Electrically Assisted Cycling around the World

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Abstract

This paper will report about Brussels's contribution to the European E-Tour (Electric Two wheelers On Urban Roads) project. This project aimed to prove the viability of electric two-wheelers in different (urban) areas, by providing European cities with a clean, efficient and reliable alternative for the car.
Based on a technical identification of different electric bicycles that are available on the European market and an extended questionnaire filled in by their users, we tried to get an idea of the potential of the electrically assisted bicycle.
The first part of the paper discusses the user's appreciation. In the past two years 250 persons could test one of five different electric bicycle models for an average period of 7 weeks. Together they drove over 44600 km. A standard questionnaire sounded out their experiences about the strengths and weaknesses of electric two-wheelers and can be found in part one of this paper.
The test persons had to fill in—next to the standard questionnaire—a log with their daily trips. In those books a lot of interesting free remarks were given. These collected remarks will also be analyzed in this report.
It may be clear that the users appreciate the reduction of physical effort, although most of them spontaneously mention different reasons why they won't buy one.
The second part of the paper discusses the performance analysis of one of the five electric bicycles. To get an objective idea of the performances of an EPAC we developed a test bench. By recording the traction force as a function of the torque applied to the crank axle and the imposed speed to the wheels, several performance parameters could be defined (see EVS19).

Keywords: recreation and light vehicles, market research, introduction and demonstration

1 Appreciation of the EPAC by its users

During the last two years, over 250 people tested an Electric Power Assist Cycle (EPAC) at the VUB university. The participants could inscribe voluntarily to test one model during several weeks. Together they cycled once around the world. They were asked about their experiences by means of a standard questionnaire. They also had to fill in a log with their daily trips. We finally received 244 of the questionnaires and 197 well kept up logs. In a first part, we filtered out the most interesting conclusions out of the standard inquiry. A second part is handling the comments in the logs.

1.1 The answers on the standard questionnaire

1.1.1 The test persons

The participants were just interested volunteers, who heard about our project. They were equally divided between male (#133) and female (#111).
First, they had to fill in some personal data.

Table 1: Personal data of the test persons:

	Men	Women	All
Average age	46.0	44.4	45.3

Average length [cm]	176.2	165.8	171.5
Average weight [kg]	77.7	64.0	71.5
Average BMI	25.0	23.3	24.2
Average term of use [months]	1.8	1.8	1.8

1.1.2 The available EPACs

At the VUB we have 47 Electric Power Assisted Cycles (EPACs) at our disposal.
The test persons could choose between five different power assisted systems:

Table 2: Available EPAC types:

Type	*#Bicycles*	*#Tests*	*Weight*	*Motor*	*Battery*
Yamaha Pas/MBK Axion	8/2	76	28 kg	Center mounted DC 24V 235W	NiCd 24V, 5Ah
Yamaha Easy/MBK Fizz	2/9	72	27kg	Center mounted DC 24V 235W	NiMh 24V, 7Ah
Sachs Elo-bike	10	50	31 kg	Hub mounted DC 24 V 300W	NiCd 24V, 7Ah
Merida/Stepscoot	10/1	33	29 kg	Center mounted DC 24V 230W	Lead acid: 2x12V, 9Ah NiMh 25.2V, 9Ah
SwissFlyer F6	5	12	33 kg	Center mounted DC 24V 250W	NiCd 24V, 5Ah

1.1.3 The covered distance

The total distance covered by all users was 44600 km, split up between the users as shown in table 3.

Table 3: The covered distance:

	Men	**Women**	**All**
Average covered distance [km]	172.9	194.6	183
Average daily covered distance [km]	4.1	4.3	4.2

Women cycled on the average 13% more than men. A possible reason can be found in figure 1. Men were more sceptical about all the aspects of the EPAC. Are they really more dissatisfied or are they just more conservative in their judgement?

