
Project PLATON

Planning Process and Tool for Step-by-Step Conversion of the Conventional or Mixed Bus Fleet to a 100% Electric Bus Fleet

Document type: Description of experimental software for solving problem OPT by randomized heuristic RH.

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Abstract

This document contains description of an experimental software for solving optimization problem OPT by randomized heuristic RH. The problem and the heuristic are described in Deliverables 4.3 and 4.4. Problem OPT assumes fast-charging technology which is currently in use in the city of Minsk, Belarus. The problem is to determine a fleet of electric buses, places for charging stations and transformers, assignment of charging stations to the selected places, assignment of charging stations to the transformers and assignment of charging stations to the routes such that all electric buses can feasibly drive, the required traffic (inter-bus) interval is maintained, and the output power of any transformer is not exceeded. The objective is to maximize the total value, provided that the total capital cost and the total operating, depreciation and energy cost do not exceed their upper bounds. The total passenger demand satisfied by the electric buses is considered as the value to be maximized.

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1 Computer implementation of RH

Algorithm RH is implemented in C++ for Windows. It can be used as an executable file *mobopt.exe* or as a DLL-file *moboptdll.dll*. These files can be used on a PC of a standard configuration. Parameters of the command line for *mobopt.exe* are:

- Full name of directory with input data.
- Full name of directory with configuration file *probl.ini*.

For example: `d:/gn/soft/bat_dll/mobopt.exe d:/gn/soft/mobility/mobopt/Minsk/4 d:/gn/soft/mobility/mobopt`, where `d:/gn/soft/bat_dll` is the directory with *mobopt.exe*, `d:/gn/soft/mobility/mobopt/Minsk/4` is the directory with the input data, and `d:/gn/soft/mobility/mobopt` is the directory with the configuration file *probl.ini*.

From Python, *mobopt.exe* can be executed in the following way:

```
import subprocess
argexe='d:/gn/soft/mobility/mobopt/bc/mobopt.exe'
arg1=' d:/gn/soft/mobility/mobopt/Minsk/4'
arg2=' d:/gn/soft/mobility/mobopt/bc'
args = argexe + arg1 + arg2
p=subprocess.Popen(args, shell = False)
p.wait()
ret=p.poll()
```

File *moboptdll.dll* contains function *MOBOPT*, whose prototype is `int MOBOPT(char * dir, char * dir_ini)`, where *dir* is the full name of the directory with the input data and *dir_ini* is the full name of the directory with the configuration file *probl.ini*. The return code of the function *MOBOPT* is equal to 0 if the optimization was successful. In this case, all the output information is placed into the file *solution.out* in the text format and in the file *solution.json* in the JSON format in the directory *dir*. If the return code is not 0, then the corresponding error information is placed into the file *errors.out* in the directory *dir*. An example of calling the function *MOBOPT* from Python (32-bit) is given below.

```
import ctypes
mobDll=ctypes.WinDLL('d:/gn/soft/bat_dll/moboptdll.dll')
from ctypes import *
p1=create_string_buffer(b'd:/gn/soft/mobility/mobopt/Minsk/4')
p2=create_string_buffer(b'd:/gn/soft/mobility/mobopt/bc')
ret=mobDll.MOBOPT(p1,p2)
```

File *probl.ini* is used for setting the following parameters:

- *json* – format of the input data, $json \in \{0, 1, 2\}$, where
 - $json = 0$ if the input data are in the text format,
 - $json = 1$ if the input data are in the JSON format in separate files,
 - $json = 2$ if the input data are in the JSON format in one file. $json = 2$ is the default value.
- *nit* – maximum number of iterations of RH, $nit = 10000$ is the default value.
- *max_time* – maximum calculation time in seconds, $max_time = 600$ is the default value.
- *m* – number of links of any charging station location with the transformers, $m = 1$ is the default value.
- *w* – control parameter ω of the PSO method, $w = 0.729$ is the default value.
- *fiP* – control parameter φ_p of the PSO method, $fiP = 1.49445$ is the default value.
- *fiG* – control parameter φ_g of the PSO method, $fiP = 1.49445$ is the default value.
- *nit_non* – maximum number of iterations of RH without improving the objective function value, $nit_non = 200$ is the default value.
- *meth* – type of execution, $meth \in \{0, 6, 7, 24, 25, 50, 51, 52, 53, 54\}$, where
 - $meth = 0$ if the optimization is executed for all routes and e-buses,
 - $meth = 6$ if the optimization is executed for one route specified by the parameter *route*,
 - $meth = 7$ if the optimization is executed for one route specified by the parameter *route* and one e-bus specified by the parameter *e – bus*,
 - $meth = 24$ if the optimization is executed for the set of routes specified by the parameter *routes*,
 - $meth = 25$ if the optimization is executed for the set of routes specified by the parameter *routes* route and the set of e-buses specified by the parameter *e – buses*,
 - $meth = 50$ if no optimization is executed and only transformation of the input text files to the separate json files is fulfilled,
 - $meth = 51$ if no optimization is executed and only transformation of the input text files to a single json file is fulfilled,
 - $meth = 52$ if no optimization is executed and only files *routesi.txt* and *eroutes.txt* are formed,

$meth = 53$ if no optimization is executed and only files *routesi.txt* and *eroutes.txt* are formed and transformed into separate json files,

$meth = 54$ if no optimization is executed and only files *routesi.txt* and *eroutes.txt* are formed and transformed into a single json file,

$meth = 0$ is the default value.

- *route* – short name of the route selected for conversion,
- *e – bus* – short name of the e-bus type selected for conversion,
- *routes* – list of short names of routes selected for conversion,
- *e – buses* – list of short names of e-bus types selected for conversion.

Remark. *GUI application (file moboptv.exe) is also available. The application supports progress dialogue, viewing and printing of the intermediate optimization results.*

2 Formats of input files

Two formats of the input files are implemented. One of them is the JSON format, see <http://www.json.org/index.html> for the description, and the other is a simple text format. If the input parameter $json = 2$, then the file *problem.json* is transformed into the following files: *probl.json*, *stations.json*, *buses.json*, *cbuses.json*, *nodes_st.json*, *graph.json*, *transf.json*, *nodes_nm.json*, *nodes_ch_time.json*, *croutes.json*, *tdepots.json*, *buses1.json* and *buses2.json*. If the parameter *form_ind* in the file *problem.json* is equal to 0, then additional files *routesi.json* and *eroutes.json* are created. Otherwise, only file *routes.json* is formed. After that, each of these files is converted into the corresponding text file. Finally, the data from the text files are imported and analysed for errors. If there are errors, then the information about them is placed into the file *errors.out* in the directory specified by the parameter *dir*.

2.1 Input file in JSON format

If the input data are prepared in the JSON format in separated files, then their names must be the following: *probl.json*, *stations.json*, *buses.json*, *cbuses.json*, *nodes_st.json*, *graph.json*, *transf.json*, *nodes_ch_time.json*, *tdepots.json*, and *routes.json*, or *routesi.json* and *eroutes.json*. File *croutes.json* is created only if there are routes already served by e-buses. File *croutes.json* is created only if there are routes already served by e-buses. File *nodes_nm.json* is prepared only if the sets NM_b are non-empty. Files *buses1.json* and *buses2.json* are prepared only if the sets B_1 and B_2 , respectively, are non-empty.

File *probl.json* includes values of the following parameters: m – number of links of any location with a new charging station with the transformer nodes, ucc – upper bound on the total capital cost, uoc – upper bound on the total operating, depreciation and energy cost, dtp – duration of the decisive time period, and *form_ind* – type of specification of eligible drive indicators. If *form_ind*=1, then the eligible drive indicators are calculated. Otherwise, they are taken from the file *eroutes.json*. For example:

```
{
  "m": 2,
  "ucc": 10000000,
  "uoc": 5000000,
  "dtp": 180,
  "form_ind": 1
}
```

File *stations.json* describes the set C of charging stations and defines values of the following parameters: *fn_c* – full name of the charging station type c , *sn_c* – short name, *po_c* – nominal power of any station, *cc_cap_c* – capital cost of any station, *cc_ope_c* – operating and depreciation cost of any station. For example:

```
{ "C": [{
  "fn_c": "Charging station 1",
  "sn_c": "CS1",
  "po_c": 200,
  "cc_cap_c": 250000,
  "cc_ope_c": 5000
}]}
```

File *buses.json* describes the set B of e-bus types and defines values of the following parameters: *fn_b* – full name of the e-bus type b , *sn_b* – short name, *cap_b* – passenger capacity of any e-bus, *cv_cap_b* – capital cost of any e-bus, and *C_b* – array of the short names of the eligible charging stations. For example:

```
{ "B": [{
  "fn_b": "Vitovt Max Electro E433",
  "sn_b": "E433",
  "cap_b": 153,
  "cv_cap_b": 475000,
  "C_b": ["CS1"]
}]}
```

File *cbuses.json* describes the set VC of the conventional vehicle types and defines values of the following parameters: fn_b – full name of the conventional vehicle type b , sn_c – short name, and cap_b – passenger capacity of any vehicle. For example:

```
{ "VC": [{  
  "fn_b": "Diesel bus MAZ-103",  
  "sn_b": "M103",  
  "cap_b": 100  
}]}
```

File *nodes_st.json* describes the set NP of the parent nodes and defines values of the following parameters: fn_p – full name of the parent node p , sn_p – short name, C_p – array of the charging station types eligible for opening at p , nc_{pc} – array of the numbers nc_{pc} of old charging stations at p , uc_{pc} – array of the upper bounds uc_{pc} on the number of charging stations of type c to be opened at p . For example:

```
{ "NP": [{  
  "fn_p": "Vaneeva",  
  "sn_p": "V",  
  "C_p": ["CS1"],  
  "nc_pc": [1],  
  "uc_pc": [4]  
}]}
```

File *graph.json* describes the set NN of the network G and defines values of the following parameters: fn_j – full name of the node j , sn_j – short name, sn_{j-p} – short name of the parent node $p(j)$, and $type_j$ – type of the node (1 for depots, 2 for terminal stops and 3 for regular stops). For example:

```
{ "NN": [{  
  "fn_j": "Vaneeva-Depot",  
  "sn_j": "Vaneeva-D",  
  "sn_{j-p}": "V",  
  "type_j": 1  
}]}
```

File *transf.json* describes the set T of transformer nodes and defines values of the following parameters: fn_q – full name of the transformer node q , sn_q – short name, o_q – transformer electrical output power, cb_q – transformer capital (building) cost, oo_q – transformer electrical power that is used to supply old charging stations, sn_{qp} – array of the short names of

eligible non-transformer parent nodes p , and cl_{qp} – array of the costs of connection of eligible non-transformer parent nodes p with the transformer node q . For example:

```
{ "EE": [{  
  "fn_q": "Vaneeva-Transformer 1",  
  "sn_q": "Vaneeva-T1",  
  "o_q": 800,  
  "cb_q": 0,  
  "oo_q": 200,  
  "sn_qp": ["V"],  
  "cl_qp": [0]  
}]}
```

If the parameter *form_ind* in the file *probl.json* is equal to 0, then the route set R is described in the file *routes.json*. Otherwise, its description is in the files *routesi.json* and *eroutes.json*.

