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D5.2.6 The potential of buses and trolleys

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1 Introduction

Various countries around the world have been developing public transportation in the recent years by giving subsidies and other support to encourage the use and development of environmentally friendly vehicles. These cover among others vehicle technologies such as trolley buses, light rail transit (LRT), trams, as well as electric vehicles that allow a clear reduction in the vehicle energy use when compared with conventional internal combustion engine-based vehicles.

This report goes into the potential of using novel technologies based on electrification. The aim is to cover reasonable future alternatives for public transportation. The report focuses on the capital city area in Finland. Particularly, attention is paid on the Vantaa city public transportation systems. The report describes some on-going trends and development projects as well as defines a few main characteristics of the Vantaa city area traffic.

2 Trolley buses on negotiating table

The city of Helsinki showed recently openness toward trolley buses. According to a Finnish newspaper Helsingin Sanomat (4/2011), the city was planning to arrange nine trolley bus lines to substitute for normal diesel buses. The cost savings spoke for themselves as set against a comparable tramline. The line infrastructure for the Helsinki trolley bus system would have incurred expenses of around 33 million Euros, whereas a comparable tramline network would have cost 300 – 600 million Euros. The total system cost – including the vehicles, line infrastructure and depots – for the planned trolley bus system was estimated to circle around 90 million Euros. Trolley buses would have covered two main South-to-North traffic lanes. Also one transverse line was planned to service between Munkkiniemi and Viikki (line #57). See Figure 1 below for the outlined trolley bus network. [1]

