MINOA Research Challenge: Problem Description – Professional

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Contents

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1 Introduction

M.A.I.O.R. (Management Artificial Intelligence and Operations Research) designs and develops advanced software solutions for service planning, vehicles and crew scheduling, and company performance analysis in several transportation industries. Its solutions help bus and rail transit providers, airline companies, air traffic controllers, and seaport agencies to optimally plan their services and manage their day-to-day operations in order to significantly reduce costs and increase customer satisfaction while respecting complex technical and regulatory constraints. With 30 years of experience, M.A.I.O.R. is a global leading company with over 100 customers in Asia, Europe, and North America, among which 8 of the 10 largest Italian cities.

Planning a public transportation system is a complex process, which has traditionally been broken down in several phases, performed in sequence. Most often, the trips required to cover a service (Time Tabling—TT) with the desired frequency (headway) are decided early on, while the vehicles needed to cover these trips (Vehicle Scheduling—VS) are determined at a later stage. This potentially leads to requiring a larger number of vehicles (and, therefore, drivers) than would be possible if the two decisions were performed simultaneously.

Reducing the number of circulating vehicles not only brings clear economic benefits to the transportation company, but it also contributes to reduce CO_2 and other harmful emissions. Environmental concerns are also the powerful incentive leading an increasing number of Local Public Transport (LPT) companies to integrate in their fleets more and more electric vehicles (EVs). However, since EVs have lower autonomy and much longer refuelling times, this introduces new technical constraints in the VS.

A further element of interest for LPT companies after the COVID-19 outbreak is the increased alert to local epidemiological situations. Restrictive measures applied by the government can cause sudden variations of flow of passengers, while social distancing dispositions can produce a variation in vehicles capability. It is therefore even more essential than ever for LPT companies to be able to plan different services according to the possible different scenarios and quickly compute contingency plans to respond to unforeseeable events.

In light of the above, we propose a challenge for the implementation of algorithms for the solution of an Integrated Timetabling and Vehicle Scheduling (ITTVS) problem with a mixed fleet of EVs and traditional Internal Combustion Engine (ICE) vehicles. A relevant characteristic of the problem is that it requires a non-periodic planning in which both travel times and required frequencies/headways significantly vary along the time horizon.

2 Description of the problem

This section describes the ITTVS problem in detail.

The main input to the integrated TT-VS problem is a *public transportation network* (PTN). In general, a PTN is given in the form of a graph, where the nodes correspond to bus stops or depots, and the links correspond to direct bus transits. Upon the given PTN, a *planned service* is specified by means of a given set L of *lines*. A line $l \in L$ is a bi-directional path AB in the PTN between two terminals A_l and B_l (i.e., start/end stops of a line). A line l has two *directions*, called in-bound and out-bound and denoted by $D_l = \{\overrightarrow{A_lB_l}, \overrightarrow{B_lA_l}\}$, respectively. We denote by $D = \cup_{l \in L} D_l$ the set of all directions, and, similarly, by $N = \cup_{l \in L}\{A_l, B_l\}$ the set of all terminals of the involved lines. For each direction, a *main stop* is identified, represented by a clock in Figure 1. The regularity of the service is measured by means of the *headways*, i.e., the interval of time between two consecutive vehicles (performing trips of that line) passing by the main stop. Although the figure may suggest that the main stop needs be the same for the two directions of a line, this is not necessarily true (especially since the stops along the two directions could be disjoint). The choice of the main stop can vary, depending on the structure of the line; usually it is a "busy" point of the line, with high passenger demand, for which the planners are interested to monitor service frequency. It may coincide with one of the terminals if it is a relevant location of the line (e.g., a railway node). For each line, for each direction of the line, and for each of the *time windows* in which the *time horizon* is subdivided, the *desired* (a.k.a. ideal) headway is given. The lines are independent in terms of the desired headways, i.e., their Time Tabling (TT) requirements, but are linked by the fact of being served by a unique pool of vehicles, i.e., by the Vehicle Scheduling (VS) requirements.

Together with the PTN, the set T of potential *trips* is specified in the input data. Each trip $i \in T$ corresponds to an uniquely identified direction $d(i)$ in a line l in the PTN, and is therefore characterized by a start and end terminal (those of $d(i)$), in the following denoted for convenience respectively by $sn(i)$ and $en(i)$, with the corresponding departure time (from $sn(i)$) and arrival time (at $en(i)$) being denoted by $st(i)$ and $et(i)$, respectively. Also, the length $l(i)$ of the trip (in km) is given. Since each trip belongs to a given direction of a line, we define $T = \{ T_d \}_{d \in D}$ as the "direction partition" of T. Note that all trips in T_d share the same length, but *not* the same duration. Indeed, the main rationale for the non-periodic setting of our ITTVS problem, as opposed to the periodic setting prevalent in the timetabling literature, is precisely that trips times on the same line at different times of the day (and even within the same time window) can be significantly different, e.g. due to congestion during rush hours. It is also important to remark that *not every trip* in T has to be operated by some vehicle, and in fact the aim of the ITTVS problem is precisely to select which of the potential trips need to be selected.

