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TNO report

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Performance of Battery Electric Buses in Practice: Energy Consumption and Range

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Management summary

Battery electric buses are an alternative for fossil fuel powered buses, because they produce no local emissions and almost no noise. (Local) air quality benefits from application of electric buses. Even if the total energy chain is taken into account, electric buses have a significant potential to reduce greenhouse gasses. To underline this, in 2012 the Netherlands Ministry of Infrastructure and the Environment signed a Green Deal [2] with the Stichting 'Zero Emission Busvervoer' with the ambition to completely change the Dutch public transport buses to zero-emission by 2025, with a transition period between 2015 and 2025. If buses are to be replaced by zero-emission versions, it is important to know what the capabilities of those buses are and how they compare to other alternatives.

At this time no method is available to compare performances of electric buses and to determine which bus consumes the least energy per distance or what the range with a full charged battery is. TNO was asked by the Netherlands Ministry of Infrastructure and the Environment to gather practical experience regarding the energy consumption and range of a full-electric 12 m bus. This practical experience serves as input for the discussion how different zero-emission buses could or should be compared, in order to assess the actual applicability in daily practice.

The performed dedicated test program consisted of a combination of existing UITP SORT and UNECE R101 fuel and energy consumption measurement procedures. The test program is not an official UITP SORT procedure, as the revised SORT procedure for hybrid and full-electric buses is not published yet. The obtained experiences lead to the following main conclusions.

1. The used test method carried out on a test track is a feasible and relative simple way to determine the energy consumption and range of a battery electric bus.
2. Each mission profile of a bus in practice is different, and therefore each generalised test procedure is partly representative. However the performance in terms of energy consumption and range could however be compared with other buses tested according to the same procedure.
3. Some influencing factors like temperature, speed profile and cycle length errors caused by the driver could hardly or not be controlled on a test track and thus deviate from official procedures. To get a better understanding of these influences and the effect they have on the results, the test should be repeated in an environment where all parameters can be controlled and manipulated. A better understanding of the influences will lead to recommendations for adjustments of an on-road test procedure.

The performed exploratory research and obtained practical experiences have led to insights that form fertile ground for a follow-up towards a procedure that can be utilized to compare different zero-emission buses.

Contents

1 Introduction

1.1 Background

Pollutant emissions from vehicles such as nitrogen (di)oxides and particulate matter cause air quality problems in urban environments in the Netherlands. Also noise caused by transport influences quality of life in urban areas. Urban buses have significant influence on the emissions and noise of the total fleet in urban areas, as explained in TNO's vision on sustainable buses [1].

Battery electric buses are an alternative for fossil fuel powered buses, because they produce no local emissions and almost no noise. (Local) air quality benefits from application of electric buses and if the total energy chain is taken into account, electric buses have a significant potential to reduce greenhouse gasses. To underline this, in 2012 the Netherlands Ministry of Infrastructure and the Environment signed a Green Deal [2] with the Stichting 'Zero Emission Busvervoer' with the ambition to completely change the Dutch public transport buses to zero-emission by 2025, with a transition period between 2015 and 2025. If buses are to be replaced by zero-emission versions, it is important to know what the capabilities of those buses are and how they compare to other alternatives.

1.2 Aim and approach

New products like battery electric buses are coming to the market. These buses are relatively new in the public transportation sector. Performances only exist on paper and little is known from practical experience. At this time no method is available to compare performances of electric buses and to determine which bus consumes the least energy per distance or what the range with a full charged battery is.

As guidelines for comparison of energy consumption and range of a battery electric bus do not exist, TNO was asked by the Netherlands Ministry of Infrastructure and the Environment to gather practical experience regarding the energy consumption and range of a full-electric 12 m bus. This practical experience serves as input for the discussion how different zero-emission buses could or should be compared, in order to assess the actual applicability in daily practice. The performed test program consisted of a combination of existing fuel and energy consumption measurement procedures, including SORT and UNECE R101.

The development of actual procedures to compare energy consumption and range of different zero-emission buses are outside the scope of this report.

1.3 Structure of the report

In this report the used guidelines and adjustments for testing electrical buses are described in chapter two. The test results are described in chapter three, and analysed and discussed in chapter four. In chapter five conclusions and chapter six recommendations are given.

2 Definition of the test program

Comparing fuel consumption of buses from different manufacturers is common ground for service companies which have to deal with the running costs of a bus. A lower fuel consumption eventually means lower fuel costs –and thus lower running costs-. The ‘fuel’ for an electric bus is however different, and uses its own method to measure. Note that no procedure for testing electric buses exists. In this chapter test procedures for both conventional buses and electric passenger cars will be described, resulting in a combination of both to be able to assess the performance of an electric bus.

2.1 Fuel consumption measurement procedure

One of the anchor points of an internationally accepted test procedure for heavy buses is the SORT procedure [3], introduced by the International Organisation for Public Transport UITP. Since this procedure is cost effective and well known by stakeholders in public transport, the SORT cycles were used as the basis for the tests performed. However, the SORT procedure is designed for conventional buses and not yet specifically for alternative powertrains such as hybrid or electric. This report will discuss the usability of the SORT procedure for the assessment of battery electric buses, based on the practical experiments.

The SORT test procedure prescribes three drive cycles (SORT 1, 2, 3) that specify speed points over distance. Figure 1, Figure 2 and Figure 3 show the speed points of the SORT 1, SORT 2 and SORT 3 cycle respectively. The SORT 1, SORT 2 and SORT 3 cycle describe different mission profiles, which are defined as:

- SORT 1: heavy urban
- SORT 2: easy urban
- SORT 3: easy suburban

The SORT cycles are mainly used on-road and can be set out on a test track using a distance measuring wheel and cones. The procedure, which is meant for outdoor testing prescribes a allowed test temperature window between 0 and 30 degrees Celsius, maximum wind speeds up to average 3 m/s and maximum wind gusts of 8m/s and a dry track.