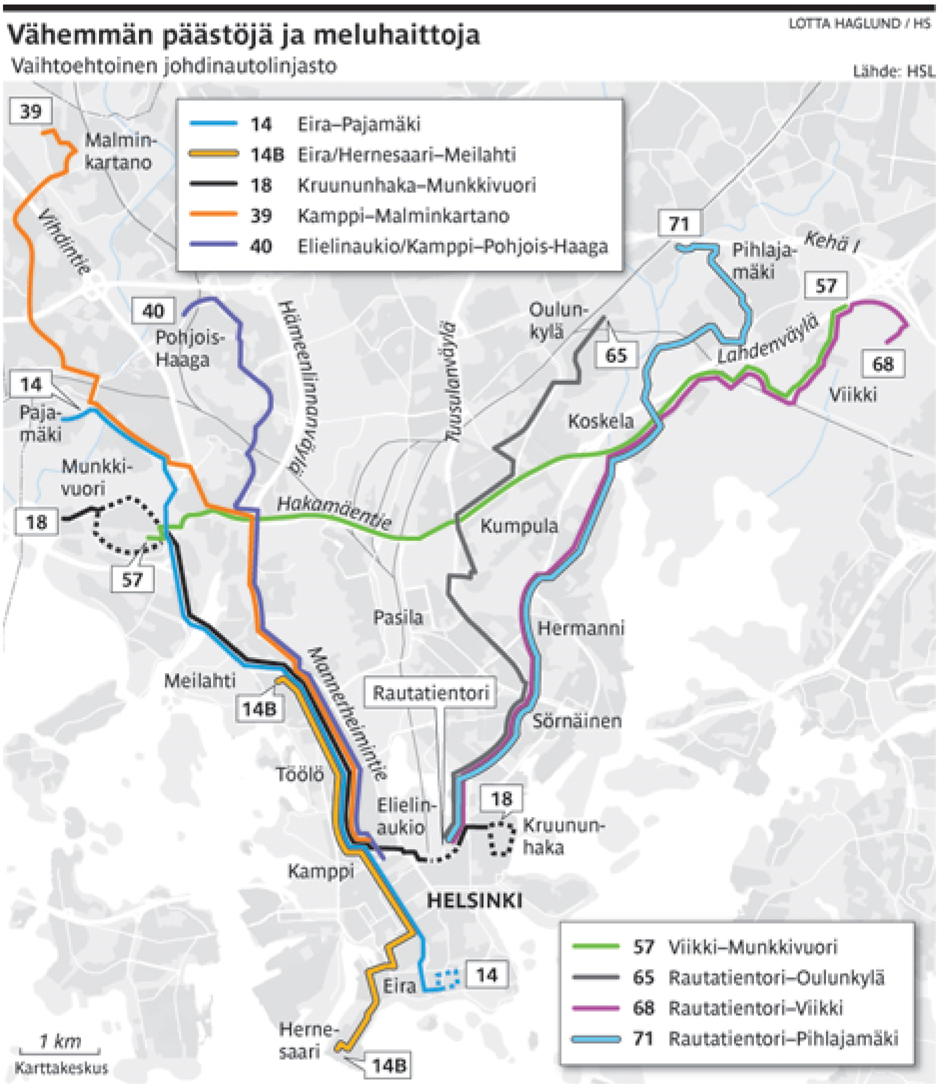

Figure 1: Trolley bus lines to Helsinki [1]

However, the city planning board of Helsinki announced 16th August 2011 that it is not favorable for the city to continue the planning of trolley bus lines at present state. Reasons were named to be the uncertainty of other technologies' development in the next 10 – 20 years and the long repayment period of 30 years for trolley bus infrastructure. Hybrid technologies were considered a possibly good competitor for trolley buses in the near future though at present they are not seen as competitive enough because of high procurement costs. The development of technologies based on vehicle electrification was regarded as quick. The city planning board suggested that instead of acquiring new vehicle fleets, in the current situation, extra resources would be used for developing the existing public transportation network. [2]

In comparison to conventional buses, trolley buses and other electric buses offer several benefits. The main contributors are the reduction of emissions as well as the improvement in vehicle efficiencies. One of the advantages speaking for trolley bus use is their passenger capacity. Trolley buses carry clearly more passengers than conventional 12-meter buses. However, trams hold even greater capacity which will straight affect the commuter traffic behavior. When comparing trams and trolley buses, one also has to understand the differences in the infrastructure. Both options involve building overhead line network for electrical operation but trolley bus networks often are more complicated in curves. The electrical wire for trams is allowed to make steep curves, whereas the curves in trolley bus overhead line network should remain smooth [3]. This is due to the essence of the differing attachment mechanisms. The main question does not pertain to money but to the visual inconvenience related to complicated, visible overhead lines.

Helsinki provides almost three times as many internal bus connections as Vantaa [4]. Helsinki, therefore, has a scale advantage which reverberates to the system costs. Whether a trolley bus system would be a competitive alternative for Vantaa city should be considered separately. Some estimations show trolley bus systems remain only a little more expensive (i.e., ~10%) than average bus systems when also the operating life and energy use of the vehicles are taken into account [5].

Nevertheless, also smaller cities can implement trolley buses successfully. Landskrona in Sweden provides a great example. The city has established one trolley bus line from the new railway station outside the city to the city center [6]. Trolley buses have reduced the use of energy per kilometer driven by public transportation vehicles in Landskrona.

3 Other possible technologies for public transportation

Helsinki Region Transport (HRT) aims for reductions in various emissions in public transportation – particles, NO_X, etc. Especially, the amount of emitted carbon dioxide has become more important choosing parameter for transportation vehicles. Objectives for emission reductions have led to serious consideration of novel vehicle technologies based on electrification.

Public transportation is mostly situated on roads and rails. Road vehicles consist of small service vehicles, minibuses, buses, trolley buses etc. Vehicles functioning on rails can be roughly divided into the next categories: train, rapid transit (as of now: metro), light rail transit and trams. Some of these already use electricity as their main traction power source, whereas electrification in buses and other road vehicles is just beginning to get more popular in large scale.