For VS purposes it is necessary to consider in the PTN, besides the terminal nodes A and B, also the single depot node O (but not any other intermediate stop of the line).

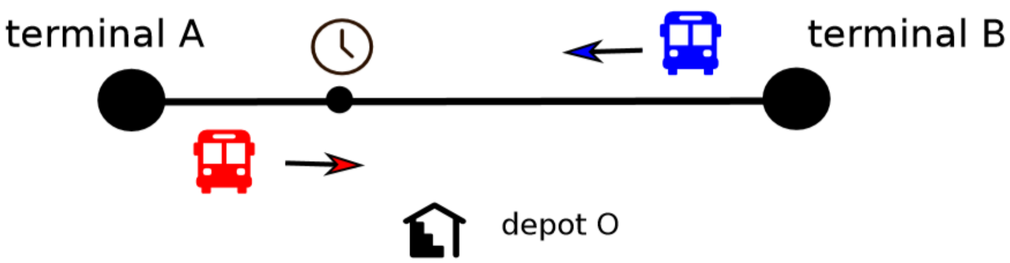


Figure 1: A line.

In the following, we will denote by $N^+ = N \cup \{ O \}$ the set of all nodes in the PTN relevant for our problem.

3 Constraints

3.1 TT Constraint

In our non-periodic planning, the *time horizon* H is given; say 5:00—27:00, i.e., each day is treated independently and with 27:00 we refer to 3:00 AM of the next day. Any time-related quantity is expressed as an integer, measuring seconds (hence, typically ≤ 97200). For each trip $i \in T$, besides the above-mentioned arrival times at the terminals, also the arrival time $a(i)$ at the main stop of $d(i)$ is known. Although we have different types of vehicle, we assume that the arrival times of all trips are independent from the type of vehicle chosen to perform them.

A *timetable* π_d for a direction $d \in D$ is a subset of its potential input trips T_d; a timetable is then just the union of $|D|$ (independent) timetables, one for each direction of each line, i.e., $\pi = \cup_{d \in D} \pi_d$. In order to measure the regularity of a timetable we have to consider the pairs of consecutive trips; thus, we denote by $P(\pi_d)$ the set of all consecutive pairs of trips in π_d. Given a trip i, its consecutive trip j is the one in π_d passing by the main stop at the closest point in time after $a(i)$ (if any), i.e., such that $a(j) \geq a(i)$ and $a(j) - a(i)$ is minimal. For any $(i, j) \in P(\pi_d)$, we define the (actual) *headway* of the pair as the amount of time separating their passing by the main stop, i.e., $w_{ij} = a(j) - a(i)$.

As the *desired frequency* of service typically varies along the day, H is partitioned into k *time windows* defined by $k + 1$ time instants $t_0, \dots, t_k$, where t_0 and t_k are the initial and final time instants of H. For each time window h and each direction $d \in D$, we are given the *ideal headway* I_d^h, together with *minimum and maximum headways* $I_{d,\min}^h \leq I_d^h \leq I_{d,\max}^h$. For each trip i, we will denote by $h(i)$ the time window in which $a(i)$ is (note that the time window is $(\, t_{h(i)-1}\, ,\, t_{h(i)}\,]$, i.e., $h(i)$ is the index of the ending instant and the starting instant do not belong to the window). Given a pair $(i, j) \in P(\pi_d)$, if both trips pass by the main stop within the same time window, i.e., $h(i) = h(j) = h$, then the *ideal, minimum and maximum headways for the pair* are simply defined as $I_{ij} = I_d^h$, $I_{ij,\min} = I_{d,\min}^h$, and $I_{ij,\max} = I_{d,\max}^h$, respectively. Only minor changes are required to account for "border effects" when $a(j)$ and $a(i)$ fall in two consecutive time windows, i.e., $h(j) = h(i) + 1$ (we assume that feasible pairs of consecutive trips can never be so far away in time as to fall in non-adjacent time windows). For the minimum and maximum headways we take

$$I_{ij,\min} = \max\left\{ I_{d,\min}^{h(i)} , I_{d,\min}^{h(j)} \right\} \qquad \text{and} \qquad I_{ij,\max} = \max\left\{ I_{d,\max}^{h(i)} , I_{d,\max}^{h(j)} \right\} \;.$$

As for the desired headway I_{ij}, we take the convex combination of $I_d^{h(i)}$ and $I_d^{h(j)}$ whose weights are $(\, t_{h(i)} - a(i)\,)/w_{ij}$ and $(\, a(j) - t_{h(i)}\,)/w_{ij}$, respectively. Note that, like all time-related quantities, the value of I_{ij} obtained by the previous formula must be expressed in seconds, and therefore rounded to the nearest second (integer).

With the above definitions, a *feasible timetable* $\pi_d \subset T_d$ for a direction $d \in D$ is a set of trips that satisfy all the minimum and maximum headway constraints, that is, such that $I_{ij,\min} \leq w_{ij} \leq I_{ij,\max}$ for each pair $(i, j) \in P(\pi_d)$. Furthermore, the first and the last trip of π_d have to belong to given subsets T_d^{ini} and T_d^{fin} of initial and final trips, specified as an input of the problem.

