Be Aware of Motorized Shopping Carts

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ABSTRACT

As the elderly population grows, the need for personal mobility devices such scooter and wheelchairs increases too. Most of these devices are being used in uncrowded environment except Motorized Shopping Carts (MSCs). MSCs are operated by elderly or people with disabilities in very confined and in times crowded environment. In a first glance, it appears that there are no safety issues in operating MSCs due to their low "walking" speed. On the contrary, there are few safety issues and this paper attempts to present some of the safety concerns related to the operation of MSCs in shopping facilities.

Keywords

Safety, Motorized Shopping Cart.

1. INTRODUCTION

There are 38441 supermarkets in the US [1] besides malls, pharmacies etc. Thus, the number of Motorized Shopping Carts (MSCs) can be estimated, with high probability, to be above 50,000. This number will increase dramatically in the future as the population of the US age. MSCs are used in confined, and in times very crowded, spaces and as a result accidents might occur.

Motorized Shopping Carts (MSCs) are fundamentally reduced speed scooters with large basket installed in their front and, in most cases, for three wheel scooters two small casters were added in the front for stability (see Figure 1).

Figure 1: Modification to a typical scooter.

In [5] the new rules regarding to mobility aids, published by the American with Disabilities Act, are explained but safety remarks or recommendation were given. In [6] the following hazards were expressed: "A concern over the carts leading to injuries when used by those who do not know how to control them. Injuries can occur to the operator, to other persons and to property if they crash into an object or a person with the equipment. Frontal crashes leading to injuries and property damage are the most common injury. Most units have back-up alarms to warn person(s) when the equipment is in reverse". In [7] other concerns brought forward: 1) "The physical and mental capability of the person operating the device. Capabilities can include; reduced eyesight, diminished capacity due to medication, or alcohol, and limited physical movement (cannot turn around to view when backing up), etc. and 2) "The speed, and the combined weight of the equipment and the operator of the scooter or cart is the best indicator of the severity of the injury or extent of the damage".

The purpose of this paper is to discuss and to some degree quantify the hazards related to the use of Motorized Shopping Carts which were mentioned in the above references.

2. START-STOP ACCELERATIONS AND JERKS

It is quite clear that MSCs are use in GO – STOP mode as shopper are driving from one location to another and stop to pick up a certain item. All MSCs are using Direct Current motors to propel the cart and magnet brakes to stop it. Direct current characteristic is high torque at law speed that can result high accelerations. Magnetic brakes are on/off devices and when engaged might cause high decelerations. Experiments, in which the acceleration of the cart along a straight path, were performed on an empty basket commercial MSC driven by 156[lb] rider. The recorded acceleration is shown in Figure 1 (F stands for forward motion, R for reverse and S for Stop). The acceleration signal was samples at 100[Hz] and filtered with a first order low pass filter with time constant of 0.2 second.

As shown in Figure 2 the acceleration in the forward or reverse direction is practically the same and its peak reaches 0.075[g]. On the other hand, when the brake is applied the deceleration peaks at 0.14[g].

To determine the jerk the acceleration signal was numerically differentiated and then filtered by a first order low pass filter with time constant of 0.2 second (see Figure 3). As shown, stopping while moving in reverse generates jerk in the order of 0.42[g/second] and 0.3[g/second] when accelerating forward.

Similar results were reported in [2] where the following measurement were taken: maximum forward acceleration of 0.163[g] stopping deceleration of 0.183[g] forward jerk of 0.29[g/second] and stopping jerk of 0.345[g/second]. In [3] four different scooters were tested on horizontal surface. The measured maximum forward acceleration was found to be 0.194[g] and in the reverse direction 0.363[g].

ANSI/ASCE Standard 21.2-08 [4] the maximum acceleration and jerk allowed in public transportation is given (see Table 1). Comparing the results mentioned above, only one scooter exceeds the allowed acceleration but in two cases the jerk is larger than the allowed values. Although this standard is not directly related to MSCs it does dictate the necessary limitation on acceleration and jerk so that the rider will be kept in his seat.

Table 1: Maximum acceleration and jerk dictated by ANSI/ASCE standard [1].

