The Segway™ Is a Vehicle

Implications for Operation and Regulation of the EPAMD in Traffic

Steven G. Goodridge, Ph.D.
Member, North Carolina Coalition for Bicycle Driving
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Introduction

The Segway™ is a two-wheeled electric scooter being marketed by its manufacturer, Segway LLC (http://www.segway.com/) as a pedestrian enhancement device for the purpose of reducing travel time, primarily in urban settings. Its parallel wheel configuration makes it compact enough to be maneuvered through most pedestrian spaces that accommodate wheelchairs. When traveling at or below walking speed, its maneuverability is similar to that of a wheelchair. At its maximum operating speed, however, its maneuverability is similar to that of a bicycle. Segway LLC seeks public acceptance of Segway use on sidewalks and in other pedestrian spaces in order to allow their customers to drive it anywhere that a pedestrian may go. Although traffic law typically prohibits or severely restricts the operation most types of vehicles (especially motorized vehicles) in pedestrian spaces, Segway LLC has promoted legislation in every U.S. state to exempt Segway-like scooters, or "Electric Personal Assistive Mobility Devices" (EPAMDs), by classifying the EPAMD driver as a pedestrian just like a wheelchair user. This classification has generated protests from some pedestrian advocates who believe that the speed and weight of EPAMDs will create hazards and discomfort for pedestrians. What has attracted less public attention is the number of hazards that pedestrian-oriented traffic regulations and pedestrian-oriented facilities pose for EPAMD drivers when these operators travel at much higher than pedestrian speeds with limited, vehicular maneuverability including longer stopping distances and wider turn radii. In many states, the legislation that has been designed for Segways mandates their operation only on sidewalks and prohibits roadway use - which is the opposite of the regulation generally applied to bicycles, especially in urban areas. This article examines the potential dangers, access barriers and inconveniences that are created for EPAMD drivers and other road users if these vehicles are regulated purely by pedestrian rules, and suggests an alternative approach based on what has been learned from bicycling.

An Example of EPAMD Legislation

The General Assembly of North Carolina ratified Senate Bill 1144 in August 2002: "AN ACT TO DEFINE AND AUTHORIZE THE USE OF NONTANDEM TWO-WHEELED PERSONAL ASSISTIVE MOBILITY DEVICES." The bill defines an "Electric Personal Assistive Mobility Device", or EPAMD, to match the characteristics of the Segway, then exempts it from the definition of a vehicle in a manner similar to that in which wheelchairs are exempted:

> "G.S. 20-4.01(49)…Vehicle. - Every device in, upon, or by which any person or property is or may be transported or drawn upon a highway, excepting devices moved by human power or used exclusively upon fixed rails or tracks; provided, that for the purposes of this Chapter bicycles shall be deemed vehicles and every rider of a bicycle upon a highway shall be subject to the provisions of this Chapter applicable to the driver of a vehicle except those which by their nature can have no application. This term shall not include a device which is designed for and intended to be used as a means of

> transportation for a person with a mobility impairment, or who uses the device for mobility enhancement, is suitable for use both inside and outside a building, including on sidewalks, and is limited by design to 15 miles per hour when the device is being operated by a person with a mobility impairment, or who uses the device for mobility enhancement. This term shall not include an electric personal assistive mobility device as defined in G.S. 20-4.01(7a)."

The legislation also specifies in Section 20-51 (c) that "A person operating an electric personal assistive mobility device shall have all rights and duties of a pedestrian, including the rights and duties set forth in Part 11 of this Article." **As a result of these descriptions, an EPAMD driver must meet all of the legal responsibilities of pedestrians, and has none of the rights that apply only to drivers of vehicles.**

Note the following NC statute section that applies to pedestrians:

> "§ 20-174. Crossing at other than crosswalks; walking along highway….(d) Where sidewalks are provided, it shall be unlawful for any pedestrian to walk along and upon an adjacent roadway. Where sidewalks are not provided, any pedestrian walking along and upon a highway shall, when practicable, walk only on the extreme left of the roadway or its shoulder facing traffic which may approach from the opposite direction. Such pedestrian shall yield the right-of-way to approaching traffic."

Thus the North Carolina EPAMD legislation requires EPAMD operators to drive on sidewalks wherever they exist, no matter which side of the street they are on, drive against the flow of traffic where sidewalks do not exist, and initiate all turns and intersection crossings from the edge of the road. EPAMDs operated at night in North Carolina are not required to have a headlight or rear reflector. This leads us to a question that must be answered: Do these non-vehicular regulations increase or decrease safety for the EPAMD driver compared to the laws that apply to other types of light vehicles?

Classifications of Road Users

There are two basic classes of street users: pedestrians and drivers of vehicles. These classes are treated differently in the traffic laws because these groups have very different operational characteristics. The fundamental difference between all pedestrians and all drivers of vehicles is maneuverability. Pedestrians can stop, pivot, back up, move laterally, and change direction in an instant. Pedestrians frequently do all of things when negotiating traffic and when interacting with other people or furnishings in the streetscape. Drivers of vehicles, however, require more time and distance to stop, cannot pivot, must use caution when backing up, cannot move laterally without also moving forward, and have a minimum turning radius that increases considerably with speed. The maneuverability limitations of vehicles requires that their drivers operate with adequate turning and stopping space in the roadway, and move very predictably according to carefully choreographed rules designed to prevent collisions. These rules include positioning one's vehicle at intersections according to one's destination, using speed positioning when traveling between intersections, and carefully yielding to traffic in the adjacent line of travel when moving laterally on the roadway.