In addition to sustainability and environmental matters there are also various other issues to be taken into account when establishing an efficient transportation system. Required routing, travelling distance, travelling speed, maximum time gap between departures as well as vehicle seating capacity among others assess the characteristics for needed vehicle types. A subtle transportation system combines various transportation methods skillfully.

Electric propulsion systems – as in trolley buses, battery-electric vehicles and fuel cell vehicles – have the advantage of carrying an electric motor that can be utilized efficiently to energy recuperation during the braking phase. Storing of recuperated energy, of course, requires batteries. Not only because of this, may battery technologies have significant potential in bus electrification. Actually, some implementations of battery-driven buses have been already introduced. One of the countries to highly promote batteries and vehicle electrification is China. In Finland, the company referred to as European Batteries has started to manufacture Lithium-ion batteries.

At present, batteries in combination with AC motors hardly offer an all-around competitor for internal combustion engines. Often used lithium-ion batteries provide energy densities of 140 Wh/kg with a cyclical life-time of 2,000 – 3,000 cycles at 80 percent depth of discharge [7] [8]. The price of a battery kilowatt-hour remains relatively high circling around 1,000 €/kWh [9]. Nevertheless, batteries already offer a great technology for range extending and hybrid vehicles utilizing several power sources for propulsion.

Electricity is more often used for rail transportation. Most of the Finnish trains utilize electric energy actively for propulsion. In Finland, all the rail transportation excluding trams and metro (Helsinki City Transport) is offered by state railway company VR Group. Commuter trains are operated in close relationship with HRT that is responsible for ticketing etc. There are several types of rail transportation varying in size, speed and capacity. Most of the rail transportation in Finland is implemented by trains but cities could also utilize lighter rail transportation solutions, such as LRT. Light rail transit offers greater passenger capacity and vehicle speed than trams or buses. LRT operates on same vehicle speeds that metro does. The advantage of LRT is small turning radius (i.e., traffic crossings) compared to cars of a metro. Additionally, LRT is more accessible than a metro as it is not fully separated from other traffic. In LRT systems as with trains, buses are used for connecting departures from the LRT station.

Comparison of rail transportation solutions and road vehicles is complex and should be done from many points of view (e.g., transportation needs and development, societal effects). One clear comparison that can be done considers vehicle energy consumption. Table 1 presents common energy consumption figures of the Finnish rail transportation system and road transportation. Regeneration of braking energy is mentioned separately when taken into account.

Table 1: Road and rail transportation energy consumption estimates (tank-to-wheel) [6] [9] [10] [11] [12] [13] [14] [15]

Vehicle type	**Vehicle energy consumption (kWh/km)**	**Vehicle energy consumption per passenger (kWh/km/passenger)**
Road transportation		
Conventional bus (diesel)	4.0-5.1	0.39
Fuel cell bus	4.3**	0.36**
Trolley bus	2.5; 1.8*	0.20; 0.15*
Battery-electric bus	1.2*[a]	0.10*
Rail transportation		
Light rail transit (Calgary Transit: SD 160NG)	3.5	-
Railcar, regional train (diesel)	6.33	0.29
Tram	3.0	0.20
Metro	3.0 (incl. heating of switches)	0.10
Pendolino, electric train	12.5	0.10
Sm4, electric commuter train	5.9	0.09
Intercity, electric train	11.0	0.06

* regeneration of braking energy; ** several vehicle types (regeneration and no regeneration);
[a] The author suspects this value not being realistic. The value seems to be too low when compared with the consumption figures of trolley buses.
NB: For buses an average passenger count of 12 persons assumed.

In general, rail transportation currently offers better energy efficiency than road transportation. From competitive road transportation alternatives trolley buses compete well with the rail modes in energy consumption and economy. Estimation for energy consumption per passenger-kilometer for trolley buses is 0.20 kWh. The lowest consumption 0.06 kWh/km/passenger is offered by Intercity-electric trains.