Direction	**Acceleration [g]**	
	Standing	**Seating**
Lateral	±0.1	±0.25
Vertical	±0.05	±0.25
Longitudinal Normal	±0.16	**±0.35**
Longitudinal Normal*	±0.32	±0.60
	Jerk [g/s]	
Lateral	±0.06	±0.25
Vertical	±0.04	±0.25
Longitudinal	±0.10	**±0.25**

*Including effect of grade

3. IMPACT WITH BY STANDING SHOPPER

MSCs operate in facilities that might be extremely crowded in times such as department stores during the holiday seasons. As a result, collisions with by standers or walking shopper are not avoidable. The following are two simple model by which the impact force can be estimated.

Applying linear momentum principle to the shopping cart:

$$m_c v_1 = \int_0^T f(t)dt + m_c v_2 \qquad (1)$$

where m_c - cart's mass (including the defendant and the basket's contain)

v_1 - cart's speed before impact

v_2 - cart's speed after the impact

$f(t)$ - force impulse

T - Impact duration

Since the cart lost speed due to the impact we can rewrite Eq. 1 as:

$$m_c(v_1 - v_2) = m_c v_1(1-L) = \int_0^T f(t)dt + m_c \qquad (2)$$

where L is the fraction of the velocity lost during the impact.

For a simple model, in which the impact force $f(t) = F_0$ [Lb] and impact duration of T [second], the magnitude of the impact force can be determined by:

$$F_0 = \frac{1}{T} m_c v_1(1-L) = K m_c v_1 \qquad (3)$$

where $K = \frac{1}{T}(1-L)$

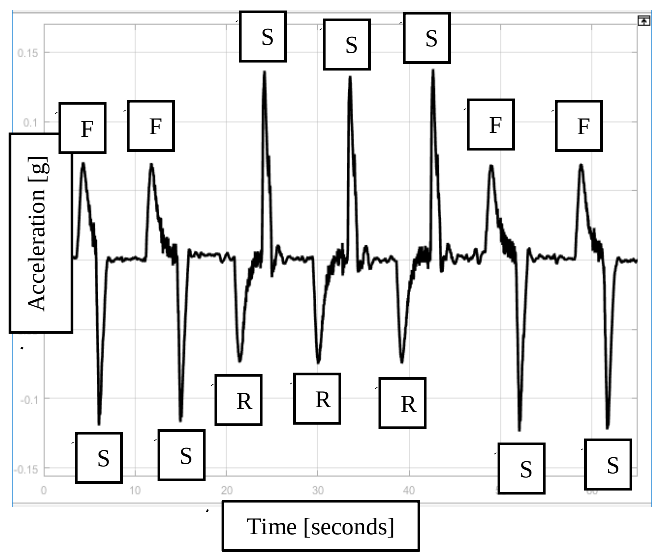

Figure 2: Acceleration recording

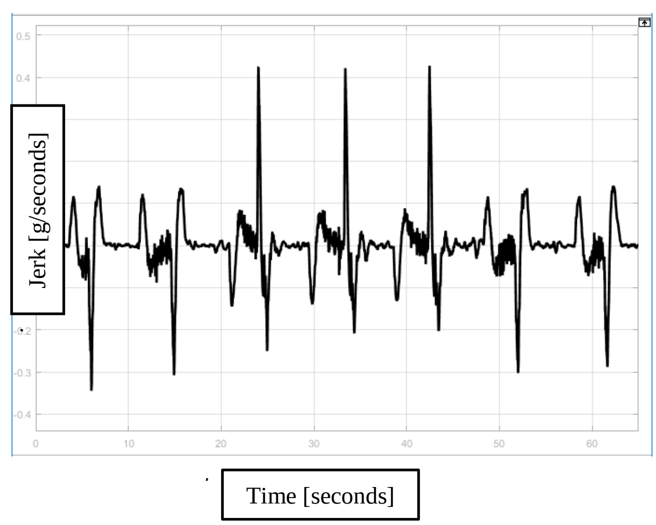

Figure 3: Calculated jerk.

Considering the following case: rider weight – 170[Lb], Basket weight=50[Lb] and the data for cart A (see Table 2) (cart weight = 190[Lb] v_1 = 3.66[ft/sec]. Figure 4 illustrates the value of F_0 as function of the impact duration time, T, and the fraction of the MSC velocity loss L. As shown, even for a long impact time of 50[ms], MSC velocity loss of 30% the impact force is 70[Lb] which is substantially enough to cause injury.

