

Written Exam Public Transport With Answers

Written Exam	Public Transport (195421200-1A)
Teacher	van Zuilekom
Course code	195421200
Date and time	5-11-2015, 8:45-11:45
Location	CR 3E
Remarks	Closed book, calculator allowed, English dictionary allowed. Formulas and tables are, when necessary, part of the question.

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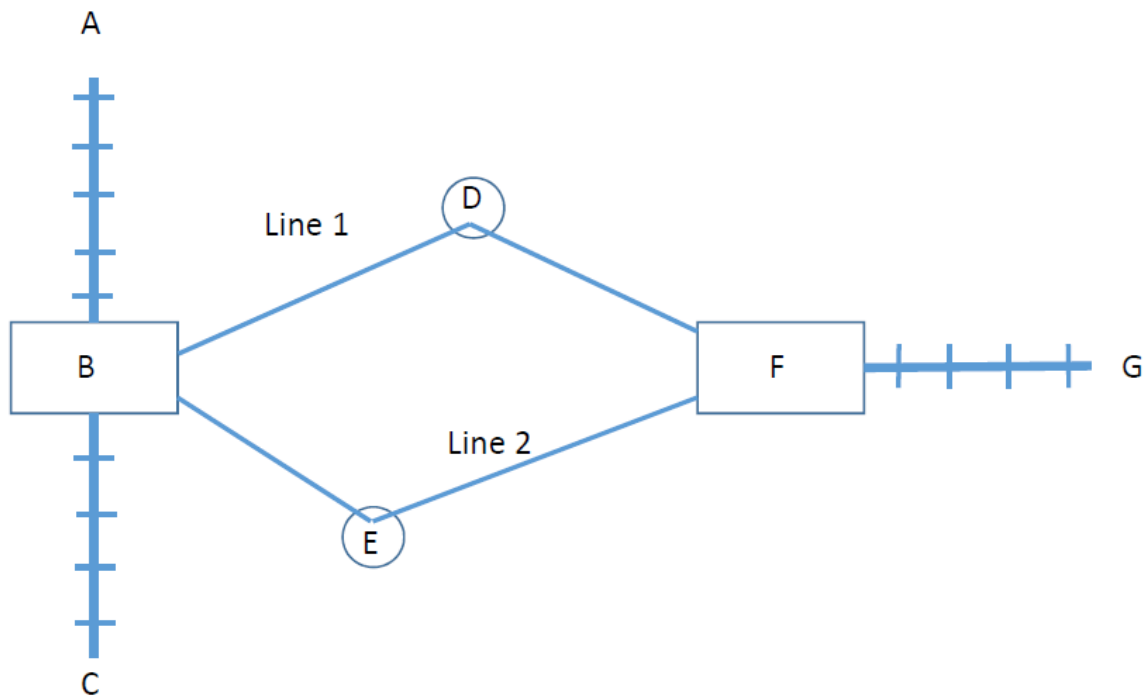
Calculation of the marks:

- The maximum number of points of this written exam, P_{max} , is 90
- The marks for the written exam, C , is calculated by the sum of points, P , times ten divided by the maximum number of points:

$$C = 1 + 9 \cdot \frac{P}{P_{max}}$$

- Available time is 180 minutes (+ 25% for 'extra time students').

Question 1 (25 points) - building a timetable



The image above is the visualization of two train stations (B and F) and two connecting bus lines 1 and 2. D and E are two small villages. A, C and G are regional destinations.

Some facts:

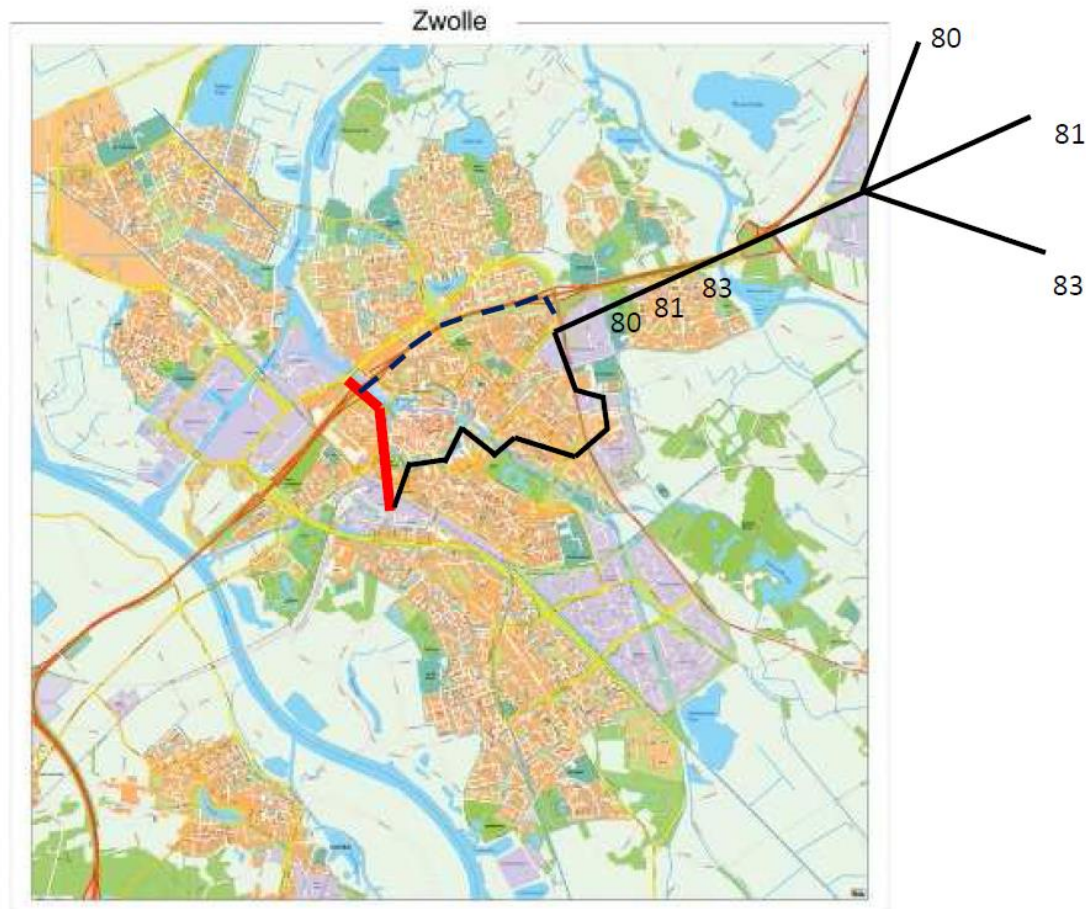
- This is a working day situation
- Trains on station B arrive at .29 and .59 and leave at .05 and .35 (direction A-B-C)
- Trains on station B arrive at .15 and .45 and leave at .20 and .50 (direction C-B-A)
- Trains on station F arrive at .13 and .43 (direction G-F) and leave at .18 and .48 (direction F-G)
- Standard-frequency bus: 2 times an hour
- Trip time line 1: 13 min per trip (the same for both directions)
- Trip time line 2: 16 min per trip (the same for both directions)
- Walking time train-bus: 4 minutes (for both stations)
- Turn-around time bus on the station: 1 minute

	A	B	C	D	E	F	G
A		1000	3000	300	600	1000	200
B			1000	100	200	200	200
C				50	50	400	200
D					50	100	200
E						50	50
F							1000
G							

Number of PT travelers (in both directions)

- a) [8 points] Make an effective connection diagram for this PT-system. Take the number of passengers into account.
- b) [9 points] Make a time-way diagram for line 2 (between 07.00 and 09.00) and make a calculation for the number of busses needed. Make a concept timetable too.
- c) [8 points] Give two suggestions how you can realize a more effective circulation for line 2. Estimation how the cost cover will develop. Be sure that the calculations are traceable. Make assumption if necessary.