3.2 VS Constraint

3.2.1 Common constraints for all vehicles

Besides performing trips in T, vehicles can move in the PTN without passengers on board, which is called a *deadhead trip*. In particular, a vehicle leaving a depot to reach the start-terminal of a trip is said to be performing a pull-out trip; similarly, it performs a pull-in trip when it returns to the depot from the end-terminal of a trip.

For each node $n \in N^+$ and for each time window h we are given a *minimum and maximum stopping time*, denoted by $\delta_{n,\min}^h$ and $\delta_{n,\max}^h$, respectively; however, we assume that there is no maximum stopping time at the depot, i.e., $\delta_{O,\max}^h = \infty$ for all h. The period during which a vehicle is stationary at a node is defined as a *break*. We distinguish between stopping-time and breaking-time: the former is the duration of a break, while the latter is the portion of stopping-time considered in the VS objective function (see item 2 in Section 4.2 for details). If a break falls in two or more consecutive time windows, its minimum and maximum stopping time are these of the first time window (arrival at the node). Note that we do not consider stopping times for any intermediate node of a line.

For each terminal $n \in N$ and for each time window h, we are also given the *travel time* for a pull-in and pull-out trip, denoted by t^h_{n+} and t^h_{n-}, respectively, as well of the corresponding lengths l_{n+} and l_{n-}. Note that, as for trips, the lengths do not depend on the time of the day; travel times do, but, unlike for trips, the time is supposed to be constant at least inside the same time window. The travel time of a deadhead is that of the time window that contains the instant (indicated as "terminal-time") in which the vehicle is at the terminal n, i.e., the initial instant in the case of pull-in and the final instant in the case of pull-out. We add that if the terminal-time of deadhead is before the beginning of the first time window or is after the end of the last time window, the travel time of that deadhead is respectively the travel time of the first or last time window.

Two trips $i, j \in T$ (not necessarily belonging to the same line) are said to be *compatible* if they can be performed consecutively by the same vehicle. This immediately implies $st(j) \geq et(i)$, i.e., trip j has to start after that trip i has finished. We distinguish two types of compatibility:

- *in-line compatibility* means that:
  1. $en(i) = sn(j)$, i.e., the trip starts at the same terminal in which it ends;
  2. $\delta^{h(i)}_{en(i),\min} \leq st(j) - et(i) \leq \delta^{h(i)}_{en(i),\max}$, i.e., the stopping time at the terminal between the end of trip i and the start of trip j is feasible;
- *out-line compatibility* means that:
  1. $en(i) \neq sn(j)$;
  2. $st(j) - et(i) \geq t^{h(i)}_{en(i)+} + \delta^{h(i)}_{O^+,\min} + t^{h(j)}_{sn(j)-}$;

  in other words, there must be enough time between the end of trip i and the start of trip j to perform a pull-in trip from $en(i)$, wait the minimum amount of time at the depot, and then perform a pull-out trip towards $sn(j)$. We observe that it is allowed to stop between a trip and a pull-in/out trip for recharging (see items 3 and 8 in Section 3.2.2 for details). But if you don't recharge, then you are not allowed to stop (with stopping time >0) at terminals between a trip and a pull-in/out trip. Note that the minimum stopping time $\delta^h_{n,\min}$ regards only the in-line compatibility and this does not refer to the stopping time between a trip and a pull-in/out trip, while the maximum stopping time $\delta^h_{n,\max}$ is always in force. It should also be noted that pull-in and pull-out (deadhead) trips are not included in T, as they are not (passenger) service trips (i.e., no passengers on board).

In our problem, if $en(i) \neq sn(j)$, the vehicle cannot move directly from one terminal to the other, but it must necessarily perform an out-line compatibility. In other words, we only allow deadhead trips that start or end at the depot (i.e., pull-in/pull-out trips).

3.2.2 Electric constraints

The use of EVs involves the introduction of further constraints due to the need of recharging. A *recharging activity* can only be carried out within a break on a node enabled to recharge or at the depot. Some nodes allow *fast recharge*, i.e., the recharge time is smaller with respect to the normal recharge time. The fast recharge time will be obtained by multiplying the normal recharge time by a suitable coefficient $\varphi \in (0, 1)$ provided as input.

We denote by V the set of *vehicle typologies* and by $V_E \subset V$ the subset of EV typologies composing the fleet. Each type of EV has an autonomy (in km) a_v^{tot} and a maximum charging time $t_{R,v}$. The vehicles are fully charged when leaving the depot for the first time. We define the residual autonomy a_{res} of a vehicle as the kilometers that the vehicle can still cover, and the complementary autonomy $a_{res}^c = a_v^{tot} - a_{res}$. The residual autonomy decreases by the kilometers traveled by the vehicle, both for passenger trips and for deadhead ones (but not during breaks), and increases in case of recharging linearly with respect to the recharge time.