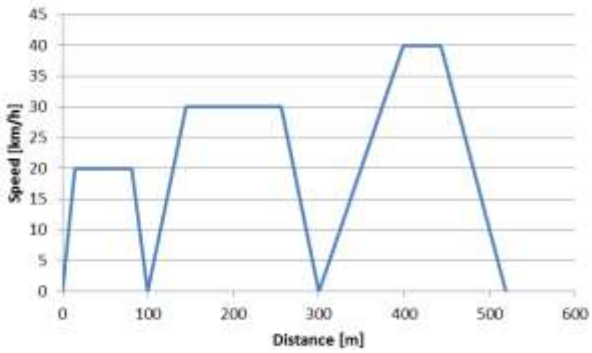

Figure 1: SORT 1 cycle

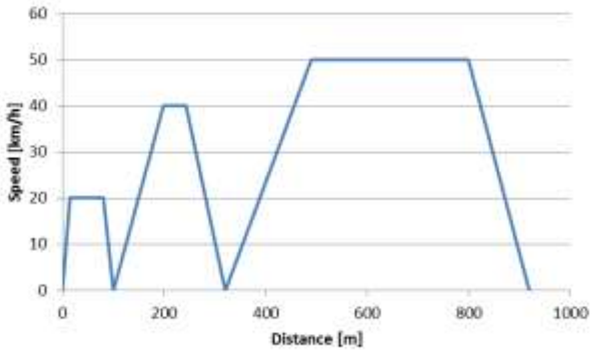

Figure 2: SORT 2 cycle

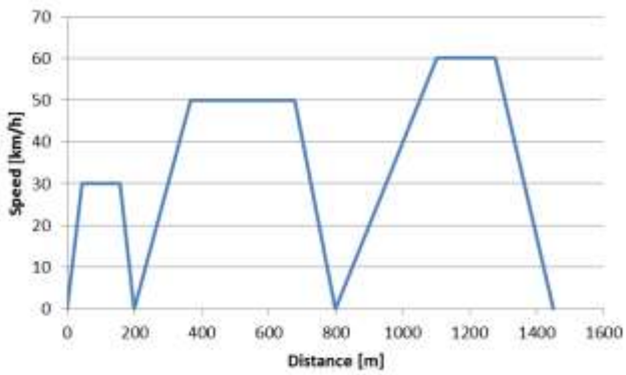

Figure 3: SORT 3 cycle

The bus is loaded with a weight calculated from the formulas of the SORT procedure. In general this calculation comes down to an lump load of approximate 50% of the maximum payload of the bus, by taking the additional optional equipment already present in the bus into account. More details can be found in the procedure [3]. With the bus loaded, the cycles set out on a closed circuit are driven.
At the end of each cycle, one door set is completely opened and closed to simulate operation at a bus stop. Each respective cycle is to be repeated until three fuel consumption measurements lie within an accuracy requirement of 2%.
All auxiliaries of the vehicle like air-conditioning, heating, ventilation, radio and lighting etc. is shut off. Only the dipped headlights are switched on. In the SORT

procedure is mentioned that fuel consumption of systems like air-conditioning and heating could easily be assessed separately.

To get an idea of the specifications of the SORT cycles, their specifications are summed up in Table 1.

Table 1: Overview of specifications of the different SORT cycles, source [3]

	SORT 1	**SORT 2**	**SORT 3**	**Unit**
Rated average speed	12.1	18	25.3	km/h
Stops/km	5.8	3.3	2.1	
Stop time	39.7	33.4	20.1	%
Trapeze 1 v-const. speed/length	20/100	20/100	30/200	km/h / m
Acceleration	1.03	1.03	0.77	m/s2
Trapeze 2 v-const. speed/length	30/200	40/220	50/600	km/h / m
Acceleration	0.77	0.62	0.57	m/s2
Trapeze 3 v-const. speed/length	40/220	50/600	60/650	km/h / m
Acceleration	0.62	0.57	0.46	m/s2
Length of stops	20/20/20	20/20/20	20/10/10	sec
Total length	520	920	1450	m
Deceleration	0.8	0.8	0.8	m/s2

Executing an energy consumption measurement instead of fuel consumption with an electric bus using the SORT procedure, adjustments have to be made to the original procedure. To do so, the regulations for the determination of energy consumption and electric range of light duty vehicles (class M_1 and N_1) is used as a reference.

2.2 Energy consumption and range determination

In Europe a regulation exists for conventional[1], hybrid electric and battery electric vehicles of class M_1 and N_1 (light duty vehicles, please note the tested bus is M_3) regarding the determination of fuel consumption, energy consumption and electric range. The regulation that describes the technical provisions for the tests is known as the UNECE R101 [4].

Energy consumption
The procedure prescribes that a fully charged battery electric vehicle (loaded with 50% payload for N_1 and ‘drive ready’ weight for M_1) should drive the MVEG-B[2] drive cycle (see Figure 4) twice (11 km each and approx. 22 km in total) on a chassis dynamometer in a climatic controlled laboratory. After driving, the vehicle is charged with an energy meter, which is placed between the charge cable and the mains. After the charging process, the energy consumption in Wh/km is calculated from the energy put in, divided by the travelled cycle distance. Difference between the fuel consumption and energy consumption measurement is that fuel consumption can

[1] Vehicles with spark-ignited and compressed ignited engines
[2] MVEG-B drive cycle, also known as NEDC, is also used for the determination of emissions and pollutants for light duty vehicle type approval.

be derived from the exhaust gas emissions or fuel flow real time and the energy consumption could only be derived after charging the vehicle.

