CHALMERS

Research report 2014:10

Implications of emerging lightweight urban personal vehicles on traffic safety, based on forecasts of technology solutions for vehicles

by

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Göteborg, Sweden 2014

Konsekvenser av framväxande lätta stadsfordon på trafiksäkerheten, baserade på prognos av tekniklösningar för fordonen

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ISSN 1652-8549

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ABSTRACT

An emerging vehicle type between bicycles and motorcycles are part of ongoing developments to provide alternatives for personal transportation primarily in urban road networks. For the purpose of this report they have been defined as Urban Personal Vehicles – Single Track (UPV-1T). A key characteristic of these vehicles are electrified powertrains, and it is expected that the vehicles will become cheaper and therefore more accessible to a greater proportion of the population but will be more powerful and lighter, therefore increasing the vehicles speed and acceleration. A detailed potential technology development path of these vehicle types, and therefore potential critical situation and collision conditions, are unknown.

A study was undertaken to look at what type of UPV-1T's are currently available on the Swedish market and the current performance specifications of these vehicles. A picture of the current situation surrounding bicycle, moped and motorcycle accidents and causation factors were presented for the Swedish market. A potential technology development path and the application of these technologies with regards to safety critical situations was undertaken.

The conclusion to the report was that assuming that the road networks and driver education remain unchanged, that critical situations will increase both in number and severity. In addition to this is that although difficult to predict the specific accident types it was most likely that single vehicle accidents would dominate, but that the possibility exists for likely emerging technologies to be utilized to help counter and reduce potential accidents.

Key words: Urban transport, Small vehicles, Electric bicycles, Sustainable transport, vulnerable road users, Safety

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PREFACE

This project was funded by Trafikverket via Skyltfonden. The reference number is TRV 2013/14713.

Thanks to Marco Dozza, Chalmers, for review reading and feedback.

Göteborg 2014-10-09

Jonathan Rice and Bengt Jacobson

1 Introduction

An emerging vehicle type between bicycles and motorcycles are part of ongoing developments to provide alternatives for personal transportation primarily in urban road networks. A key characteristic of these vehicles are electrified powertrains, which are now cheaper, more powerful and lighter, which are increasing the vehicles speed and acceleration. A detailed potential technology development path of these vehicle types, and therefore potential critical situation and collision conditions, are unknown.

The purpose of the project is to forecast the likely technology development of this vehicle type, the resulting vehicle performance characteristics and as a result, to forecast potential critical situations and collision types within the existing Swedish road network. Such a forecast would be a starting point for continued research, which would have the purpose to recommend Performance Based Standards based on the likely vehicle technologies to mitigate the resulting collisions and for potential changes that could be made to the road network to ensure safe integration of the new vehicle types.

1.1 Emerging Vehicle Types

The emerging vehicle type between bicycles and motorcycles are part of ongoing developments to provide alternatives for personal transportation. The primary usage area is within urban road networks but there is the potential, depending upon the technology development path, that these vehicles could be used for inter-urban transportation. As this vehicle is a new concept there is a desire to move away from common terms such as car, motorcycle and bicycle as these terms carry with them preconceptions and expectations. It has therefore been decided that the term Urban Personal Vehicle (UPV) will be used to describe this vehicle type.

A UPV carries between 1 and 3 passengers, has between 2 and 4 wheels and these wheels are arranged either symmetrically or asymmetrically in relation to the longitudinal median plane inline. A vehicle with 3 or 4 wheels arranged symmetrically or asymmetrically in relation to the longitudinal median plane are known as UPV – 2 Track (UPV-2T), due to the vehicle having two tracks. A vehicle with 2 wheels arranged symmetrically in relation to the longitudinal median plane is known as a UPV – 1 Track (UPV-1T), due to the vehicle having only a single track. The UPV-2T shall not be considered in this report as the focus of this report is UPV-1T only.

1.2 Legislation

UPV’s are currently governed by the United Nations Economic Commission for Europe (UNECE) L Category (light) Vehicles. The guidelines governing these are shown in Table 1.

UNECE - L Category Vehicles

Category	Wheels	Max Power (kW)	Speed (kph)	Weight (kg)	ICE Capacity (ccm)
L1	2	-	< 50	-	< 50
L2	3	-	< 50	-	< 50
L3	2	-	> 50	-	> 50
L4	3*	-	> 50	-	> 50
L5	3**	-	> 50	-	> 50
L6	4	< 4	< 45	< 350***	< 50 (< 4kW)
L7	4	< 15	-	< 400 (< 550 if goods vehicle) ***	-

*: asymmetrically arranged in relation to the longitudinal median plane
**: symmetrically arranged in relation to the longitudinal median plane
***: excluding the mass of the batteries

Table 1: UNECE Guidelines governing L-Category vehicles.