The management of recharges has to satisfy the following rules:

1. The full recharge time is proportional to the complementary autonomy a_{res}^c, being equal to $t_{R,v}(a_{res}^c/a_v^{tot})$.

2. It is possible to carry out partial recharges with a duration greater than or equal to the *minimum recharge time* $t_{\min,v}$ provided as input, for all nodes with recharging capabilities.

3. The autonomy gained from a recharge of duration τ_r is equal to $a_v^{tot}(\tau_r/t_{R,v})$, with $t_{\min,v} \leq \tau_r \leq t_{R,v}(a_{res}^c/a_v^{tot})$.

4. In case the recharge is a fast one (see the following points), the value $t_{R,v}$ is intended to be replaced by $\varphi t_{R,v}$ in the items 1—3.

5. At each instant it must be $a_{res} \geq 0$.

6. The *slow charging capacity* s_n and the *fast charging capacity* f_n are provided for each node n, and represent, respectively, the maximum number of vehicles which can simultaneously perform a slow charge or a fast charge. If a node n is not enabled to slow/fast charge, the corresponding s_n/f_n will be zero.

7. The parking capacity c_n is provided for each node n, and represents the maximum number of vehicles not occupying a charging slot which can simultaneously perform a break. It is possible for all type of vehicle (also for ICE ones) to perform a break either in a parking or in a charging slot. If a node n is not enabled to parking, the corresponding c_n will assume the value zero (but note that the node may still have nonzero s_n/f_n, and therefore that breaks may still be allowed there).

8. If a vehicle remains at a node for a period τ, and it recharges at the node for a period $\tau_r \leq \tau$, then

   - if the the break is between two trips compatible in-line, all the non-recharging time in excess of the minimum stopping time, i.e., $\tau - \max\{\tau_r, \delta_{n,\min}^h\}$ is considered as break time for the purpose of the VS objective computation (see item 2 in Section 4.2). The time spent in a parking slot in excess to the minimum stop time is always considered as break time;
   - otherwise, if the break is between a trip and pull-in/out trip, the break has to be used exclusively to recharging, or rather $\tau = \tau_r$. In particular, in this case either $\tau_r = 0$ or $t_{\min,v} \leq \tau_r \leq \min\{t_{R,v}(a_{res}^c/a_v^{tot}), \delta_{n,\max}^h\}$.

9. A vehicle can move from a parking slot to a charging slot in the same node and vice versa, but it is not allowed to split recharge neither in two or more different times nor in different charging slots during a single activity break. The minimum and maximum stopping times are unaffected by changes of slot, i.e., they have to be computed (even for the purpose of the break-time computation) w.r.t. the total time that the vehicle remains in the node, even if it moves between different slots.

The availability of electric vehicles of type v is bounded by a given N_v, while we suppose the number of ICE vehicles to be unbounded.

3.2.3 Feasible vehicle schedule

A *feasible vehicle block* is the workplan for a vehicle for a whole day, composed of an initial pull-out trip, a sequence of (compatible) trips in T, possibly separated by breaks (including recharges) or pull-in/out trips, and a final pull-in trip to return to the depot, with all the activities satisfying the corresponding constraints. A *feasible vehicle schedule* Ω is a subset of the input potential trips T that can be partitioned in feasible vehicle blocks. Each of the vehicle blocks in the vehicle schedule must be annotated with the type of the vehicle performing it for the purpose of also satisfying the specific constraints for EVs. The number of vehicle blocks corresponding to each type of vehicle must not exceed the maximum number of available vehicles of that type available in the fleet.

3.3 Linking constraint

The constraint linking the TT and VS part of the problem is simply that each trip in the TT must be performed by exactly one vehicle. In other words, the set of trips in the feasible timetable and in the feasible vehicle schedule must coincide.

4 Objective function

The objective of our integrated problem is to provide a solution that optimally balances the service provider cost (VS objective) and the users satisfaction (TT objective). The latter is captured by a measure all the (relative) deviations between the actual headways and the desired ones, by means of the penalty function described below. The former is somewhat more complex. Since one of the main costs for the service provider is usually the number of vehicles used weighted with the type of vehicle used (electric/ICE), the primary VS objective is the minimization of the number of vehicle blocks. Secondary metrics for the service provider cost consist in the time spent by the vehicles waiting at the terminals in excess to the minimum waiting time and recharge time (for drivers will typically have to man them even when stationary, thus increasing labour cost), the time spent by the vehicles performing pull-in and pull-out trips (for the same reason as above, plus the fact that vehicles typically consume some fuel), and the driving time in the case of ICE vehicles (CO_2-cost).