File *routes.json* defines values of the following parameters: fn_r – full name of the route r , sn_r – short name, w_r – preference coefficient, ut_r – upper bound on the average length of the traffic interval of all e-buses and conventional buses of any type, s_r – array of the short names of the nodes in r , L_r – array of the distances between the nodes in r , B_r – array of the short names of the e-bus types eligible for the route, nbo_{rb} – array of the numbers nbo_{rb} of old e-buses of type b serving the route, dm_{rb} – array of the single-charge ranges (maximal single-charge travel distances) of e-buses of type b , ce_{rb} – array of the operating, depreciation and energy costs cv_{rb}^{ope} , d_{rb} – array of the durations d_{rb} of any single cycle of any e-bus eligible for the route, do_{rb} – array of the durations do_{rb} of any single cycle of any old e-bus eligible for the route, VC_r – array of short names of the types of conventional vehicles serving the route, nvc_{rb} – array of the numbers nvc_{rb} of conventional vehicles serving the route, and doc_{rb} – array of the durations dc_{rb} of any single cycle of conventional vehicles serving the route. For example:

```
{ "R": [{  
  "fn_r": "Railway Station - DS Viasnjanka",  
  "sn_r": "A1",  
  "w_r": 1,  
  "ut_r": 18,  
  "s_r": ["Vaneeva-D", "Kira-T", "Vias-T", "Kira-T"],  
  "L_r": [7, 9, 9],  
  "B_r": ["E433", "E420", "E321", "E490", "T32100D", "T42003D"],  
  "nbo_rb": [4, 0, 0, 0, 0, 0],  
  "dm_rb": [15, 20, 30, 25, 16, 15],  
  "ce_rb": [15, 20, 30, 25, 16, 15],  
  "d_rb": [15, 20, 30, 25, 16, 15],  
  "do_rb": [15, 20, 30, 25, 16, 15],  
  "VC_r": ["Vias-T", "Kira-T", "Vaneeva-D"],  
  "nvc_rb": [1, 1, 1],  
  "doc_rb": [15, 20, 30, 25, 16, 15],  
  "dc_rb": [15, 20, 30, 25, 16, 15]  
}]}
```



```
"ce_rb": [268880,209520,209520,168400,209520,209520],  
"d_rb": [60,60,60,60,60,60],  
"do_rb": [72,72,72,72,72,72],  
"VC_r": ["M103","M1035"],  
"nvc_rb": [3,2],  
"doc_rb": [60,60]  
}  
}}
```

Eligible drive indicators for each route are formed based on the arrays l_r and dm_{rb} .

File *routesi.json* defines values of the following parameters: fn_r – full name of the route r , sn_r – short name, w_r – preference coefficient, ut_r – upper bound on the average length of the traffic interval of all e-buses and conventional buses of any type, s_r – array of the short names of the nodes in r , B_r – array of the short names of the e-bus types eligible for the route, nbo_{rb} – array of the numbers nbo_{rb} of old e-buses of type b serving the route, ce_{rb} – array of the operating, depreciation and energy costs cv_{rb}^{ope} , d_{rb} – array of the durations d_{rb} of any single cycle of any e-bus eligible for the route, do_{rb} – array of the durations do_{rb} of any single cycle of any old e-bus eligible for the route, VC_r – array of short names of the types of conventional vehicles serving the route, nvc_{rb} – array of the numbers nvc_{rb} of conventional vehicles serving the route, and doc_{rb} – array of the durations dc_{rb} of any single cycle of conventional vehicles serving the route.

For example:

```
{ "R": [{  
  "fn_r": "Railway Station - DS Viasnjanka",  
  "sn_r": "A1",  
  "w_r": 1,  
  "ut_r": 18,  
  "s_r": ["Vaneeva-D","Kira-T","Vias-T","Kira-T"],  
  "l_r": [7,9,9],  
  "B_r": ["E433","E420","E321","E490","T32100D","T42003D"],  
  "nbo_rb": [4,0,0,0,0,0],  
  "dm_rb": [15,20,30,25,16,15],  
  "ce_rb": [268880,209520,209520,168400,209520,209520],  
  "d_rb": [60,60,60,60,60,60],  
  "do_rb": [72,72,72,72,72,72],  
  "VC_r": ["M103","M1035"],  
  "nvc_rb": [3,2],  
  "doc_rb": [60,60]}]
```

```
}  
]}
```

File *eroutes.json* defines the following parameters for each route: sn_r – short name of the route r and arrays $e_{rb_1}, \dots, e_{rb_n}$ of eligible drive indicators for each e-bus type b_h , where n is the number of e-bus types eligible for serving route r . The array e_{rb_h} is a 0-1 vector of length k , where k is equal to the number of stops in the route r minus 1. Element (i, j) of this vector is equal to 1 if and only e-bus of type b_h can drive from stop i to stop j of the route r , provided that it is charged at stop i .

For example:

```
{ "ER": [{  
  "sn_r": "A1",  
  "e_rb_1": [0,1,0,1,0,1,1,1,0],  
  "e_rb_2": [0,1,1,1,0,1,1,1,0],  
  "e_rb_3": [0,1,1,1,0,1,1,1,0],  
  "e_rb_4": [0,1,1,1,0,1,1,1,0],  
  "e_rb_5": [0,1,0,1,0,1,1,1,0],  
  "e_rb_6": [0,1,0,1,0,1,1,1,0]  
}]
```

File *nodes_ch_time.json* describes charging times for the set NP of the parent nodes and defines: sn_p – short name of the parent node p , and ct_{pbc} – array of the charging times ct_{pbc} , $c \in C_p$, $b \in B_c$. For example:

```
{ "CT_NP": [{  
  "sn_p": "V",  
  "ct_pb_1": [6,6,10,6,40,30]  
}]
```

File *croutes.json* is formed if there are routes that are already served by e-buses. It describes charging station types associated with nodes of each route served by e-buses. This file contains the following information: sn_r – short name of the route, and c_r – array of the short names of the existing charging station types associated with each node from $\pi_r = (j_0, j_1, \dots, j_r)$. If no station is opened at a parent node of node j_k , then string "-1" is used as the corresponding name. For example:

```
{ "CO": [{  
  "sn_r": "A1",  
  "c_r": ["CS1", "CS1", "CS1"]  
}]
```

```
}}
```

File *tdepots.json* describes the set ND of depot nodes and defines: sn_j – short name of the depot node j , and t_{depot_j} – duration t_j^{tdepot} of a time interval of maximum length, in which all e-buses assigned to the depot at node $j \in ND$ are in this depot. For example:

```
{ "ND": [{  
  "sn_j": "Vaneeva-D",  
  "t_depot_j": 240  
}]
```

File *nodes_nm.json* describes sets NM_b of “obligatory” nodes for an e-bus of type b and defines: sn_b – short name of the e-bus type b , and sn_{b_j} – array of the short names of the nodes from NN such that if j belongs to r to be served by an e-bus of type b , then at least one charging station of type $c \in C_b$ must be opened at parent node $p(j)$. For example:

```
{ "NM_b": [{  
  "sn_b": "E433",  
  "sn_{b_j}": ["Kira-D", "Vias-S"]  
}]
```

File *buses1.json* describes the set B_1 of e-buses with batteries which have enough capacity to drive with a single charge at the corresponding depot during the day and defines sn_b – array of the short names of the e-bus types from B_1 . For example:

```
{ "B_1": {  
  "sn_b": ["E420"]  
}
```

File *buses2.json* describes the set B_2 of e-buses with one charge at the corresponding depot and one charge at a non-depot node during the day and defines sn_b – array of the short names of the e-bus types from B_2 . For example:

```
{ "B_2": {  
  "sn_b": ["E333"]  
}
```

2.2 Input files in text format

If input data are prepared in the text format, then the following files must be prepared: *probl.txt*, *stations.txt*, *buses.txt*, *cbuses.txt*, *nodes_st.txt*, *graph.txt*, *transf.txt*, *routes.txt*, *nodes_ch_time.txt*, and *tdepots.txt*. File *croutes.txt* is created only if there are routes already served by e-buses. File *nodes_nm.txt* is prepared only if the sets NM_b are non-empty. Files

buses1.txt and *buses2.txt* are prepared only if the sets B_1 and B_2 are non-empty, respectively. Each file can include comments. The comments must start with the symbols `//` and be placed in the beginning of the file. The main body of the file starts with a new line immediately after the comments. Values of different input parameters are separated by the comma symbol.

File *probl.txt* consists of one row with the following values: number m of links of any new charging station with the transformer nodes, upper bound ucc on the total capital cost, upper bound uoc on the total operating, depreciation and energy cost, duration dtp of the decisive time period, and type $form_ind$ of specification of eligible drive indicators. If $form_ind=1$, then eligible drive indicators are calculated. Otherwise, they are taken from the file *eroutes.txt*. For example:

2,10000000,5000000,180,1

File *stations.txt* consists of one row for each element of the set C . Each row contains: full name of the charging station type, short name of the charging station type, nominal power po_c , capital cost cc_c^{cap} and operating and depreciation cost cc_c^{ope} . For example:

Charging station 1,CS1,200,250000,5000

File *buses.txt* consists of two rows for each element of the set B . The first row contains: full name of the e-bus type, short name of the e-bus type, passenger capacity cap_b , capital cost cv_b^{cap} . The second row contains the short names of the eligible charging stations for the e-bus type. For example:

Vitovt Max Electro E433,E433,153,475000
CS1

File *cbuses.txt* consists of one row for each element of the set VC of conventional vehicle types. Each row contains: full name of the conventional vehicle type, short name of the conventional vehicle type, and passenger capacity cap_b . For example:

Diesel bus MAZ-103,M103,100

File *nodes_st.txt* consists of 4 rows for each element of the set NP of parent nodes. First row contains full name of parent a node p and short name of this node. Next rows contain short names of the eligible charging station types, numbers nc_{pc} of the old charging stations and the upper bounds uc_{pc} . For example:

Vaneeva,V
CS1
1
4

File *graph.txt* consists of one row for each element of the set NN . Each row contains: full name of the node, short name of node, short name of the parent node and the node type (1 for the depot node, 2 for the terminal node and 3 for the en route node). For example:

Vaneeva-Depot,Vaneeva-D,V,1

Kira-Terminal, Kira-T, Kira, 2

Ch.Ri-Stop, Ch.Ri-S, Ch.Ri, 3

File *transf.txt* consists of 3 rows for each element of the set T . The first row contains: full name of the transformer, short name of the transformer, transformer electrical output power o_q , transformer capital (building) cost cb_q (0 if it has already been built), and already used transformer electrical power oo_q to supply old charging stations. The second row contains short names of the non-transformer parent nodes eligible for linking with the transformer node. The third row contains costs of connection of nodes in the second row with the transformer node (0 if the corresponding connection exists). For example:

Vias-Transformer 1, Vias-T1, 800, 0, 200

Vias

0

If the parameter *form.ind* in the file *probl.txt* is equal to 0, then the set R of the routes is described in the file *routes.txt*. Otherwise, its description has to be in the files *routesi.txt* and *eroutes.txt*.