Legislation can provide barriers to new solutions that can create social and market change therefore although Category L1 and L3 would apply to UPV-1T, for the purpose of this project it should be assumed that the relative legislation does not always apply. In taking this approach, the development path of individual technologies (materials, motors, sensors, etc) can be mapped out. These can then be combined to provide a potential development path for UPV-1T's, their performance characteristics, the resulting critical situation and collision conditions and thus potential methods of mitigation.

The Swedish "Moped klass II", although with a maximum speed of 25 kph fits in together with Swedish "Moped klass I" in category L1. Electric bicycles are EN 15194 but they are covered later in this report.

1.3 Current Market Situation

The current indication for UPV-1T's is sales in Sweden of bicycles and motorcycles. Currently there are 555,000 bicycles sold per year of which 6,500 were recorded as being electric bicycles. Of these 550,000, 115,000 are built in Sweden, meaning 348,000 were imported and an additional 76,000 bicycles were built for export. [Ref 1]

In Sweden today there are approximately 300,000 motorcycles registered and in the period 2003 to 2012, this has grown at a rate of roughly 8,000 motorcycles purchased per year. The number of electric motorcycles sold in Sweden is unknown, but the Swedish market is notable for purchasing high end motorcycles. There are no motorcycle manufacturers remaining in Sweden and the distribution of manufacturers for newly sold vehicles is 60% Japanese, 13% American and 27% European. [Ref 2]

2 Information Survey

The objective of this section is to outline existing UPV 1T vehicles and give an overview of their technology and performance characteristics.

UPV-1T: Current Specification

Category	Max Power (kW)	Speed (kph)	Weight (kg)	Range (km)	Battery Type
Electric Bicycle - Basic	0,25	25	24	120*	Li-Ion
Electric Bicycle - Advanced	4,5	80	53	80	LiFePO4
Electric Scooter	11	120	265	120	Li-Ion
El Motorcycle	50	164	205	186	Li-Ion

*: including user pedalling
Li-Ion: Lithium Ion
LiFePO4: Lithium Polymer Phosphate

Table 2: An overview of the highest performing vehicles separated into categories which were the result of a market analysis of existing vehicles.

2.1 Electric Bicycle - basic

An electric bicycle can be characterised by a single seat, a wheel motor mounted primarily in the rear wheel but on some examples in the front wheel, with a chassis mounted removable battery pack. In additional to the UNECE L-Category vehicle regulations, the EU Directive 2002/24/EC and EU15194 applies to two wheeled vehicles which intend to travel on the road. This directive states that cycles with pedal assistance which are equipped with an auxiliary electric motor will have a maximum continuous rated power of 0,25 kW, that the output should progressively reduce and finally cut off as the vehicle reaches a speed of 25 kph, or sooner, if the cyclist stops pedalling. This means that any bicycle designed to these regulations will have a maximum power of 0,25kW and speed of 25kph. These bicycles are readily available and will not be covered in depth. These vehicle types have not typically been purposely designed with the battery, motor and ancillaries as integrated systems. Such an example is shown in Figure 1.

Figure 1: Retrofitted electric bicycle [Ref: 3]

2.2 Electric Bicycle – advanced

A market has emerged above the 0,25kW bicycle for vehicles which have multiple capabilities. Multiple capabilities mean that the rider has the ability to limit the performance to meet either road legal or licensing requirements and when not on a regulated road, they can switch to an unlimited performance. These bicycles when unlimited on road would be required to meet either L1 or L3 category regulations. They are characterised by a single seat, a wheel motor mounted either in the wheel or chassis in which case it drive the rear wheel via the chain, and a chassis mounted battery pack. These vehicle types have been typically been purposely designed with the battery, motor and ancillaries as integrated systems. Such an example is shown in Figure 2.

Figure 2: An example of an electric bicycle – advanced [Ref: 4]

2.3 Scooters (In Swedish: Lätt-MC)

The electric scooter market is one with many examples being imported from overseas, typically the Asian market, with the manufacturers being less established than those already in the market. These vehicle types have not typically been purposely designed with the battery, motor and ancillaries as integrated systems, however a number of examples are beginning to emerge from well-established manufacturers. They are characterised by two seats, a swingarm mounted motor driving the rear wheel through a toothed belt, and a chassis mounted battery pack. Such an example is shown in Figure 3.