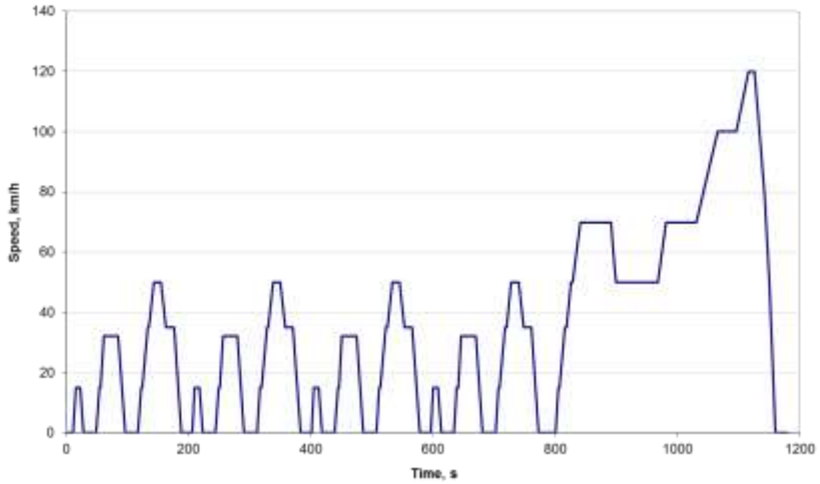

Figure 4: MVEG-B cycle

Range

The same UNECE R101 also describes the procedure for the determination of the range of a light duty electric vehicle. For this test a vehicle is driving repeatedly MVEG-B cycles till the vehicle isn't capable of reaching 50 km/h. The travelled distance after repetition of the drive cycle till the vehicle reached the end of test speed, is the electrical range. This test will become longer to execute when the battery capacity is higher. With an average cycle speed of 33.6 km/h, testing a vehicle with a range of 200 km will take approximate 6 hours to complete without interruptions. When the capacity of battery electric vehicles become larger, a determination of range based on battery capacity and energy consumption will become viable options. This last mentioned method is used to determine the range of conventional vehicles.

2.3 Applied test procedure for the electric bus assessment

Energy consumption and range measurements of an electric bus can be performed, combining the SORT procedure and the UNECE R101. Due to the combination of both methods, the following is taken into account as main deviations on the SORT and UNECE R101 guidelines.

Energy consumption:

- The distance travelled during an energy consumption measurement in the UNECE R101 for light duty vehicles is approximate 22 km. Driving this distance with SORT 1, 2 and 3 this would take 109, 73 and 52 minutes. The tests were scheduled to be performed in one day. Therefore each cycle was driven continuously for half an hour and arriving at the same point the vehicle was started –due to location of the mobile power supply-. This results in driving SORT 1, 2 and 3, 10, 9, and 8 times, resulting in approximate 26, 28, 27 minutes of driving. Due to limited time, only one energy consumption measurement can be conducted instead of the minimum of three, where the results are within a difference of 2% on energy consumption.

- The tests are conducted outside. Therefore preconditioning and testing of the vehicle cannot be performed within the allowed temperature window that is prescribed in the UNECE R101.

Range

- Main purpose of the range test is to define the usable battery capacity rather than defining the range of the bus for a specific cycle. To define the usable capacity, the battery is discharged with a dynamic drive pattern instead of a constant load. For this purpose the SORT cycle with the highest average speed is used (SORT 3 with 25.3 km/h) due to the limitations of the one-day test programme. Note that normally a range test of a bus with a rated range of 200 km would last about 8 hours (SORT 3), 11 hours (SORT 2) and 16,5 hours (SORT 1) without interruptions.
- Range calculations for other cycles (with their own energy consumption characteristics) can be made by dividing the available battery capacity by the cycle specific energy consumption. The end of test criteria in the UNECE R101 range test is when the vehicle isn't capable of reaching 50 km/h. As there is no official SORT range test, and no end of test speed exist, the speed of 30 km/h is chosen. This speed was considered as the lowest speed a bus should be capable of driving in a city.

2.4 Practical limitations

The SORT energy consumption and range test are performed on the RDW TRL concave test track (see also Appendix A: Test track) where continuous cycles can be driven without significant turning and reverse driving manoeuvres. Steering and reversing would cause unnecessary energy consumption when the total length of a straight test track isn't long enough for driving SORT cycles repeatedly. By making this test track choice, the following practical issues occurred and were taken into consideration.

Power supply
Before the start of an energy consumption or range measurement, the vehicle needs to be charged without driving on its own power before the test is started. For this reason a mobile power supply was made available alongside the start point (and thus also end point) of the track.

Energy meter
The used energy meter is classed as a 1.0 meter (1% accuracy on kWh-measurement) instead of the recommended class 0.1 (0.1% accuracy on kWh-measurement) in the UNECE R101. The accuracy is however within the accuracy specifications of 2% of fuel consumption in litres for the SORT procedure. During charging the 3 x 63 Ampere, 400 Volt 'charge mode' was selected instead of the 125 Ampere the bus was capable of. Main reason for this was the current specification of the energy meter (maximum of 63 Ampere).

Curve radius
The SORT procedure proposes to use a straight test track. Curves use energy, which will affect the results. However tracks with large radii, such as long rang shaped tracks, will hardly have a negative effect. The radii of the used test track

curves is 160m and were used as part of the successive SORT cycles that were set out on the track.

Curve gradient
The inner track –one of three- was used for the tests which has a cross-section curve gradient of 5%. Curve gradients decrease the road load of a vehicle which are higher when driving a curve without a cross-section gradient. With speeds in the corner not exceeding 50 km/h and given radius, it is expected that this would hardly have effect on energy consumption.

Length of track
The measured track length –centerline- is 2795,4 meter. Given the lengths of the SORT cycles (1: 520m, 2: 920m, 3: 1450m) this resulted in 'adjusting' the SORT cycles to make a complete round to make the begin point the end point. This was done to avoid setting out multiple sets of cones on the track, introducing a higher chance on driver errors, and to enable having the power supply on one place on the circuit. Given the track length boundaries, the following adjustments were made.

- SORT 1: Five times the complete trajectory was set out. The remaining gap from the last cone till the start point of the first cycle was 195 meter. In this space, an extra speed trajectory of 30 km/h was set out (200 meter in length) and reduced the constant speed length with 5 meter.
  NOTE: After driving 10 times the SORT 1 cycle during the energy consumption measurement, the extra 30 km/h trajectory was only driven once in total.
- SORT 2: Three times the complete trajectory was set out. There was a remaining gap of 35 meter from end till begin. This gap was closed by lengthened the constant speed distance of the last 50 km/h trajectory.
- SORT 3: Two times the complete trajectory was set out. There was an overlap of 105 meters from the end till begin. This overlap is avoided by shortening the last constant speed distance of the 60 km/h trajectory.