File *routes.txt* consists of 12 rows for each route of the set R . The rows contain:

- row 1: full name of the route, short name of the route, preference coefficient w_r , and upper bound ut_r .
- row 2: sequence $\pi_r = (j_0, j_1, \dots, j_r)$ of short names of the nodes.
- row 3: distances between stops (nodes).
- row 4: short names of e-bus types eligible for the route.
- row 5: numbers nbo_{rb} of old e-buses serving the route.
- row 6: maximal distance of e-buses eligible for the route, without recharging.
- row 7: operating, depreciation and energy cost cv_{rb}^{ope} .
- row 8: durations d_{rb} .
- row 9: durations do_{rb} .
- row 10: short names of conventional vehicle types serving the route.
- row 11: numbers nvc_{rb} of conventional vehicles.
- row 12: durations dc_{rb} .

For example:

Railway Station - DS Viasnjanka, A1, 1, 18
Vaneeva-D, Kira-T, Vias-T, Kira-T
7, 9, 9
E433, E420, E321, E490, T32100D, T42003D
4, 0, 0, 0, 0, 0
15, 20, 30, 25, 16, 15
268880, 209520, 209520, 168400, 209520, 209520
60, 60, 60, 60, 60, 60
72, 72, 72, 72, 72, 72
M103, M1035
3, 2
60, 60

File *routesi.txt* consists of 10 rows for each route of the set R . The rows contain:

- row 1: full name of the route, short name of the route, preference coefficient w_r , and upper bound ut_r .
- row 2: sequence $\pi_r = (j_0, j_1, \dots, j_r)$ of short names of the nodes.
- row 3: short names of e-bus types eligible for the route.
- row 4: numbers nbo_{rb} of old e-buses serving the route.
- row 5: operating, depreciation and energy costs cv_{rb}^{ope} .
- row 6: durations d_{rb} .
- row 7: durations do_{rb} .
- row 8: short names of conventional vehicle types serving the route.
- row 9: numbers nvc_{rb} of conventional vehicles.
- row 10: durations dc_{rb} .

For example:

Railway Station - DS Viasnjanka, A1, 1, 18
Vaneeva-D, Kira-T, Vias-T, Kira-T
E433, E420, E321, E490, T32100D, T42003D
4, 0, 0, 0, 0, 0
268880, 209520, 209520, 168400, 209520, 209520

60,60,60,60,60,60

72,72,72,72,72,72

M103,M1035

3,2

60,60

The file *eroutes.txt* consists of $1 + |B_r|$ rows for $r \in R$. The first row contains short name of route r . Each row from the next $|B_r|$ rows contains eligible drive indicators $ei_{r(i,j)b}$ for route r and each $b \in B_r$. Values $ei_{r(i,j)b}$ are defined by a 0-1 matrix of dimension $m \times m$, where m is equal to the number of stops in the route minus 1. Element (i, j) of this matrix is equal to 1 if e-bus of type b can drive to from stop i to stop j of route r if it is charged at stop i , and it is equal to 0, otherwise. For example:

A1

0,1,0,1,0,1,1,1,0

0,1,1,1,0,1,1,1,0

0,1,1,1,0,1,1,1,0

0,1,1,1,0,1,1,1,0

0,1,0,1,0,1,1,1,0

0,1,0,1,0,1,1,1,0

File *nodes_ch_time.txt* consists of $1 + |C_p|$ rows for $p \in NP$. The first row contains short name of the parent node p . Each row from the next $|C_p|$ rows contains charging times ct_{pbc} of e-buses at charging station of type $c \in C_p$ for each $b \in C_b$. For example:

V

6,6,10,6,40,30

File *croutes.txt* is created only if there are routes that are already served by the e-buses. It describes charging stations that have already been opened at the nodes belonging to the routes from R . It consists of two rows for each route. The first row contains short name of the route r . The second row contains short names of the charging stations opened at the corresponding parent node for each node from $\pi_r = (j_0, j_1, \dots, j_r)$. If no station is opened for some node j_k , then symbols "-1" are used as the short name. For example:

A1

CS1,CS1,-1

File *tdepots.txt* consists of one row for each element from the set ND of depot nodes. The row for node j contains short name of the depot node and the duration t_j^{depot} in minutes. For example:

Vaneeva-D,240

File *stops obl.txt* consists of two rows for each set NM_b of "obligatory" nodes for e-bus of type b . The first row contains only the short name of the e-bus type b . The second row contains

short names of the nodes $j \in NN$. If node j belongs to a route to be served by an e-bus of type b , then at least one charging station of type $c \in C_b$ must be opened at node $p(j)$. For example:

E433

Kira-D, Vias-S

File *buses1* consists of one row with short names of e-bus types from the set B_1 associated with batteries having enough capacity to drive with a single charge at a depot during the day. For example:

E420

File *buses2.txt* consists of one row with short names of e-bus types from the set B_2 associated with batteries having enough capacity to drive with one charge at a depot and one charge at a non-depot node during the day. For example:

E333

3 Formats of output files

Two formats of the output file are implemented. One of them is the JSON format, and the second is a simple text format.

3.1 Output file in JSON format

Object *Solutions* defines output objects CR and X for each of the obtained solutions. The object CR defines values of the following parameters: V – total value $V(X)$, CC – total capital cost $CC(X)$, and OC – total operating, depreciation and energy cost $OC(X)$. For example:

$\{ \text{"CR"} : \{ \text{"V"}: 1260, \text{"CC"}: 7.88e+006, \text{"OC"}: 3.01224e+006 \} \}$

Object X defines values of the following parameters: R_X – routes selected for the introduction of e-buses and their parameters, S – charging stations to be opened and transformers to be built, and T – power requirements for the transformers.

Object R_X defines values of the following parameters for each route r : r – full name of the route, ATE_r – length of the traffic interval, Z_r – total passenger demand to be satisfied by the new e-buses, NV_r – total number of new buses, B_r – full names of the e-bus types, NV_{rb} – numbers of new e-buses of each type b , CH – nodes where new e-buses will be charged for each route and e-bus type, t – recommended departure order for all the vehicles. For example:

$\{ \text{"R_X"}: [\{ \text{"r"}: \text{"Slavinskogo - Old Airport"}, \text{"ATE_r"}: 7, \text{"Z_r"}: 1260, \text{"NV_r"}: 16, \text{"B_r"}: [\text{"Vitovt Electro E420"}, \text{"Model E321"}, \text{"Vitovt Mini Electro E490"}], \text{"NV_rb"}: [1, 6, 9], \text{"CH"}: [\{ \text{"b"}: \text{"Vitovt Electro E420"}, \text{"Nbc_r"}: [\{ \text{"c"}: \text{"Charging station 1"}, \text{"j"}: \text{"Kazlova-Depot(Kazlova)} \}, \{ \text{"c"}: \text{"Charging station 1"}, \text{"j"}: \text{"KalSlav-Terminal(KalSlav)} \}, \{ \text{"c"}: \text{"Charging station 1"}, \text{"j"}: \text{"Aera1-Terminal(Aera1)} \}]], \text{"t"}: [\text{"E321"}, \text{"E490"},$

"E490", "E321", "E490", "E490", "E321", "E490", "E321", "E420", "E490", "E490", "E321", "E490", "E490", "E321"] }] }

Object *S* defines values of the following parameters: *p* – full name of the parent node *p*, *c* – full type names of new charging stations, *NC_pc* – numbers of new charging stations, *L_p* – full names of transformer types to be connected with the parent node. For example:

{ "S": [{"p": "Kazlova", "c": ["Charging station 1"], "NC_pc": [1], "L_p": ["Kazlova-Transformer 1", "Kazlova-Transformer 2"]}] }

Object *T* defines the list of full names of the types of new transformers. For example:

{ "T": ["Vaneeva-Transformer 1", "Vaneeva-Transformer 2"] }

Object *TP* defines values of the following parameters: *q* – full name of the transformer type, and *TP_q* – total transformer power requirement. For example:

{ "TP": [{"q": "Vaneeva-Transformer 1", "TP_q": 200}, {"q": "Vaneeva-Transformer 2", "TP_q": 200}] }

3.2 Output files in text format

All the obtained solutions are placed into the unique file *solution.out*. The output for each solution includes: values $V(x)$, $CC(x)$ and $OC(x)$; selected routes for the introduction of e-buses; places for new charging stations and transformers; power requirement for each transformer.

For each selected route, the output is:

- Sequence of stops.
- Selected e-bus types.
- Numbers of new e-buses of each type.
- Total passenger capacity of new e-buses.
- Capital cost of new e-buses.
- Operating and energy cost of new e-buses.
- Conventional vehicle types remained in operation.
- Numbers of the remained conventional vehicles of each type.
- Average length of the traffic interval for all vehicles serving the route.
- Parent nodes at which new charging stations have to be opened.
- Recommended departure order of all the vehicles.

4 Input files for Minsk case

4.1 Input file *problem.json* for Minsk case

```
{
  "probl":
  {
    "m": 2,
    "ucc": 1e+007,
    "uoc": 5e+006,
    "dtp": 180,
    "form_ind": 1
  }
,
  "stations":
  {
    "C": [
      {
        "fn_c": "Charging station 1",
        "sn_c": "CS1",
        "po_c": 200,
        "cc_cap_c": 250000,
        "cc_ope_c": 5000
      }
    ]
  }
,
  "e-buses":
  {
    "B": [
      {
        "fn_b": "Vitovt Max Electro E433",
        "sn_b": "E433",
        "cap_b": 153,
        "cv_cap_b": 475000,
        "C_b": ["CS1"]
      }
    ]
  }
,
  {
    "fn_b": "Vitovt Electro E420",
    "sn_b": "E420",
    "cap_b": 87,
    "cv_cap_b": 350000,
    "C_b": ["CS1"]
  }
,
  {
    "fn_b": "Model E321",
    "sn_b": "E321",
    "cap_b": 83,
    "cv_cap_b": 400000,
    "C_b": ["CS1"]
  }
,
  {
    "fn_b": "Vitovt Mini Electro E490",
    "sn_b": "E490",
    "cap_b": 75,
    "cv_cap_b": 400000,
    "C_b": ["CS1"]
  }
}
```

```
,
{
  "fn_b": "Trolleybus 32100D",
  "sn_b": "T32100D",
  "cap_b": 85,
  "cv_cap_b": 370000,
  "C_b": ["CS1"]
}
,
{
  "fn_b": "Trolleybus 42003D",
  "sn_b": "T42003D",
  "cap_b": 85,
  "cv_cap_b": 400000,
  "C_b": ["CS1"]
}
]}
,
"vehicles":
{
  "VC": [{
    "fn_b": "Diesel bus MAZ-103",
    "sn_b": "M103",
    "cap_b": 100
  }
  ,
  {
    "fn_b": "Diesel bus MAZ-1035",
    "sn_b": "M1035",
    "cap_b": 160
  }
  ,
  {
    "fn_b": "Trolleybus model 420",
    "sn_b": "T420",
    "cap_b": 115
  }
  ,
  {
    "fn_b": "Trolleybus model 333",
    "sn_b": "T333",
    "cap_b": 170
  }
  ]
}
,
"charging stops":
{
  "NP": [{
    "fn_p": "Vaneeva",
    "sn_p": "V",
    "C_p": ["CS1"],
    "nc_pc": [1],
    "uc_pc": [4]
  }
  ,
  {
    "fn_p": "Kirava",
    "sn_p": "Kira",