Figure 3: An example of an electric Scooter (Lätt MC) [Ref: 5]

2.4 Motorcycles (In Swedish: Tung-MC)

The electric motorcycle market is one where neither well established manufacturers or less established Asian manufacturers are entering. The market is one that is primarily occupied by well-funded start-up firms, primarily in the USA. An electric motorcycle is characterised by two seats, with either a wheel mounted or chassis mounted motor, driving in most cases the rear wheel directly or via a chain or belt. These vehicle types have typically been purposely designed with the battery, motor and ancillaries as integrated systems. Such an example is shown in Figure 4.

Figure 4: An example of an electric Motorcycle (Tung MC) [Ref: 6]

3 Current technologies

This section will study the current technologies with respect to UPV-1T's.

3.1 Motors, Batteries and Controllers

The most common type of motor used is a Permanent Magnet Synchronous Motor (Brushless) and although these have the highest efficiency and performance of all alternatives, they are also the most expensive type. A trend being observed in the passenger car market is to use Induction Machines which although have lower performance and efficiency are roughly 20 to 40% cheaper to produce.

The most common types of batteries in use are Lithium Ion (Li-ion) or Lithium Iron Phosphate (LiFePO4). Their weight and price are reducing by between 10 – 15% every three years. A lot of research is being undertaken however it will take a research breakthrough to deliver the power density that current vehicle customer's demand.

The controllers and control strategies are becoming more capable which provides for better controllability of the motor both in acceleration and braking, when regeneration can take place. This has an implication both for the range of the vehicle, but also braking performance and potential use for better braking stability. An example using regenerative braking is [Ref: 19].

3.2 Chassis, Suspension and Steering

Most vehicles are currently using an aluminium chassis, which is also common with the established combustion powered motorcycle manufacturers and bicycles. The advantage is low cost of the raw materials, easier manufacturability and ability to obtain the required chassis stiffness. Although most are open vehicles in the classical style of Motorcycles, some manufacturers (BMW C1, Lit Motors C1) have chosen to fully or partly enclose the vehicles. This enables the meeting of required chassis stiffness more easily but adds additional benefits of weather and crash protection. The drawbacks of this however arise when the motorcycle experiences a side wind with the resulting aerodynamic forces causing instability for the rider.

The suspension and steering employed by most of the vehicles are close to both motorcycle and advanced bicycles. They are usually dual front forks and a single rear damper, sometimes utilizing a multi-link suspension system. Mechatronics although expensive, are becoming more prevalent in more expensive performance focused motorcycles and utilized within the damper units, however most mechanisms in the suspension and steering systems remain primarily mechanical.

3.3 Safety

Currently, only the most advanced 1T vehicles have any safety features at all. These features are Anti-lock Braking Systems (ABS) and traction control (TC). In some senses the brake regeneration can also be seen as a form of safety system as the electric motor can be used to increase or decrease the braking effect depending upon the requested input.

4 Information Survey – UPV1T Critical Situations

4.1 Bicycles

Between 2007 and 2012, 44,146 people with a classified injury of which 8420 were serious injuries (Person med skada/skador som ger en medicinsk invaliditet på 1% eller mer) and 1099 were very serious injuries (Person med skada/skador som ger en medicinsk invaliditet på 10% eller mer). Of all accidents the main type is a "single bicycle" accident (between 72-80%), the secondary type being "bicycle – motor vehicle (between 10-17%) and the tertiary type being "bicycle – bicycle" (6-8%).

When studying the "single bicycle" type of incidents, the main causes where as follows;

Description	All Injuries (34112)	Serious injuries (6550)	Very serious injuries (798)
Samspel med övriga trafikanter	7%	8%	7%
Cyklistens beteende och tillstånd	20%	19%	25%
Cyklisten i interaktion med cykeln	20%	20%	18%
Vägutformning	17%	17%	17%
Drift och underhåll	37%	37%	35%

Table 3: Causes for single bicycle accidents

Breaking down the statistics for ”Drift och Underhåll”, the primary reason is "ice or snow", secondary is "uneven surface" and tertiary is "gravel".