Road and rail transportation are basically used for different purposes. Specifically, rail transportation is not only designed to service people but also goods transportation. The modifiability of rail network (e.g., tram network) is very weak. Trolley bus network can be modified with less effort yet weakly. For trolley buses, there is no need to do massive infrastructure on the ground level. Line network hanging above the vehicle is enough to feed electric energy to the vehicle. Versatile use of differing service routes can be made possible by use of independent vehicles not supported by external power sources during drive – e.g., diesel buses, fuel cell buses, as well as battery-electric buses.

While battery-electric vehicles have been mostly tested as single prototypes, fuel cell buses (FCBs) have already been introduced to public transportation in small fleets. Several projects around the world have showed the potential of these vehicles. FCBs use fuel cells to turn chemical energy into electric energy for traction power. In Table 1 FCB energy consumption estimates are converted from the outcomes of three different US Department of Energy project evaluation sites in 2005 – 2006. [9] [13]

When considering the energy efficiencies of different vehicle modes, there are also other influencing factors than the vehicle itself. For rail transportation with densely situated underground stations (e.g., metro), a lot of energy is used for heating and ventilation. Also the operation of bus terminals and train stations is energy consuming. Extra costs and environmental aspects should be taken into account when designing a functional transportation system. [15]

4 Traffic characteristics in Vantaa

Vantaa city public transportation is operated by HRT that coordinates the public transportation in the Helsinki city region including several nearby municipalities (www.hsl.fi). Vantaa city public transportation consists of regional and internal traffic. In internal traffic, there are 34 bus lines. For better understanding of the scale of the public transportation, Helsinki has 96 internal bus lines in comparison. Vantaa's regional buses consist of five daytime buses and one bus operating in the night-time [4].

At present there are some major building projects working around the ring rail line that will connect Vantaankoski in the west to Tikkurila in the east of Vantaa. The ring rail line will necessitate changes in the bus network too. Existing bus depots in Tuupakka and Hakunila will be relocated and their capacity will be increased. New locations involve Myllykylä in the west and Koivukylä in the east. Both will offer placements for around 200 buses. [3]

Figure 2 illustrates the main traffic lines – bus and rail traffic prospective – in Vantaa master plan. The ring rail line can be seen as a red line connecting the east and west through the airport. Future locations for bus depots are marked with orange circles. For transversal traffic Vantaa city has planned a possibility of establishing a light rail transit line that would have a depot located near to the red circle marked in the Figure 2. Presumably though this connection will be arranged using bus traffic. Furthermore, goods transportation traffic will have a rest area more north to its current location (see dark red circle in Figure 2).

See Figure 3 for more explanation on Figure 2.