4.1 TT-costs

To evaluate the quality of a (feasible) timetable, a quadratic penalty function is given depending on the absolute value of the relative deviation of each (feasible) actual headway $w_{ij} = a(j) - a(i)$ of each pair $(i, j) \in P(\pi_d)$ from its ideal one I_{ij}, i.e.,

$$c_{TT} = \sum_{d \in D} \sum_{(i,j) \in P(\pi_d)} p\left(\frac{|w_{ij} - I_{ij}|}{I_{ij}} \right) .$$

The penalty function $p(z)$ satisfies $p(0) = 0$, while for $z > 0$ the value of $p(z)$ is that of is a polynomial of degree two in z with given coefficients. Note that the constant term of the polynomial is not necessarily zero, i.e., a fixed cost may be paid whenever $w_{ij} \neq I_{ij}$ irrespectively of the size of the (relative) difference.

4.2 VS-costs

The component of VS-cost is composed of different terms. With B denoting the set of vehicle blocks, for each $b \in B$ the following quantities are defined:

1. a fixed cost c_v for using the vehicle (depending on the type $v \in V$, and being typically higher for ICE vehicles), irrespectively on how much time it is used and how many times it re-enters and leaves the deposit during the block;
2. a break cost, proportional to the break time t_b^{break} spent at the nodes of the block (which does not include the minimum stopping-times and the recharge times) by a coefficient c^{break};
3. pull-in/pull-out costs, proportional to sum of the pull-in and pull-out times t_b^{pi} and t_b^{po} by a coefficient c_v^{pio} (also depending on the type of vehicle);
4. a cost for CO_2 emissions produced, proportional to the total driving time $d(b)$ by a coefficient c_v^{CO2} depending on the type of the vehicle (clearly, $c_v^{CO2} = 0$ for $v \in V_E$).

All in all, the VS-cost is obtained as

$$c_{VS} = \sum_{b \in B} \left(c_v + c^{break} t_b^{break} + c_v^{pio}(t_b^{pi} + t_b^{po}) + c_v^{CO2} d(b) \right) .$$

4.3 Global cost

The TT and VS target functions are added together to get the total cost. The formula for the objective function is

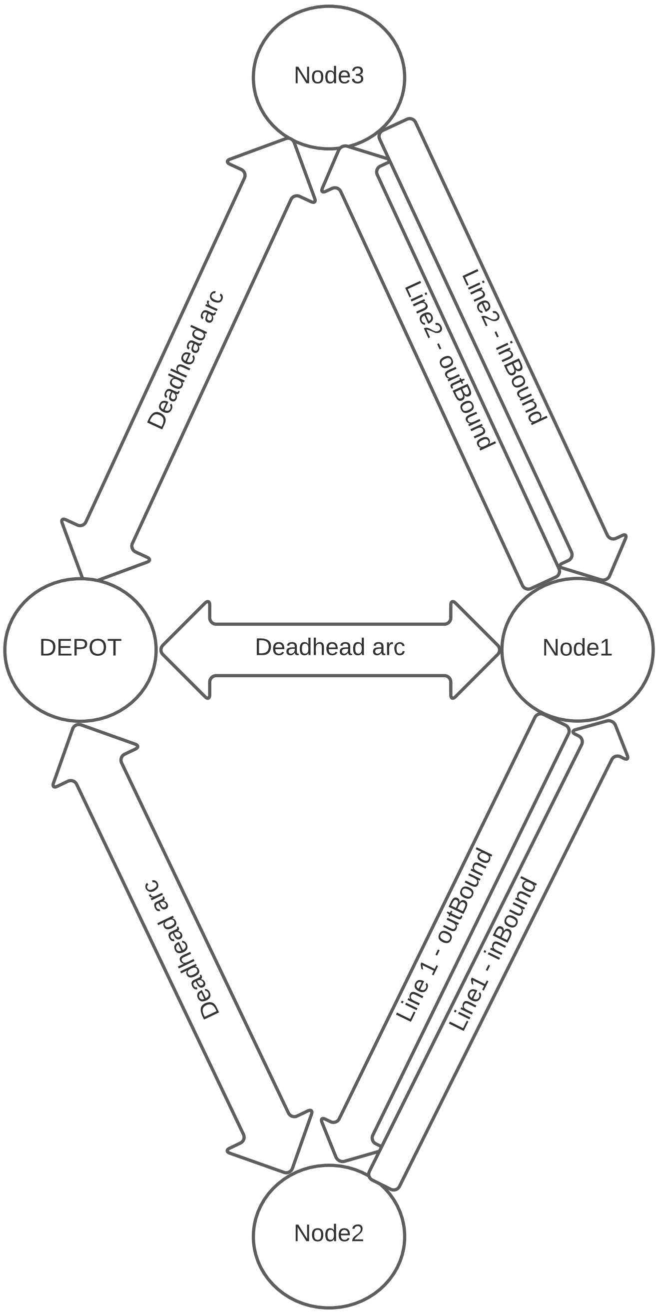
$$c = c_{TT} + c_{VS} .$$

5 Solution

The solution must specify the subset $T_S \subset T$ of the potential trips which represents both a feasible timetable and a feasible vehicle schedule. T_S must be explicitly partitioned into a set of feasible vehicle blocks, each annotated with the type of vehicle performing it, in such a way as to satisfy the fleet capacity constraints. A minimum-cost solution is sought for.