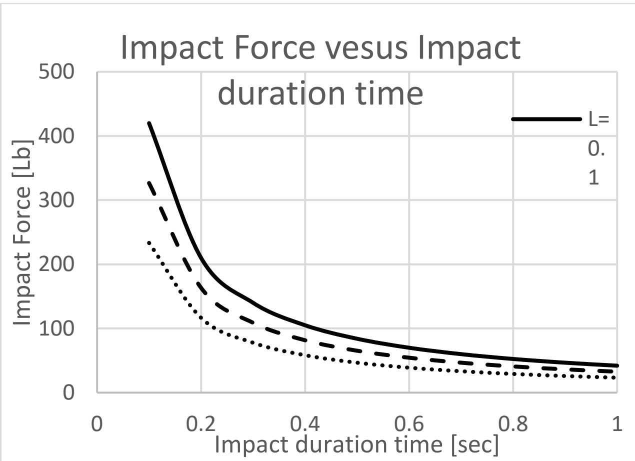

Figure 4: Impact force as function of impact duration time and cart's velocity lose.

Table 2: Data for two commercial MSCs.

Property		Cart A	Cart B
Weights [Lb]	Rider	750	500
	Cart	190	167
	Basket	250	250
	Total	1190	917
Cart Dimensions [in]		55L 26W 38H	56L 24W 33H
Basket dimensions [in]		23L 25.5W 20H	23.6L 19W 14.8H
Speed [mph]	Forward	2.5	2.3
	Reverse	1.5	1.4
Wheel diameter [in]		8	8 - rear 6 - front
Turning radius [in]		34	38
Stopping Distance [in]			18"

In a better model the force impulse behaves as sin function with half a period T/2[s] and is given by:

$$f(t) = F_0 \sin(\omega t) = F_0 \sin(\frac{2\pi}{T} t) \quad (4)$$

where F_0 is the maximum value of the force.

The total force impulse, I, is given by:

$$I = F_0 \int_0^{T/2} \sin\left(\frac{2\pi}{T} t\right) dt = F_0 \frac{T}{\pi} \quad (5)$$

Thus the magnitude of the force can be determined

$$F_0 = \frac{\pi}{T} m_c v_1 (1 - L) \quad (6)$$

Equation 6 indicates in this, which is more realistic response, the maximum value of the impact force is □ time larger. Figure 5 illustrates the impact force as function of time for F_0=300[lb] and MSC's speed used in Figure 3, with impact duration time of 0.25 [second] and L=0.25. The graph indicates that the MSC will exert a force of 250[Lb] for 0.1[second] during the impact.

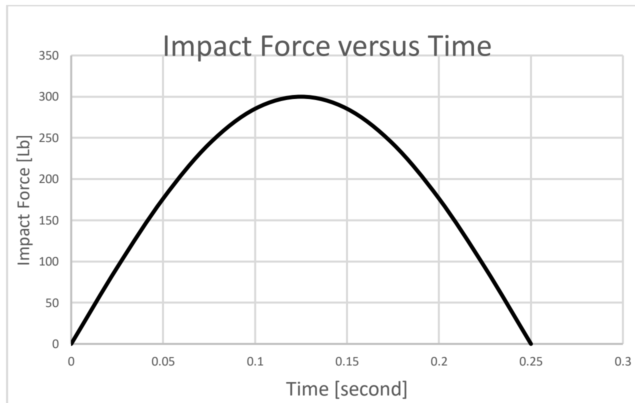

Figure 5: Impulse shape for a maximum force of 100[lb] and a period of 0.5[second].

This impact force might be exerted, with high probability, in two body locations: at the torso (impact with the top of the basket) or the ankle (impact with the cart's bumper) as shown in Figure 6. In the first case a person might lose his stability and fall and in the second case a person will injure or even brake his ankle which requires a long heeling time.

To estimate the magnitude of the impact force, exerted by the basket tip, required to tip over a person, a multibody human model must be used. However, a rough estimation can be obtained by considering the human body as a rigid body.

Figure 7 illustrates the Free Body Diagram which describes all the forces acting on a person at the tipping instant. The magnitude of the impact force, F_0, is given by:

$$F_0 = \frac{Wd}{2H} \quad (7)$$

where H is the height of the tip of the basket and d is the span between the feet of standing person.