Time
Given the available time of a day for setting out the cones on the track, practicing the cycles with the driver and charging, the energy consumption measurement of each SORT cycle is performed once. Although cycle errors and interruptions are not allowed, these events are taken as is. Main goal of the measurements is to gain experience and learn from the irregularities.

2.5 Used vehicle and state

The used vehicle is a 12 m bus with battery electric powertrain and no additional power source. The batteries are charged using regenerative braking while driving and conductive from the grid with a cable while stationary. More details of the tested vehicle are not made public in this report.

All auxiliaries of the vehicle like air-conditioning, heating, ventilation, radio and lighting etc. are shut off. Only the dipped headlights were switched on like recommended in the SORT procedure. The manufacturer of the bus provided drivers and technical experts to ensure the bus was driven and operating properly.

3 Test results

Using the procedure constructed from the available guidelines and regulations, energy consumption measurements (SORT 1, 2, 3) and a range test (SORT 3) were performed on Saturday 24th and Sunday 25th of November 2012 on the RDW TCL test track in Lelystad, the Netherlands. The results of these measurements are depicted in Table 2. Note that the weather conditions, especially on the day the range test was conducted, were severe with wind gusts up to 24 m/s. Detailed weather information can be found in Appendix B: Weather conditions.

Table 2: Overview of the weight and load of the tested bus and the results of the energy consumption and range test.

	SORT 1	**SORT 2**	**SORT 3**	**Unit**
Vehicle specific information				
Empty vehicle weight	Approx. 11,000-13,000			kg
Lump load	Approx. 3,000			kg
Total vehicle weight	Approx. 14,000-16,000			kg
Energy consumption test				
Travelled distance	5395,4	8386,2	11181,6	m
Energy charged after test	6,21	9,57	12,87	kWh
Energy consumption	**1,15**	**1,14**	**1,15**	kWh/km
Range test				
Travelled distance	-	-	**177**	km
Charged energy after test	-	-	210,85	kWh
Energy consumption	-	-	**1,19**	kWh/km
Net operational time	-	-	7,5	hours
Total time of interruptions	-	-	1	hour
Net energy consumption over time	-	-	28	kWh/hour

Statistic figures on how the speed profile was driven by the driver are depicted in Appendix C: Target speed profile results. The speed profiles of the SORT energy consumption tests can be found in Appendix D: Speed profiles. Figure 5 shows the last kilometres of the range test, where the vehicle wasn't able to reach 30 km/h anymore.

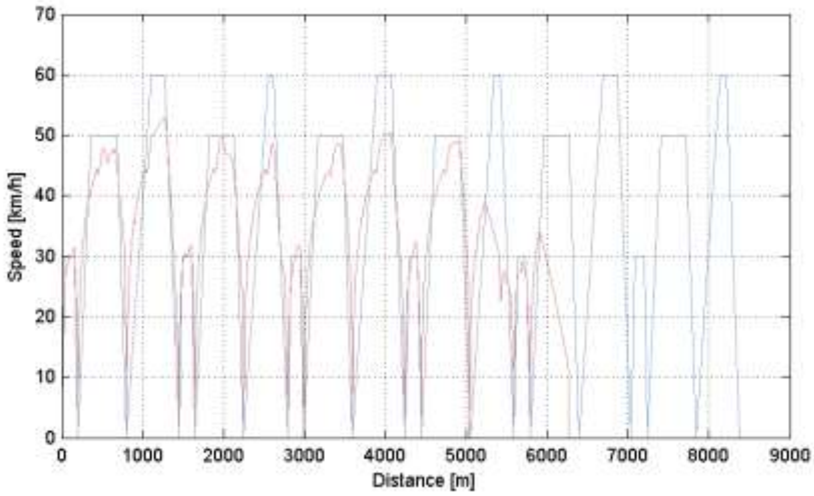

Figure 5: End of range test for the tested electric bus where the red line represents the bus and the blue line the speed target

Further analysis and discussion of the results are made in the chapter 4.

4 Analysis and discussion

The composed test procedure as described in paragraph 2.3 was put into practice. Based on this practical experience, the following factors that have an influence on energy consumption and range are analysed and discussed:

- Driver influence
- Vehicle capabilities
- Ambient conditions
- Track conditions

Following influencing factors are not discussed:

- Drive cycle: covered by the choice of the SORT procedure, open question is how well the SORT results relate to practice
- Energy consumption of auxiliaries: limited covered by SORT, as auxiliaries like heating and air-condition are switched off
- Vehicle mass: covered by SORT
- Battery aging: not covered by SORT, needs to be investigated

4.1 Vehicle and driver performance

1. Energy consumption over the different cycles doesn't differ much, where conventional buses have the highest fuel consumption in SORT 1, less in SORT 2, and the lowest in SORT 3. It is not exactly clear why in the tests the results are close to each other, some possible causes are given:
    a. Due to the behaviour of energy recuperation during braking e.g. more energy recuperation during SORT 1 compare to SORT 3. Or a more general analysis could be that the electric powertrain is more efficient at low speed dynamic cycles compare to higher speed dynamic profiles.
    b. Speed and acceleration/deceleration targets that failed more on specific cycles, and have different effects on SORT 1, 2, and 3 energy consumption. How much these faults could have influenced the results is not investigated.
    c. Speed targets that could not be met in SORT 2 and 3 (50 and 60 km/h) could have a positive effect on SORT 2 and SORT 3 energy consumption. As a result of this, SORT 1 –where a higher energy consumption is expected- has a relative low energy consumption, where much higher was expected.
    d. The cycles were adjusted at the constant speed distances, which were considered to have the least influence on energy consumption value compared to the acceleration (high energy consumption) or deceleration phases (recuperation of energy). The exact effect on energy consumption of shortening or lengthening parts of the cycles was not investigated.
2. The range of the bus (SORT 3 range) could only be used as a reference. Main purpose of testing according to SORT has the purpose of weighting the SORT cycles according to every specific expected mission it will operate in. Given this, the range for other situations, could be calculated based on energy consumption of the SORT cycles, their weighting and the usable battery capacity this range test derived. This test was very time

consuming, more efficient ways of defining the usable battery capacity in practice should be considered.