Question 2 (20 points) – steps in developing a new network in Zwolle



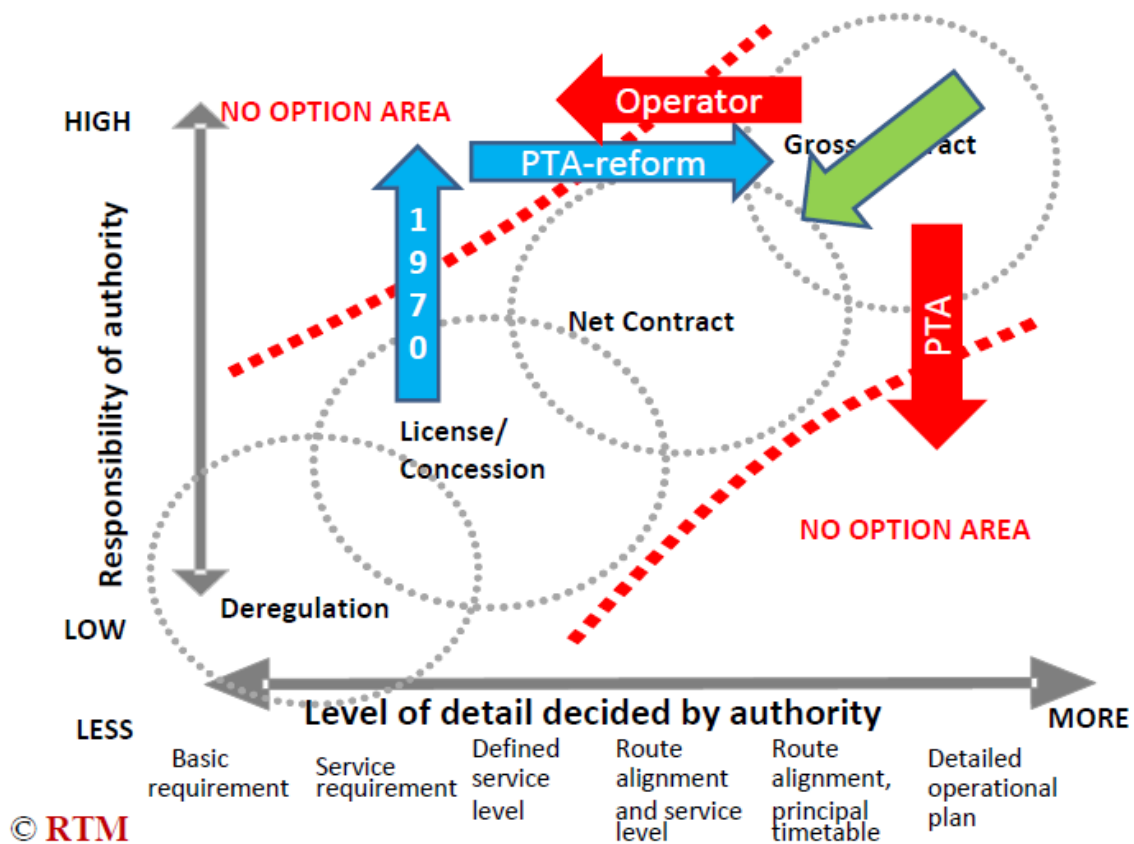
The province of Overijssel and the municipality of Zwolle are very proud on the new dedicated bus infrastructure near the city Centre (in red). Several city lines are using the infrastructure. It provides in a faster bus network and an higher reliability. The province believes that some of the regional bus lines (80, 81 and 83) should also use the new infrastructure. In the current situation these lines have to struggle through the eastern part of Zwolle, with a lot of delays. On the other hand, there are a lot of students and scholars using these lines to get to the educational institutions in this part of Zwolle. Some 50% of the passengers use these connections to get to school.

You – as an external advisor – are asked to do some research in developing a possible new network for these regional connections. The basic question is if the idea of the regional lines using the new infrastructure is a promising idea or not. And if so, what are the conditions to make it work. You need to take costs of exploitation and infrastructure into account and the passenger revenues on the other hand.

- [5 points] Name the general 8 steps in 'building a timetable'**
- [10 points] Make a well structured plan for the research (with steps to be taken) you want to do in order to answer the central question. The province and the municipality will provide the necessary data.**
- [5 points] Describe what you think the outcome of the research will be and why. You are also asked to do some out-of-the box suggestions.**

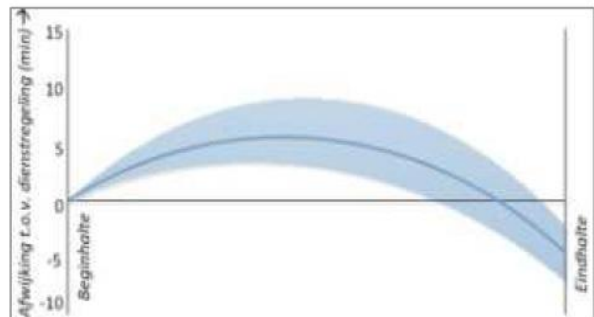
Question 3 (10 points) – long distance busses

Contract models and roles



- [4 points] The image above is the so-called 'Swedish model'. In recent years the number of long distance busses is growing in Europe. Where would you place these kind of connections in the model above. Give good arguments.
- [4 points] Apparently there's a good market for long distance busses in several European countries. Give at least 5 reasons why the market is good.
- [2 points] Describe why exploiting these kind of connections in the Dutch situation could be a problem and for whom.

Question 4 (10 points) – data



Both images show the average delay of busses (vertical) on several busstops and for one direction (horizontal). The image on the left is labelled as the 'ideal situation'.

