks to propose design solutions for the problem through design analysis of the environmental needs, using existing mobility solutions to drive the design for the new mobility system.
Existing Mobility Solutions

Due to the different design specifications, each of the 4 wheelchair typology is optimised either for internal or external environments. The self-propelled wheelchair is optimised for the internal environment and the Scooter type mobility solution optimised for the external environment.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Weight</th>
<th>Turning radius</th>
<th>Stability</th>
<th>Speed, range</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>indoor wheelchair</td>
<td>◆◆◆◆</td>
<td>◆◆◆◆</td>
<td>◆◆ ◆◆◆</td>
<td>◆◆</td>
<td>◆ ◆◆◆◆◆</td>
</tr>
<tr>
<td>power wheelchair</td>
<td>◆ ◆</td>
<td>◆</td>
<td>◆ ◆ ◆◆</td>
<td>◆ ◆◆</td>
<td>◆◆ ◆◆</td>
</tr>
<tr>
<td>indoor/outdoor power wheelchair</td>
<td>◆ ◆</td>
<td>◆</td>
<td>◆ ◆◆◆</td>
<td>◆ ◆◆</td>
<td>◆◆ ◆◆</td>
</tr>
<tr>
<td>Scooter</td>
<td>◆ ◆</td>
<td>◆</td>
<td>◆ ◆◆◆</td>
<td>◆ ◆◆</td>
<td>◆◆ ◆◆</td>
</tr>
<tr>
<td>Power attachment</td>
<td>◆◆◆◆</td>
<td>◆◆</td>
<td>◆◆◆◆◆</td>
<td>◆ ◆</td>
<td>◆◆ ◆◆</td>
</tr>
</tbody>
</table>

Figure 2 Comparing different typologies of wheelchairs and their performance characteristics.
Figure 2 shows the comparative advantage of the various typologies of wheelchairs. The manual wheelchair excels in dimension, weight, turning radius and cost, while the scooter excels in stability and range. Hence the combination of the 2 types of mobility devices would be ideal.

Manual wheelchairs Figure 3 are excellent for indoor use due to its agility. The two large wheels typology gives the user precise control over its speed and direction while providing instantaneous response which is critical for tight space maneouvre. It allows also for turning on a spot which is critical for tight space. This design feature is not found in other wheelchair typology systems.

Figure 3  An example of a manual folding wheelchair
Source : Invacare Tracer EX, Invacare Corp.

Power wheelchairs Figure 4 are totally electric powered and do not allow the use of manual propulsion. Due to its machineries, the wheelchairs are extremely heavy and bulky – it is difficult to transport in a vehicle. Such wheelchairs are usually prescribed to users of the most severe disabilities.

Power wheelchairs are desired for the greater mobility it provides, however as they are often very expensive and usually not covered by medical insurances or social welfare schemes, patients of lower income levels who desire higher mobility could not afford the mobility devices. The power wheelchair are primarily designed for the indoor environment, however due to its cumbersome operation, power wheelchairs are less suitable than the manual wheelchair for the indoor environment. Hybrid indoor/outdoor wheelchairs attempt to address the issues of outdoor mobility through the design of the wheels and propulsion system and stability of the wheelchairs. These new generations of power wheelchair are more agile. A point to note when using such mobility devices is power propulsion failure; the user will be stranded.

Figure 4  An example of power wheelchair
Source : The Merits MP3HD, Merits Corp

Figure 5  An example of power indoor/outdoor power wheelchair
Source: Jazzy 1120, Pride Mobility Products Ltd
There is indeed a need for a type of wheelchair system to address the needs of both indoor and outdoor requirements. An existing solution attempt is the power attachment systems which enable greater propulsion ability to manual wheelchairs. They allow the users to use power assist in travelling long distance, up slopes or for general propulsion needs. In case of power failure or when the user feels like exercising, the wheelchair can be pushed with manual propulsion means. This is generally beneficial for marginal users as they need the exercise associated with manual propulsion and yet on some occasions, they may need power assistance to fulfil certain mobility needs, and in case of power failure, will not be stranded.

There are a few methods of power assistance: pulling, pushing and more recently, power augmentation. Attachment of power assist systems are usually done on the two large wheels under the frame, either in front or behind the chair. Due to the ergonomic work-sphere of a seated user, a rear frame attachment requires the help of an assistant, and the user cannot engage and disengage the system while seated.