Pedestrian traffic is segregated from vehicle traffic because of this maneuverability disparity and because pedestrian movements are much less predictable. Pedestrians often exploit the limits of their maneuverability when changing direction, avoiding collisions with other pedestrians, stopping to talk to other people, window-shopping, sightseeing, or walking their dog. Pedestrians mix well with other pedestrians because they all have similar maneuverability. Yet when pedestrian paths cross vehicular paths, pedestrians must carefully constrain their movements in order to accommodate the limited maneuverability of vehicle traffic. Rather than expecting pedestrians to utilize destination positioning at intersections, which would require pedestrians to merge with vehicle traffic, traffic law requires pedestrians to turn at right angles and cross streets by yielding to thru-traffic, by waiting for priority from a traffic signal, or by using crosswalks (marked or unmarked). But without the benefits of destination positioning, many conflicts are created between the paths of drivers and the paths of pedestrians. Drivers turning to or from cross streets and driveways often interrupt the paths of pedestrians walking straight on the sidewalk or crosswalk. Drivers or pedestrians must often stop suddenly when a conflict appears and someone must yield. This can be frustrating to both drivers and pedestrians, and can also be very dangerous. The danger is mitigated somewhat because the straight-traveling pedestrian is moving slowly enough to see vehicles and be seen by drivers for what is usually an adequate period of time for either party to react in advance of a potential collision, and because pedestrians can yield quickly. Segregation of vehicular and pedestrian traffic is therefore a compromise that allows vehicle traffic to move with relative convenience despite limited maneuverability, while also allowing pedestrians to utilize their maneuverability and stop at any time to interact with other people or facilities alongside the street.

On roadways where there are no sidewalks but vehicle operators wish to pass, pedestrians are usually required to yield sufficient passing space on the roadway surface by stepping sideways. This is most important in darkness, where motorists may have difficulty seeing and stopping for pedestrians who are not ordinarily equipped with lights or reflectors. Pedestrians walking on narrow roads without sidewalks must walk facing vehicular traffic in order to know in a timely manner when it is necessary to yield, especially at night. Note that the slow travel speed of pedestrians walking toward traffic does not significantly reduce the available reaction time for motorists or pedestrians.

Because all vehicles have very similar principles of maneuverability, the traffic laws are written to treat them all in an equivalent manner. Drivers of horse-drawn carriages, motorcycles, cars, bicycles, tractors, scooters, and trucks all must follow the same rules of the road that apply to vehicles. All drivers must watch where they are going and drive slowly enough and far back enough to not collide with other road users ahead of them. All drivers must obey the same right-of-way laws at junctions, use proper destination positioning at intersections, pass only where and when it is safe, and yield when moving laterally. If any driver violates these rules, the breakdown in choreography could cause a collision. However, there are some additional restrictions that apply only to *motorized* vehicles due to the greater potential danger that heavy, powerful motor vehicles pose to other road users. The most obvious special restriction for drivers of most motor vehicles is the requirement of an operator’s license. Another is that motorized vehicles are usually restricted from most pedestrian facilities, while non-motorized vehicles may not be.

In some cases, lightweight vehicles with low-power motors are deemed to be less dangerous to the public than ordinary full-size motor vehicles. These lightweight motorized vehicles are often exempted from registration or operator licensing requirements, and may be exempted from some of the other regulations placed on larger motor vehicles such as prohibition from pedestrian spaces. Electric bicycles are an example of a category of motorized vehicle that is not classified as an ordinary "motor vehicle" in most state laws and is legally permitted to be operated on many mixed-use facilities shared by pedestrians and cyclists. In the case of EPAMDs, proponents of these devices maintain that they are lightweight enough and low enough in power to be exempted from the strictest regulations of motor vehicles such as registration, and at low enough travel speeds are harmless enough around pedestrians for them to be permitted to mix with pedestrians on pedestrian facilities. EPAMDs are also unlike most vehicles because they can pivot in place, allowing operators to perform pedestrian-like maneuvers more easily that operators of vehicles such as bicycles.

Facility Designs for Vehicles and Pedestrians

Roadway engineers design streets to accommodate a wide diversity of vehicle types. They try to accommodate the widths and turning radii of large vehicles, the speed capabilities of faster vehicles, the support requirements of heavy vehicles, and the smooth surface conditions needed by two-wheeled vehicles. Although a street may have moderately fast "design speed" at which vehicles may move when traffic conditions permit, drivers of slower vehicles are equally entitled to use the roadway. Sight lines and passing facilities are usually engineered to accommodate a wide variance in vehicle speeds. Only special roads such as controlled access freeways, which are redundant to ordinary surface streets and do not service local destinations, are prohibited to slower traffic such as tractors, mopeds, and bicycles.

Pedestrians present design requirements that are different from vehicles. Pedestrians typically walk at between two and four miles per hour, which means that sight lines and sight triangles at building corners and junctions can be much smaller for pedestrian facilities than for vehicle facilities. Figure 1 illustrates the difference between sight triangles for vehicle and pedestrian facilities at an intersection. The tinted region represents the area that the driver of the car in the right lane can see past sight obstructions, in this case a building corner and a van. The 'X's mark possible collision locations. Since the pedestrian facility is positioned close to the sight obstructions, both the automobile driver and the pedestrian facility users have very short distances in which they must be able to stop to avoid a collision with one another. The vehicle lane, however, is placed farther out past the sight obstructions. This provides more time for vehicle facility users to see one another and twice as much distance to slow or stop in order to avoid a collision. Sight line limitations create significant hazards for pedestrians at driveways and intersections, especially when vehicles in adjacent lanes are parked very close to the crossing area. These problems become progressively worse as the pedestrian moves faster, requires more time to stop, or does not look for cross-traffic at every junction.