6 Example

In this section, we provide a graphic representation of a test case. The PTN in this case is made up of two lines and four nodes (one of which is the depot). For each line we provide the data related to the headways and an admissible solution (not necessarily optimal). The solution shows the details of the timetabling and of the activities of each vehicle block in the solution.



Nodes				
Name	node1	node2	node3	depot
break Capacity	2	1	1	1000
fastCharge Capacity	1	0	0	1000
slowCharge Capacity	1	0	0	0

LineName		line1	line1	line2	line2
Direction		inbound	outBound	inbound	outBound
Time window 1	Min	480	480	480	480
	Ideal headway	780	780	780	780
	Max headway	1080	1080	1080	1080
Time window 2	Min headway	480	480	480	480
	Ideal headway	1320	1320	1200	1200
	Max headway	1820	1820	1820	1820
Time window 3	Min headway	480	480	480	480
	Ideal headway	780	780	840	840
	Max headway	1080	1080	1080	1080

Hedway report	
Line	Line1
Direction	InBound
Start node	Node2
End node	Node1
Main stop	Node2
Time	Achieved headway
29580	780
30360	780
31140	780
31920	780
32700	780
33480	780
34200	720
34980	780
35700	720
36780	1080
38100	1320
39420	1320
40740	1320
42060	1320
43320	1260
44100	780
44880	780
45660	780
46440	780
47220	780
48000	780
48780	780
49560	780
50340	780

Hedway report	
Line	Line1
Direction	OutBound
Start node	Node1
End node	Node2
Main stop	Node2
Time	Achieved headway
29220	840
30060	840
30840	780
31620	780
32400	780
33180	780
33960	780
34740	780
35820	1080
37140	1320
38460	1320
39780	1320
41100	1320
42420	1320
43260	840
44040	780
44820	780
45600	780
46380	780
47160	780
47940	780
48720	780
49500	780

Hedway report	
Line	Line2
Direction	InBound
Start node	Node3
End node	Node1
Main stop	Node3
Time	Achieved headway
29100	840
29880	780
30660	780
31440	780
32220	780
33000	780
33780	780
34560	780
35520	960
36720	1200
37920	1200
39120	1200
40320	1200
41580	1260
42720	1140
43560	840
44400	840
45240	840
46080	840
46920	840
47760	840
48600	840
49440	840

Hedway report	
Line	Line2
Direction	OutBound
Start node	Node1
End node	Node3
Main stop	Node3
Time	Achieved headway
29940	840
30720	780
31500	780
32280	780
33060	780
33840	780
34620	780
35400	780
36420	1020
37620	1200
38820	1200
40020	1200
41220	1200
42480	1260
43560	1080
44400	840
45240	840
46080	840
46920	840
47760	840
48600	840
49440	840
50280	840

Vehicle block report					
Vehicle block			0		
Vehicle type			Electric		
Vehicle autonomy			60 mi		
Type of activity	Start node	Start time	End node	End time	autonomy at activity end
pull-out:	Depot	28260	Node2	28800	57.44
trip:	Node2	28800	Node1	29760	53.56
break:	Node1	29760	Node1	29880	53.56
trip:	Node1	29880	Node3	30600	49.37
break:	Node3	30600	Node3	30720	49.37
trip:	Node3	30720	Node1	31500	44.66
break:	Node1	31500	Node1	31620	44.66
trip:	Node1	31620	Node2	32340	40.96
break:	Node2	32340	Node2	32700	40.96
trip:	Node2	32700	Node1	33660	37.08
break:	Node1	33660	Node1	33780	37.08
trip:	Node1	33780	Node3	34500	32.89
break:	Node3	34500	Node3	34620	32.89
trip:	Node3	34620	Node1	35400	28.18
break:	Node1	35400	Node1	35520	28.18
trip:	Node1	35520	Node3	36240	23.99
break:	Node3	36240	Node3	36420	23.99
trip:	Node3	36420	Node1	37200	19.28
break:	Node1	37200	Node1	37920	19.28
trip:	Node1	37920	Node3	38640	15.09
break:	Node3	38640	Node3	38820	15.09
trip:	Node3	38820	Node1	39600	10.37
fCharge:	Node1	39600	Node1	40320	34.37
trip:	Node1	40320	Node3	41040	30.19
break:	Node3	41040	Node3	41220	30.19
trip:	Node3	41220	Node1	42000	25.47
fCharge:	Node1	42000	Node1	42420	39.47
trip:	Node1	42420	Node2	43140	35.77
break:	Node2	43140	Node2	43320	35.77
trip:	Node2	43320	Node1	44280	31.89
fCharge:	Node1	44280	Node1	44400	35.89
trip:	Node1	44400	Node3	45120	31.70
break:	Node3	45120	Node3	45240	31.70
trip:	Node3	45240	Node1	46020	26.99
break:	Node1	46020	Node1	46380	26.99
trip:	Node1	46380	Node2	47100	23.28
break:	Node2	47100	Node2	47220	23.28
trip:	Node2	47220	Node1	48180	19.40
break:	Node1	48180	Node1	48600	19.40
trip:	Node1	48600	Node3	49320	15.22
break:	Node3	49320	Node3	49440	15.22
trip:	Node3	49440	Node1	50220	10.50
pull-in:	Node1	50220	Depot	50820	7.82