<table>
<thead>
<tr>
<th>Models</th>
<th>Mount position</th>
<th>Self attaching/detaching while seated</th>
<th>Control method</th>
<th>Foldable with unit</th>
<th>Propulsion</th>
<th>Weight (Kg)</th>
<th>Speed (km/h)</th>
<th>Range (Km)</th>
<th>Battery System, Capacity, Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>* WDU</td>
<td>Rear frame</td>
<td>No, Attendant</td>
<td>Yes</td>
<td>pushing</td>
<td>&lt;4.5</td>
<td>2.1</td>
<td>6.4</td>
<td></td>
<td>12V, 7.5ah, 2.7kg</td>
</tr>
<tr>
<td>* TGA</td>
<td>Rear frame</td>
<td>No, Attendant</td>
<td>No</td>
<td>pushing</td>
<td>12.7</td>
<td>6.4</td>
<td>9.6</td>
<td></td>
<td>12V, 17ah, 6.4kg</td>
</tr>
<tr>
<td>* Alber E-fix</td>
<td>Wheels replacement</td>
<td>No, Self</td>
<td>No</td>
<td>augmenting</td>
<td>26.9</td>
<td>3.8</td>
<td>15</td>
<td></td>
<td>2x12V, 12ah, 4.5kg each</td>
</tr>
<tr>
<td>* Alber E-motion</td>
<td>Wheels replacement</td>
<td>No, Self</td>
<td>No</td>
<td>augmenting</td>
<td>24</td>
<td>5.0</td>
<td>20</td>
<td></td>
<td>2x12V, 19ah, 2.5kg each</td>
</tr>
<tr>
<td>* Alber Viamobil</td>
<td>Rear Frame</td>
<td>No, Attendant</td>
<td>No</td>
<td>pushing</td>
<td>22.8</td>
<td>5.0</td>
<td>20</td>
<td></td>
<td>2x12V, 12Ah, 2Kg each</td>
</tr>
<tr>
<td>+ Atac trac</td>
<td>Addition of front wheel</td>
<td>Yes, Self</td>
<td>No</td>
<td>pulling</td>
<td>65</td>
<td>10</td>
<td>30</td>
<td></td>
<td>24V, 40 Ah, NA</td>
</tr>
<tr>
<td>+ Pdq power trike</td>
<td>Addition of front wheel</td>
<td>Yes, Self</td>
<td>No</td>
<td>pulling</td>
<td>18</td>
<td>17</td>
<td>30</td>
<td></td>
<td>NA, NA, 7kg</td>
</tr>
</tbody>
</table>

+Source: View and Reviews Power Assists/Add ons, (2002)

Figure 6  Comparison between various power attachment units.
Figure 6 compares the operation characteristics of various power attachment devices. Few of the power attachment systems for wheelchair researched so far are designed for independent user operation. Most require a personal assistant to help in securing the attachment. As an assistant may not be around when the need arises, it is necessary to design a system to allow the user to be able to engage and disengage the system himself.

A recent innovation is the attachment of the power and drive unit to the wheels. The Alber E-motion system (Figure 7) and the Alber E-fix system, each comprises of a set of wheels with built in motor, built in batteries and built in control system. This wheel system can be attached to almost any type of manual wheelchairs. The operation is simple and effective in reducing the amount of energy required for manual propulsion. Also, in reducing the effort needed to propel the wheelchair, the risk of repetitive strain injuries is reduced. New interface methods of operation of using electronic sensors have also been introduced to complement the system.

The E-motion system also allows for effective indoor use as a “manual wheelchair”. Having the weight acting down the Centre of Gravity of the chair, the system is easy to manoeuvre manually on flat terrains. However, on inclines with its increased weight, manoeuvring will prove to be difficult.

Nonetheless, the E-motion system is essentially an indoor mobility system as the wheel base is not wide enough to provide additional stability necessary outdoors. Moreover, the use of the system in both the indoor and outdoor environment will lead to hygiene problems. Also, the wheels which contain the motors and the electronics can be heavy and thus difficult to remove for washing.

Scooters types Figure 8 are typically 3 wheelers which are usually used to assist outdoor mobility for elderly users or for marginal users who can walk with the help of crutches in the house but do require some assistance for outdoor long distance travel.