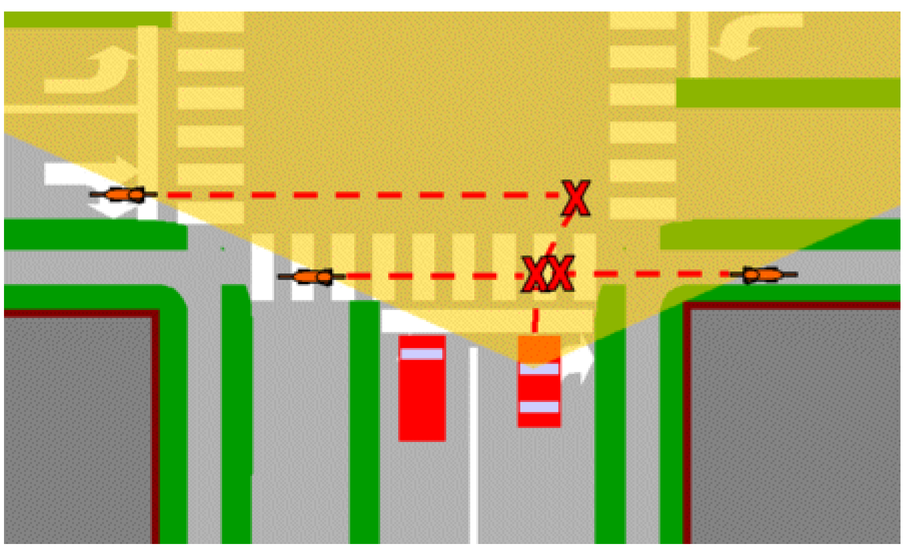

Figure 1: Relationship of intersection sight triangle to collision-avoidance distances for different cross-traffic locations.

Pedestrians pivot in place to turn at right angles when negotiating corners and crossing streets. In the past, pedestrians were expected to step over curbs at street crossings. In new and retrofitted pedestrian facilities, wheelchair users are accommodated with ramps at designated crossing locations, but these ramps are often missing on older streets. Many new sidewalks are built to a minimum specification of five feet wide to allow wheelchair users to squeeze by one another at slow speed; older sidewalks may be even narrower. Sidewalks feature a multitude of surface irregularities including bumps from tree roots, broken concrete and odd curb configurations, and feature numerous obstacles including fire hydrants, signs, utility poles, benches, mailboxes, planters, street trees, and low tree limbs. On many suburban and rural streets lacking sidewalks, pedestrians must walk on a soft shoulder, grass, or in the roadway. Pedestrians traveling in the roadway must often step sideways to yield to vehicle traffic, but there is often a change in elevation from the pavement to the shoulder, ditch, gutter, or curb. The existing pedestrian infrastructure is thus designed with the expectation that users would be traveling at walking speed and have the ability to quickly stop, turn, yield, maneuver around and under obstacles and negotiate surface discontinuities including abrupt elevation changes.

EPAMD Maneuverability Limitations

If an EPAMD is to be classified as either a pedestrian tool or a vehicle, it is important to analyze its maneuverability and compare this maneuverability to other vehicles. Some EPAMD proponents have claimed that an EPAMD is so much more maneuverable than other light vehicles such as bicycles that regulations intended for vehicles should never apply to it. The following discussion examines this claim.

Stopping Distance

A critical difference between pedestrians and vehicles is stopping distance. Most pedestrians can come to a complete stop in one or two steps, while vehicles require greater time and distance to stop from their typical free-flow travel speeds. Segway LLC has not published stopping distance data for the Segway EPAMD operated at cruising speed, so an emergency-stopping-distance experiment was conducted with the assistance of an experienced, physically fit college-age Segway owner/operator. The Segway operator was signaled to stop as fast as possible on level, dry asphalt from the Segway's top speed of approximately 12.5 mph upon an acoustic or visual signal as shown in Figure 2. The total stopping distance including reaction time was recorded.

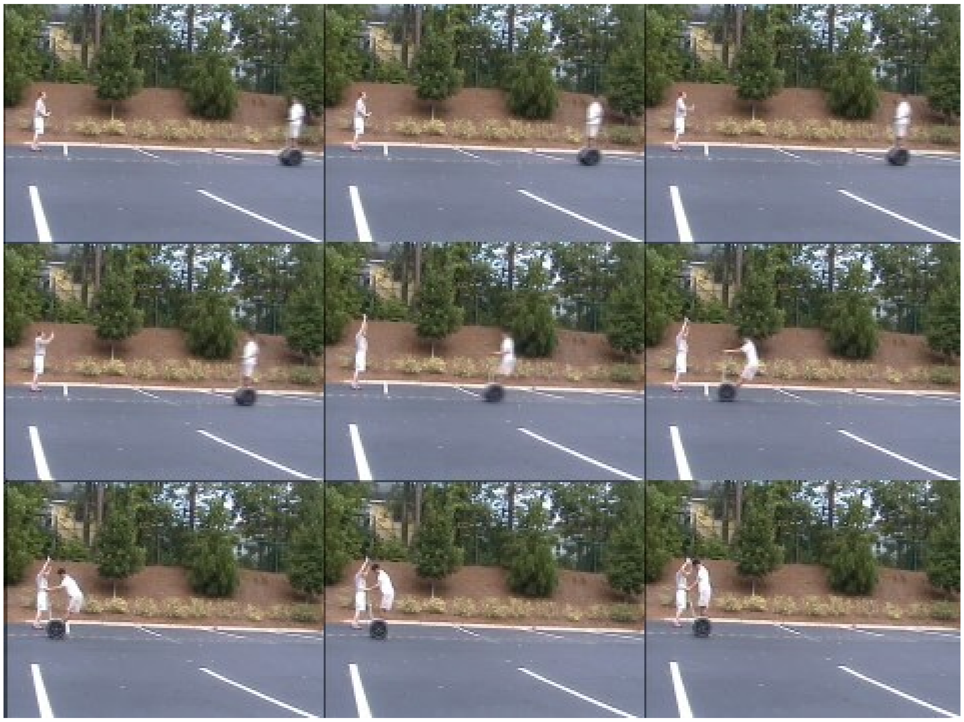

Figure 2: Nine video frames of one trial of the 12.5 mph stopping distance experiment. The approach and visual signal of raising hands are shown in the first four images. The Segway operator has begun braking by the fifth image and reaches maximum distance at the seventh. Note that the spacing between parking stall markings is nine feet.