3. More speed deviations than allowed in the SORT procedure did occur, due to the limited performance of the bus, drivers that had no previous experience with the SORT drive procedure and also the difficulty of concentrating for multiple cycles right after each other. It showed to be very hard to drive the SORT cycles without overruling the boundaries of the SORT speed prescriptions (plus minus 1 km/h and short time of plus minus 3 km/h is allowed during transition from acceleration to constant speed, or from constant speed to deceleration). Based on the tests that have been performed, no conclusions can be drawn with respect to reproducibility because one test result could not provide input for statistical analysis. Statics about the specific speed faults can be found in Appendix C: Target speed profile results.

4.2 Test conditions

1. Weather conditions were to severe (wind speed, and a wet test track) when compared with the prescribed test conditions for the SORT procedure. This procedure allows maximum wind speeds up to average 3 m/s and maximum wind gusts of 8m/s (day one averages 2,9 m/s and maximum wind gusts of 9 m/s , day 2 showed extreme weather conditions with averages of 10,7 m/s (!) and maximum wind gusts of 24 m/s (!)). However the temperature for SORT should be between 0 and 30 degrees Celsius (day 1 on average 4,8 degrees Celsius and day 2 on average 9,8 degrees Celsius) it is well known that low temperatures –like 0 instead of 30 degrees Celsius- has a negative effect on the usable capacity of the battery. Given the temperatures during testing, the results are related to this test temperature.
2. The test track surface and longitudinal gradient is within the SORT boundaries (maximum gradient of 1,5%) but contained a radius of 160m and a cross-section curve gradient of 5% and this could have influenced a slight increase in rolling resistance, but is held to have in minimal increase of energy consumption.
3. Testing the range with buses with high battery capacities is time consuming, and eventually the result that matters is that with different mission profiles (combination of SORT cycles and weighting factors) the range of the bus can be calculated based on the usable battery capacity and the specific energy consumptions of the SORT cycles. The operational time, which come in hand for service companies, can also be calculated based on the usable battery capacity and specific energy consumption.
4. In the test procedures SORT and UNECE R101, the auxiliaries like air-conditioning, heating, ticket equipment etc. is switched-off but consume in practice a lot of energy, and if powered by the battery, cost range. As stated in the SORT procedure, these components could be assessed separately. By knowing the usable battery capacity after the range test, the range reduction can be calculated.

5 Conclusions

A battery electric bus is tested on its range and energy consumption in a test program that consist of a combination of the existing fuel consumption procedure SORT and a light duty vehicle energy consumption and range procedure UNECE R101. Main purpose was to gain experience and discuss a method to test and compare the range and energy consumption performances of battery electric buses. The performed exploratory test programme lead to the following conclusions.

1. The used test program existing of SORT cycles set out on a test track is a feasible and relative simple way to determine the energy consumption and range of a battery electric bus. In practice it was inevitable to make adjustments to the cycle lengths due to the chosen track, allow more speed target errors than prescribed and accept the weather conditions. The results have to be taken in that perspective.
2. It is not exactly clear how much effect the speed deviations, weather conditions, track limitations have on the energy consumption. It is expected that even the allowable boundaries of conditions, mainly temperature, could have a significant influence on the performance, as well as positive as negative, related to the reported results.
3. Each mission profile of a bus in practice is different, and therefore each generalised test procedure is partly representative. However the performance in terms of energy consumption and range could however be compared with other buses tested according to the same procedure. The method could, like it is designed, derive the input (energy consumption of typical heavy urban, easy urban and easy suburban drive pattern) for a mission specific ‘weighted’ energy consumption calculation. The input for ‘weighting’ in this case is always defined by a reproducible test method in which certain influence parameters are defined (temperature, weather conditions, speed profile, allowable faults etc.). Such ‘weighting’ is done by the service companies based on their experience.
4. The charged energy after the range test is considered as more important than the range itself. With this ‘usable’ battery capacity, the practical range (and also operational time) can be calculated based on the before mentioned ‘weighted’ energy consumption.

6 Recommendations

Based on the conclusions, the following recommendations are given to reach answers to the uncertainties of the conclusions of the previous chapter.

1. The used method, a combination of the SORT procedure and UNECE R101 energy measurements, performed outside on a test track, showed that factors like, temperature, speed profile errors, length of cycles, and wind speeds can hardly or not be controlled. To get a better understanding of these influences and the effect they have on the results, the test should be repeated in an environment where all parameters can be controlled and manipulated. The main parameters considered are:
    a. Temperature
    The SORT procedure allows a temperature range between 0 and 30 degrees Celsius. This leads to a main question that should be addressed in a possible follow-up of the work: What is the influence of ambient temperature on the range and energy consumption of a battery electric bus?
    b. Speed profile faults
    Repeating driving cycles introduce the possibility for speed profile errors. This leads to a main questions that should be addressed in a possible follow-up of the work: How many cycles have to be driven, to generate a reproducible energy consumption, what accuracy is necessary? What effect do speed profile errors have on the results? And what error margin can be allowed?
    c. Cycle length deformation
    Cycles were shortened, lengthened and in one case and an extra speed trajectory was added due to the given length of a circular or straight track. This leads to a main questions that should be addressed in a possible follow-up of the work: What effect do cycle adjustments have on the results? How much, and which adjustments should be allowed?

    The questions that remain could be answered in a climatic controlled room, which is equipped with a chassis dynamometer, capable of driving dynamic cycles. A more cost effective option might be a combination of on-road testing with vehicle modelling. When there is a better understanding of the influences, adjustments and recommendations can be made for the test procedure on a test track performed in an outside environment.
2. The range test derived a very static range based only on a SORT 3 cycle (with speed errors and under severe wind conditions), where the most value can be found after charging the empty bus. In the conducted tests a dynamic drive cycle is used to be representative for depleting the battery of an electric bus. Due to the fact that this method is very time consuming, exhausting for the driver and test engineers, the following questions should be answered to consider the usability / applicability of this method:
    a. Are there other faster methods to deplete the battery?
    b. How does the measured ‘usable’ battery capacity of these methods differ from the now used range test?