- [6 points] Explain from the perspective of PT company why the image on the right is realistic and logical.
- [4 points] Explain why there will be a shift in the next years towards the 'ideal situation'.

Question 5 (15 points) – Energy efficient speed adaption

A train needs to lower the speed from v_0 to v_1 . There are two basic strategies to do so:

1. The coasting strategy: stop propulsion till the desired speed of v_1 is reached. During coasting the deceleration is a_{coast} .
2. The default strategy: brake with the regular comfortable deceleration of $a_{default}$ till the desired speed of v_1 is reached.

Both strategies are feasible as:

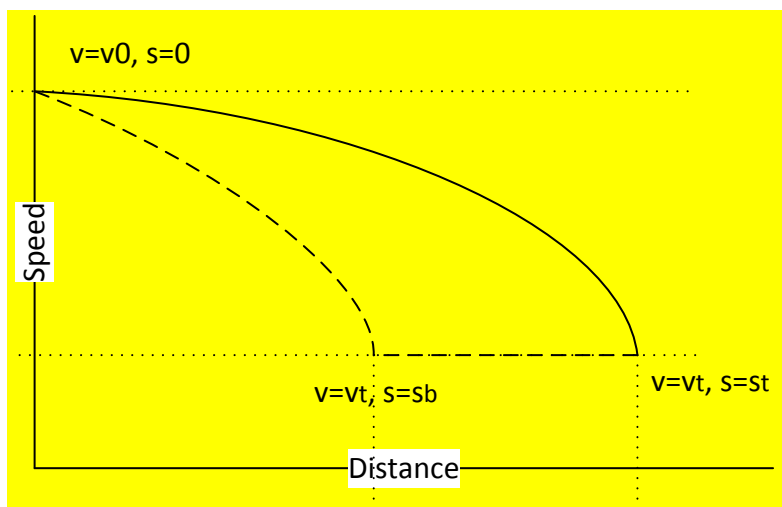
- there safe (no speed regulation is violated)
- the next destination is reached in time.

The train is capable to recuperate the brake energy without an efficiency of τ .

a) [15 points] If it comes to energy consumption: Is there a best strategy if there are no recuperation losses ($\tau = 1$)? Give proof.

The energy basics $F = m \cdot a$ $W = F \cdot s$ $P = \frac{W}{t} = F \cdot \frac{s}{t} = F \cdot v$ $P = 2 \cdot \pi \cdot M \cdot \frac{n}{60}$ $E_k = \frac{1}{2} \cdot m \cdot v^2$ $E_p = m \cdot g \cdot h$	Equation of motion $v_t = v_0 + a \cdot t$ $S_t = S_0 + v_0 \cdot t + \frac{1}{2} \cdot a \cdot t^2 = S_0 + \frac{v_t^2 - v_0^2}{2 \cdot a}$
With $m[kg]$ $s[m]$ $v[m/s]$ $a[m/s^2]$ $F[N]$ $W, E_k, E_p[Ws, J]$ $P[W]$ $M[Nm]$ $n[1/min]$	

Picture:



Formulas	Example
τ_R = efficiency of recuperation τ_P = efficiency of propulsion (extension to question)	$V_0=11, V_1=1, a_c=-0.1, a_b=-0.5, m=1, \tau_R=1, \tau_P=1$
Scenario 1: Coasting $\Delta E_k = \Delta W$ $\frac{1}{2} \cdot m \cdot (v_t^2 - v_0^2) = m \cdot a_c \cdot s_c$ $\frac{1}{2} \cdot m \cdot (v_t^2 - v_0^2) = m \cdot a_c \cdot \frac{(v_t^2 - v_0^2)}{2a_c}$ $\frac{1}{2} \cdot m \cdot (v_t^2 - v_0^2) = \frac{1}{2} \cdot m \cdot (v_t^2 - v_0^2)$ Conclusion the kinetic energy is transformed to movement without loss. This means that scenario 2 can't be better than scenario 1. $S_t = \frac{v_t^2 - v_0^2}{2 \cdot a_c}$	$\Delta E_k = \frac{1}{2} \cdot 1 \cdot (1^2 - 11^2)$ $\Delta E_k = (1 - 121) / 2 = 60$ Distance for speed adaptation: $S_t = \frac{1^2 - 11^2}{2 \cdot -0.1} = \frac{-120}{-0.2} = 600$
Scenario 2: Braking First stage: from v_0 to v_t $\Delta E_k = \Delta W$ as for scenario 1 $s_b = \frac{v_t^2 - v_0^2}{2 \cdot a_b}$ Recuperation of braking energy, W_R , when neglecting that recuperation only is possible on top of a_c : $W_R = \frac{1}{2} \cdot m \cdot (v_t^2 - v_0^2) \cdot \tau_R = m \cdot a_b \cdot s_b \cdot \tau$ Second stage from S_b to S_t :	Scenario 2: Braking First stage: from v_0 to v_t Distance for speed adaptation: $S_b = \frac{1^2 - 11^2}{2 \cdot -0.5} = \frac{-120}{-1.0} = 120$ Recuperation of braking energy, W_R , when neglecting that recuperation only is possible on top of a_c : $W_R = \frac{1}{2} \cdot 1 \cdot (1^2 - 11^2) \cdot 1.0 = (1 - 121) / 2 = 60$ Second stage from S_b to S_t :