The average abrupt-stopping distance of the experiments from 12.5 mph was 18.6 feet. A 9.3 Megabyte MPEG-1 video file showing several of the braking experiment trials is available for download at http://humantransport.org/bicycledriving/library/segway/Segway.mpg.

Stopping distance for various speeds may also be estimated from the physical laws of motion and the top speed allowed for EPAMDs in the law. The simple equation for braking distance *d* to arrive at a stop, assuming a constant rate of deceleration, is

$$d = 0.5(v^2)/a$$

where *v* is the starting velocity and *a* is the rate of negative acceleration. The braking distance of a vehicle is proportional to the square of its initial speed; traveling at 15 miles per hour requires four times the braking distance as traveling at 7.5 miles per hour. At the slowest speeds, the braking distance of an EPAMD may be negligible.

Braking distance is inversely proportional to the rate of deceleration. On dry pavement, vehicles with high centers of gravity such as bicycles and EPAMDs will pitch forward before their front wheel(s) can skid. On an EPAMD, the rate of deceleration in Gs is equal to the tangent of the angle that the center of gravity is shifted back from vertical. (One G is about 32.2 feet per second per second of acceleration.) On a bicycle, the maximum rate of deceleration is limited by this angle. Figure 3 shows the angle of the center of gravity with respect to the front wheel for a bicycle and for an EPAMD at three leaning positions. The tangent of the bicycle's mass angle is about 0.6, allowing a deceleration of up to an absolute theoretical limit of 0.6 Gs before the bike will flip forward. The tangent of the EPAMD's mass angle is 0 for the upright position in Figure 3B; the operator must initiate a lean backward before deceleration begins. Figure 3C shows an EPAMD and operator leaning backward at an angle for a deceleration rate of 0.3 Gs. In order to attain a deceleration rate greater than 0.6 Gs, the maximum theoretical braking ability of the bicycle, the EPAMD and operator must attain a more extreme center-of-mass angle as shown in Figure 3D. Many Segway operators can achieve extreme lean angles by bending their waist and knees and dropping their body weight backward and down with respect to the platform.

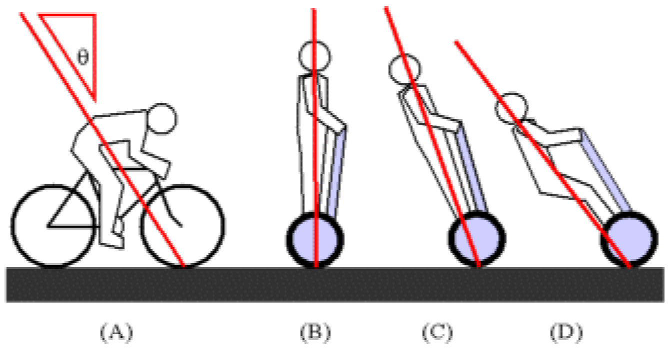

Figure 3: Angle of center of mass of (A) a bicycle; (B) an EPAMD traveling at constant speed; (C) an EPAMD in a fast stopping position; (D) an EPAMD in an extreme braking position.

The maximum deceleration rate may also be limited by tire friction on the travel surface. For vehicles with a low center of gravity, tire friction is the limiting factor in braking. Different surfaces have different frictional coefficients based on their surface texture and any loose material or liquid on top of them. The coefficient of static friction, i.e. when a tire is not skidding, is higher than the coefficient of friction when the tire is sliding. Cars with anti-lock brakes detect when tires begin to slide and reduce braking enough to return to static friction conditions. Bicyclists can usually correct for a skid, but face a challenge maintaining balance if the front tire begins to slide. On an EPAMD, wheel traction is extremely important for active balance control. If the wheels slip during hard braking, gravity will pull the operator toward the ground very quickly. It may or may not be possible for the EPAMD's computer control system to regain traction in time to prevent the fall, especially since the torque required to regain balance will be greater than that which produced the skid in the first place. For this reason, the EPAMD operator may need to be careful about not attempting to brake harder than the surface friction allows. On clean, smooth pavement, the maximum safe deceleration for an EPAMD may exceed 0.8 Gs; this drops to 0.3 Gs or less on poor braking surfaces.

Table 1 shows a list of approximate friction coefficients for rubber tires on different surfaces with a range of textures.