Vehicle block report					
Vehicle block			1		
Vehicle type			Electric		
Vehicle autonomy			60 mi		
Type of activity	Start node	Start time	End node	End time	autonomy at activity end
pull-out	Depot	27780	Node1	28380	57.14
trip:	Node1	28380	Node2	29100	53.44
break:	Node2	29100	Node2	29580	53.44
trip:	Node2	29580	Node1	30540	49.56
break:	Node1	30540	Node1	30660	49.56
trip:	Node1	30660	Node3	31380	45.37
break:	Node3	31380	Node3	31500	45.37
trip:	Node3	31500	Node1	32280	40.66
break:	Node1	32280	Node1	32400	40.66
trip:	Node1	32400	Node2	33120	36.95
break:	Node2	33120	Node2	33480	36.95
trip:	Node2	33480	Node1	34440	33.07
break:	Node1	34440	Node1	34560	33.07
trip:	Node1	34560	Node3	35280	28.89
break:	Node3	35280	Node3	35400	28.89
trip:	Node3	35400	Node1	36180	24.17
fCharge:	Node1	36180	Node1	37140	56.17
trip:	Node1	37140	Node2	37860	52.47
break:	Node2	37860	Node2	38100	42.47
trip:	Node2	38100	Node1	39060	48.59
break:	Node1	39060	Node1	39780	48.59
trip:	Node1	39780	Node2	40500	44.89
break:	Node2	40500	Node2	40740	44.89
trip:	Node2	40740	Node1	41700	41.00
break:	Node1	41700	Node1	42720	41.00
trip:	Node1	42720	Node3	43440	36.82
break:	Node3	43440	Node3	43560	36.82
trip:	Node3	43560	Node1	44340	32.10
break:	Node1	44340	Node1	44820	32.10
trip:	Node1	44820	Node2	45540	28.40
break:	Node2	45540	Node2	45660	28.40
trip:	Node2	45660	Node1	46620	24.52
break:	Node1	46620	Node1	46920	24.52
trip:	Node1	46920	Node3	47640	20.34
break:	Node3	47640	Node3	47760	20.34
trip:	Node3	47760	Node1	48540	15.62
break:	Node1	48540	Node1	48720	15.62
trip:	Node1	48720	Node2	49440	11.92
break:	Node2	49440	Node2	49560	11.92
trip:	Node2	49560	Node1	50520	8.04
Pull-in	Node1	50250	Depot	51120	5.36

Vehicle block report					
Vehicle block			2		
Vehicle type			Electric		
Vehicle autonomy			60 mi		
Type of activity	Start node	Start time	End node	End time	autonomy at activity end
pull-out:	Depot	28260	Node1	29220	57.14
trip:	Node1	29220	Node2	29940	53.44
break:	Node2	29940	Node2	30360	53.44
trip:	Node2	30360	Node1	31320	49.56
break:	Node1	31320	Node1	31440	49.56
trip:	Node1	31440	Node3	32160	45.37
break:	Node3	32160	Node3	32280	45.37
trip:	Node3	32280	Node1	33060	40.66
break:	Node1	33060	Node1	33180	40.66
trip:	Node1	33180	Node2	33900	36.95
break:	Node2	33900	Node2	34200	36.95
trip:	Node2	34200	Node1	35160	33.07
break:	Node1	35160	Node1	35820	33.07
trip:	Node1	35820	Node2	36540	29.37
break:	Node2	36540	Node2	36780	29.37
trip:	Node2	36780	Node1	37740	25.49
break:	Node1	37740	Node1	38460	25.49
trip:	Node1	38460	Node2	39180	21.78
break:	Node2	39180	Node2	39420	21.78
trip:	Node2	39420	Node1	40380	17.91
fCharge	Node1	40380	Node1	41100	41.91
trip:	Node1	41100	Node2	41820	38.20
break:	Node2	41820	Node2	42060	38.20
trip:	Node2	42060	Node1	43020	34.32
break:	Node1	43020	Node1	43560	34.32
trip:	Node1	43560	Node3	44280	30.14
break:	Node3	44280	Node3	44400	30.14
trip:	Node3	44400	Node1	45180	25.42
sCharge:	Node1	45180	Node1	45600	28.92
trip:	Node1	45600	Node2	46320	25.22
break:	Node2	46320	Node2	46440	25.22
trip:	Node2	46440	Node1	47400	21.34
break:	Node1	47400	Node1	47760	21.34
trip:	Node1	47760	Node3	48480	17.15
break:	Node3	48480	Node3	48600	17.15
trip:	Node3	48600	Node1	49380	12.44
break:	Node1	49380	Node1	49500	12.44
trip:	Node1	49500	Node2	50220	8.73
break:	Node2	50220	Node2	50340	8.73
trip:	Node2	50340	Node1	51300	4.85
pull-in	Node1	51300	Depot	51900	2.17