Labor, W_p, needed for a constant speed of v_t over $(s_t - s_b)$: $W_p = m \cdot a_c \cdot (s_t - s_b) / \tau_p$ Recuperation of braking energy, W_R, without neglecting recuperation only is possible on top of a_c : $W_R = m \cdot (a_b - a_c) \cdot s_b \cdot \tau_R$ Conservation of energy: $W_R \leq W_p$	Labor, W_p, needed for a constant speed of v_t over $(s_t - s_b)$: $W_p = 0.1 \cdot (600 - 120) = 48$ As $W_p < W_R$ we have gained energy by recuperation (better than a perpetual mobile?). This can't be true. Recuperation of braking energy, W_R, without neglecting recuperation only is possible on top of a_c : $W_R = 1 \cdot (0.5 - 0.1) \cdot 120 \cdot 1 = 48$ $W_R \leq W_p$
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Conclusion: only in an ideal situation, $\tau_R = 1$, both strategies are equal. In reality the coasting strategy is always superior as it comes to energy consumption.

If we include the efficiency of the propulsion, τ_p , the difference between the two scenarios increases even more as τ_p is around 0.8 for electric propulsion (excluding well-to-energy plant losses) and around 0.2 to 0.3 for ICE. But this was no part of the question.

Marking: less formal proof is considered good too. Desired elements:

- Definition of the situation which has to be compared. A drawing helps.
- Full transformation of Ek to propulsion when coasting $\rightarrow$ scenario 2 can't be better.
- Recognition of the two stages 1 for strategy 2.
- Recognition that recuperation takes place on top of cruising
- Recognition of the labour over stage 2

Question 6 (5 points) – Advancing from efficiency to sustainability in Swedish medium-sized cities

In the article 'Advancing from efficiency to sustainability in Swedish medium-sized cities: an approach for recommending powertrains and energy carriers for public bus transport systems.' by Lisiana Nurhadi et al. the authors compare several bus configurations. The current economic potential is estimated using the total cost of ownership (see the figure below).