Table 1: Coefficients of Friction for Rubber Tires on Common Travel Surfaces

Surface	Coefficient of static friction	Coefficient of sliding friction
Asphalt (dry)	0.8 - 0.9	0.6
Asphalt (wet)	0.4 - 0.7	0.3
Portland cement concrete (dry)	0.6 - 0.9	0.3
Portland cement concrete (wet)	0.3 - 0.7	0.2

Sand on pavement	0.3 - 0.6	0.2
Wet leaves on pavement	0.2 - 0.6	0.1
Ice	0.1	<0.1

With an initial velocity of 12.5 miles per hour (18 feet per second) and an immediate deceleration rate of 0.3 Gs, the braking distance of a bicycle or EPAMD is about 17 feet. With a deceleration rate of 0.6 Gs, the maximum theoretical braking expected from a bicycle, this shortens to 8.5 feet. Experimentation with the Segway EPAMD suggests that a greater deceleration rate of 0.8 Gs can be realistically obtained by a skilled operator on good pavement. For an EPAMD or automobile braking at 0.8 Gs from 12.5 miles per hour, the braking distance is about 6.5 feet. However, these figures do not include reaction time, which depends on age and level of preparation. The standard driver reaction time used in traffic accident reconstruction cases is 1.5 seconds. An above-average reaction time for a driver is 0.75 seconds. For the Segway stopping distance experiments, the prepared, college-age operator's reaction time was between 0.6 and 0.7 seconds.

For the purpose of estimating typical stopping times, an alert operator reaction time of 0.75 seconds adds about 14 feet to the stopping distance of any vehicle when traveling at 12.5 miles per hour. Thus the estimated total stopping distances for cars, bikes, and EPAMDs on level surfaces may be estimated as follows:

Table 2: Theoretical Stopping Distance Comparisons at Different Speeds and Deceleration Rates

Vehicle traveling at initial speed	Deceleration rate (Gs) (1 G = 32.2 ft/sec/sec)	Reaction distance in .75 seconds (feet)	Braking distance (feet)	Total stopping distance (feet)
EPAMD at 12.5 mph (18 ft/sec)	0.8	14	6.5	20.5
EPAMD at 12.5 mph (18 ft/sec)	0.3	14	17	31
Car at 12.5 mph (18 ft/sec)	0.8	14	6.5	20.5
Bicycle at 12.5 mph (18 ft/sec)	0.6	14	8.5	22.5
Bicycle at 12.5 mph (18 ft/sec)	0.3	14	17	31
EPAMD at 15 mph (22 ft/sec)*	0.8	16	9	25
EPAMD at 15 mph (22 ft/sec)*	0.3	16	25	41
Car at 15 mph (22 ft/sec)	0.8	16	9	25
Bicycle 15 mph (22 ft/sec)	0.6	16	12.5	28.5
Bicycle at 15 mph (22 ft/sec)	0.3	16	25	41

* This travel speed is allowed under the North Carolina law defining EPAMDs, but is above the software-limited top speed of those EPAMDs available for purchase by the general public at the time of this writing.

Note that the above chart does not consider hazard perception/recognition time, which is the amount of time that may elapse before a vehicle operator notices that braking is needed. Hazard perception time may easily be longer than one second when the user is looking at road signs, instrumentation, people, or adjacent traffic. This delay adds 18 additional feet to the stopping distance at 12.5 miles per hour regardless of vehicle type. This analysis illustrates that the EPAMD-class device has similar stopping characteristics to a car or bicycle when operated at its maximum legal (North Carolina) cruising speed of 15 mph or at an electronically governed top speed of 12.5 mph.

Cornering

When stationary, the EPAMD can turn in place by rotating its wheels in opposite directions. This gives it greater maneuverability than most vehicles in the special case of standing still. At higher speeds, however, the EPAMD's turning radius is limited by the tendency of its high center of gravity and narrow wheelbase to flip the EPAMD and operator over sideways, much like a top-heavy off-road vehicle. Bicycles are also top-heavy, but bicyclists lean into turns as shown in Figure 4(A). The tangent of the lean angle equals the bicycle's centripetal acceleration in Gs, which is limited only by the coefficient of adhesion of the tires on the pavement. The maximum centripetal acceleration of an EPAMD is limited by the tangent of the angle of the system's center of gravity with respect to the outside wheel, as shown in Figure 4(B), or the coefficient of tire adhesion, whichever is less. Given the upright position of the EPAMD operator, the operator is unable to adjust his or her weight far enough to the side to skid the tires sideways on dry pavement. However, it is likely that potential loss of control due to non-ideal pavement conditions including water, oil, sand, gravel, leaves, and broken asphalt will discourage bicyclists and EPAMD operators from pushing the limits of their tire adhesion. Although the coefficient of friction of rubber on clean, dry asphalt can be over 0.9, it can drop to about 0.4 for wet or sandy conditions. The tangent of the lean angles shown in Figure 4 is 0.3, which is probably a realistic lean for both a bicycle and an EPAMD operator under wet pavement conditions.

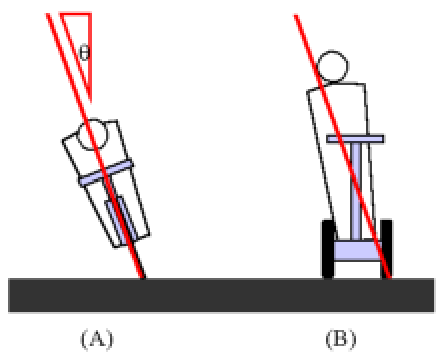

Figure 4: Cornering on (A) a bicycle; (B) an EPAMD

The cornering radius r for a given lateral acceleration is

$$r = v^2/a$$

Where *v* is the forward velocity and *a* is the centripetal acceleration. With a forward cruising speed of 12.5 mph (18 feet per second) and a centripetal acceleration of 0.3 Gs (10 feet per second per second) the turn radius of a bicycle or an EPAMD-class device is approximately 34 feet. With a forward cruising speed of 15 mph (maximum allowed under NC Law) and the same centripetal acceleration, the turn radius of these vehicles is approximately 48 feet.