    These questions could be answered on a chassis dynamometer or battery charge/discharge equipment in a climatic controlled environment.

7 Signature

Delft, 5 February 2013

Willar Vonk
Project leader

Sam van Goethem
Author

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A Test track

Table 3: Specifications of the concave RDW TCL test track in Lelystad –source: http://www.rdw.nl/TCL/en/TCL/testfacilities/concavetrack/Pages/default.aspx

Specifications	**Value**	**Suitable for**
Length of test track	2,850 m. (length of inner lane, centerline, 2795,4m measured by TNO)	71/320/EEC
Length of straight ends	720 m.	75/443/EEC
Width of straight ends	19 m. and 25 m.	93/14/EEC
Curves radius	160 m.	ECE R13/R13H
Curves gradients	5%, 30%,60%	ECE R39
Maximum axle load	15,000 kg	ECE R 78
Friction coefficient	0.6 µ	
Longitudial gradient	0%	

B Weather conditions

Het weer op zaterdag 24 november 2012 te Lelystad					
Temperatuur		**Normaal**	**Neerslag**		
Gemiddelde	4.8 °C	5.1 °C	Hoeveelheid	5.4 mm	
Maximum	8.1 °C	7.5 °C	Duur	5.4 uur	
Minimum	-0.3 °C	2.5 °C			
Zon, bewolking & zicht			**Wind**		
Duur zonneschijn	0.0 uur		Gemiddelde snelheid	2.9 m/s	= 2 Bft
Rel. zonneschijnduur	0 %	20%	Maximale uurgemiddelde snelheid	6.0 m/s	= 4 Bft
Gem. bedekkingsgraad	8 octa's		Maximale stoot	9.0 m/s	
	Geheel bewolkt				
Minimaal zicht	< 0.1 km		Overheersende richting	103 °	O
Relatieve luchtvochtigheid			**Luchtdruk**		
Gemiddelde	98 %	92%	Gemiddelde luchtdruk	1015.7 hPa	

Figure 6: Weather on the first test date, at which the SORT energy consumption tests were conducted – source: http://www.knmi.nl/klimatologie/daggegevens/index.cgi

Het weer op zondag 25 november 2012 te Lelystad					
Temperatuur		**Normaal**	**Neerslag**		
Gemiddelde	9.8 °C	5.1 °C	Hoeveelheid	1.3 mm	
Maximum	12.5 °C	7.5 °C	Duur	1.7 uur	
Minimum	8.0 °C	2.5 °C			
Zon, bewolking & zicht			**Wind**		
Duur zonneschijn	2.4 uur		Gemiddelde snelheid	10.7 m/s	= 5 Bft
Rel. zonneschijnduur	29 %	20%	Maximale uurgemiddelde snelheid	15.0 m/s	= 7 Bft
Gem. bedekkingsgraad	8 octa's		Maximale stoot	24.0 m/s	
	Geheel bewolkt				
Minimaal zicht	3.7 km		Overheersende richting	214 °	ZZW
Relatieve luchtvochtigheid			**Luchtdruk**		
Gemiddelde	80 %	92%	Gemiddelde luchtdruk	1004.2 hPa	

Figure 7: Weather on the second test date, at which the SORT 3 range test was conducted – source: http://www.knmi.nl/klimatologie/daggegevens/index.cgi