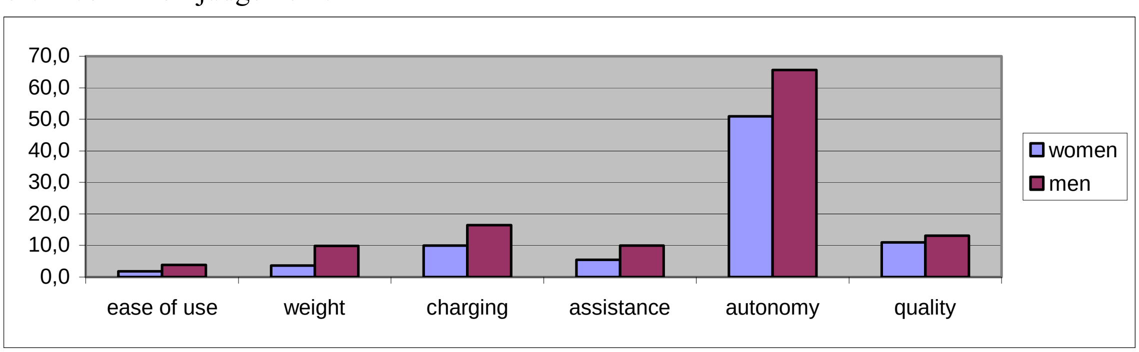

Figure 1: Percentage of people dissatisfied with different aspects

We registered the total and the average covered distance for every separate EPAC. These are given in figure 2.

The first place for the Swiss Flyer in average covered distance is not really a surprise. They were mainly placed at the disposal of people who were used to cycle.
The low average covered distance for the Yamaha Easy may be due to the higher percentage of technical problems with this model (see figure 6).

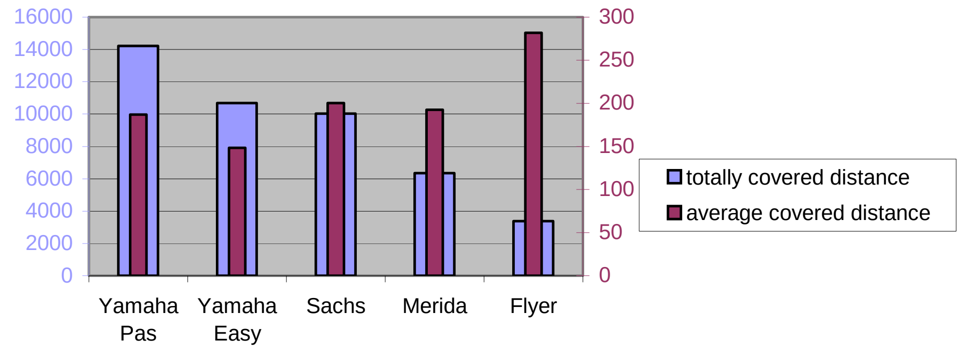

Figure 2: Covered distance versus type

1.1.4 The EPACs participation in traffic

The introduction of the electric bicycle may introduce a new behaviour of people in the daily traffic. Therefore we asked the respondents which of their common means of transport they replaced by the EPAC during the test period. Most of the respondents mentioned several categories. The results are given in figure 3.

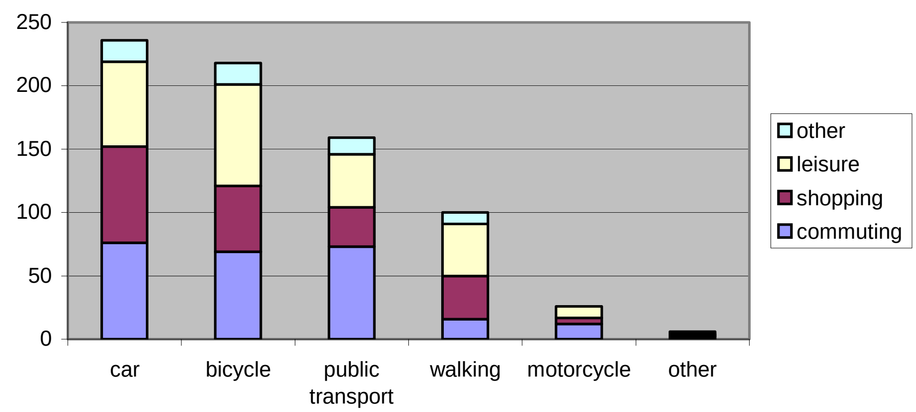

Figure 3: What did the EPACs replace and what were they used for?

The high score of the conventional bicycle replacement is not surprising, considering the resemblance with the EPAC. Iit may be hopeful to see that almost everybody mentioned that at least for some displacements the EPAC could replace King Car.
Especially for displacements in the city the EPAC was also appreciated as a good alternative for the public transport.
Except of the (typically male) motorbike, there was no difference between the sexes.

Asked about the reason of their displacements with the EPAC, the test persons gave three almost equally distributed answers: commuting, leisure and shopping (figure 3).