For H=33[in] (above the center of gravity of the standing person) and d=12[in] Eq. yields $F_0 = 31[lb]$. As shown above the impact force can assume by far larger magnitude which for certain might cause a by stander to lose his balance, fall and possibly be injured.

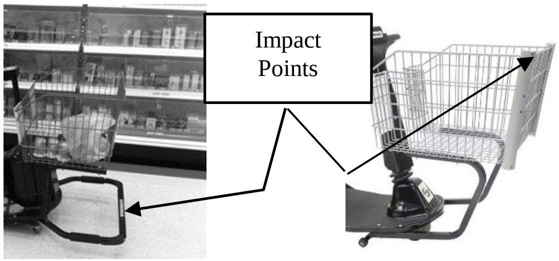

Figure 6: High probability impact points.

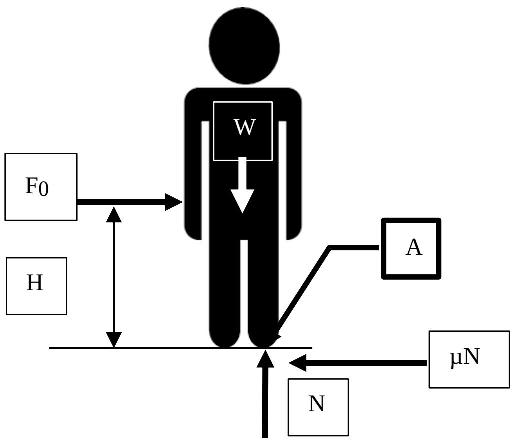

Figure 7: Free body diagram of a person on a verge of tipping.

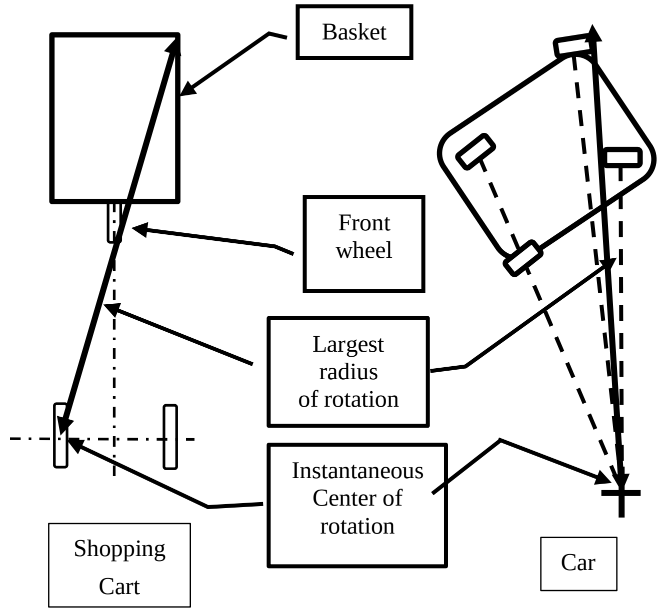

Figure 8: Turning radii of a car and a MSC

4. OTHER ISSUES

4.1 Turning Radius

Users of MSCs most probably drove standard family vehicle for many years and got used to their performance. One issue in driving a car is to clear its corner while making a turn in a tight space. With a car the maximum radius of rotation is slightly larger than the radius of rotation of front wheel (left front in the Figure 8), In contrast, the maximum radius of rotation of a typical MSC is by far larger than the radius of rotation of front wheel. This fact presents a major difficulty when a tight turning maneuver is performed such as turning into a narrow isle since the rider has to clear the edge of the basket. In comparison, driving the MSC is like driving a mini excavator where the bucket is extended. Also, one has to realize that most of the MSCs users are probably using scooters for daily mobility. These scooters do not have baskets, or very small ones, thus they need some adjustment time to drive a MSC which has a large basket in is front.