The scooters are a very popular form of transportation for the elderly. It has less social stigma than the wheelchair and enable high mobility for the user in the outdoor environment. However in the indoor environment, it cannot be effectively used due to its bulk and size. Furthermore, the front steering column hinders the activity of the user.

The power attachment systems have both the indoor manoeuvrability of the manual wheelchair and power assistance to overcome range and terrain. The recent innovation in the models Yamaha JW II and the Alber-E motion are excellent elegant solutions. However, they are lacking in range and speed desired by wheelchair users. None of the wheelchair attachment system, provide for a system to solve the hygiene issue in the house through the mix use of indoor and outdoor environment. Power assist systems still has a problem of the wheels picking up the dirt and bacteria.
Environment difference and its functional requirements

The internal environment, being a clean and closed environment, has tight spaces and smooth level terrain. It requires a wheelchair system that is light and agile, providing high manoeuvrability in tight spaces. Cleanliness is also an issue faced in the internal environment; hence non-marking wheels would be preferred.

The task environment of the indoor wheelchair would be to manoeuvre through tight space which requires tight control and excellent manoeuvrability. Mobility in internal environments requires precise control (which is best achieved by hand power), responsiveness, rigidity (un-sprung), low wheel base, low mass (lightness) and clean non-marking wheels – all of which manual wheel chairs have.

The external environment is characterised by large open spaces and possibility of uneven terrain. Typical travel distance is long and the terrain is uneven. Long distance travel can cause strain and fatigue for the users.

The task environment of the outdoor wheelchair would be to provide ease of travelling over long distance and uneven terrain at a good speed. Comfort of ride is important here as uneven terrain makes for a bumpy ride which causes discomfort for the users.

This task environment of the outdoor wheelchair would require the wheelchair to be power assisted to achieve a good range and speed, maintain stability over uneven terrain while providing a plush ride for comfort.

Mobility in External Environments requires external power (as ranges are long and motion continuous) motion control, wide wheel base (for stability), suspension and pneumatic wheels (for greater comfort).

Due to cross environmental use, there are also hygiene issues involved. Hence it is also an important factor to consider in designing the new mobility system.

Criteria common for the two environments are: comfort of ride (can be achieved with adequate damping), responsiveness in control and manoeuvrability. These are important considerations for the design of the new system. Light weight is also valued in both environments.

Mutually exclusive design factors are the wheel characteristics. Rubber pneumatic tires are excellent for outdoor use but they tend to mark the floor. Polyurethane non-marking wheels are desired for indoor use but they do not provide good traction for external environment usage. The width of the wheels also has an effect on the effectiveness of the wheelchairs in the two environments. Although thin wheels are more efficient, they are not suitable for outdoor use as they tend to get caught in small cracks and drain covers and soft grounds.

The outdoor environment is exposed to the elements and the system will have to consider the effects of weather.
<table>
<thead>
<tr>
<th></th>
<th>Indoor</th>
<th>Functional Requirements</th>
<th>Outdoor</th>
<th>Functional Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
<td>Clean, Closed, controlled environment</td>
<td>Light, Agile, highly manoeuvrable, quiet operation, non-marking wheels</td>
<td>Dirty, Exposed to weather</td>
<td>Wheels must be cleaned before entering Indoors</td>
</tr>
<tr>
<td><strong>Space</strong></td>
<td>Tight</td>
<td>Maneuverable, turn in tight corners, slow close control</td>
<td>Open</td>
<td>Power augmented, higher speed</td>
</tr>
<tr>
<td><strong>Terrain</strong></td>
<td>Level Smooth</td>
<td>Thin non-marking wheels</td>
<td>Uneven, bumpy, level to sloping to steep slope.</td>
<td>Power augmentation, High traction rubber wheels. (marking).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[Uneven]</td>
<td>Stability, shock absorbance</td>
<td></td>
</tr>
<tr>
<td><strong>Distance</strong></td>
<td>Short &lt; 10 m</td>
<td>Slow tight control</td>
<td>Long &gt; 10 m</td>
<td>Power augmented, Comfort in ride</td>
</tr>
<tr>
<td><strong>Obstacles</strong></td>
<td>Furniture</td>
<td>Slow control movement</td>
<td>Drops in levels, cracks, uneven ground, soft ground</td>
<td>Large Wide wheels, Suspension</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Kerbs</td>
<td>kerb climbing system</td>
</tr>
</tbody>
</table>