66% used the bicycle at least once for commuting. Probably due to the first contact of most of the test persons with the phenomenon of the EPAC, 60% of the respondents made trips for pure leisure.
In spite of some complaints of the bad facilities for shopping, 57% succeed doing his/her shopping with the EPAC.

42.6% of the respondents also made mention of new displacements due to the disposal of the EPAC. So people seem to become more mobile with the possession of the EPAC.

1.1.5 Time gain

37.3 % of the test persons realized a time gain when using the electric two-wheeler for commuting.
The average time gain is 10 minutes for a single trip, resulting in more than 76 hours less traffic jam for a single EPAC user in one year.

1.1.6 Appreciation of the EPAC

The test persons were asked about the performance of their bicycle on 6 domains: the global ease of use, the weight, the ease of charging, the appreciation of the assistance, the autonomy and the global quality and reliability.

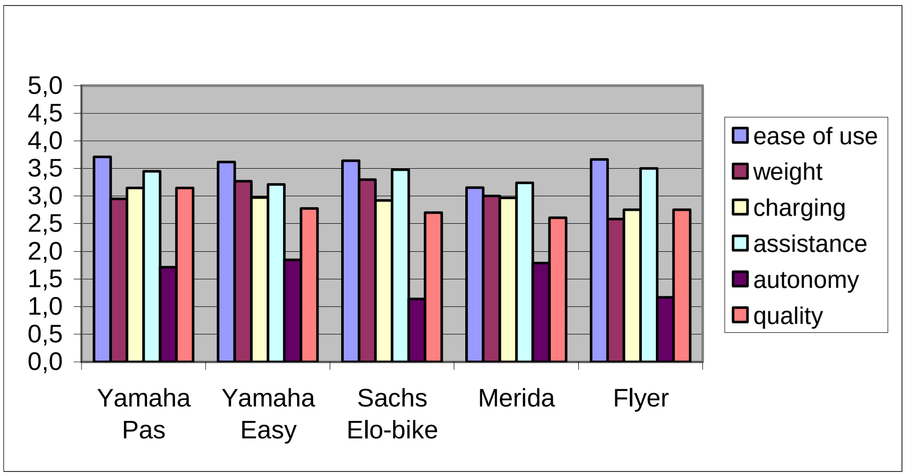

Figure 4: Appreciation of the EPACs (max. score = 5)

In figure 4 these categories are given for every model. There only seems to be slight differences between the models:

- The Merida scores worst for ease of use
- The users of the Flyer seem to suffer the most of the weight
- The limited autonomy is most experienced by Sachs and Flyer riders

The last two remarks can be partly explained by the fact that the Flyer users were mostly trained cyclists with other expectations of an EPAC.
Except for the autonomy the EPAC seems to pass for all mentioned categories, although the results betray that there are still a lot of things to improve:

- 8% of the respondents found the assistance inefficient
- 12% had doubts about the quality/reliability
- 13% disagreed with the quote “the charging is easy”
- 58% wanted the bicycle to have a greater autonomy

1.1.7 After the test

One of the positive effects of the test period is the changed cycling behaviour of the participants. At least 36% said that they ride more kilometres with their conventional bicycle since they finished the test.
About buying an EPAC there was more doubt: Mentioning a (low) catalogue price of 1000 EUR, 56% of the male respondents called themselves prepared to buy an electric bicycle, although only less than 3% really bought one.
From the female participants only 43% was prepared to buy one despite their more positive remarks.

1.1.8 Infrastructure

Everybody who cycled once in a city such as Brussels knows that the cycle infrastructure is inadequate. So 79% of the test persons complained about the lack of cycle tracks. 65% was dissatisfied about the number of parking places for bicycles.

1.1.9 The most typical user

Another question asked to all participants was: ”who’s the most typical user for this new mean of transport?” The answers were very different but we categorized them in table 4.

Table 4: Who’s the most typical user?

Most typical user	%
1. Commuters	61,4
2. (Middle)aged people	32,5
3. Less sporty people wanting to move	24,9
4. People in hilly regions	12,7
5. Everybody	11,7
6. Disabled persons	10,7
7. Sporty people	6,6
8. Shopping people	5,6
9. Recreational users	4,6
10. Workers in suit	3,6
11. People living in rather flat areas	3,6
12. Long distance cyclists	1,5
13. Students and daredevils	1,5

Commuters are supposed to be the main target group. Off course the distance between work and place of residence may not be too long. If the distance is out of the autonomy range, a combination of public transport and EPAC may be a solution. Considering the fear for theft (table 5), there should be at least a guarded parking place at work or at the station. Because of the time people spend at their job, charging at work is no problem. In that case a portable battery is certainly an advantage.