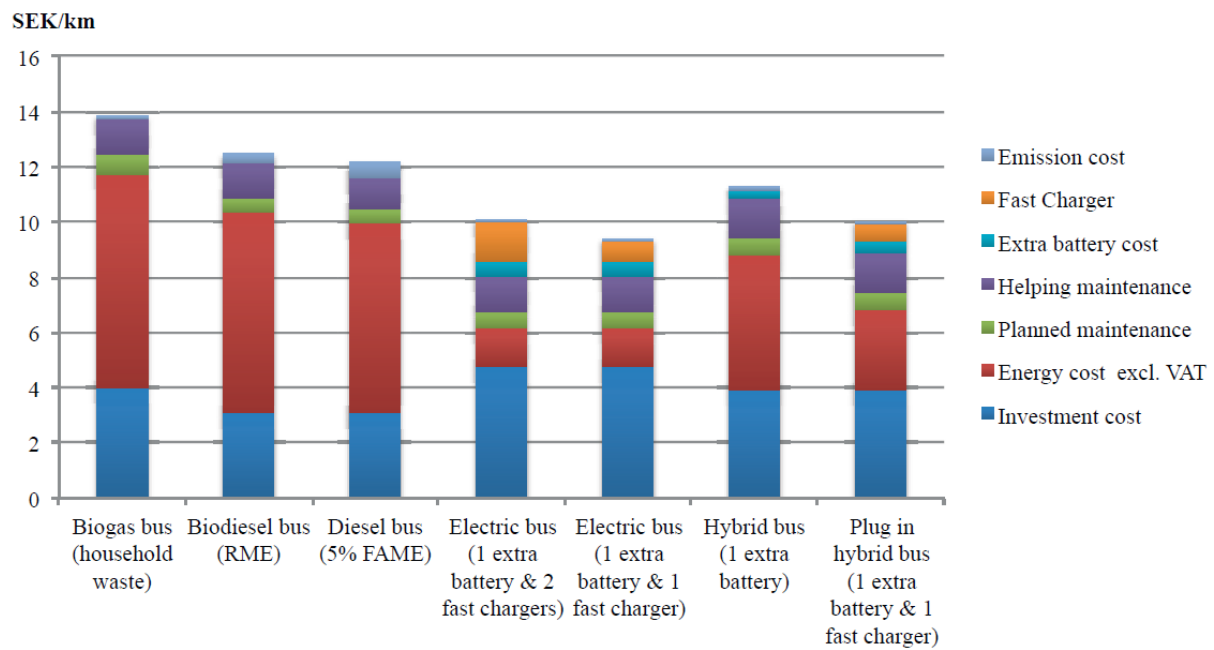


Fig. 4. Total Cost of Ownership (SEK/km) 2013-2020

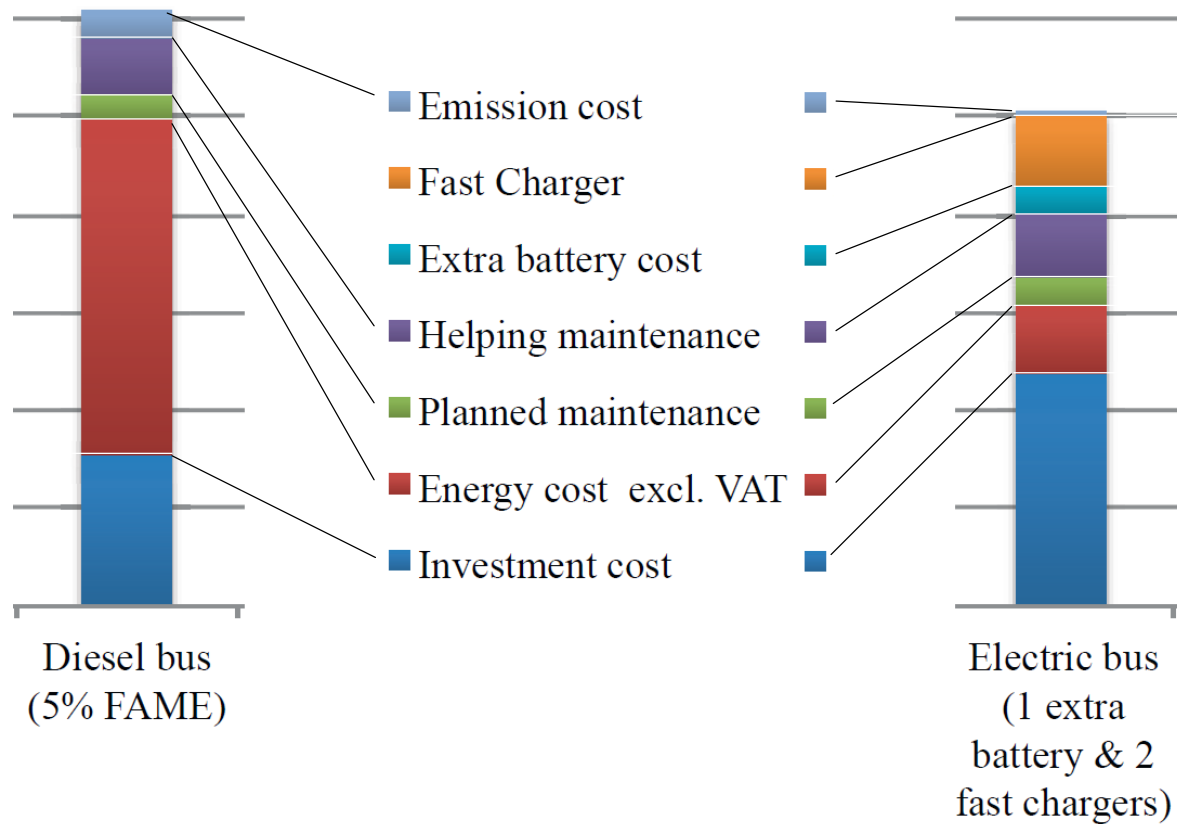
According to this figure the Total Cost of Ownership of an electric bus is considerable lower than a conventional bus. Still we see in many current Public Transport concessions the Diesel bus as the favoured bus. At the same time full electric busses are rare up till now.