*Figure 9  Indoor, outdoor functional requirements*
<table>
<thead>
<tr>
<th></th>
<th>Manual Wheelchair</th>
<th>Indoor Functional Requirements</th>
<th>Power wheelchair / scooters</th>
<th>Outdoor Functional Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
<td>light, agile</td>
<td>Light, Agile, highly manoeuvrable, quiet operation, non-marking wheels</td>
<td>heavy bulky more stable</td>
<td>Fast, stable, long range with adequate suspension.</td>
</tr>
<tr>
<td></td>
<td>Up to 20kg</td>
<td></td>
<td>Up to 85kg for some models</td>
<td></td>
</tr>
<tr>
<td><strong>Manoeuvrability</strong></td>
<td>excellent manoeuvrability depending on user physical ability</td>
<td>tight space requirement</td>
<td>Ease of handling depends on the fluency of control Generally less agile</td>
<td>Not a critical aspect.</td>
</tr>
<tr>
<td><strong>Turning radius</strong></td>
<td>Turn on a dime</td>
<td>Critical</td>
<td>Turning radius of about 1m</td>
<td>Not a critical aspect.</td>
</tr>
<tr>
<td><strong>speed</strong></td>
<td>slow &lt; 10km/h</td>
<td>Slow, deliberate movement required. Speed not advisable</td>
<td>up to 20km/h Limited by user’s ability level rather than technology</td>
<td>High speed of &gt;10km/h to enjoy the benefit of speed.</td>
</tr>
<tr>
<td><strong>range</strong></td>
<td>Depends on ability of user &lt;10 m</td>
<td>up to 30 km per charge</td>
<td>10m or more per trip</td>
<td></td>
</tr>
<tr>
<td><strong>Over coming terrain</strong></td>
<td>Have problems overcoming slopes and drops in levels</td>
<td>level terrain</td>
<td>power augmentation provides power to climb slopes and overcome drops in levels Kerbs require kerb climbing system.</td>
<td>Must overcome uneven, even sloping terrain, drops in levels, Kerbs</td>
</tr>
<tr>
<td><strong>Stability</strong></td>
<td>unstable when overcoming terrain</td>
<td>Stability is not an issue at low speed stable condition.</td>
<td>Heavier, more stable than manual wheelchair</td>
<td>Uneven terrain requires stable vehicle configuration.</td>
</tr>
<tr>
<td><strong>Hygiene</strong></td>
<td>non-marking polyurethane wheels</td>
<td>Clean environment</td>
<td>pneumatic rubber wheels may mark the floor</td>
<td>dirty environment requires wheels to be cleaned before entering indoors</td>
</tr>
<tr>
<td><strong>Transportability</strong></td>
<td>Easier to transport. folding model / dismantle-able wheelchairs are able to fit into disabled vehicle more easily</td>
<td></td>
<td>Heavy, unable to dismantle easily into vehicles Have problems fitting into disabled vehicles.</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 10  Manual wheelchair vs. Power wheelchair / scooter functional comparisons.*
The indoor requirements and the outdoor requirements of wheelchairs are analysed in Figure 9. Thin non-marking wheels are desirable in indoor environment while wide wheels are desirable outdoors. The attachment of Power assistance device contradicts lightness and agility needed by the indoor system.

Resolving these contradictions by integrating the two different sets of requirements would lead to a compromise in the performance of the wheelchair in each environment. There needs a new method of resolving the issues.

*Figure 10* compares the characteristics of manual wheelchairs vs. power wheelchairs / scooters with respect to the two opposing environmental requirements. The manual wheelchairs with its two large wheels are excellent to address the indoor environment. However it is lacking when addressing the outdoor requirements. Power wheelchairs and scooters are excellent in addressing outdoor issues of range and stability but is lacking in addressing indoor requirement of tight space mobility control. Furthermore, the weight and the bulk of the power wheelchairs and scooters make vehicular transport, which the mobility impaired require from time to time, problematic.