4.2 Stopping Distance

The stopping distance provided by the manufacturer of cart B is 1.5[t] which relates to the capability of the brake to bring the cart to halt. This value agrees with measurements taken in several experiments. One such is shown in Figure 9 where the acceleration signal was integrated twice and the stopping distance was estimated. The actual stopping distance should include the distance the cart travels during the reaction time of the rider. Typical response time is 1.5[second] and for elderly people it might me higher. Thus for a traveling speed of 2.4[mph], as specified by the manufacturer of cart B, the stopping distance is:

$$S = 1.5 + 1.5 * 2.4 * 1.466 = 6.78[ft] \quad (8)$$

Thus the stopping distance, if the rider pay full attention, is about 2[ft] assuming that the rider full attention is in driving. One has to realize that the attention of the rider in finding a particular product. While driving along an isle the products are located on shelves on both of his sides and as a result he is not looking forward in the driving direction. In this case stopping distance becomes very critical in particular in crowded store.

In [3] one of the four scooters tested had a stopping distance of 7.578[ft] from a speed of 2.51[ft/second]. This value is comparable to the calculated in Eq. 8.

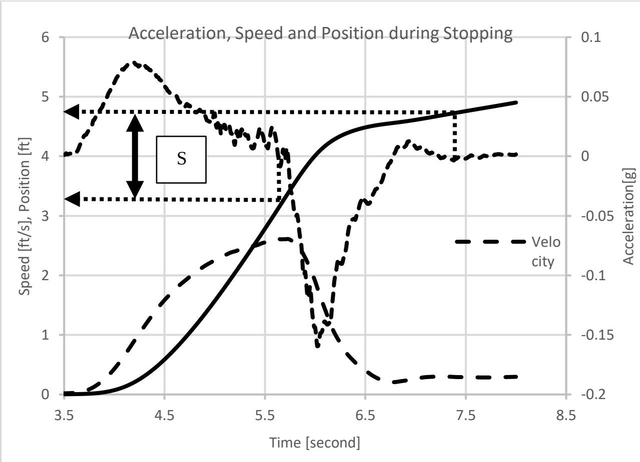

Figure 9: Determination of stopping distance.

4.3 Tipping Over

Some three wheel MSCs do not have stabilizing casters and as a result, they are more susceptible to tipping. In this case, the MSC will tip to the right once the center combined center of gravity of the rider, the cart and the basket and its content will cross the tip over line that connects the centers of the right rear and the front wheel (see Figure 10). Tipping can occurs when the rider over extends his arm and shift his weight in order to reach a product or while standing on the platform and shifting his weigh to one foot in order to reach a product on a high shelf.

In this regard the label attached to the MSC warns: 1) "Do not stand on the platform; and 2) "Distribute weight evenly in basket". The only question is: "how many of the users actually reading the label?"

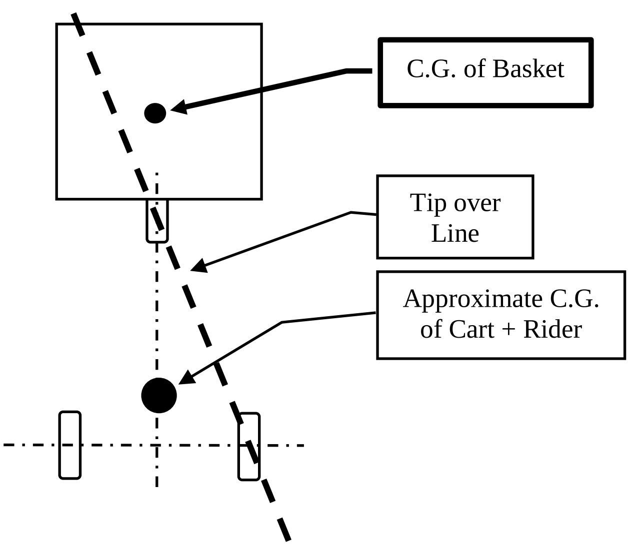

Figure 10: Tipping diagram of an MSC.

5. CONCLUSIONS

It is expected that the number of Motorized Shopping Cart will increase considerably in the near future as the population age. MSCs do present risk to an inexperienced rider and bystanders in particular in crowded spaces like department store during the holiday season.

Injuries due to impact with bystanders, tip over, high acceleration and other reasons were presented in this paper. Some changes in the design of these carts, such as soft bumpers and limiting the acceleration and decelerations, will certainly reduce the risk. However, the real problem is that the accessibility to these carts is not monitored by the facility personnel. Therefore anybody, capable or not, experienced or not, can use these carts. Since these facilities are providing these carts to their customers it is their responsibility for their safe usage. A few minutes of instructions will make the user aware of the safety issues and thus reduce the risk.

6. REFERENCES

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