Vehicle block report					
Vehicle block			3		
Vehicle type			Electric		
Vehicle autonomy			60 mi		
Type of activity	Start node	Start time	End node	End time	autonomy at activity end
pull-out	Depot	27660	Node1	28260	57.14
trip:	Node1	28260	Node3	28980	52.96
break:	Node3	28980	Node3	29100	52.96
trip:	Node3	29100	Node1	29880	48.24
break:	Node1	29880	Node1	30060	48.24
trip:	Node1	30060	Node2	30780	44.53
break:	Node2	30780	Node2	31140	44.53
trip:	Node2	31140	Node1	32100	40.66
break:	Node1	32100	Node1	32220	40.66
trip:	Node1	32220	Node3	32940	36.47
break:	Node3	32940	Node3	33060	36.47
trip:	Node3	33060	Node1	33840	31.75
break:	Node1	33840	Node1	33960	31.75
trip:	Node1	33960	Node2	34680	28.05
break:	Node2	34680	Node2	34980	28.05
trip:	Node2	34980	Node1	35940	24.17
sCharge:	Node1	35940	Node1	36720	30.67
trip:	Node1	36720	Node3	37440	26.49
break:	Node3	37440	Node3	37620	26.49
trip:	Node3	37620	Node1	38400	21.77
sCharge:	Node1	38400	Node1	39120	27.77
trip:	Node1	39120	Node3	39840	23.59
break:	Node3	39840	Node3	40020	23.59
trip:	Node3	40020	Node1	40800	18.87
break:	Node1	40800	Node1	41580	18.87
trip:	Node1	41580	Node3	42300	14.68
break:	Node3	42300	Node3	42480	14.68
trip:	Node3	42480	Node1	43260	9.97
fCharge:	Node1	43260	Node1	44040	35.97
trip:	Node1	44040	Node2	44760	32.26
break:	Node2	44760	Node2	44880	32.26
trip:	Node2	44880	Node1	45840	28.38
break:	Node1	45840	Node1	46080	28.38
trip:	Node1	46080	Node3	46800	24.20
break:	Node3	46800	Node3	46920	24.20
trip:	Node3	46920	Node1	47700	19.48
break:	Node1	47700	Node1	47940	19.48
trip:	Node1	47940	Node2	48660	15.78
break:	Node2	48660	Node2	48780	15.78
trip:	Node2	48780	Node1	49740	11.90
pull-in	Node1	49740	Depot	50340	9.22

Vehicle block report					
Vehicle block			4		
Vehicle type			Electric		
Vehicle autonomy			60 mi		
Type of activity	Start node	Start time	End node	End time	autonomy at activity end
pull-out:	Depot	28500	Node1	29100	57.14
trip:	Node1	29100	Node3	29820	52.96
break:	Node3	29820	Node3	29940	52.96
trip:	Node3	29940	Node1	30720	48.24
break:	Node1	30720	Node1	30840	48.24
trip:	Node1	30840	Node2	31560	44.53
break:	Node2	31560	Node2	31920	44.53
trip:	Node2	31920	Node1	32880	40.66
break:	Node1	32880	Node1	33000	40.66
trip:	Node1	33000	Node3	33720	36.47
break:	Node3	33720	Node3	33840	36.47
trip:	Node3	33840	Node1	34620	31.75
break:	Node1	34620	Node1	34740	31.75
trip:	Node1	34740	Node2	35460	28.05
break:	Node2	35460	Node2	35700	28.05
trip:	Node2	35700	Node1	36600	24.17
pull-in	Node2	36600	Depot	37200	21.49
sCharghe	Depot	37200	Depot	42260	60.00
pull-out:	Depot	42260	Node2	43260	57.14
trip:	Node1	43260	Node2	43980	53.44
break:	Node2	43980	Node2	44100	53.44
trip:	Node2	44100	Node1	45060	49.56
break:	Node1	45060	Node1	45240	49.56
trip:	Node1	45240	Node3	45960	45.37
break:	Node3	45960	Node3	46080	45.37
trip:	Node3	46080	Node1	46860	40.66
break:	Node1	46860	Node1	47160	40.66
trip:	Node1	47160	Node2	47880	36.95
break:	Node2	47880	Node2	48000	36.95
trip:	Node2	48000	Node1	48960	33.07
break:	Node1	48960	Node1	49440	33.07
trip:	Node1	49440	Node3	50160	28.89
break:	Node3	50160	Node3	50280	28.89
trip:	Node3	50280	Node1	51060	24.17
pull-in	Node1	51060	Depot	51660	21.49

7 Glossary

Headway: in transit speak headway is the amount of time between transit vehicle arrival at a stop. A route that has a vehicle once an hour have a 60 minute headway.
Line: a line is a grouping of routes that is generally known to the public by a similar name or number
Route: a route is a link sequence, defined by an ordered sequence of (two or more) points on route. A *route* may pass through the same route point more than once, as in the case of a loop.