Breaking down "Cyklistens beteende och tillstånd", the primary reason is ” tappat kontrollen på cykeln utan yttre påverkan", secondary reason is ”lekt under cykling" and tertiary is ”egen hund". Breaking down ” tappat kontrollen på cykeln utan yttre påverkan" further, 40% is due to ”operator error", 10% is due each to ”alcohol consumption", "high speed, losing balance" and "distraction".

Breaking down "Cyklisten i interaktion med cykeln", the primary reason is "fault with the bicycle", the secondary reason is "stuck something in the bicycle" and the tertiary reason is "fell off the bicycle". [Ref: 7]

4.2 Motorcycles

Of the 964 seriously injured motorcyclists, 44% of these were involved in a single vehicle accident, 15% were at a turning (“avsvängande”), 13% were at a junction (“korsande”) and 10% were rear-end collisions (upphinnande). In total 46% of these were involving another motor vehicle. [Ref: 8]

Of the 259 motorcyclists who died in the period 2005-2010, 44% of these were involved in a single vehicle accident, 28% were at a junction (korsning) and 15% of these were head on (mote).[Ref: 9]

Of those involved in single accidents, 24% of these was due to being inexcess of 30kph over the speedlimit. [Ref: 10]

4.3 Mopeds

Studying mopeds, 60% of those seriously injured were involved in a single vehicle accident and 31% of those were involved with another motor vehicle. This is contrast to who were “svårt skadade” or killed, in which a collision with another vehicle accounted for these by 59% and 62% respectively and a single vehicle accident accounted for 34% and 40% respectively. [Ref: 11]

4.4 Critical Situation Discussion

What is clear is that when studying bicycles, motorcycles and mopeds the primary type of critical situations is single vehicle accidents except in the case of mopeds were most serious injuries and deaths were caused by collisions with other motor vehicles. When breaking down the statistics on the causation factors of these accidents, in the case of motorcycles it is primarily excess speed and for bicycles it is primarily the type or condition of the surface the bicycles are on. However a high causation for bicycles was how the rider was operating the bicycle and the same statement can be made for moped users.

These (high speed, poor road surface, rider operation) are not excluding each other, but they can instead typically appear in a causation sequence in a certain accident. The driver operation is reasonably always one part of the accident causation chain (as well as a part of avoiding accidents!). Therefore, the analysis could be more precise, having a differentiation of driver operation causation factors, e.g. distraction, interaction with other road users and weird manoeuvring. Such differentiation is generally not available in the data bases.

5 Potential Technology Development and Application

As UPV1T's develop further, the power density of batteries and power of motors will increase while the weight and cost will reduce. This will mean that the classes of bicycles and motorcycles will begin to merge together and the vehicles will become more accessible to a greater selection of the population. What was clear from the accident statistics is that single vehicle accidents are most common with the main causation factors being less than optimal surface conditions or poor rider operation.

The objective of this section is therefore to look at how current technologies and are developing and how technologies from other vehicle types or industries could be applied with respect to UPV 1T vehicles to help reduce the likelihood of critical situations.

5.1 Driveline and Braking

UPV 1T powertrain technology will most likely be electrified and electric propulsion presents opportunities for increased utilization for dynamic performance, including in safety critical situations. In addition an increase in power will lead to increases in both speed and acceleration but this will also require a relative increase in braking performance

5.1.1 Two Wheel Drive (2WD)

Currently 1T vehicles are fitted primarily with a single electric motor, either chassis mounted or in-wheel, with the favoured driven wheel being the rear. Under braking conditions in a 1T vehicle it is favourable that the majority of braking is undertaken by the front wheel. Therefore most is to be gained both from braking (in normal and safety critical situations) and a power regeneration perspective by having an electric motor fitted in the front wheel. With Motor technology reducing in both weight and cost, this presents an opportunity to exploit for 2WD.

5.1.2 Active Drive

Active Drive implies that the user requested torque is adjusted to the given situation by an on-board active control system and can therefore result in a different wheel torque being applied. Active drive is commonly used in electrified 2T vehicles to create torque vectoring, whereby the driven wheels are over- or under-sped for increased dynamic performance in the case of normal driving conditions or in safety critical situations. Torque vectoring cannot be achieved by a 1T due to the wheels being in line with one another, but the theory can be applied when considering over- or under-speeding the driven wheel. When combined with 2WD the Active Drive option opens possibilities for greater control in normal driving and safety critical situations. The advantage to be gained is due to the increasing ability of the on-board control systems and advanced control strategies that can be employed.