There were some remarkable things about the answers on this question:
The young and sporty participants mentioned the elder and less sporty people as target group. They mainly mentioned points 2, 3, 4 and 6. The elder and less sporty participants on the other hand mainly answered that an EPAC is something for young and dynamic people (points 7, 9, 10 and 13).
Should we conclude that these bicycles are still too much human powered for the people who already gave up cycling long time ago and give too few surplus value for the real cyclists?

11 % thinks the bicycle is a typical product for slightly disabled people (people with heart or breathing problems, with limited force,…) while the test persons with heart problems still doubted about the product.
Also the contrast in opinion about the adequacy for hilly regions (table 4) is remarkable.

Other unexpected but mentioned target groups were ‘people with a lot of time’ and ‘environmental conscious people’. Some participants explicitly told us that the EPAC is suitable neither for the busy city traffic nor for leisure cycling.

1.2 The collected remarks of the logs

1.2.1 General remarks

In the logs people have a lot of comment about their experiences with the electrical bicycle. We tried to categorize these spontaneous information.
We worked with a smaller group of participants because not everyone took the time to write down his experience. So only those who gave at least 2 remarks were seen as valuable. This resulted in a group of 182 test persons. The most quoted remarks are given in the following table 5.

Table 5: General remarks

Remarks		%
1	Technical problems	51,6
2	Too heavy	46,7
3	Little autonomy	42,9
4	Lack of cycling infrastructure in the city	25,8
5	Dangerous in busy traffic	22,0
6	I used the eco-assistance	22,0
7	It’s a real pleasure to cycle	21,4
8	Too expensive	19,8
9	I was afraid that my bike would be stolen	19,8
10	The weather conditions influenced my cycling behaviour	19,8
11	Parking place on first floor without threshold is needed	18,7
12	Too few assistance	15,9
13	Inadequate gearbox	15,4
14	Electric cycling needs a learning process	13,7
15	Luggage problems	9,9
16	Bad seat comfort	9,3
17	Needs extra suspension	6,0
18	Assistance should last above 25 km/h	6,0
19	Poor design	4,9
20	I enjoyed the curiosity of the people in the street	4,9
21	Assisted cycling results in laziness	3,8
22	I was really dissatisfied	3,8

1.2.2 Technical problems

More than 50% of the participants had to cope with technical problems. We distinguished between mechanical problems and problems due to the electrical character of the bicycle.

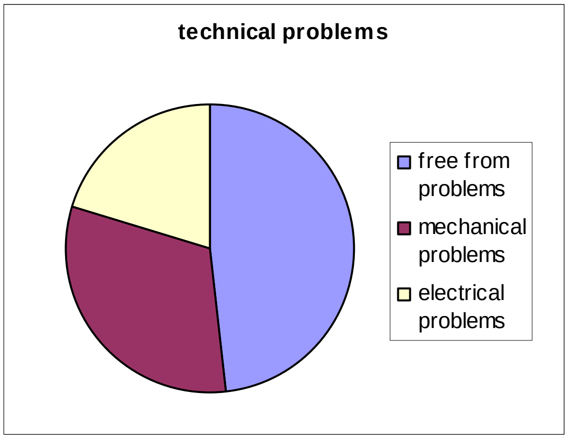

Figure 5: Technical problems

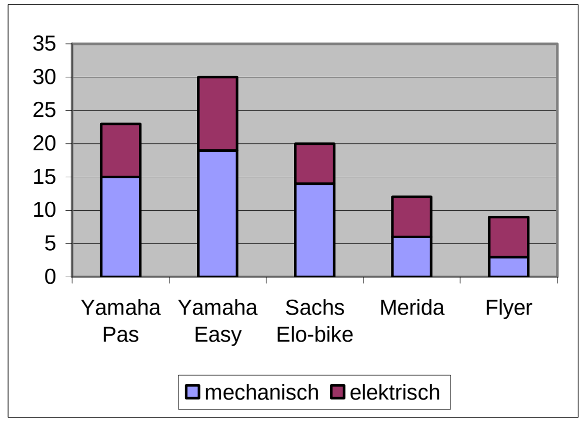

Figure 6: Technical problems versus type

1. *Mechanical problems*
    - flat tyre
    - malfunctioning of the mileometer
    - defective light
    - problems with the gearbox
    - chain problems
    - bad seal attachment
    - problems with pedal brake
    - …