- a) [5 points] What explains this discrepancy between this forecasted Total Cost of Ownership (which would make a high market share of full electric busses likely) and the actual fleet of full electric busses (which shows a low market share)? Please focus on the Diesel bus and the Electric bus (1 extra battery & 2 fast chargers). In order to avoid misinterpretation of this figure you find the re-arranged details of this figure on the next page.

Typical for electric vehicles are: (1) small variable costs due to low energy price of electricity and (2) high investment costs. In the article a yearly growth of the energy price is assumed of 6% while during the last years the energy prices have shrunk. This makes electric busses less attractive which leads to lower production volumes. This delays the economy of scale which is essential for lowering the investment costs.

Other supporting arguments could be true too. For example: the government doesn't provide the long term commitment.

Re-arranged details of Figure 4, Total Cost of Ownership (SEK/km) 2013-2020



Explanation of the acronyms in Figure 4:

FAME = Fatty Acid Methyl Ester. In common spoken language Diesel with 5% FAME means Diesel fuel with 5% of bio-Diesel.

RME = Rapeseed Methyl Ester. In common spoken language 100% bio-Diesel.

VAT = Value Added Tax

SEK = Swedish Kronor

Note: the aspects 'Fast Charger' and 'Extra battery costs' do not apply to a Diesel Bus

Question 7 (15 points) – A systems approach to reduce urban rail energy consumption

In the article 'A systems approach to reduce urban rail energy consumption' by A. González-Gil et al. a typical traction energy flow in urban rail systems is given (see the figure 3 of this article below).

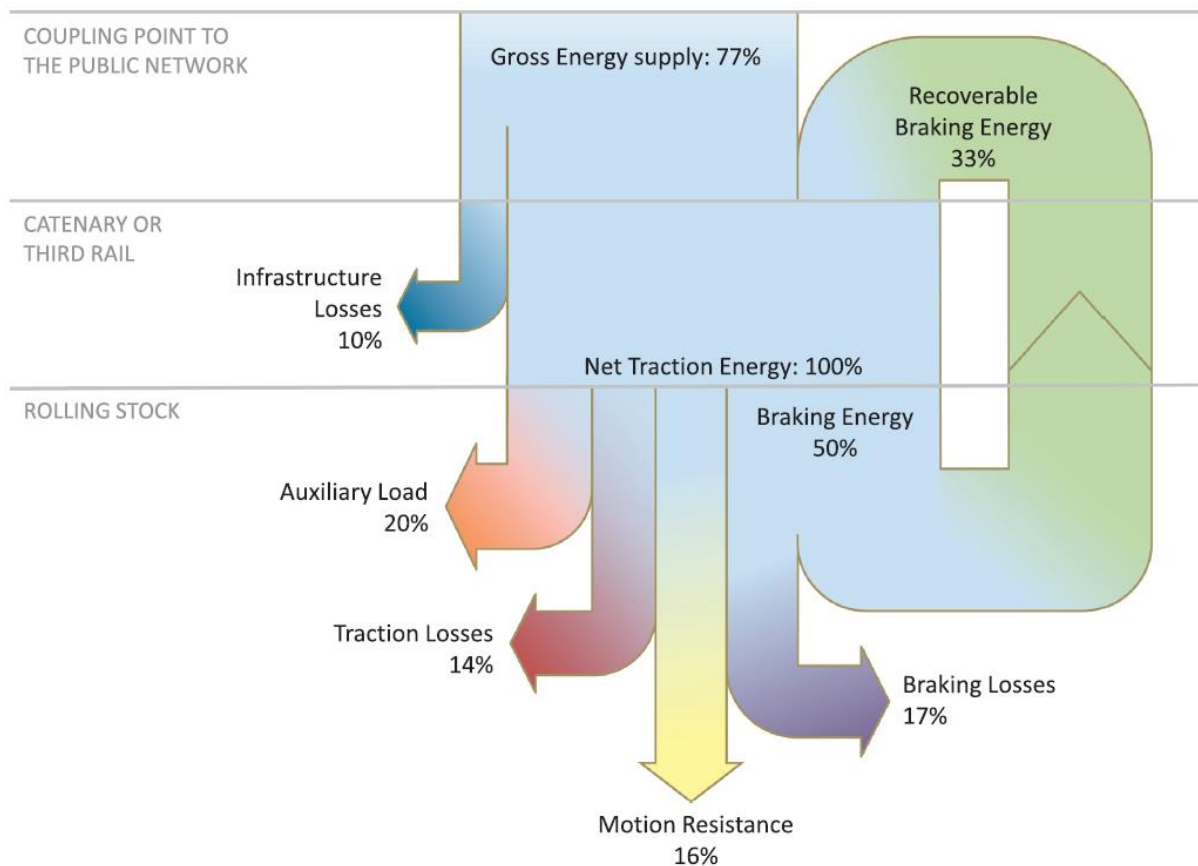


Fig. 3. Typical traction energy flow in urban rail systems.