```

```
"C_p": ["CS1"],
"nc_pc": [1],
"uc_pc": [4]
},
{
"fn_p": "Viasnjanka",
"sn_p": "Vias",
"C_p": ["CS1"],
"nc_pc": [1],
"uc_pc": [4]
},
{
"fn_p": "Akvapark",
"sn_p": "Akva",
"C_p": ["CS1"],
"nc_pc": [0],
"uc_pc": [4]
},
{
"fn_p": "RKMC",
"sn_p": "RKMC",
"C_p": ["CS1"],
"nc_pc": [0],
"uc_pc": [4]
},
{
"fn_p": "Ch.Rinok",
"sn_p": "Ch.Ri",
"C_p": ["CS1"],
"nc_pc": [0],
"uc_pc": [4]
},
{
"fn_p": "Loshica2",
"sn_p": "Losh2",
"C_p": ["CS1"],
"nc_pc": [0],
"uc_pc": [4]
},
{
"fn_p": "Masukovscina",
"sn_p": "Masu",
"C_p": ["CS1"],
"nc_pc": [0],
"uc_pc": [4]
},
{
}
```

```
"fn_p": "V",
"sn_p": "VS",
"C_p": ["CS1"],
"nc_pc": [0],
"uc_pc": [4]
}
{
"fn_p": "DS Searjabrjanka",
"sn_p": "DS Sera",
"C_p": ["CS1"],
"nc_pc": [0],
"uc_pc": [4]
}
{
"fn_p": "AV Centralny",
"sn_p": "AV Ca",
"C_p": ["CS1"],
"nc_pc": [0],
"uc_pc": [4]
}
{
"fn_p": "YgoZapad",
"sn_p": "YZap",
"C_p": ["CS1"],
"nc_pc": [0],
"uc_pc": [4]
}
{
"fn_p": "Daugbrodskaja",
"sn_p": "Daug",
"C_p": ["CS1"],
"nc_pc": [1],
"uc_pc": [4]
}
{
"fn_p": "Siarova",
"sn_p": "Siar",
"C_p": ["CS1"],
"nc_pc": [1],
"uc_pc": [4]
}
{
"fn_p": "Druznaja",
"sn_p": "Druz",
"C_p": ["CS1"],
"nc_pc": [1],
"uc_pc": [4]
}
```

```
,
{
  "fn_p": "Karastojanovoy",
  "sn_p": "Kara",
  "C_p": ["CS1"],
  "nc_pc": [0],
  "uc_pc": [4]
}
,
{
  "fn_p": "Kazlova",
  "sn_p": "K",
  "C_p": ["CS1"],
  "nc_pc": [0],
  "uc_pc": [4]
}
,
{
  "fn_p": "Suharevo5",
  "sn_p": "Suh5",
  "C_p": ["CS1"],
  "nc_pc": [0],
  "uc_pc": [4]
}
,
{
  "fn_p": "Malinovka4",
  "sn_p": "Mal4",
  "C_p": ["CS1"],
  "nc_pc": [0],
  "uc_pc": [4]
}
,
{
  "fn_p": "Kalinovskogo",
  "sn_p": "KalSlav",
  "C_p": ["CS1"],
  "nc_pc": [0],
  "uc_pc": [4]
}
,
{
  "fn_p": " Aeropr t 1",
  "sn_p": "Aera1",
  "C_p": ["CS1"],
  "nc_pc": [0],
  "uc_pc": [4]
}
,
{
  "fn_p": "Vesninka",
  "sn_p": "Vsnin",
  "C_p": ["CS1"],
  "nc_pc": [0],
```

```
"uc_pc": [4]
},
{
  "fn_p": "Liabjagiy",
  "sn_p": "Liab",
  "C_p": ["CS1"],
  "nc_pc": [0],
  "uc_pc": [4]
},
{
  "fn_p": "Pl.Y.Kolasa",
  "sn_p": "Pl.Y.Kol",
  "C_p": ["CS1"],
  "nc_pc": [0],
  "uc_pc": [4]
},
{
  "fn_p": "Zdanovichi",
  "sn_p": "Zdan",
  "C_p": ["CS1"],
  "nc_pc": [0],
  "uc_pc": [4]
}
]}
"stops":
{ "NN": [{
  "fn_j": "Vaneeva-Depot",
  "sn_j": "Vaneeva-D",
  "sn_j_p": "V",
  "type_j": 1
},
{
  "fn_j": "Kazlova-Depot",
  "sn_j": "Kazlova-D",
  "sn_j_p": "K",
  "type_j": 1
},
{
  "fn_j": "Kira-Terminal",
  "sn_j": "Kira-T",
  "sn_j_p": "Kira",
  "type_j": 2
},
{
  "fn_j": "Vias-Terminal",
  "sn_j": "Vias-T",
  "sn_j_p": "Vias",
  "type_j": 2
}
```

```
}  
,  
{  
  "fn_j": "Akva-Terminal",  
  "sn_j": "Akva-T",  
  "sn_j-p": "Akva",  
  "type_j": 2  
}  
,  
{  
  "fn_j": "RKMC-Terminal",  
  "sn_j": "RKMC-T",  
  "sn_j-p": "RKMC",  
  "type_j": 2  
}  
,  
{  
  "fn_j": "Ch.Ri-Terminal",  
  "sn_j": "Ch.Ri-T",  
  "sn_j-p": "Ch.Ri",  
  "type_j": 2  
}  
,  
{  
  "fn_j": "Losh2-Terminal",  
  "sn_j": "Losh2-T",  
  "sn_j-p": "Losh2",  
  "type_j": 2  
}  
,  
{  
  "fn_j": "Masu-Terminal",  
  "sn_j": "Masu-T",  
  "sn_j-p": "Masu",  
  "type_j": 2  
}  
,  
{  
  "fn_j": "DS Sera-Terminal",  
  "sn_j": "DS Sera-T",  
  "sn_j-p": "DS Sera",  
  "type_j": 2  
}  
,  
{  
  "fn_j": "YZap-Terminal",  
  "sn_j": "YZap-T",  
  "sn_j-p": "YZap",  
  "type_j": 2  
}  
,  
{  
  "fn_j": "AV Ca-Terminal",  
  "sn_j": "AV Ca-T",  
  "sn_j-p": "AV Ca",  
  "type_j": 2
```



```
}  
,  
{  
  "fn_j": "Daug-Terminal",  
  "sn_j": "Daug-T",  
  "sn_j_p": "Daug",  
  "type_j": 2  
}  
,  
{  
  "fn_j": "Siar-Terminal",  
  "sn_j": "Siar-T",  
  "sn_j_p": "Siar",  
  "type_j": 2  
}  
,  
{  
  "fn_j": "Druz-Terminal",  
  "sn_j": "Druz-T",  
  "sn_j_p": "Druz",  
  "type_j": 2  
}  
,  
{  
  "fn_j": "Kara-Terminal",  
  "sn_j": "Kara-T",  
  "sn_j_p": "Kara",  
  "type_j": 2  
}  
,  
{  
  "fn_j": "Suh5-Terminal",  
  "sn_j": "Suh5-T",  
  "sn_j_p": "Suh5",  
  "type_j": 2  
}  
,  
{  
  "fn_j": "Mal4-Terminal",  
  "sn_j": "Mal4-T",  
  "sn_j_p": "Mal4",  
  "type_j": 2  
}  
,  
{  
  "fn_j": "KalSlav-Terminal",  
  "sn_j": "KalSlav-T",  
  "sn_j_p": "KalSlav",  
  "type_j": 2  
}  
,  
{  
  "fn_j": "Aera1-Terminal",  
  "sn_j": "Aera1-T",  
  "sn_j_p": "Aera1",  
  "type_j": 2  
}
```

```
}  
,  
{  
  "fn_j": "Vsnin-Terminal",  
  "sn_j": "Vsnin-T",  
  "sn_j_p": "Vsnin",  
  "type_j": 2  
}  
,  
{  
  "fn_j": "Liab-Terminal",  
  "sn_j": "Liab-T",  
  "sn_j_p": "Liab",  
  "type_j": 2  
}  
,  
{  
  "fn_j": "Pl.Y.Kol-Terminal",  
  "sn_j": "Pl.Y.Kol-T",  
  "sn_j_p": "Pl.Y.Kol",  
  "type_j": 2  
}  
,  
{  
  "fn_j": "Zdan-Terminal",  
  "sn_j": "Zdan-T",  
  "sn_j_p": "Zdan",  
  "type_j": 2  
}  
,  
{  
  "fn_j": "Vias-Stop",  
  "sn_j": "Vias-S",  
  "sn_j_p": "Vias",  
  "type_j": 3  
}  
,  
{  
  "fn_j": "Vias-Stop-2",  
  "sn_j": "Vias-S2",  
  "sn_j_p": "Vias",  
  "type_j": 3  
}  
,  
{  
  "fn_j": "Ch.Ri-Stop",  
  "sn_j": "Ch.Ri-S",  
  "sn_j_p": "Ch.Ri",  
  "type_j": 3  
}  
,  
{  
  "fn_j": "Ch.Ri-Stop-2",  
  "sn_j": "Ch.Ri-S2",  
  "sn_j_p": "Ch.Ri",  
  "type_j": 3  
}
```

```
}
,
{
  "fn_j": "V-Stop",
  "sn_j": "V-S",
  "sn_j_p": "V",
  "type_j": 3
}
,
{
  "fn_j": "V-Stop-2",
  "sn_j": "V-S2",
  "sn_j_p": "V",
  "type_j": 3
}
,
{
  "fn_j": "AV Ca-Stop",
  "sn_j": "AV Ca-S",
  "sn_j_p": "AV Ca",
  "type_j": 3
}
,
{
  "fn_j": "AV Ca-Stop-2",
  "sn_j": "AV Ca-S2",
  "sn_j_p": "AV Ca",
  "type_j": 3
}
,
{
  "fn_j": "Druz-Stop",
  "sn_j": "Druz-S",
  "sn_j_p": "Druz",
  "type_j": 3
}
,
{
  "fn_j": "Druz-Stop-2",
  "sn_j": "Druz-S2",
  "sn_j_p": "Druz",
  "type_j": 3
}
}]
,
"transformers":
{
  "EE": [{
    "fn_q": "Vaneeva-Transformer 1",
    "sn_q": "Vaneeva-T1",
    "o_q": 800,
    "cb_q": 0,
    "oo_q": 200,
    "sn_qp": ["V"],
    "cl_qp": [0]
  }
  ],
,
```

```
{
  "fn_q": "Vaneeva-Transformer 2",
  "sn_q": "Vaneeva-T2",
  "o_q": 800,
  "cb_q": 0,
  "oo_q": 200,
  "sn_qp": ["V"],
  "cl_qp": [0]
},
{
  "fn_q": "Kira-Transformer 1",
  "sn_q": "Kira-T1",
  "o_q": 800,
  "cb_q": 0,
  "oo_q": 200,
  "sn_qp": ["Kira"],
  "cl_qp": [0]
},
{
  "fn_q": "Kira-Transformer 2",
  "sn_q": "Kira-T2",
  "o_q": 800,
  "cb_q": 0,
  "oo_q": 200,
  "sn_qp": ["Kira"],
  "cl_qp": [0]
},
{
  "fn_q": "Vias-Transformer 1",
  "sn_q": "Vias-T1",
  "o_q": 800,
  "cb_q": 0,
  "oo_q": 200,
  "sn_qp": ["Vias"],
  "cl_qp": [0]
},
{
  "fn_q": "Vias-Transformer 2",
  "sn_q": "Vias-T2",
  "o_q": 800,
  "cb_q": 0,
  "oo_q": 200,
  "sn_qp": ["Vias"],
  "cl_qp": [0]
},
{
  "fn_q": "Akva-Transformer 1",
  "sn_q": "Akva-T1",
  "o_q": 800,
  "cb_q": 200000,
```

```
"oo_q": 0,
"sn_qp": ["Akva"],
"cl_qp": [5000]
},
{
"fn_q": "Akva-Transformer 2",
"sn_q": "Akva-T2",
"o_q": 800,
"cb_q": 200000,
"oo_q": 0,
"sn_qp": ["Akva"],
"cl_qp": [5000]
},
{
"fn_q": "RKMC-Transformer 1",
"sn_q": "RKMC-T1",
"o_q": 800,
"cb_q": 200000,
"oo_q": 0,
"sn_qp": ["RKMC"],
"cl_qp": [5000]
},
{
"fn_q": "RKMC-Transformer 2",
"sn_q": "RKMC-T2",
"o_q": 800,
"cb_q": 200000,
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  "ce_rb": [268880,209520,209520,168400,209520,209520],
  "d_rb": [60,60,60,60,60,60],
  "do_rb": [0,0,0,0,0,0],
  "VC_r": ["M103", "M1035"],
  "nvc_rb": [2,2],
  "doc_rb": [60,60]
```

```
}
{
  "fn_r": "Suharveo - DS Drugnaja",
  "sn_r": "A50c",
  "w_r": 1,
  "ut_r": 30,
  "s_r": ["Kazlova-D", "Suh5-T", "Druz-T", "Suh5-T"],
  "l_r": [7,15,15],
  "B_r": ["E433", "E420", "E321", "E490", "T32100D", "T42003D"],
  "nbo_rb": [0,0,0,0,0,0],
  "dm_rb": [15,20,30,25,16,15],
  "ce_rb": [268880,209520,209520,168400,209520,209520],
  "d_rb": [100,100,100,100,100,100],
  "do_rb": [0,0,0,0,0,0],
  "VC_r": ["M103", "M1035"],
  "nvc_rb": [3,3],
  "doc_rb": [100,100]
}
{
  "fn_r": "AV Centralny - DS Suharevo-5 ",
  "sn_r": "T7",
  "w_r": 1,
  "ut_r": 28,
  "s_r": ["Kazlova-D", "Suh5-T", "AV Ca-T", "Suh5-T"],
  "l_r": [7,14,14],
  "B_r": ["E433", "E420", "E321", "E490", "T32100D", "T42003D"],
  "nbo_rb": [0,0,0,0,0,0],
  "dm_rb": [15,20,30,25,16,15],
  "ce_rb": [268880,209520,209520,168400,209520,209520],
  "d_rb": [90,90,90,90,90,90],
  "do_rb": [0,0,0,0,0,0],
  "VC_r": ["T420", "T333"],
  "nvc_rb": [2,4],
  "doc_rb": [90,90]
}
{
  "fn_r": "DS Drugnaja - DS Suharevo-5 ",
  "sn_r": "T9",
  "w_r": 1,
  "ut_r": 26,
  "s_r": ["Kazlova-D", "Suh5-T", "Druz-T", "Suh5-T"],
  "l_r": [7,13,13],
  "B_r": ["E433", "E420", "E321", "E490", "T32100D", "T42003D"],
  "nbo_rb": [0,0,0,0,0,0],
  "dm_rb": [15,20,30,25,16,15],
  "ce_rb": [268880,209520,209520,168400,209520,209520],
  "d_rb": [80,80,80,80,80,80],
  "do_rb": [0,0,0,0,0,0],
  "VC_r": ["T420", "T333"],
  "nvc_rb": [1,3],
}
```

```
"doc.rb": [80,80]
}
,
{
  "fn_r": "DS Malinovka-4 - DS Drugnaja ",
  "sn_r": "A32c",
  "w_r": 1,
  "ut_r": 28,
  "s_r": ["Kazlova-D", "Mal4-T", "Druz-T", "Mal4-T"],
  "l_r": [7,14,14],
  "B_r": ["E433", "E420", "E321", "E490", "T32100D", "T42003D"],
  "nbo.rb": [0,0,0,0,0,0],
  "dm.rb": [15,20,30,25,16,15],
  "ce.rb": [268880,209520,209520,168400,209520,209520],
  "d.rb": [90,90,90,90,90,90],
  "do.rb": [0,0,0,0,0,0],
  "VC_r": ["M103", "M1035"],
  "nvc.rb": [3,6],
  "doc.rb": [90,90]
}
,
{
  "fn_r": "Slavinskogo - Old Airport",
  "sn_r": "A100",
  "w_r": 1,
  "ut_r": 24,
  "s_r": ["Kazlova-D", "KalSlav-T", "Aera1-T", "KalSlav-T"],
  "l_r": [7,12,12],
  "B_r": ["E433", "E420", "E321", "E490", "T32100D", "T42003D"],
  "nbo.rb": [0,0,0,0,0,0],
  "dm.rb": [15,20,30,25,16,15],
  "ce.rb": [268880,209520,209520,168400,209520,209520],
  "d.rb": [90,90,90,90,90,90],
  "do.rb": [0,0,0,0,0,0],
  "VC_r": ["M103", "M1035"],
  "nvc.rb": [3,6],
  "doc.rb": [90,90]
}
,
{
  "fn_r": "DS Kalinovskogo - Vesninka",
  "sn_r": "A91",
  "w_r": 1,
  "ut_r": 40,
  "s_r": ["Kazlova-D", "Vsnin-T", "Vias-S", "KalSlav-T", "Vias-S2", "Vsnin-T"],
  "l_r": [7,2,18,18,2],
  "B_r": ["E420", "E321", "E490"],
  "nbo.rb": [0,0,0],
  "dm.rb": [20,30,25],
  "ce.rb": [9520,9520,8400],
  "d.rb": [140,140,140],
  "do.rb": [0,0,0],
  "VC_r": ["M103", "M1035"],
```

```
"nvc_rb": [2,5],
"doc_rb": [140,140]
}
{
  "fn_r": "DS Siarova - Liabjagiy",
  "sn_r": "A73",
  "w_r": 1,
  "ut_r": 36,
  "s_r": ["Kazlova-D", "Siar-T", "Druz-S", "Vias-S", "Liab-T", "Vias-S2", "Druz-S2", "Siar-T"],
  "l_r": [7,7,9,2,2,9,7],
  "B_r": ["E433", "E420", "E321", "E490", "T32100D", "T42003D"],
  "nbo_rb": [0,0,0,0,0,0],
  "dm_rb": [15,20,30,25,16,15],
  "ce_rb": [268880,209520,209520,168400,209520,209520],
  "d_rb": [120,120,120,120,120,120],
  "do_rb": [0,0,0,0,0,0],
  "VC_r": ["M103", "M1035"],
  "nvc_rb": [5,7],
  "doc_rb": [120,120]
}
{
  "fn_r": "DS Karastojanovoy - Pl.Y.Kolasa",
  "sn_r": "T22",
  "w_r": 1,
  "ut_r": 12,
  "s_r": ["Kazlova-D", "Kara-T", "Pl.Y.Kol-T", "Kara-T"],
  "l_r": [7,6,6],
  "B_r": ["E433", "E420", "E321", "E490", "T32100D", "T42003D"],
  "nbo_rb": [0,0,0,0,0,0],
  "dm_rb": [15,20,30,25,16,15],
  "ce_rb": [268880,209520,209520,168400,209520,209520],
  "d_rb": [40,40,40,40,40,40],
  "do_rb": [0,0,0,0,0,0],
  "VC_r": ["T420"],
  "nvc_rb": [3],
  "doc_rb": [40]
}
{
  "fn_r": "DS Karastojanovoy - Zdanovichi Station",
  "sn_r": "A44",
  "w_r": 1,
  "ut_r": 50,
  "s_r": ["Kazlova-D", "Kara-T", "Vias-S", "Zdan-T", "Vias-S2", "Kara-T"],
  "l_r": [7,9,16,16,9],
  "B_r": ["E420", "E321", "E490"],
  "nbo_rb": [0,0,0],
  "dm_rb": [20,30,25],
  "ce_rb": [9520,9520,8400],
  "d_rb": [100,100,100],
  "do_rb": [0,0,0],
```

```
"VC_r": ["M103","M1035"],
"nvc_rb": [2,5],
"doc_rb": [100,100]
}
,
{
"fn_r": "DS Karastojanovoy - Zdanovichi Health Center",
"sn_r": "A136",
"wr": 1,
"ut_r": 52,
"sr": ["Kazlova-D","Kara-T","Vias-S","Zdan-T","Vias-S2","Kara-T"],
"lr": [7,9,17,17,9],
"Br": ["E420","E321","E490"],
"nbo_rb": [0,0,0],
"dm_rb": [20,30,25],
"ce_rb": [9520,9520,8400],
"drb": [110,110,110],
"do_rb": [0,0,0],
"VC_r": ["M103","M1035"],
"nvc_rb": [1,2],
"doc_rb": [110,110]
}
,
{
"fn_r": "DS Suharevo-5 - Kalinovskogo",
"sn_r": "T38",
"wr": 1,
"ut_r": 42,
"sr": ["Kazlova-D","Suh5-T","KalSlav-T","Suh5-T"],
"lr": [7,21,21],
"Br": ["E321","E490"],
"nbo_rb": [0,0],
"dm_rb": [30,25],
"ce_rb": [9520,8400],
"drb": [140,140],
"do_rb": [0,0],
"VC_r": ["T420","T333"],
"nvc_rb": [6,8],
"doc_rb": [140,140]
}
]}
,
{
"charging times":
{
"CT_NP": [{
"sn_p": "V",
"ct_pb_1": [6,6,10,6,40,30]
}
,
{
"sn_p": "Kira",
"ct_pb_1": [6,6,10,6,40,30]
}
}
,
{