The characteristics of the manual wheelchair, which is excellent indoors, could be a good starting for designing the new system.
Design Strategy

The requirements of the indoor and outdoor environments are analysed and the functional requirements mapped against the existing design solutions (Figure 9 and Figure 10) to drive the design of the new mobility solution. The typology of the manual wheelchair is a very useful solution for the indoor environment but has often been overlooked in the existing design solutions of the power wheelchair systems. As discussed earlier, the two large wheels enable precise manual control in the close confines of the indoor environment. It is an excellent starting point for the new design solution.

The main contraries between the indoor and the outdoor mobility solution are the wheels and the propulsion system.

The indoor wheels requirements are thin, non-marking, pneumatic (better performance); the outdoor wheels requirements are traction (friction), pneumatic (shock absorbance) and wide (soft terrain). The indoor wheels and the outdoor wheels performance requirements are different and at present, there is not a single wheel solution that addresses the two contrary requirements.

Manual propulsion system works better in the indoor environment as the controls can be more precise and it enables the solution to be much lighter and hence more agile; the power system is more useful in the outdoor environment.

These two fundamental differences drive the design strategy for the new mobility system. The system can be tackled from the design of the wheels and the design of the drive system. A system that solves the problem of contamination as well as to add power to the manual wheelchair is needed.

Other design considerations include the ergonomic reach of the user. To be really useful, it has to be operable independently by the user. As the user is unable to walk, he will have to operate the docking system while seated on the chair. The ergonomic work sphere of the user is limited, and in a seated position, strength is compromised. Hence the design of the mobility attachment was recommended to be less than 20 lbs per piece. (Bauer 1999)

Attaching the power unit under the constrained space of the wheelchair is extremely difficult. Firstly, the ergonomic work-sphere of the user is limited and secondly, the space available for attachment is also small and varies from manufacturer to manufacturer. Considering also the control interfaces which had been predominantly manual, space requirements and drive system configurations are not flexible which make attachment to a constrained position the all more difficult.

Many environment task requirements of the indoor and outdoor wheelchair are contradictory and mutually exclusive. It is important to overcome such exclusive demands and incorporate both the advantages of self-propelled wheelchair and that of the power wheelchair to design the new system.

The proposed solution for the new indoor-outdoor mobility system is the design of a modular dockable wheelchair system. Dockable wheelchair system allows optimisation in the indoor environment and also to achieve external mobility without dirtying the wheels.

The typology of the self-propelled wheelchair, excellent for indoor use is often overlooked in the design of the indoor/outdoor wheelchair system. The typology of having two large control wheels still is the most direct and precise way of control over direction and speed. Hence the design of the new system builds on the tried and tested centuries old design solution with a “platform” attachment to enable it performance in the outdoors.

The mobility platform will provide power, stability and shock absorbance to the self-propelled wheelchair to achieve the task environment requirement.
**By-wire control**

Modern electronics control give rise to tremendous design possibilities for the wheelchair. Large bulky gear box can now be replaced with electronically controlled hub motors which are lighter, improves the aesthetics of the wheelchair, and ease maintenance. Modern electric bikes fitted with hub motors are gaining popularity and can drive the cost of the hub motors down.

Revolutionary mobility solution could also be created. Utilising gyroscopes for stabilisation, the Segway human transporter redefine mobility. The ibot, using the same technology as the Segway, enables stair climbing for a wheelchair, an unprecedented ability.

![The Segway human transporter](Source: Segway LLC)

![The ibot stair climbing wheelchair](Source: Johnson & Johnson/AP Photo)

The integration of fuel cell technology coupled with by-wire design enables a revolutionary automobile design: the Hy-wire prototype car produced by General Motors. *(Burns et al 2002).*

> "Because we did not seek to shoehorn these new technologies into existing vehicle architectures, we avoided design trade-offs that had to be made in the past. We also opened up new opportunities to improve ride and handling, interior spaciousness and flexibility and exterior styling."

--- Borroni-Bird, C.E., *Designing AUtonomy* 2002

The previously bulky mechanical systems of steering, braking, throttling, and other functions are removed with electronic controls, freeing up space and weight. This application allows for radical changes to the design concept of the automobile and this new concept is also applicable to similar mobility products.

With the advancement in prime mover technology and by-wire control interface, a new wave of thoughts about the formal typology of existing products is now a possibility.