C Target speed profile results

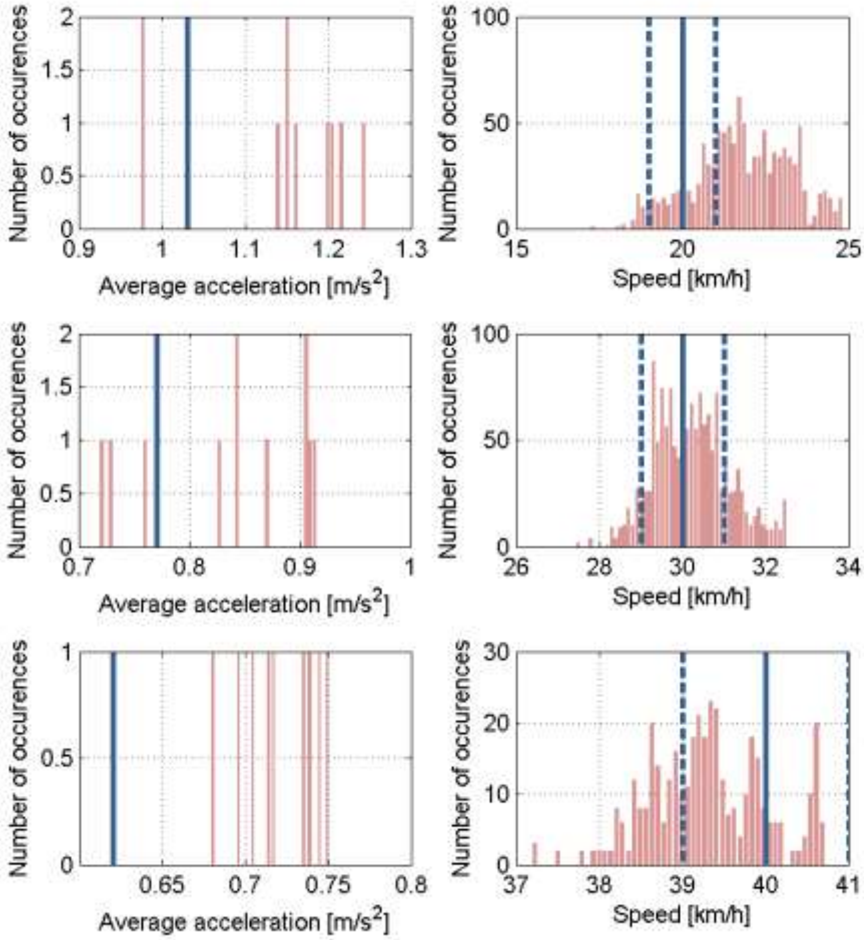

Figure 8: Speed target results of the SORT 1 cycle energy consumption

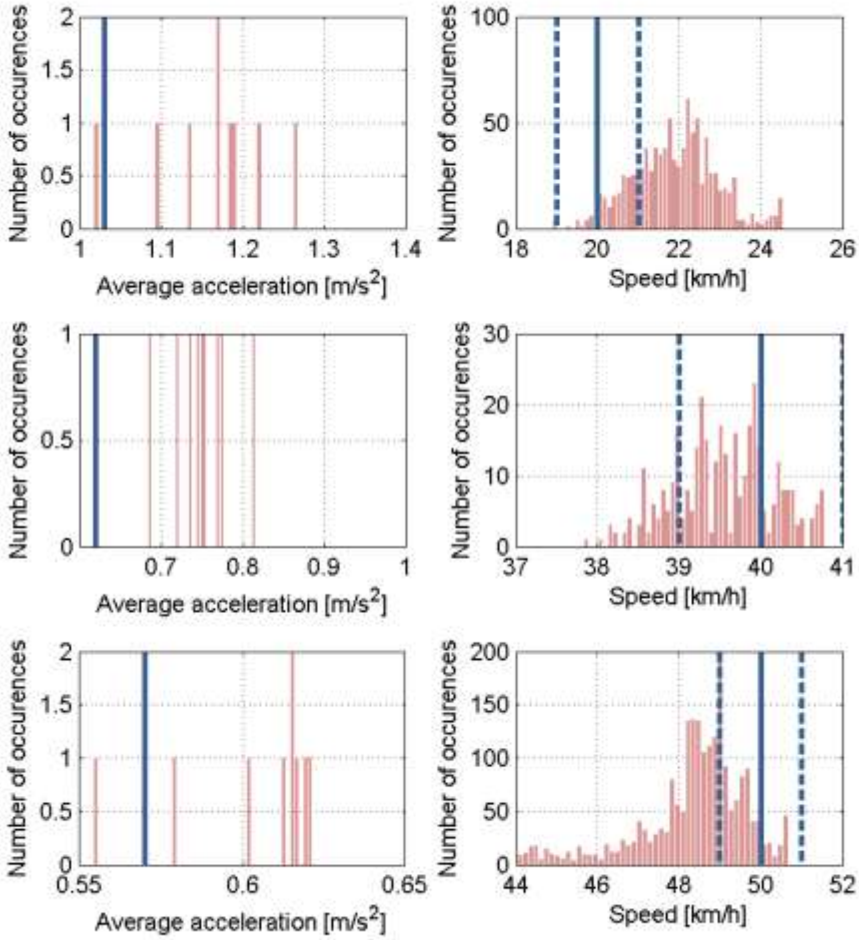

Figure 9: Speed target results of the SORT 2 cycle energy consumption

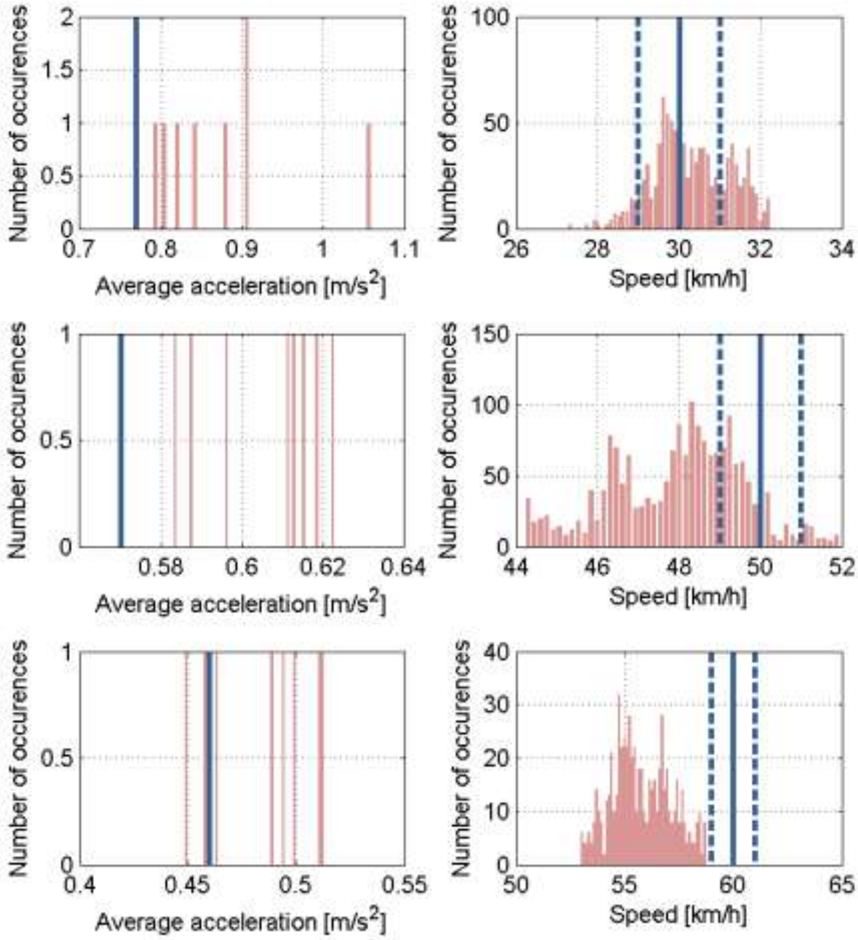

Figure 10: Speed target results of the SORT 3 cycle energy consumption

D Speed profiles

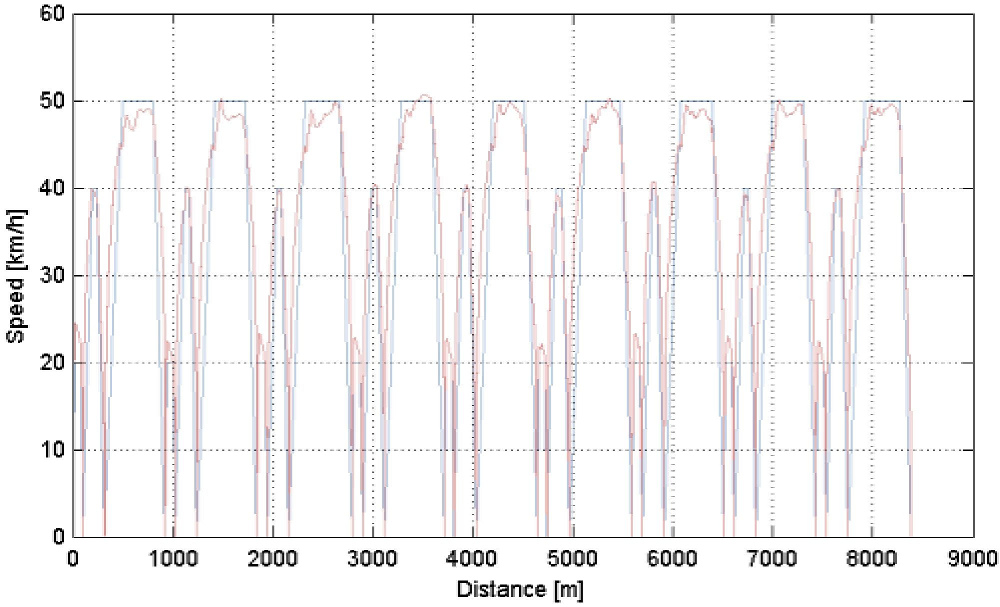