EPAMD Travel Speeds

Segway LLC is marketing the EPAMD as a "mobility enhancement device" allowing able-bodied pedestrians to travel much faster than ordinary pedestrian speed. The convenience that comes with increased speed is essential to the EPAMD’s market success, since able-bodied pedestrians would probably not otherwise bother with the cost, recharging chores, and endpoint storage requirements of the EPAMD. In providing faster trip times the EPAMD finds itself in competition with other products including automobiles, motor scooters, and bicycles. If the the EPAMD's target market of urban users finds inadequate automobile parking near trip endpoints in cities to be a major disadvantage of automobile use, then motor scooters, bicycles, and EPAMDs may be viable alternatives. Although motor scooters are enjoying great popularity in urban areas around the world, it is possible that a motor scooter would be heavier and more expensive than the urban traveler might prefer for short trips. This leaves bicycles as the primary competition for the EPAMD market for short-distance urban travel. Average bicycle commuting speeds range from 12 to 20 miles per hour depending on the level of exertion that the cyclist is able and willing to expend. Those people looking to avoid significant exertion in their street clothes while still enjoying the speed of bicycle travel can purchase electric bicycles that cost less and have longer range than an EPAMD. These bicycles can easily maintain 15-20 mph. Given the abundance of products that can carry the user to his or her destination at average speeds of about fifteen miles per hour, the market viability of the EPAMD among the majority of able-bodied private citizens may depend on its ability to travel at least this fast.

Upon the first public unveiling of the Segway in December of 2001, the media reported the consumer version of the Segway LLC as having a top cruising speed of 17-18 miles per hour [1, 2, 9]. The speed capability of the Segway was an important part of their early marketing; for instance, the original version of a page on the Segway LLC web site (http://www.segway.com/segway/save_time.html) stated: "Using Segway HT instead of walking increases the area you can cover 50-fold—whether you're working or running errands." Since the reachable area is proportional to the square of the travel speed, this means the Segway speed is assumed to be more than seven times walking speed, or about 18 miles per hour. Although Segway LLC has equipped the current consumer model of the Segway with a software-controlled maximum speed limit of 12.5 miles per hour, the North Carolina law allows the EPAMD to travel up to 15 miles per hour, and the New Hampshire law allows up to 20 miles per hour. No existing law would prevent the sale of EPAMDs capable of even faster speeds.

Segway proponents have suggested that the EPAMD can be commercially viable with a lower maximum speed capability because the EPAMD has the advantage over other vehicles by transporting drivers through pedestrian-only spaces. This is of limited benefit to most able-bodied persons, however, because there are few pedestrian-only spaces where it is safe to operate significantly above pedestrian speed, and pedestrian areas rarely extend very far away from vehicle routes. Although it can be somewhat inconvenient to park a bicycle or motor scooter outside of a pedestrian-only zone, the vast majority of a user’s travel time will likely be spent outside of pedestrian-only areas, where the EPAMD must compare favorably with the speed of other vehicles in order to be marketable.

When pedestrian advocate groups began protesting the allowance of EPAMDs on pedestrian facilities, Segway LLC downplayed the speed advantages of the EPAMD technology and proposed that electronic speed governors could be set for even lower speeds on sidewalks to protect pedestrians. But might slow enough to be safe be too slow to sell? If the travel speed of the EPAMD is made much slower than a bicycle, then the EPAMD cannot compete in the transportation marketplace. Furthermore, EPAMD owners may eventually find a way to bypass the electronic speed governor by modifying the hardware or replacing the software, in much the same way that owners of cars, computers and DVD players make unsupported performance enhancements using aftermarket technology and technical know-how. Given that most automobiles on US roadways today are capable of traveling at nearly twice the maximum posted speed limit, it seems inevitable that EPAMDs will be operated at speeds of at least 15 miles per hour. And like other light powered vehicles such as electric bicycles, mopeds, and electric scooters, EPAMDs will be operated at their top cruising speed whenever conditions allow their users to do so. It is therefore appropriate to consider the implications of the traffic laws for the EPAMD when it is operated at the maximum legal speed.

Lessons from Bicycling

The previous discussion suggests that the EPAMD will be operated at a range of speeds similar to that of an adult bicycle commuter, with maneuverability similar to that of a bicycle. It follows that the safety of EPAMD travel on various facilities and according to various methods of traffic negotiation will be similar to the safety of bicycle travel. Using bicycle accident statistics and crash analysis provides useful insight into the most likely crash scenarios and best practices to recommend for EPAMD use.

Cycling safety studies are presented by Kaplan [3], Cross and Fischer [4], Wachtel and Lewiston [5], and Moritz [6], and have been analyzed by Forester [7]. Most injuries to cyclists are caused by falls and collisions with fixed objects, other cyclists, or pedestrians. These accidents are much more likely on sidewalks and paths than on roadways with adequate widths and good surface conditions. Less than 20% of recorded cycling accidents involve automobiles. Analysis of the locations and causes of car-bike crashes reveals that cyclist behavior is a major factor in determining crash rates. Adult cyclists who regularly operate on roadways, including major roads, but habitually operate according to the basic rules that apply to drivers of vehicles, have far fewer accidents per mile of travel than teen cyclists, who are more likely to behave as "rolling pedestrians". Although "avid" adult commuting and recreational road cyclists travel about 80% of the miles cycled on roadways and often ride under more challenging conditions including rain and darkness, they amount to only about 20% of the cycling population, and represent less than half of reported bicycling accidents.

The most common scenarios for urban car-bike crashes are shown in Table 3, listed separately for teen and adult cyclists (from Forester [7].)