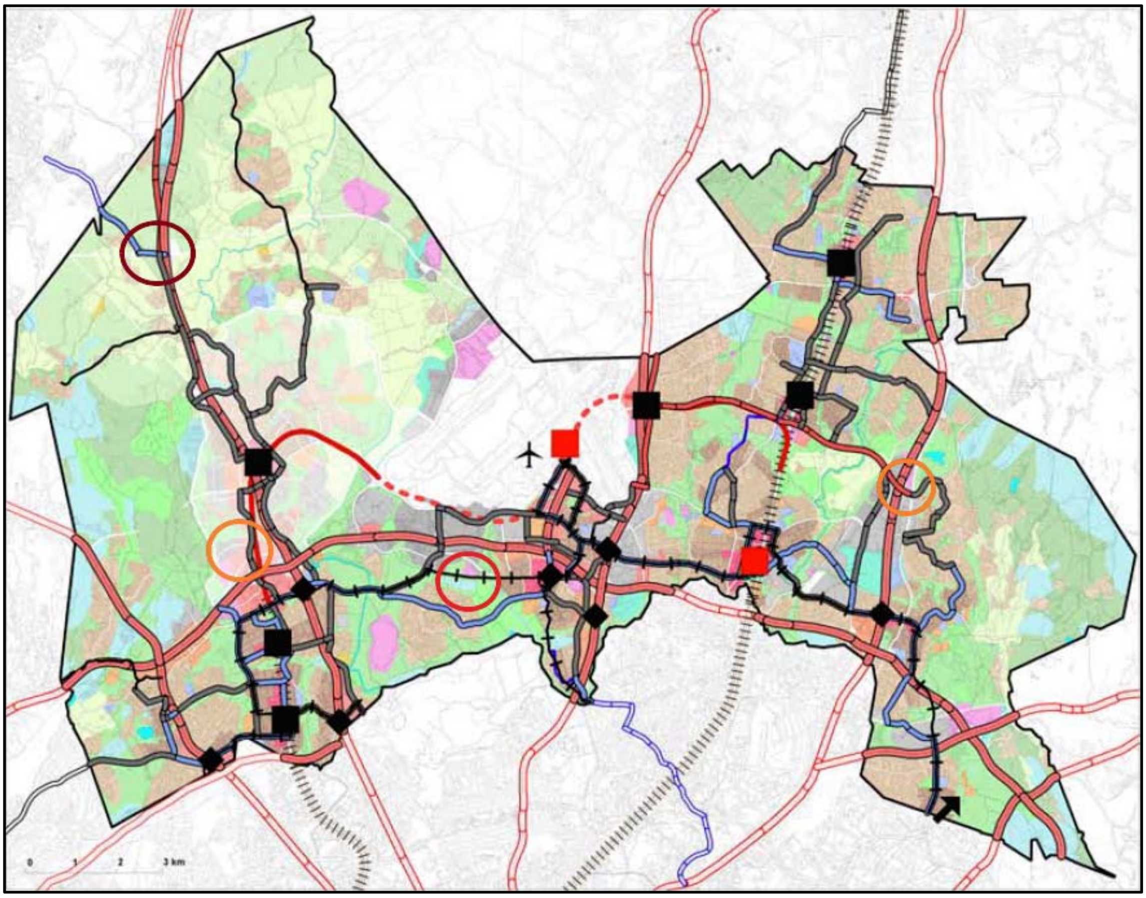

Figure 2: Main traffic lines in Vantaa master plan 2007 [3] [16]

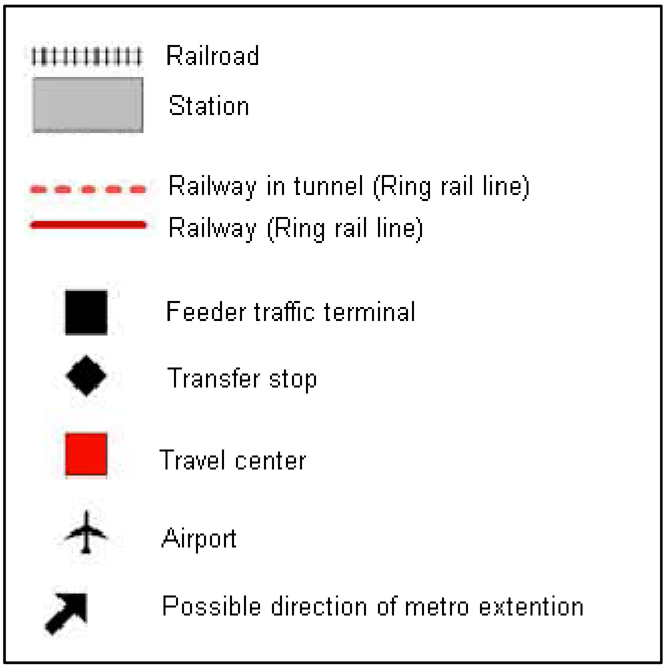

Figure 3: Additional declaration of Figure 2 [16]

Route Network Plan for Vantaa 2008 – 2013 [17] gives a view of the development of Vantaa internal and regional bus services. According to the plan, the total amount of bus-driven kilometers in internal transportation will increase, whereas the mileage of regional transportation will reduce. The net effect will be a decrease in mileages. On the contrary, the amount of single departures will increase servicing people more efficiently. For 2013 the estimated mileage of internal bus transportation is said to be 9,929,000 kilometers. Corresponding figure for regional transportation is 7,677,000 kilometers. In 2013 there will be 111 vehicles in traffic for internal transportation and 85 vehicles for regional transportation.