Figure 11: Speed profile of the bus (red) and target speed (blue) for energy consumption measurement of SORT 1

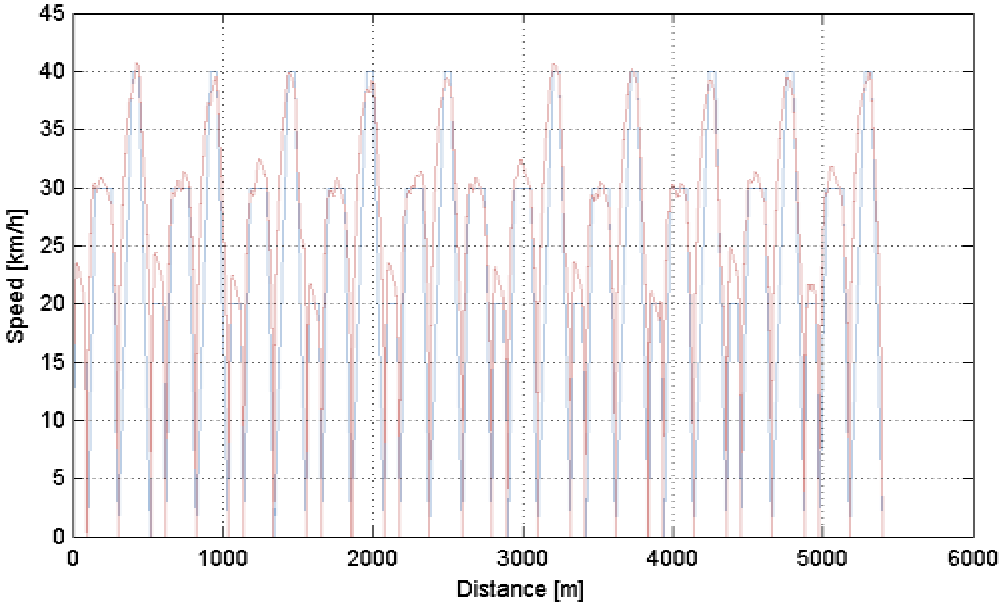

Figure 12: Speed profile of the bus (red) and target speed (blue) for energy consumption measurement of SORT 2

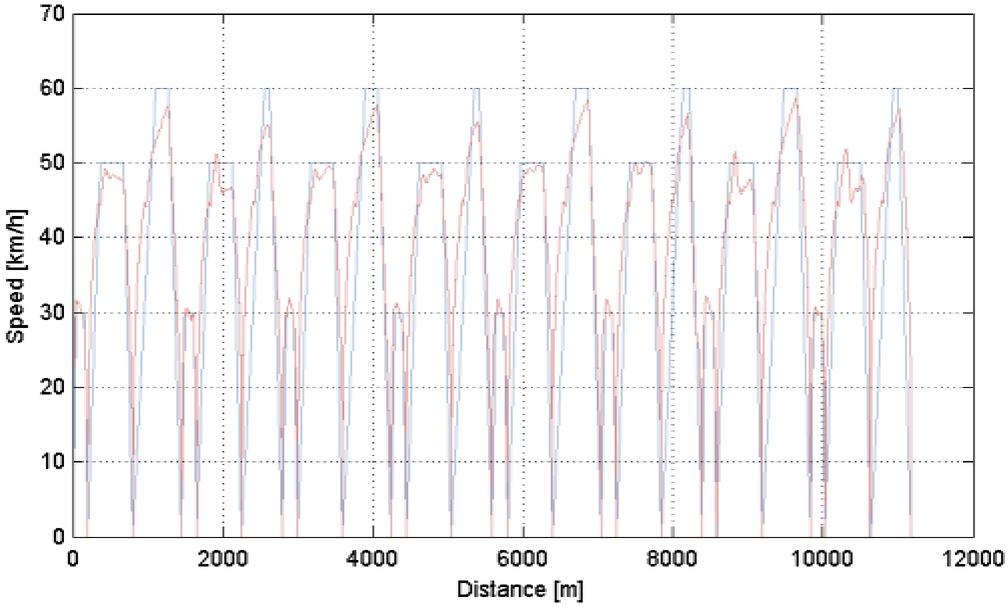

Figure 13: Speed profile of the bus (red) and target speed (blue) for energy consumption measurement of SORT 3