The technology would function by either over- or under-speeding the wheel in normal operating conditions. This could be applied by: varying front/rear regeneration bias to improve braking performance; varying front/rear driven bias there is an ability to tightening or loosen corner trajectory, improve traction in varied grip conditions; and by varying both regeneration and drive to affect safety critical situations pre- or post-incident.

5.2 Dynamics

Conventional 1T vehicles are reliant primarily upon hard point location for their dynamic characteristics to be defined, but the following section proposes a number of potential technology developments to influence this in normal and safety critical driving conditions.

5.2.1 Gyroscope

The gyroscopic effect is already utilized by experienced 1T riders to initiate the "turn in" and affect the trajectory by either tightening or opening the corner. This is achieved by counter steering the front wheel, utilizing the gyroscopic forces created by the wheel, to obtain the desired effect. A chassis mounted gyroscope could be utilized to create all of the listed effects for both experienced and inexperienced riders in normal driving conditions and safety critical situations Such safety critical situations could be pre or post-impact, with the vehicle remaining either upright or enabling the user to maintain control of the vehicle.

Lit Motors are employing the gyroscopic effect in their C1 concept vehicle, but this has been utilized to maintain the vehicle in an upright position rather than for cornering stability or in safety critical situations. [Ref: 12]

5.2.2 Active Steering

An alternative or complimentary technology to the gyroscope would be active steering. Active steering implies that the user requested steering torque is adjusted to the given situation by an on-board active control system and can therefore result in a different steering torque being applied. This can be used in both normal driving conditions and safety critical situations and would therefore mean that the mechanical disconnect between the rider and the wheels would be replaced by an electrical motor, as is currently the case in passenger cars.

5.3 Safety

Safety systems on 1T vehicles are currently limited to ABS, TC and dual braking systems, but the scope exists to adopt technologies currently used within 2T vehicles as they become increasingly cheaper and more readily available.

5.3.1 Radar + Camera

Radar and Camera systems are more increasingly being utilized by passenger vehicle manufacturers as safety aids, typically for systems to enable automatic braking, lane departure warning and to enable to keep a safe distance to leading vehicles. These systems could be utilized also by 1T's to undertake the same actions in conjunction with other proposed technologies.

5.3.2 Rider Safety Systems

A challenge individual to 1T's in comparison to 2T enclosed vehicles is that the driver and their passenger are both exposed in the event of a collision.

5.3.2.1 Airbags

Airbags mounted in the Riders clothing has been pioneered by Alpinestars but is not yet commercially available, still only being used by riders in the Motorcycle Grand Prix championships.

Figure 5: Alpinestars TechAir Air Bag [Ref: 13]

Dianese however in conjunction with Ducati Motorcycles have produced a wirelessly operated airbag jacket which is commercially available.

Figure 6: Ducati/Dianese jacket Airbag [Ref: 14]

Honda has taken an alternative approach by introducing a motorcycle mounted airbag on the Goldwing class of motorcycles. They are however alone with this approach as no other manufacturer has adapted the idea

Figure 7: Honda Motorcycle Airbag [Ref: 15]

5.3.2.2 Restraints

Seat belts are common among passenger vehicles but are only used on one commercially available motorcycle, the BMW C1. Honda are working on a motorcycle seatbelt combined with a "seat release"

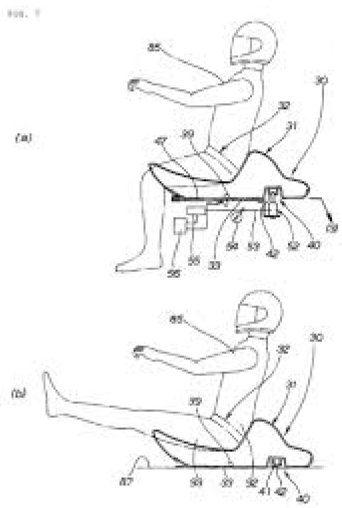

Figure 8: Honda seatbelt and seat release patent drawings [Ref: 16]

This appears to have been designed to ensure the rider stays on the motorcycle while upright and until it has been deemed necessary for them to be released. At this point the seat will detach from the motorcycle and allow the rider to slide away from the motorcycle.

5.4 Aerodynamics

Aerodynamic improvements have a short history in 1T primarily due to the banning of faired motorcycles in motorsport with legislation following on from this. BMW were revolutionary with their C1 vehicle, a scooter which was fully enclosed except for their sides and they are revisiting this concept once more with an electrified version.