The energy use of transportation vehicles greatly depend on the vehicle type. Trolley buses consume on average 2.5 kWh per kilometer whereas a conventional city diesel bus reaches a consumption of 4.0 – 5.1 kWh per driven kilometer depending on the amount of passengers [9] [10] (see Table 1). Pure battery-electric buses could reach even lower values but are an unrealistic alternative to efficiently service public transportation at present. Assume that all the departures would be driven by conventional diesel buses. If all the diesel buses were replaced by trolley buses, the maximum potential of reducing energy consumption without energy recuperation regarding the yearly driven kilometers in Vantaa internal bus transportation comes close to 25 GWh and equals around 220 MWh/vehicle/year. See Table 2 for breakdown of bus transportation energy consumption estimates. This scenario is just an example to give a view of the amounts of energy involved. In reality, not all conventional bus lines can be reasonably replaced by trolley bus lines.

Table 2: Energy consumption estimates for Vantaa bus transportation [9] [17]

Year	**Internal transportation**		**Regional transportation**		**Energy consumption estimate, GWh; (internal transportation)**	
	kilometers/year	buses	kilometers/year	buses	diesel buses (5.0 kWh/km)	trolley buses (2.5 kWh/km)
2007	8,427,000	106	9,922,000	119	42.1	21.1
2009	8,380,000	108	9,755,000	119	41.9	21.0
2011	9,826,000	124	8,540,000	100	49.1	24.6
2013	9,929,000	111	7,677,000	85	49.6	24.8

On larger scale yearly savings of 25 GWh form a notable amount of energy. Shifting from the diesel bus use to trolley buses would of course set the demand of diesel to zero but show as an increase in electric power demand. The amount of diesel equal to 49.6 kWh of energy (see Table 2) is 4.9 million liters [18]. Thus, this is the amount of diesel saved per year (2013).

Moreover, assuming that 70 percent of the bus departures are driven within 12 hours of a day (see Appendices: Figure 5 and Figure 6), the continuous power requirement of the intense bus operation time would be around 4 MW. Martinlaakso power plant produced 1041 GWh of electric energy in Vantaa in 2010 [19]. Divided to the whole year, an average electric power production would equal a little less than 120 MW. Comparing the electric power requirement of trolley buses and 2010 electric power production, trolley buses would increase the electric power production need with circa 3.4 percent (%) during 12 hours of a weekday. Energy-wise trolley buses would increase the energy demand with approximately 2.4 percent (%) when regarding the energy consumption of trolley buses and Martinlaakso power plant yearly production.

To give a view of other vehicles' energy consumption, Figure 3 illustrates the theoretical yearly energy consumption figures for various vehicle types for the past couple of and coming years according to the Vantaa internal bus transportation assumptions. Energy consumption rates for different vehicles are taken from Table 1. Remember that these graphs assume the full usage of given vehicle types at each calculation.