2. *Electrical problems*
    - sudden break down of the motor
    - annoying noise while charging
    - difficulties with charging by cold weather
    - inadequate brakes for the heavy weight
    - interrupted assistance
    - problems for complete charging
    - bad fixation of the battery
    - instability by weight

The percentage of technical problems seems to be high, but the EPACs were lent to a lot of people who were not always taking enough care of them. Off course the opinion about EPACs will be hardly influenced by the number of technical problems people had to cope with. Moreover we asked the users not to repair the bikes themselves, but bring the defective EPAC back to the university to repair. This extra effort also may have caused annoyance.

1.2.3 The weight

In the standard form the participants were rather mild in the condemnation of the weight. It is conspicuous that in their spontaneous comments almost half of them mention that heaviness and flexibility are real problems.

The second remark was mainly given by people who ended up without battery power and had to cycle unassisted. It's a fact that although an EPAC can be used without assistance, the efficiency is lower than that of a common city bike.

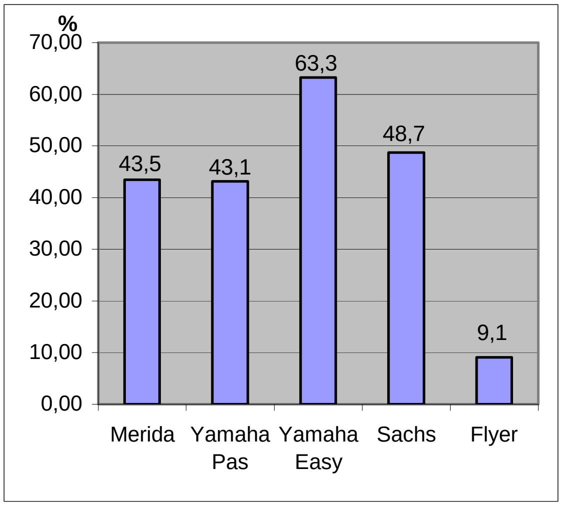

Figure 7: The bicycle is too heavy (46.7%)

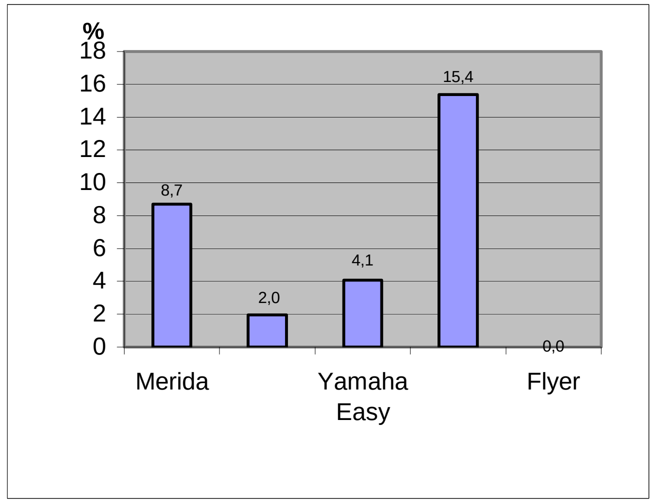

Figure 8: extra suspension is needed (6.9%)

Looking at figure 7, the users of the Yamaha Easy seem to suffer the most of the extra weight (64%). The need for extra suspension is biggest (15%) for users of the Sachs Elo-bike (figure 8).

1.2.4 Other remarks

The table with general remarks (table 5) also shows the importance of a parking place on the ground floor. 19% of the test persons mentioned that they had parking problems because of one or more stairs. The extra effort caused by this, combined with the multiple anti-theft systems make the EPAC less attractive for very short distances. Knowing that their autonomy is also rather small, we can conclude that the electrically assisted bicycle is most interesting for distances between 5 and 15 km.