```

```
"sn_p": "Vias",
"ct_pb_1": [6,6,10,6,40,30]
},
{
"sn_p": "Akva",
"ct_pb_1": [6,6,10,6,40,30]
},
{
"sn_p": "RKMC",
"ct_pb_1": [6,6,10,6,40,30]
},
{
"sn_p": "Ch.Ri",
"ct_pb_1": [6,6,10,6,40,30]
},
{
"sn_p": "Losh2",
"ct_pb_1": [6,6,10,6,40,30]
},
{
"sn_p": "Masu",
"ct_pb_1": [6,6,10,6,40,30]
},
{
"sn_p": "VS",
"ct_pb_1": [6,6,10,6,40,30]
},
{
"sn_p": "DS Sera",
"ct_pb_1": [6,6,10,6,40,30]
},
{
"sn_p": "AV Ca",
"ct_pb_1": [6,6,10,6,40,30]
},
{
"sn_p": "YZap",
"ct_pb_1": [6,6,10,6,40,30]
},
{
"sn_p": "Daug",
"ct_pb_1": [6,6,10,6,40,30]
},
{
"sn_p": "Siar",
```

```
"ct_pb_1": [6,6,10,6,40,30]
}
,
{
"sn_p": "Druz",
"ct_pb_1": [6,6,10,6,40,30]
}
,
{
"sn_p": "Kara",
"ct_pb_1": [6,6,10,6,40,30]
}
,
{
"sn_p": "K",
"ct_pb_1": [6,6,10,6,40,30]
}
,
{
"sn_p": "Suh5",
"ct_pb_1": [6,6,10,6,40,30]
}
,
{
"sn_p": "Mal4",
"ct_pb_1": [6,6,10,6,40,30]
}
,
{
"sn_p": "KalSlav",
"ct_pb_1": [6,6,10,6,40,30]
}
,
{
"sn_p": "Aera1",
"ct_pb_1": [6,6,10,6,40,30]
}
,
{
"sn_p": "Vsnin",
"ct_pb_1": [6,6,10,6,40,30]
}
,
{
"sn_p": "Liab",
"ct_pb_1": [6,6,10,6,40,30]
}
,
{
"sn_p": "Pl.Y.Kol",
"ct_pb_1": [6,6,10,6,40,30]
}
,
{
"sn_p": "Zdan",
"ct_pb_1": [6,6,10,6,40,30]
}
```

```
}  
}  
,  
"stations routes":  
{ "CO": [{  
  "sn_r": "A1",  
  "c_r": ["CS1", "CS1", "CS1"]  
},  
{  
  "sn_r": "T59",  
  "c_r": ["CS1", "CS1", "CS1"]  
},  
{  
  "sn_r": "T43",  
  "c_r": ["CS1", "CS1", "CS1"]  
}]  
,  
"depots":  
{ "ND": [{  
  "sn_j": "Vaneeva-D",  
  "t_depot_j": 240  
},  
{  
  "sn_j": "Kazlova-D",  
  "t_depot_j": 240  
}]  
}
```