Figure 9: BMW Motorrad C1 [Ref: 17]

A study was undertaken at Chalmers on behalf of Trafikverket [Ref: 18] (TRV 2012/14955) to look at new motorcycle design for increased safety and lower flow resistance. The study primarily focused on the implications of ABS and the ability for a rider to keep themselves and the vehicle upright post impact. Although primarily looking at what changes could be made to motorcycle design in the near term, they discovered that the driver could be protected in an impact up to 30 degrees and maintain better control of the vehicle post impact.

These discoveries were achieved by enclosing the front wheel and providing better enclosure of the rider utilizing side fairings and front screen. This was a primary study looking at near term gains so could not investigate the impact of enclosing the rider more would have on vehicle stability in side winds due to the increased surface area exposed.

6 Results and Conclusions

It is difficult to derive a clear prognosis for future, but the following is the author's judgement:

The emerging vehicle type between bicycles and motorcycles will become more affordable and therefore more accessible to a greater proportion of the population. This vehicle type will have higher acceleration and top speed capability than bicycles but will be less manoeuvrable and have lower cornering and braking performance capabilities than motorcycles. Assuming unchanged road networks and unchanged driver education, critical situations will therefore increase both in number and severity. It is not possible to identify one specific accident type due to the many factors both known and unknown influencing these situations. However, single vehicle accidents are the most common type for all existing 1T vehicles, so this type of accident will most likely dominate also for the emerging vehicle type. For motorcycles, the main reason is high speed and for bicycles it was a combination of driver errors and road conditions or design. There is the possibility however for likely emerging technologies to help counter and reduce the potential accidents.

7 Recommendations and Further Work

- Vehicle engineering from MC have to be moved down to e-bike engineering. To give mechanically good bikes.
- Novel technolgoy solutions have to be utilised: ADAS? ABS/EBD/ESC-like systems? Utilise e-prop system?
- Find ways of measuring safety related (complete vehicle) performance in forecasted critical traffic situations, see Section 7.1. Separate the performance from the actual vehicle design parameters, see Section 7.2.

7.1 Safety Related Performance

- Maneuverability
    - Steady state cornering (Centrifugal)
        - Velocity @ given radius?
        - Understeering coefficient
        - Taking a curve without Roll-over=high-side (also transient?)
        - Taking a curve without Set down/slide (also transient?)
    - Transient
        - **Single Lane Change** (single maneuver)
        - **Double Lane Change** = ”Elk test” (double maneuver)
- Acceleration/Top Speed
    - Longtitudinal Acceleration
        - Acceleration straight-line/curve, lo/hi/split-mu
        - Braking straight-line, lo/hi/split-mu
        - Braking + Turning (directional stability)
            - Rear brake only, locked or not
            - Front brake only, locked or not
            - Both brakes applied, rear locked
            - Both brakes applied, front locked
- *Stability*
    - *” Stability is the tendency to return to an equilibrium position (also known as a trim state) after being disturbed from that same equilibrium state.”*
    - Speed + excitation (stationary oscillation or step response?)
        - External/rider excitation
            - Shimmy
            - Wobble – harmonic motion
                - *” when the front wheel is displaced by some road irregularity, the restoring torque created by the trail happens to be strong enough to over-correct for the initial disturbance.”*
            - Weave
                - *“An oscillation of the rear steered mass (the main part of the bike and rider) about the steering axis. The whole motion is a complex combination of yaw, roll, suspension and steering displacements.”*
- Sensitivity to steering input/Yaw balance???

    - Under/Oversteer (Push/Loose) #would be interesting to learn!
        - *” the under-/over-steer possibilities are more numerous in the case of motorcycles, depending on the relationship between the values of camber and steering stiffnesses at the two ends. In fact there are thirty three different combinations that we could consider.”*
- *Vertical? Probably not typical safety ?*

7.2 Vehicle design parameters

Vehicle design parameters Affecting Performance Characteristics (investigate, measure, predict, compare) Design parameters

- Tyre Diameter (Tyre type)
- Steering (rake&trail)
- Suspension
    - Characteristics
        - Antidive
        - Antilift
        - Antisquat
        - CoG position
        - Wheelbase
- Chassis
    - Stiffness
        - Torsion
        - Bending
- Rolling resistance
- Aerodynamic characterstics (frontal/side)
- Power
- Weight
- Cost
    - Product cost
    - Milage cost

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