1.2.5 Correlation of remarks with covered distance

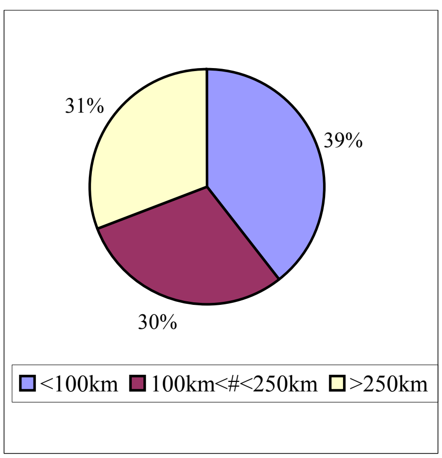

Figure 9: category of covered distance

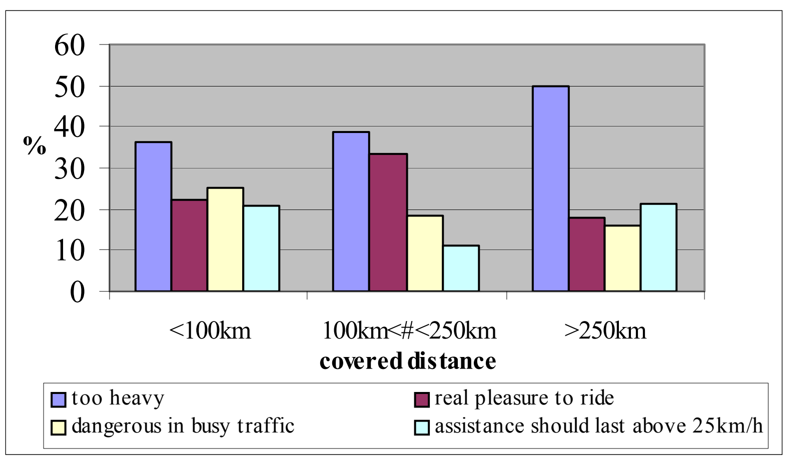

Figure 10: correlation of remarks with covered distance

Dividing the cyclists into three categories (figure 9), we investigated the correlation of the covered distance with the given remarks.
Only the remarks mentioned in figure 9 seemed to correlate with the covered distance.

- The problem of the weight becomes bigger by covered distance. Knowing that people of the third category (>250 km) were used to cycle, they had different expectations of their EPAC. Some of them suggested that they were faster with their light conventional bicycle. However speed seems to be of secondary importance for most constructors: the reduction of the effort has priority.

- Curiously enough, mainly those who cycled least kilometres were complaining the most about the busy traffic.
- It is mainly the middle category that enjoyed riding.

2 Performance analysis of the Flyer

2.1 The test bench

At EVS19 we proposed a paper about the performances of the Sachs elo-bike, the Merida and the Yamaha Easy. To compare the performances of the different EPACs we designed a test bench. Every bicycle is tested in its common operation area: A maximum power of 300 W of the cyclist, a torque between 0 and 115 Nm and a pedal frequency between 0 and 160 rpm.

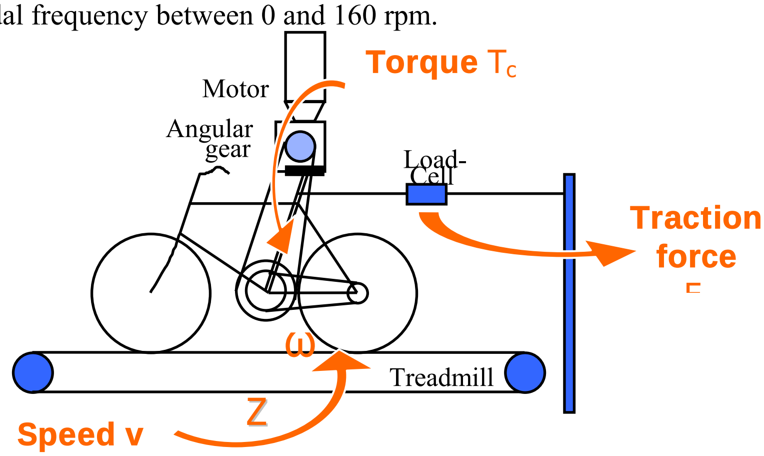

Figure 11

We impose a torque to the pedal axis by means of a torque controlled motor. The speed of the bicycle is determined by a controlled treadmill. As a result of these two inputs we get a traction force on the load-cell that is fixed on the back of the bicycle so that it can't move with respect to the conveyor belt (figure 11). Every combination of imposed speed and torque results in a certain traction force, giving a surface in the speed-torque plane. For every bicycle we recorded two surfaces: the lowest surface is the traction force without assistance, the upper surface represents the traction force with the assistance motor switched on. The middle surface of figure 13 is the traction force using the assistance in the economic mode.