4.2 Input text files for Minsk case

4.2.1 File "probl.txt"

This file consists of one row containing parameters m , ucc , uoc and dtp . The row is
2,1e+007,5e+006,180,1

4.2.2 File "stations.txt"

This file consists of one row containing parameters Full name, Short name, Nominal power, Capital cost and Operating cost for each charging station type. For Minsk case, there is a single charging station type and the corresponding row is

Charging station 1,CS1,200,250000,5000

4.2.3 File "buses.txt"

This file consists of two rows for each e-bus type. The first row contains parameters Full name, Short name, Passenger capacity and Capital cost for each e-bus type. The second row contains parameters Short name of charging station 1, ..., Short name of charging station n . For Minsk case, there are six e-bus types and the corresponding rows are:

Vitovt Max Electro E433,E433,153,475000

CS1

Vitovt Electro E420,E420,87,350000

CS1
Model E321,E321,83,400000
CS1
Vitovt Mini Electro E490,E490,75,400000
CS1
Trolleybus 32100D,T32100D,85,370000
CS1
Trolleybus 42003D,T42003D,85,400000
CS1

4.2.4 File "cbuses.txt"

This file consists of one row for each conventional vehicle type. The row contains parameters Full name, Short name and Capacity. For Minsk case, there are four conventional vehicle types and the corresponding rows are:

Diesel bus MAZ-103,M103,100
Diesel bus MAZ-1035,M1035,160
Trolleybus model 420,T420,115
Trolleybus model 333,T333,170

4.2.5 File "graph.txt"

This file consists of one row for each stop. The row contains parameters Full name, Short name and Type $\in \{1, 2, 3\}$, where 1, 2 and 3 denote depot, terminal and en route stop, respectively. For Minsk case, the corresponding rows are:

Vaneeva-Depot,Vaneeva-D,V,1
Kazlova-Depot,Kazlova-D,K,1
Kira-Terminal,Kira-T,Kira,2
Vias-Terminal,Vias-T,Vias,2
Akva-Terminal,Akva-T,Akva,2
RKMC-Terminal,RKMC-T,RKMC,2
Ch.Ri-Terminal,Ch.Ri-T,Ch.Ri,2
Losh2-Terminal,Losh2-T,Losh2,2
Masu-Terminal,Masu-T,Masu,2
DS Sera-Terminal,DS Sera-T,DS Sera,2
YZap-Terminal,YZap-T,YZap,2
AV Ca-Terminal,AV Ca-T,AV Ca,2
Daug-Terminal,Daug-T,Daug,2
Siar-Terminal,Siar-T,Siar,2
Druz-Terminal,Druz-T,Druz,2
Kara-Terminal,Kara-T,Kara,2
Suh5-Terminal,Suh5-T,Suh5,2
Mal4-Terminal,Mal4-T,Mal4,2
KalSlav-Terminal,KalSlav-T,KalSlav,2
Aera1-Terminal,Aera1-T,Aera1,2
Vsnin-Terminal,Vsnin-T,Vsnin,2
Liab-Terminal,Liab-T,Liab,2
Pl.Y.Kol-Terminal,Pl.Y.Kol-T,Pl.Y.Kol,2
Zdan-Terminal,Zdan-T,Zdan,2
Vias-Stop,Vias-S,Vias,3
Vias-Stop-2,Vias-S2,Vias,3
Ch.Ri-Stop,Ch.Ri-S,Ch.Ri,3
Ch.Ri-Stop-2,Ch.Ri-S2,Ch.Ri,3
V-Stop,V-S,V,3
V-Stop-2,V-S2,V,3
AV Ca-Stop,AV Ca-S,AV Ca,3
AV Ca-Stop-2,AV Ca-S2,AV Ca,3

Druz-Stop,Druz-S,Druz,3
Druz-Stop-2,Druz-S2,Druz,3

4.2.6 File "transf.txt"

This file consists of three rows for each transformer. The first row contains parameters Full name, Short name, Transformer power, Capital cost and Used power. The second row contains short names of parent nodes connected with the transformer. The third row contains connection costs for the parent nodes in the second row. The cost is equal to zero if the corresponding connection exists. For Minsk case, the three rows for each transformer are:

```
Vaneeva-Transformer 1,Vaneeva-T1,800,0,200
V
0
Vaneeva-Transformer 2,Vaneeva-T2,800,0,200
V
0
Kira-Transformer 1,Kira-T1,800,0,200
Kira
0
Kira-Transformer 2,Kira-T2,800,0,200
Kira
0
Vias-Transformer 1,Vias-T1,800,0,200
Vias
0
Vias-Transformer 2,Vias-T2,800,0,200
Vias
0
Akva-Transformer 1,Akva-T1,800,200000,0
Akva
5000
Akva-Transformer 2,Akva-T2,800,200000,0
Akva
5000
RKMC-Transformer 1,RKMC-T1,800,200000,0
RKMC
5000
RKMC-Transformer 2,RKMC-T2,800,200000,0
RKMC
5000
Ch.Ri-Transformer 1,Ch.Ri-T1,800,0,0
Ch.Ri
5000
Ch.Ri-Transformer 2,Ch.Ri-T2,800,0,0
Ch.Ri
5000
Losh2-Transformer 1,Losh2-T1,800,0,0
Losh2
5000
Losh2-Transformer 2,Losh2-T2,800,0,0
Losh2
5000
Masu-Transformer 1,Masu-T1,800,0,0
Masu
5000
Masu-Transformer 2,Masu-T2,800,0,0
Masu
5000
V-Transformer 1,V-T1,800,200000,0
V
5000
V-Transformer 2,V-T2,800,200000,0
V
5000
DS Sera-Transformer 1,DS Sera-T1,800,0,0
```

DS Sera
5000
DS Sera-Transformer 2,DS Sera-T2,800,0,0
DS Sera
5000
AV Ca-Transformer 1,AV Ca-T1,800,200000,0
AV Ca
5000
AV Ca-Transformer 2,AV Ca-T2,800,200000,0
AV Ca
5000
YZap-Transformer 1,YZap-T1,800,0,0
YZap
5000
YZap-Transformer 2,YZap-T2,800,0,0
YZap
5000
Daug-Transformer 1,Daug-T1,800,0,200
Daug
0
Daug-Transformer 2,Daug-T2,800,0,200
Daug
0
Siar-Transformer 1,Siar-T1,800,0,200
Siar
0
Siar-Transformer 2,Siar-T2,800,0,200
Siar
0
Druz-Transformer 1,Druz-T1,800,0,200
Druz
0
Druz-Transformer 2,Druz-T2,800,0,200
Druz
0
Kara-Transformer 1,Kara-T1,800,0,0
Kara
5000
Kara-Transformer 2,Kara-T2,800,0,0
Kara
5000
Kazlova-Transformer 1,Kazlova-T1,800,0,0
K
5000
Kazlova-Transformer 2,Kazlova-T2,800,0,0
K
5000
Suh5-Transformer 1,Suh5-T1,800,0,0
Suh5
5000
Suh5-Transformer 2,Suh5-T2,800,0,0
Suh5
5000
Mal4-Transformer 1,Mal4-T1,800,0,0
Mal4
5000
Mal4-Transformer 2,Mal4-T2,800,0,0
Mal4
5000
KalSlav-Transformer 1,KalSlav-T1,800,0,0
KalSlav
5000
KalSlav-Transformer 2,KalSlav-T2,800,0,0
KalSlav
5000
Aera1-Transformer 1,Aera1-T1,800,0,0

```

Aera1
5000
Aera1-Transformer 2,Aera1-T2,800,0,0
Aera1
5000
Vsnin-Transformer 1,Vsnin-T1,800,200000,0
Vsnin
5000
Vsnin-Transformer 2,Vsnin-T2,800,200000,0
Vsnin
5000
Liab-Transformer 1,Liab-T1,800,200000,0
Liab
5000
Liab-Transformer 2,Liab-T2,800,200000,0
Liab
5000
Pl.Y.Kol-Transformer 1,Pl.Y.Kol-T1,800,200000,0
Pl.Y.Kol
5000
Pl.Y.Kol-Transformer 2,Pl.Y.Kol-T2,800,200000,0
Pl.Y.Kol
5000
Zdan-Transformer 1,Zdan-T1,800,200000,0
Zdan
5000
Zdan-Transformer 2,Zdan-T2,800,200000,0
Zdan
5000

```

4.2.7 File "routes.txt"

This file consists of 12 rows for each route. The 1-st row contains parameters Full name, Short name, Preference coefficient and Upper bound on the traffic interval length for the route. The 2-nd row contains sequence of short names of nodes eligible for opening a charging station on this route in the format: Short name of depot, Short name of terminal 1, Short names of en route stops, Short name of terminal 2, Short names of en route stops, Short name of terminal 1. The 3-rd row contains distances between stops according to the sequence of stops in the 2-nd row. The 4-th row contains short names of e-bus types eligible for this route. The 5-th row contains numbers of old e-buses operating on this route according to the sequence of e-bus types in the 4-th row. The 6-th row contains single charge ranges of e-buses according to the sequence of e-bus types in the 4-th row. The 7-th row contains operating and depreciation costs of e-buses according to the sequence of e-bus types in the 4-th row. The 8-th row contains durations of a single cycle of new e-buses without the charging time, according to the sequence of e-bus types in the 4-th row. The 9-th row contains durations of a single cycle of old e-buses including the charging time, according to the sequence of e-bus types in the 4-th row. The 10-th row contains short names of conventional vehicle types serving the route. The 11-th row contains numbers of conventional vehicles serving the route according to the sequence of vehicle types in row 10. The 12-th row contains durations of a single cycle of conventional vehicles according to the sequence of vehicle types in row 10. For the Minsk case, the twelve rows for each route are:

```

Railway Station - DS Viasnjanka,A1,1,18
Vaneeva-D,Kira-T,Vias-T,Kira-T
7,9,9
E433,E420,E321,E490,T32100D,T42003D
4,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
60,60,60,60,60,60
72,72,72,72,72,72
M103,M1035
3,2