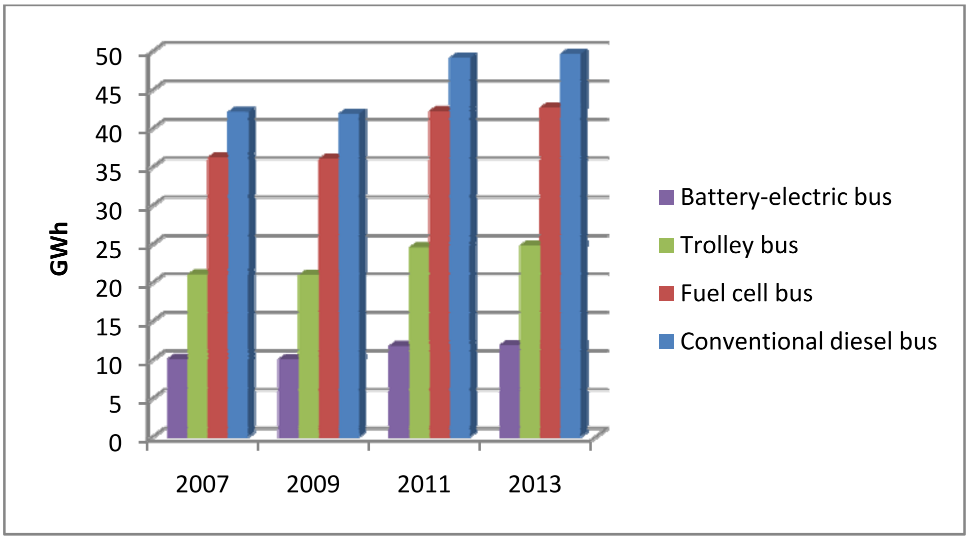

Figure 4: Energy consumption estimates for various vehicle types in internal bus transportation in Vantaa

Appendices

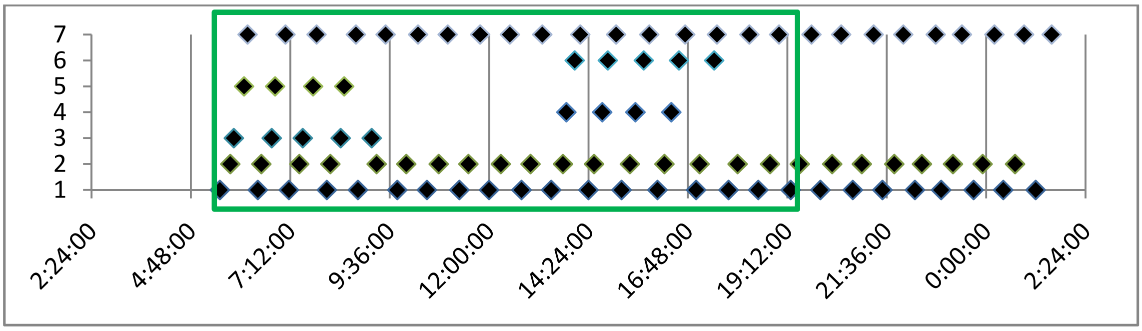

Figure 5: Departures of HRT-operated bus line #14B (winter weekdays, route 6.4 kilometers) [20]

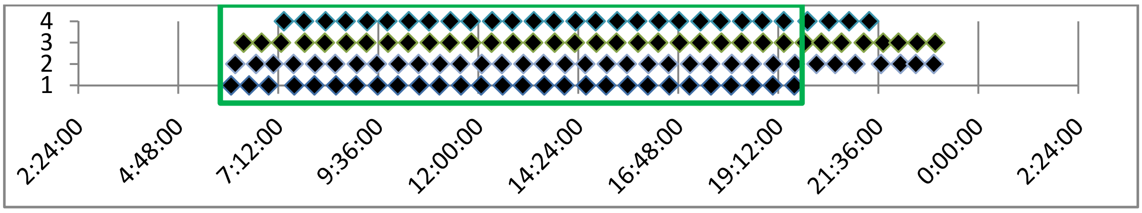

Figure 6: Departures of HRT-operated bus line #74 (winter weekdays, route ca 18 kilometers) [20]

In Figure 5 and Figure 6 the Y-axis presents the bus group inside the particular bus line (i.e., 14B or 74) and the X-axis expresses time of departure. As seen in Figure 5, extra bus groups are operated on rush hours. Approximately 70 percent of all the departures on the two bus lines are operated within 12 hours.

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