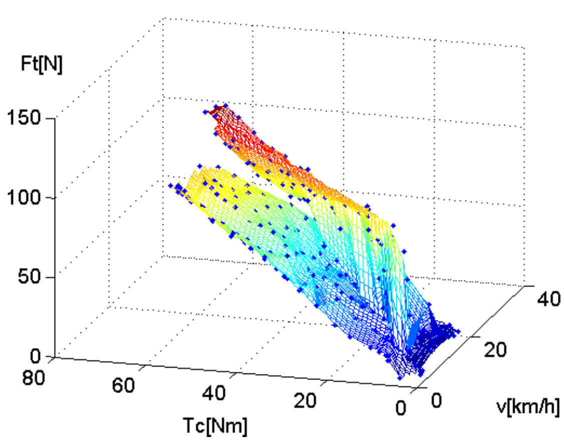

Figure 12:Tracion force of the Flyer

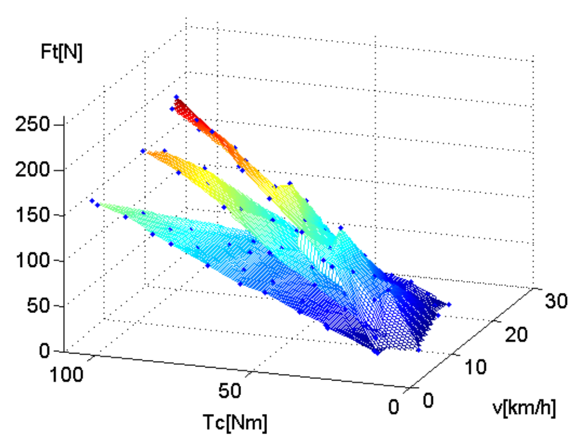

Figure 13:Traction force of the Yamaha Easy

2.2 The assistance factor ξ

An interesting parameter is the part of assistance ξ in the total power output as a function of torque and speed.

$$\xi = f(\omega, T_c) \tag{1.}$$

The assistance factor ξ will be defined as the average power output coming from the assistance motor divided by the average total power output:

$$\xi = \frac{P_{as}}{P_t} = \frac{\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} F_{as}(t).v(t).dt}{\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} F_t(t).v(t).dt} = \frac{\overline{F_{as}}}{\overline{F_t}} = 1 - \frac{\overline{F_c}}{\overline{F_t}} \tag{2.}$$

F_c represents the calculated contribution of the cyclist to the traction force, F_{as} the contribution of the assistance motor. F_t is the total measured traction force.

The last two steps of equation 2 are only allowed when the speed and the torque are kept constant during the time t_2-t_1.

The assistance factor ξ=0 if $\overline{F_c} = \overline{F_t}$, thus if all traction originates from the cyclist, ξ=1 if $\overline{F_c} = 0$, thus if all traction originates from the assistance motor.

2.3 The traction force of the Flyer

Compared to the other tested EPACs (for instance the Yamaha Easy), the assisted surface of the Flyer (figure 12) looks different. Where the surface of the others has a rather flat course, the surface of the Flyer has a steep flank between torques of 18 and 28 Nm. Figure 13 shows slices of the surface for a constant speed of 5 km/h and 13 km/h, assisted as well as non-assisted.