```

60,60
Railway Station - Akvapark,A119c,1,26
Vaneeva-D,Kira-T,Vias-S,Akva-T,Vias-S2,Kira-T
7,9,4,4,9
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
50,50,50,50,50,50
0,0,0,0,0,0
M1035
2
50
Railway Station - RKMC,A190e,1,30
Vaneeva-D,Kira-T,Vias-S,RKMC-T,Vias-S2,Kira-T
7,9,6,6,9
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
60,60,60,60,60,60
0,0,0,0,0,0
M103,M1035
1,2
60,60
Railway Station - Chervenskiy Market,T5,1,10
Vaneeva-D,Kira-T,Ch.Ri-T,Kira-T
7,5,5
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
40,40,40,40,40,40
0,0,0,0,0,0
T420,T333
2,5
40,40
Railway Station - DS Loshica-2,T6,1,18
Vaneeva-D,Kira-T,Ch.Ri-S,Losh2-T,Ch.Ri-S2,Kira-T
7,5,4,4,5
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
60,60,60,60,60,60
0,0,0,0,0,0
T420,T333
4,6
60,60
Railway Station - Masukovschina,A69,1,22
Vaneeva-D,Kira-T,Masu-T,Kira-T
7,11,11
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
80,80,80,80,80,80
0,0,0,0,0,0
M103
5

80
Railway Station - DS Searjabrjanka,T20,1,18
Vaneeva-D,Kira-T,V-S,DS Sera-T,V-S2,Kira-T
7,5,4,4,5
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
80,80,80,80,80,80
0,0,0,0,0,0
T420,T333
2,5
80,80
DS Searjabrjanka - DS YZapad,T36,1,36
Vaneeva-D,DS Sera-T,AV Ca-S,YZap-T,AV Ca-S2,DS Sera-T
7,5,13,13,5
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
130,130,130,130,130,130
0,0,0,0,0,0
T420,T333
3,6
130,130
AV Centralny - Masukovschina,A46,1,18
Vaneeva-D,AV Ca-T,Masu-T,AV Ca-T
7,9,9
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
70,70,70,70,70,70
0,0,0,0,0,0
M1035
2
70
AV Centralny - Masukovschina,T58,1,18
Vaneeva-D,AV Ca-T,Masu-T,AV Ca-T
7,9,9
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
60,60,60,60,60,60
0,0,0,0,0,0
T420,T333
2,2
60,60
Dolgobrodskaja - DS Siarova,T59,1,26
Vaneeva-D,Daug-T,Siar-T,Daug-T
7,13,13
E433,E420,E321,E490,T32100D,T42003D
7,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
80,80,80,80,80,80
92,92,92,92,92,92
T420
2

80
DS Drugnaja - Karastojanovoy,A38,1,16
Vaneeva-D,Druz-T,Kara-T,Druz-T
7,8,8
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
60,60,60,60,60,60
0,0,0,0,0,0
M103,M1035
1,2
60,60
DS Drugnaja - DS Siarova,T43,1,14
Vaneeva-D,Druz-T,Siar-T,Druz-T
7,7,7
E433,E420,E321,E490,T32100D,T42003D
4,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
50,50,50,50,50,50
56,56,56,56,56,56
T420
2
50
DS Karastojanovoy - DS YZapad,T40,1,28
Vaneeva-D,Kara-T,Druz-S,YZap-T,Druz-S2,Kara-T
7,7,7,7,7
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
100,100,100,100,100,100
0,0,0,0,0,0
T420,T333
2,5
100,100
DS Drugnaja - DS YZapad,T63,1,18
Kazlova-D,Druz-T,YZap-T,Druz-T
7,9,9
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
60,60,60,60,60,60
0,0,0,0,0,0
M103,M1035
2,2
60,60
Suharveo - DS Drugnaja,A50c,1,30
Kazlova-D,Suh5-T,Druz-T,Suh5-T
7,15,15
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
100,100,100,100,100,100
0,0,0,0,0,0
M103,M1035
3,3

100,100
AV Centralny - DS Suharevo-5 ,T7,1,28
Kazlova-D,Suh5-T,AV Ca-T,Suh5-T
7,14,14
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
90,90,90,90,90,90
0,0,0,0,0,0
T420,T333
2,4
90,90
DS Drugnaja - DS Suharevo-5 ,T9,1,26
Kazlova-D,Suh5-T,Druz-T,Suh5-T
7,13,13
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
80,80,80,80,80,80
0,0,0,0,0,0
T420,T333
1,3
80,80
DS Malinovka-4 - DS Drugnaja ,A32c,1,28
Kazlova-D,Mal4-T,Druz-T,Mal4-T
7,14,14
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
90,90,90,90,90,90
0,0,0,0,0,0
M103,M1035
3,6
90,90
Slavinskogo - Old Airport,A100,1,24
Kazlova-D,KalSlav-T,Aera1-T,KalSlav-T
7,12,12
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
90,90,90,90,90,90
0,0,0,0,0,0
M103,M1035
3,6
90,90
DS Kalinovskogo - Vesninka,A91,1,40
Kazlova-D,Vsnin-T,Vias-S,KalSlav-T,Vias-S2,Vsnin-T
7,2,18,18,2
E420,E321,E490
0,0,0
20,30,25
9520,9520,8400
140,140,140
0,0,0
M103,M1035

2,5
140,140
DS Siarova - Liabjagiy,A73,1,36
Kazlova-D,Siar-T,Druz-S,Vias-S,Liab-T,Vias-S2,Druz-S2,Siar-T
7,7,9,2,2,9,7
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
120,120,120,120,120,120
0,0,0,0,0,0
M103,M1035
5,7
120,120
DS Karastojanovoy - Pl.Y.Kolasa,T22,1,12
Kazlova-D,Kara-T,Pl.Y.Kol-T,Kara-T
7,6,6
E433,E420,E321,E490,T32100D,T42003D
0,0,0,0,0,0
15,20,30,25,16,15
268880,209520,209520,168400,209520,209520
40,40,40,40,40,40
0,0,0,0,0,0
T420
3
40
DS Karastojanovoy - Zdanovichi Station,A44,1,50
Kazlova-D,Kara-T,Vias-S,Zdan-T,Vias-S2,Kara-T
7,9,16,16,9
E420,E321,E490
0,0,0
20,30,25
9520,9520,8400
100,100,100
0,0,0
M103,M1035
2,5
100,100
DS Karastojanovoy - Zdanovichi Health Center,A136,1,52
Kazlova-D,Kara-T,Vias-S,Zdan-T,Vias-S2,Kara-T
7,9,17,17,9
E420,E321,E490
0,0,0
20,30,25
9520,9520,8400
110,110,110
0,0,0
M103,M1035
1,2
110,110
DS Suharevo-5 - Kalinovskogo,T38,1,42
Kazlova-D,Suh5-T,KalSlav-T,Suh5-T
7,21,21
E321,E490
0,0
30,25
9520,8400
140,140
0,0

T420,T333
6,8
140,140

4.2.8 File "nodes_st.txt"

This file consists of 4 rows for each element of the set NP of parent nodes. First row contains full name of parent a node p and short name of this node. Next rows contain short names of the eligible charging station types, numbers nc_{pc} of the old charging stations and the upper bounds uc_{pc} . For the Minsk case, the 4 rows for each parent node are:

```
Vaneeva,V  
CS1  
1  
4  
Kirava,Kira  
CS1  
1  
4  
Viasnjanka,Vias  
CS1  
1  
4  
Akvapark,Akva  
CS1  
0  
4  
RKMC,RKMC  
CS1  
0  
4  
Ch.Rinok,Ch.Ri  
CS1  
0  
4  
Loshica2,Losh2  
CS1  
0  
4  
Masukovscina,Masu  
CS1  
0  
4  
V,VS  
CS1  
0  
4  
DS Searjabrjanka,DS Sera  
CS1  
0  
4  
AV Centralny,AV Ca  
CS1  
0  
4  
YgoZapad,YZap  
CS1  
0  
4  
Daugbrodskaja,Daug  
CS1  
1  
4  
Siarova,Siar  
CS1  
1  
4
```

Druznaia,Druz
CS1
1
4
Karastojanovoy,Kara
CS1
0
4
Kazlova,K
CS1
0
4
Suharevo5,Suh5
CS1
0
4
Malinovka4,Mal4
CS1
0
4
Kalinovskogo,KalSlav
CS1
0
4
Aeroprt 1,Aera1
CS1
0
4
Vesninka,Vsnin
CS1
0
4
Liabjagiy,Liab
CS1
0
4
Pl.Y.Kolasa,Pl.Y.Kol
CS1
0
4
Zdanovich,Zdan
CS1
0
4

4.2.9 File "nodes_ch.time.txt"

This file consists of $1 + |C_p|$ rows for $p \in NP$. The first row contains short name of the parent node p . Each row from the next $|C_p|$ rows contains charging times ct_{pbc} of e-buses at charging station of type $c \in C_p$ for each $b \in C_b$. For the Minsk case, these rows are:

V
6,6,10,6,40,30
Kira
6,6,10,6,40,30
Vias
6,6,10,6,40,30
Akva
6,6,10,6,40,30
RKMC
6,6,10,6,40,30
Ch.Ri
6,6,10,6,40,30
Losh2
6,6,10,6,40,30
Masu
6,6,10,6,40,30

VS
6,6,10,6,40,30
DS Sera
6,6,10,6,40,30
AV Ca
6,6,10,6,40,30
YZap
6,6,10,6,40,30
Daug
6,6,10,6,40,30
Siar
6,6,10,6,40,30
Druz
6,6,10,6,40,30
Kara
6,6,10,6,40,30
K
6,6,10,6,40,30
Suh5
6,6,10,6,40,30
Mal4
6,6,10,6,40,30
KalSlav
6,6,10,6,40,30
Aera1
6,6,10,6,40,30
Vsnin
6,6,10,6,40,30
Liab
6,6,10,6,40,30
Pl.Y.Kol
6,6,10,6,40,30
Zdan
6,6,10,6,40,30

4.2.10 File "croutes.txt"

This file is created because there are routes that are already served by the e-buses. It describes charging stations that have already been opened at the nodes belonging to the routes from R . It consists of two rows for each route. The first row contains short name of the route r . The second row contains short names of the charging stations opened at the corresponding parent node for each node from $\pi_r = (j_0, j_1, \dots, j_r)$. If no station is opened for some node j_k , then symbols "-1" are used as the short name. For the Minsk case this file is:

A1
CS1,CS1,CS1
T59
CS1,CS1,CS1
T43
CS1,CS1,CS1

4.2.11 File "tdepots.txt"

This file consists of one row for each element from the set ND of depot nodes. The row for node j contains short name of the depot node and the duration t_j^{depot} in minutes. For the Minsk case it is:

Vaneeva-D,240
Kazlova-D,240

5 Output files for Minsk case

5.1 Output file *solution.json* for Minsk case

```
{
  "Solutions": [{
    "CR": {
      "V": 2763,
      "CC": 9.855e+006,
      "OC": 4.96888e+006},
    "X": {
      "R_X": [
        {
          "r": "A1",
          "ATE_r": 9,
          "Z_r": 612,
          "NV_r": 4,
          "BO_r": ["E433"],
          "nv_rb": [4],
          "B_r": ["E433"],
          "NV_rb": [4],
          "CH": [
            {"b": "E433", "Nbc_r": [
              {"c": "CS1", "j": "Vaneeva-D(V)"},
              {"c": "CS1", "j": "Kira-T(Kira)"},
              {"c": "CS1", "j": "Vias-T(Vias)"}]}],
          "t": [
            "E433", "E433", "E433", "E433", "E433", "E433", "E433", "E433"]
          }
        ],
        {
          "r": "T59",
          "ATE_r": 11,
          "Z_r": 153,
          "NV_r": 1,
          "BO_r": ["E321"],
          "nv_rb": [7],
          "B_r": ["E433"],
          "NV_rb": [1],
          "CV_r": ["T420"],
          "nvc_rb": [1],
          "CH": [
            {"b": "E433", "Nbc_r": [
              {"c": "CS1", "j": "Vaneeva-D(V)"},
              {"c": "CS1", "j": "Daug-T(Daug)"},
              {"c": "CS1", "j": "Siar-T(Siar)"}]}],
          "t": [
            "E433", "E433", "E433", "E433", "T420", "E433", "E433", "E433", "E433"]
          }
        ]
      }
    ]
  }
```

```
"r": "T43",
"ATE_r": 10,
"Z_r": 228,
"NV_r": 2,
"BO_r": ["E321"],
"nv_rb": [4],
"B_r": ["E433", "E490"],
"NV_rb": [1,1],
"CH": [
{"b": "E433", "Nbc_r": [
{"c": "CS1", "j": "Vaneeva-D(V)"},
{"c": "CS1", "j": "Siar-T(Siar)"}]}
, {"b": "E490", "Nbc_r": [
{"c": "CS1", "j": "Vaneeva-D(V)"},
{"c": "CS1", "j": "Siar-T(Siar)"}]}
],
"t": [
"E433", "E433", "E420", "E433", "E433", "E433"
]
,
{
"r": "T20",
"ATE_r": 12,
"Z_r": 1005,
"NV_r": 7,
"B_r": ["E433", "E420"],
"NV_rb": [6,1],
"CV_r": ["T420"],
"nvc_rb": [1],
"CH": [
{"b": "E433", "Nbc_r": [
{"c": "CS1", "j": "Vaneeva-D(V)"},
{"c": "CS1", "j": "DS Sera-T(DS Sera)"}]}
, {"b": "E420", "Nbc_r": [
{"c": "CS1", "j": "Vaneeva-D(V)"},
{"c": "CS1", "j": "DS Sera-T(DS Sera)"}]}
],
"t": [
"E433", "E433", "T420", "E433", "E433", "E420", "E433", "E433"
]
}
,
{
"r": "T40",
"ATE_r": 14,
"Z_r": 765,
"NV_r": 5,
"B_r": ["E433"],
"NV_rb": [5],
"CV_r": ["T420", "T333"],
"nvc_rb": [1,2],
"CH": [
{"b": "E433", "Nbc_r": [
{"c": "CS1", "j": "Vaneeva-D(V)"},
```

```
{ "c": "CS1", "j": "Kara-T(Kara)" },
{ "c": "CS1", "j": "YZap-T(YZap)" } ]
},
"t": [
"E433", "T333", "E433", "T420", "E433", "E433", "T333", "E433"
]
},
"S": [
{ "j": "DS Sera", "c": ["CS1"], "NC_jc": [1],
"L_j": ["DS Sera-T1", "DS Sera-T2"] },
{ "j": "YZap", "c": ["CS1"], "NC_jc": [1],
"L_j": ["YZap-T1", "YZap-T2"] },
{ "j": "Siar", "c": ["CS1"], "NC_jc": [1] },
{ "j": "Kara", "c": ["CS1"], "NC_jc": [1],
"L_j": ["Kara-T1", "Kara-T2"] }
]
},
"T": [
],
"TP": [
{ "i": "Vaneeva-T1", "TP_i": 200 }
,
{ "i": "Vaneeva-T2", "TP_i": 200 }
,
{ "i": "Kira-T1", "TP_i": 200 }
,
{ "i": "Kira-T2", "TP_i": 200 }
,
{ "i": "Vias-T1", "TP_i": 200 }
,
{ "i": "Vias-T2", "TP_i": 200 }
,
{ "i": "DS Sera-T1", "TP_i": 200 }
,
{ "i": "DS Sera-T2", "TP_i": 200 }
,
{ "i": "YZap-T1", "TP_i": 200 }
,
{ "i": "YZap-T2", "TP_i": 200 }
,
{ "i": "Daug-T1", "TP_i": 200 }
,
{ "i": "Daug-T2", "TP_i": 200 }
,
{ "i": "Siar-T1", "TP_i": 200 }
,
{ "i": "Siar-T2", "TP_i": 200 }
,
{ "i": "Druz-T1", "TP_i": 200 }
,
{ "i": "Druz-T2", "TP_i": 200 }
,
{ "i": "Kara-T1", "TP_i": 200 }
,
{ "i": "Kara-T2", "TP_i": 200 }
]
}
```

}
}
}
}

5.2 Output text file *solution.out* for Minsk case

Value=2763
Capital cost=9855000
Operating cost=4968880
Route <A1>
Stops: <Vaneeva-D(V)> <Kira-T(Kira)> <Vias-T(Vias)> <Kira-T(Kira)>
Total passenger capacity of new e-buses=612
Length of the traffic interval=9
The required length of the traffic interval=18
E-bus <E433>
The number of new e-buses=4
Capital cost of new e-buses=1900000
Operating and energy cost of new e-buses=1075520
Bus is charged at:
Station type <CS1> at node <Vaneeva-D(V)>
Station type <CS1> at node <Kira-T(Kira)>
Station type <CS1> at node <Vias-T(Vias)>
The number of old e-buses <E433>=4
The order of departures
E433
E433
E433
E433
E433
E433
E433
E433
Route <T59>
Stops: <Vaneeva-D(V)> <Daug-T(Daug)> <Siar-T(Siar)> <Daug-T(Daug)>
Total passenger capacity of new e-buses=153
Length of the traffic interval=11
The required length of the traffic interval=26
E-bus <E433>
The number of new e-buses=1
Capital cost of new e-buses=475000
Operating and energy cost of new e-buses=268880
Bus is charged at:
Station type <CS1> at node <Vaneeva-D(V)>
Station type <CS1> at node <Daug-T(Daug)>
Station type <CS1> at node <Siar-T(Siar)>
1 <T420> with total passenger capacity=115
The number of old e-buses <E433>=7
The order of departures
E433
E433
E433
E433
T420
E433
E433
E433
E433
Route <T43>
Stops: <Vaneeva-D(V)> <Druz-T(Druz)> <Siar-T(Siar)> <Druz-T(Druz)>
Total passenger capacity of new e-buses=228
Length of the traffic interval=10

The required length of the traffic interval=14
E-bus <E433>
The number of new e-buses=1
Capital cost of new e-buses=475000
Operating and energy cost of new e-buses=268880
Bus is charged at:
Station type <CS1> at node <Vaneeva-D(V)>
Station type <CS1> at node <Siar-T(Siar)>
E-bus <E490>
The number of new e-buses=1
Capital cost of new e-buses=400000
Operating and energy cost of new e-buses=168400
Bus is charged at:
Station type <CS1> at node <Vaneeva-D(V)>
Station type <CS1> at node <Siar-T(Siar)>
The number of old e-buses <E433>=4
The order of departures
E433
E433
E420
E433
E433
E433
Route <T20>
Stops: <Vaneeva-D(V)> <Kira-T(Kira)> <V-S(V)> <DS Sera-T(DS Sera)> <V-S2(V)>
<Kira-T(Kira)>
Total passenger capacity of new e-buses=1005
Length of the traffic interval=12
The required length of the traffic interval=18
E-bus <E433>
The number of new e-buses=6
Capital cost of new e-buses=2850000
Operating and energy cost of new e-buses=1613280
Bus is charged at:
Station type <CS1> at node <Vaneeva-D(V)>
Station type <CS1> at node <DS Sera-T(DS Sera)>
E-bus <E420>
The number of new e-buses=1
Capital cost of new e-buses=350000
Operating and energy cost of new e-buses=209520
Bus is charged at:
Station type <CS1> at node <Vaneeva-D(V)>
Station type <CS1> at node <DS Sera-T(DS Sera)>
1 <T420> with total passenger capacity=115
The order of departures
E433
E433
T420
E433
E433
E420
E433
E433
Route <T40>
Stops: <Vaneeva-D(V)> <Kara-T(Kara)> <Druz-S(Druz)> <YZap-T(YZap)> <Druz-S2(Druz)> <Kara-T(Kara)>
Total passenger capacity of new e-buses=765
Length of the traffic interval=14
The required length of the traffic interval=28
E-bus <E433>
The number of new e-buses=5

Capital cost of new e-buses=2375000
Operating and energy cost of new e-buses=1344400
Bus is charged at:
Station type <CS1> at node <Vaneeva-D(V)>
Station type <CS1> at node <Kara-T(Kara)>
Station type <CS1> at node <YZap-T(YZap)>
1 <T420> with total passenger capacity=115
2 <T333> with total passenger capacity=340
The order of departures
E433
T333
E433
T420
E433
E433
T333
E433
New charging stations
Charging stations at node <DS Sera>
Type <CS1> number=1
Capital cost of stations=250000
Operating cost of stations=5000
Connected to transformers:
<DS Sera-T1> (cost of connection=5000)
<DS Sera-T2> (cost of connection=5000)
Charging stations at node <YZap>
Type <CS1> number=1
Capital cost of stations=250000
Operating cost of stations=5000
Connected to transformers:
<YZap-T1> (cost of connection=5000)
<YZap-T2> (cost of connection=5000)
Charging stations at node <Siar>
Type <CS1> number=1
Capital cost of stations=250000
Operating cost of stations=5000
Charging stations at node <Kara>
Type <CS1> number=1
Capital cost of stations=250000
Operating cost of stations=5000
Connected to transformers:
<Kara-T1> (cost of connection=5000)
<Kara-T2> (cost of connection=5000)
Transformer power demand
<Vaneeva-T1> power=200
<Vaneeva-T2> power=200
<Kira-T1> power=200
<Kira-T2> power=200
<Vias-T1> power=200
<Vias-T2> power=200
<DS Sera-T1> power=200
<DS Sera-T2> power=200
<YZap-T1> power=200
<YZap-T2> power=200
<Daug-T1> power=200
<Daug-T2> power=200
<Siar-T1> power=200
<Siar-T2> power=200
<Druz-T1> power=200

<Druz-T2> power=200
<Kara-T1> power=200
<Kara-T2> power=200