Table 3. Common Urban Car-Bike Crash Types

Teen cyclists	Adult Cyclists
1. Wrong-way cyclist hit by motorist restarting from stop sign 2. Cyclist turning left from curb lane	1. Motorist turning left 2. Signal light change

3. Cyclist exiting commercial driveway	3. Motorist turning right
4. Wrong-way cyclist running stop sign	4. Motorists restarting from stop sign
5. Wrong-way cyclist head-on	6. Motorist exiting commercial driveway
6. Right-of-way error at uncontrolled intersection	7. Motorist overtaking unseen cyclist (mostly in darkness)
7. Motorist entering commercial driveway	8. Motorist overtaking too closely
8. Cyclist running red light	9. Cyclist hitting slower-moving car
9. Cyclist turning left from curb lane, hitting car coming from opposite direction	
10. Wrong-way cyclist hit by motorist turning right on red	

Table 3 illustrates why teen cyclists suffer higher crash rates than adult cyclists. The most common causes of car-bike crashes involve bicyclist behavior that differs from the rules that apply to all drivers of vehicles. Particularly dangerous is wrong-way cycling which causes the most common crashes as shown in Table 3. Wrong-way cyclists approach intersections where motorists are not looking for vehicles, and the combined speed of the motor vehicle and bicycle makes avoidance more difficult and crashes more traumatic. Of those crashes that do involve lawful cyclists and are caused by motorist error, most are caused by turning and crossing actions, not overtaking. Visible and predictable operation as the driver of a vehicle – especially at intersections – prevents crashes caused by cyclists, increases motorists' ability to see and avoid cyclists, and maximizes cyclists' ability to avoid motorists' errors. Behaving as a pedestrian-on-wheels greatly increases the likelihood of being in one of the most common crash types listed in Table 3.

Sidewalks have been found to be particularly hazardous and inconvenient places for bicycle operation. Falls and collisions with obstacles, pedestrians, and other cyclists are much more frequent per bicycling mile on sidewalks than on roadways [6]. A study by Wachtel and Lewiston [5] shows that the car-bike accident rate for sidewalk cyclists is about twice that of road cyclists, and that wrong-way sidewalk cycling creates about four times the crash rate of cycling with traffic on the roadway. The 1999 AASHTO Guidelines for the Development of Bicycle Facilities specifically warns against sidewalk bicycle riding: "...Sidewalks are typically designed for pedestrian speeds and maneuverability and are not safe for higher speed bicycle use.... At intersections, motorists are often not looking for bicyclists (who are traveling at higher speeds than pedestrians) entering the crosswalk area, particularly when motorists are making a turn. Sight distance is often impaired…." Cyclists on sidewalks must travel much more slowly than on roadways in order to try to compensate for a multitude of hazards, including pedestrians who may change direction unpredictably.

In *The Traffic Safety Toolbox* published by the ITE [8] we read:

> "Sidewalk bike paths. From the late 1970s through the mid-1980s a number of communities signed some sidewalks or built new paths for bicyclists parallel to roadways. Several states even passed laws forcing bicyclists to use such facilities if they existed. Bicycle/car crashes increased dramatically in some corridors, especially at driveways, intersections, on bridges, and other locations. Sidewalks or paths parallel to a roadway force bicyclists to ride against traffic half of the time. In either direction, motorists are often surprised by the presence of cyclists [on sidewalks], since [motorists] are neither conditioned nor capable of searching these locations for traffic moving at 8-15 mph. Many pedestrians were also hurt, or complained that it was no longer comfortable to walk. Also, many motorists became less considerate of bicyclists who continued to use the often safer roadway sections.…in no case should a bicyclist be forced to use the sidewalk pathway. Never sign a sidewalk or parallel path as a bikeway, since many motorists who see these signs will assume that those bicyclists riding on the roadway section are not permitted to be there."

For these reasons, cyclist safety instruction (such as the *Effective Cycling* program developed by John Forester) organized by cyclists for cyclists has advocated that cyclists follow the rules that apply to all drivers of vehicles, in particular:

1. Traveling on the right half of the roadway, with traffic, and not on the sidewalk
2. Yielding when crossing more important roadways; obeying signals and signs
3. Looking back and yielding when moving laterally
4. Approaching intersections in the proper lane or lateral position for one's destination
5. Positioning oneself according to one's speed when between intersections
6. Always using a white headlight and bright rear reflector and/or red rear lamp when traveling at night

Traffic laws in all 50 US states regulate cyclists as drivers of vehicles, allowing or requiring them to operate on roadways instead of sidewalks and requiring them to obey vehicular traffic laws.

Likely Consequences of the EPAMD Legislation

The previous section describes how operators of vehicles with speeds and maneuverability similar to EPAMDs suffer greater accident rates and less convenient travel when acting as rolling pedestrians than when acting as drivers of vehicles. Now consider the requirements of the new laws for EPAMD drivers. Since the new laws classify EPAMD drivers as pedestrians, EPAMD operators are *required* to operate on the left side of the road against traffic on roads that lack sidewalks. On a road with 25 mph automobile traffic, the velocity difference between 15 mph EPAMD operators and automobiles will be 40 mph, instead of the 10 mph difference between lawfully operating 15 mph cyclists and automobiles. Automobile drivers who come upon a cyclist on a narrow road may need to slow down and follow the cyclist at reduced speed until a safe passing opportunity presents itself. But when an automobile comes upon an EPAMD operator traveling on a head-on collision course, the pedestrian-based EPAMD law requires the EPAMD operator to yield by leaving the roadway. Given the fast approach speed, the EPAMD driver may not have time to come to a complete stop before leaving the roadway, and may have difficulty negotiating soft shoulders, soil erosion, drainage ditches, mailboxes, and other hazards at the edge of the road. Note also that the EPAMD law for North Carolina does not require the EPAMD to be equipped with lights or reflectors, making it nearly invisible at night as they approach motorists head-on. It can therefore be predicted that EPAMD drivers will suffer a high rate of head-on collisions and falls when traveling on roadways against traffic.