![General Motor Skateboard concept Car AUtonomy](Source: General Motors)
The generative idea of the wheelchair attachments most likely evolved from the traditional form of scooters design; the “steering column” is still a feature found in most wheelchair attachment solutions. The use of “precedent” (precedent here refers to existing mobility solutions) as a generative idea, is often used by designers (architects) to solve design issues. According to Eckert and Stacey 2000, previous designs and other sources of ideas furnish a vocabulary both for thinking about new designs and for describing designs to others.

“Designers cannot just jump (referring to paradigms shift); they need a primary generator, dealing with analogies, relating “needs” to targets”

-- Kroll, Condor & Johnson 2001

The scooter became an analogy for generating ideas for the creation of the mobility attachment devices, for example, Coker, US patents 4386672 & 5016720, Kleinwolterink, US Patent 5050695, Rabjohn, US patent 3387681, Casali, US patent 5651422, hence the steering column remained and that the steering column according to Clark 1997, hinders the daily activity of the users, therefore a new typology would have to emerge.

This new typology of wheelchairs will have to ‘jump’ out of the paradigm of the wheelchair being a chair on wheels but rather design from wheels (with chairs) up. The inspiration to approach the subject matter like this arises from the new technology emerging in the market (the concept of modular interchangeable mobility solutions design with by-wire control technology). (General Motors 2002). The modular, scalable, dockable concept of approaching the solution is the only way to enable optimizations in two contradictory requirements to be attained.
Multi-criteria Design

Engineering Design is determined by Analysing Functional requirements. Engineers use a Quality Functional Deployment, (Cross 2000) which maps the functional requirements to the engineering requirements. In multi criteria design, differential weightages are given to the different criteria. From a set of solutions, the designer can determine the pareto optimal solutions.(Radford and Gero 1985).

Functions vs Disfunctions

The design of multi use, multi criterion products are a tricky business indeed. In Multi Criteria Design Optimization, the “trade-off” method was used (Oscyczka 1985). One function’s optimization will undermine another’s. In addressing opposing design constraints, the solution is often a compromised one.

Integrated Multi purpose vs Modular dedicated

Designs are driven by requirements, the reconciliation of very different and contradictory requirements resulted in a new thinking in the design process. Integration, miniaturisation and multifunctionalism have been the main design focus thus far. However, it is a design approach that compromises on the optimal functionalism of each component.

They are few successful products that reconcile the different requirements satisfactorily. The Swiss army knife (Figure 11) is one of the few that succeeded. The individual tools however were compromised in their intended functionality. The main design focus however was tool management in a small package, which was done extremely well.

Figure 15 The Swiss army knife is an epitome of multifunctionalism
Source: www.swissarmy.com

Figure 16 The Auastrada
Source: CNN
The Aquastrada (Figure 12), is a hybrid car/boat attempts to create a vehicle that can work as well as a car and a boat. The requirements of road transport are different from that of sea. Hybridising it means extra weight on the roads and on water, which decreases the efficiency of both. Such requirements require trade-offs in arriving at the acceptable solution.

Contradictory requirements can be resolved differently by using the modular, scalable or dockable approach. The dockable approach is used especially in today’s mobile computing products. While ergonomic requirements of input device would require them to be big, mobility requirements necessitate portability.

The PDA is a good example of reconciliation of very different requirements. The mobility requirements entail constructing it small, opposing ergonomic requirements. The result is a highly mobile unit with modular features to enhance usability.

Figure 17  Modular Docking concept enables best of both world designs for the PDA system
Source: Targus Inc

The treatment of contrary functional requirements for the indoor and outdoor wheelchair suggests a method of analysing that requires aparadigm jump from analysing wheelchair as a chair but as a vehicle that operates in different environments.

Without such change in framework, optimal operation requirements dictate trade-offs be made. Such trade-offs may not be necessary if a change in paradigm allows the wheelchair to perform in one environment extremely well and yet docked onto a “platform,” enabling it to perform as well in the other.

This basic concept forms the basis of the new modular, scalable, dockable wheelchair system.

Conclusion

The problem of mobility for the mobility impaired has encouraged us to view this as a multi-criteria design problem and study the design issues involved in detail. The result of this study has generated a docking solution for this particular problem. This general theory of responding to multi-criteria design requirements of using docking concept was applied to the proposed solution of the mobility issues discussed. This solution has been shown to experts, physiotherapists, and users. The responses to the design have been optimistic and many expressed interest in the outcome of the system.

We believe that this design strategy will help develop wheelchair for unprecedented mobility.
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