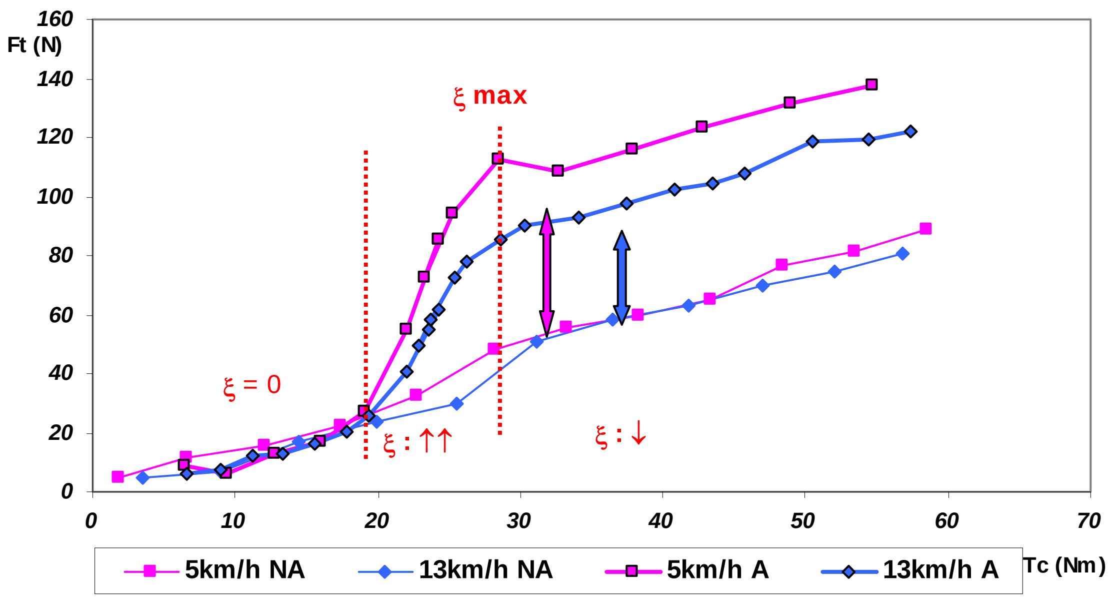

Figure 14: Slices of the Flyer surface

Three areas can be determined.

- Torque between 0 and 18 Nm.
  There's practically no difference in traction force between the assisted and the non-assisted case and ξ≈0. So, when cycling asks few power, the Flyer is not helping anymore, this would only be a waste of energy.
- Torque between 18 and 28 Nm.

In this area the traction force as well as the assistance factor (figure 15) rises from 0 to a maximum (≈0.7). When cycling gets harder (slopes, wind, departure,,…) the Flyer extremely helps to keep or to reach the desired speed. In that way the cyclist is forced to a certain operation point and has to learn (some test persons were explicitly describing this learning process) to shift gear if he wants to change his operation point with a maximum of support of the motor.
Unfortunately, this situation cannot be kept for higher speeds, due to the limited power of motor and limited energy of the battery. That's why the curve for 13 km/h is already lower than the one of 5 km/h.

- Torques bigger than 28 Nm.
  The assistance factor knows a small relapse and then decreases slightly. The gain in traction force is kept constant for the same speed. So if the torque is still increasing, you get a constant assistance of the motor. This assistance decreases with speed.

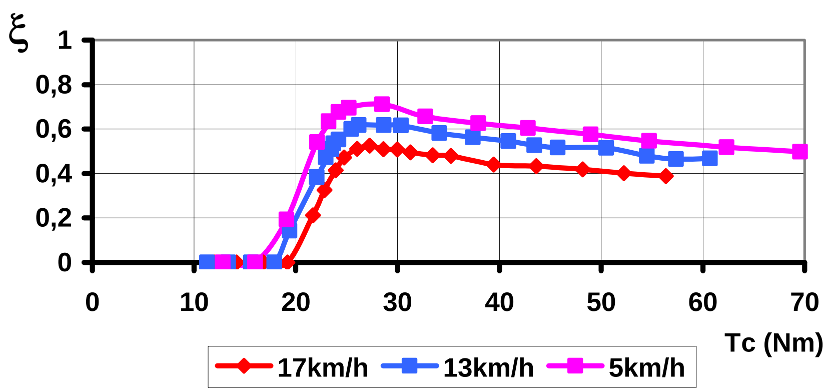

Figure 15: The evolution of the assistance factor for constant speed as a function of the cyclist's torque

These observations show that the control of the motor is based on a torque as well as a frequency measurement. The difference with the other EPACs that have a flat surface for their traction force can be felt well by the user.

3 Conclusion

After two years of organizing test rides with electrically assisted bicycles, we collected a lot of feedback from the users. A standard questionnaire and a log gave us an idea of the appreciation by the users.
We learned that electric bicycles can be used for commuting as well as shopping and leisure. In a lot of cases they can replace the other means of transport in a city.
One third of the respondents even realized a time gain of ten minutes by using the EPAC for commuting.
The participating women cycled more kilometers and they appreciated more the possibilities of the electric bicycle. Especially the lack of autonomy, the high weight, the lack of cycling infrastructure in the city and the rather high price seem to withhold the people of buying an EPAC.
The respondents say that commuters and (middle)aged people are the ideal users for the EPAC.
The most given remarks were about technical problems, autonomy and weight.
Another aspect discussed in this paper is the performance analysis of the Flyer. This EPAC has a rather different behaviour than the earlier (EVS19) discussed bicycles. The assistance factor is changing as a function of the torque. This results in a very comfortable cycling feeling.
Undoubtedly electrically assisted bicycles have a certain future, but there is still some work to do.

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