Wherever sidewalks are found on the side of the roadway, the EPAMD law requires EPAMD operators to use them. If the sidewalk starts and stops on different sides of the road, the EPAMD operator is required by law to cross the road to stay on the sidewalk. On roads where a sidewalk exists on only one side, EPAMD users will be traveling against traffic half of the time. EPAMD drivers are required by law to turn left from the curb, and stay to the right of right-turning traffic when traveling straight through an intersection. Note that doing these things on a bicycle leads to the most common crash types for unlawfully operating cyclists as shown in Table 2. These crash types can be avoided by operating according to the rules for drivers of vehicles, but not according to the rules created for EPAMDs. Since contra-flow travel on bicycles at intersections is responsible for a disproportionately high percentage of car-bike crashes, we should expect one of the leading causes of car-EPAMD crashes to involve car drivers turning right at intersections. [10]

If the operational characteristics of EPAMDs are indeed similar to those of bicycles when operated at speed, we can see that the EPAMD legislation prohibits the safest and most effective known methods for traffic negotiation (the rules for drivers of vehicles) and mandates behavior that is known to be more hazardous and less convenient. the EPAMD legislation also reduces safety for pedestrians, cyclists, and motorists, because the non-vehicular rules for EPAMD driving will increase conflicts with users as well by making EPAMD users less visible and making traffic interactions less predictable. When traffic laws based on flawed pedestrian-on-wheels ideas have occasionally been proposed for bicyclists by less enlightened regulators, bicycle user groups have successfully organized in opposition in order to protect their own safety and convenience. Unfortunately, there is no EPAMD user group yet to protect the interests of EPAMD drivers.

An Alternative Approach

The first priority of EPAMD legislation should be to do no harm. Responsible traffic laws are carefully crafted such that they never require a driver to operate more dangerously than an alternative method. In the case of the EPAMD, it is likely that following the rules that apply to drivers of vehicles will be safer than following the rules for pedestrians in most situations. EPAMD laws should therefore *allow* EPAMD operators to travel according to vehicular rules and prohibit EPAMD drivers from doing things that have been demonstrated to be especially hazardous, *such as traveling at night without lights or traveling against traffic on the roadway.* However, there may be many situations where it will be advantageous and reasonably safe to allow EPAMD operation on pedestrian facilities if EPAMD operators can be educated and enforced to travel at slow pedestrian speeds and to use due care.

It is therefore proposed that EPAMDs be regulated similarly to electric bicycles because these vehicles have similar maneuverability, similar cruising speeds, similar weights, and similar uses. Like bicycle drivers, EPAMD operators would be required to follow vehicular traffic rules, including the correct direction of travel on roadways and use of proper lights at night. (Note that special lights would be needed to compensate for the variable tilt of the EPAMD.) EPAMDs would be allowed on all facilities on which bicycles (electric or otherwise) are allowed. This may include some or most pedestrian-oriented facilities, provided that EPAMD and bicycle drivers reduce their speed and use proper care. EPAMDs and/or bicycles could be prohibited from pedestrian facilities in those special locations where local authorities believe their operation would be particularly dangerous to pedestrians. (Segway, LLC contends that its product is substantially safer and less obtrusive to pedestrians in pedestrian areas than is a bicycle, and therefore warrants less restriction from pedestrian spaces. This contention may be true and deserves to be tested in practice in this author's opinion.) This approach would minimize accidents involving EPAMDs and limit the government’s liability for creating unsafe laws and unsafe facilities, while still allowing EPAMD users reasonable access to their destinations. States that have passed laws requiring the operation of these vehicles according to pedestrian rules should therefore be advised to repeal or amend such laws and increase public awareness of contra-flow collision hazards before people are needlessly hurt.

References:

[1] "Its average speed is 8 mph, but it can travel up to 17 or 18 mph." Lisa Wangsness, Concord Monitor, Tuesday, December 4, 2001.

[2] "The Segway's two batteries recharge in four to five hours, and a charge will take you 10 to 15 miles with a top speed of about 18 miles per hour", Marsha Walton, CNN Sci-Tech, January 16, 2002.

[3] Kaplan, J., *Travel and Accident Characteristics of the Regular Adult Bicycle User*, FHA, Washington, DC, 1976.

[4] Cross K. and Fisher G., *A Study of Bicycle/Motor Vehicle Accidents: Identification of Problem Types and Countermeasure Approaches,* NHTSA, 1977.

[5] Wachtel, A. and Lewiston, D. Risk Factors for Bicycle-Motor Vehicle Collisions at Intersections; *ITE Journal*, September, 1994.

[6] Moritz, W. Survey of North American Bicycle Commuters: Design and Aggregate Results. *Transportation Research Record* 1578: pp. 91-101, 1997.

[7] Forester, J, *Effective Cycling*, MIT Press, 1996. Also Forester, J., *Bicycle Transportation*, MIT Press, 1994

[8] *The Traffic Safety Toolbox*, ITE, page 208, 1993.

[9] John Heilemann, "Reinventing the Wheel", *Time*, Sunday, December 2, 2001. http://www.time.com/time/business/article/0,8599,186660,00.html

[10] As in many cities, right-turning motorists colliding with contra-flow cyclists was the leading cause of reported car-bike collisions in Cary, NC from 1997 to 2002, described here: http://www.humantransport.org/bicycledriving/library/collisions/cary2003.pdf