- [3 points] What is meant with 'Infrastructure losses'?
- [2 points] What is the purpose of the 'Auxiliary Load'?

Infrastructure losses: "infrastructure losses refer to the electric losses occurring from the point of common coupling to the pantograph (or collector shoes); that is, the electric losses in the substations and the distribution network, the latter being significantly higher. Infrastructure losses principally depend on the voltage level of the rail system and its traffic load, being more important for lowvoltage networks with heavy traffic. Additionally, in "coupled through" systems, where several electric sections of the line are connected to favour the regenerative energy transfer between vehicles, the electric losses are also higher. Typical values for infrastructure energy losses can be as high as 22%, 18%, 10% and 6% for 600 V, 750 V, 1500 V and 3000 V-DC networks, respectively."

Auxiliary Load: all energy consumption which is not directly related to propulsion. In general these are safety and comfort related.

The authors (A. González-Gil et al.) give a literature overview of the energy measures for urban rail. The 21 main actions which are distinguished are classified according to two scopes:

- Whole system, Infrastructure & Rolling stock
- Operation & Technology

Apart from these scopes five Clusters of Technology & Operational Measures are identified: (1) Regenerative Braking, (2) Energy-Efficient Driving, (3) Traction Efficiency, (4) Comfort Functions and (5) Measurement & Management.

In the table below you find some, but not all, of the energy measures classified in these scopes and clusters. Note that the classification in the scope Operation & Technology is not strict. Some measures are a mix of Operation and Technology (for instance 5, 6 & 7).

The 21 measures in the table are in alphabetic order.

#		Clusters					Scope			Scope	
		Regenerative braking	Energy-Efficient Driving	Traction Efficiency	Comfort Functions	Measures & Management	Whole System	Infra Structure	Rolling Stock	Operation	Technology
1	ATO		X						X		X
2	DAS		X						X		X
3	Eco-driving Techniques										
4	Energy Metering					X	X				X
5	Lighting & HVAC in Parked Mode				X				X	X	X
6	Lighting & HVAC in Service				X				X	X	X
7	Lighting & HVAC in Stations				X			X		X	X
8	Low-Energy Tunnel Cooling				X			X			X
9	Mass Reduction										
10	On-Board ESS	X							X		X
11	Optimised Traction Software			X					X	X	
12	Optimised Traffic Management		X				X			X	X
13	Passenger Movement in Stations				X			X		X	X
14	PMSM										
15	Reduced Power Supply Losses			X				X		X	X
16	Renewable Energy Generation					X	X				X
17	Reversible Substations	X						X			X
18	Smart Energy Management					X	X			X	X
19	Thermal Insulation				X				X		X
20	Timetable Optimisation	X					X			X	
21	Wayside ESS	X						X			X

c) [5 points] Classify the energy measures 3, 9 and 14.

d) [5 points] What are the advantages of Wayside ESS above On-Board ESS?

Explanation of the acronyms in the table:

HVAC = Heating, Ventilation and Air-Conditioning

ESS = Energy Storage System

ATO = Automatic Train Operation

PMSM = Permanent Magnet Synchronous Motor

DAS = Driving Advice Systems

#		Clusters						Scope				Scope	
		Regenerative braking	Energy-Efficient Driving	Traction Efficiency	Comfort Functions	Measures & Management		Whole System	Infra Structure	Rolling Stock		Operation	Technology
3	<i>Eco-driving Techniques</i>		X							X		X	
9	<i>Mass Reduction</i>			X						X			X
14	<i>PMSM</i>			X						X			X

Marking

9 (=3*3) elements in this answer. Marking table:

# correct elements	Points
9	5
8	4
7	3
6	2
5 and 4	1
else	0

Dominant advantages of Wayside ESS:

- Avoiding of extra vehicle weight and thus avoiding extra energy use

- *Avoiding large investment costs in refurbishing existing vehicles. With relative limited investment existing vehicles can be made suited for Wayside ESS.*
- *Share of recuperated energy over all vehicles in the section*
- *Stationary ESS is relative cheap.*