POLITECNICO DI MILANO

Performance Evaluation and Applications

Project A

Recharging of an electric car on a highway

2023-2024

Angelo Maximilian Tulbure

10931652

Project A - Recharging of an electric car on a highway

Problem description:

• An electric car has to travel a distance which is slightly longer than the one allowed by its battery capacity: it must stop exactly once for recharging on the way!

• There are four road segments on the route, with three charging stations in between: each station has a number of chargers available, and a different loads in number of requests.

• Considering a given probability of choosing exactly one of the charging station, compute the average total travelling time.

Project A - Recharging of an electric car on a highway

The travelling times of the four segments, is distributed according to the following traces [all times are expressed in minutes]:

Segment	Trace
I	`TraceA-I.txt`
II	`TraceA-II.txt`
III	`TraceA-III.txt`
IV	`TraceA-VI.txt`

- Charging time are exponentially distributed, according to an exponential distribution, with an average of 30 minutes.
- The request rate by other cars at the station, and the number of chargers, is given in the following table.
- A station is identified by the number of the segments it is between.

Station	Other traffic [car / hour]	Number of chargers
I-II	6	4
II-III	4	3
III-IV	5	3

• Determine the **best stopping probability distribution**: test a few alternatives of probabilities of stopping at each station, and for each scenario determine the average travelling time.

• Hint: the motion of the car can be considered as a closed system, with a single job, where the car once it has completed its course, it is teleported back to the initial position to immediately start another trip.

• Other cars competing for the charger, can be seen as an open process.

My Approach:

Initially, I attempted to model this issue by experimenting with various distributions for each trace using Matlab, aiming to identify the ones that best matched the samples.

To obtain the most precise result I tested 6 different distributions: Uniform, Exponential, Erlang, Hypo Exponential, Weibull and Pareto (Hyper Exponential couldn't be used because the CoV of all the traces was < 1).

Parameters of the distributions in **Trace 1**:

Uniform:

- a = 3.174544069688094
- b = 10.84496975111904

Exponential:

- lambda = 0.142658299393572

Erlang:

- k = 10
- lambda = 1.426582993935715

Hypo Exponential:

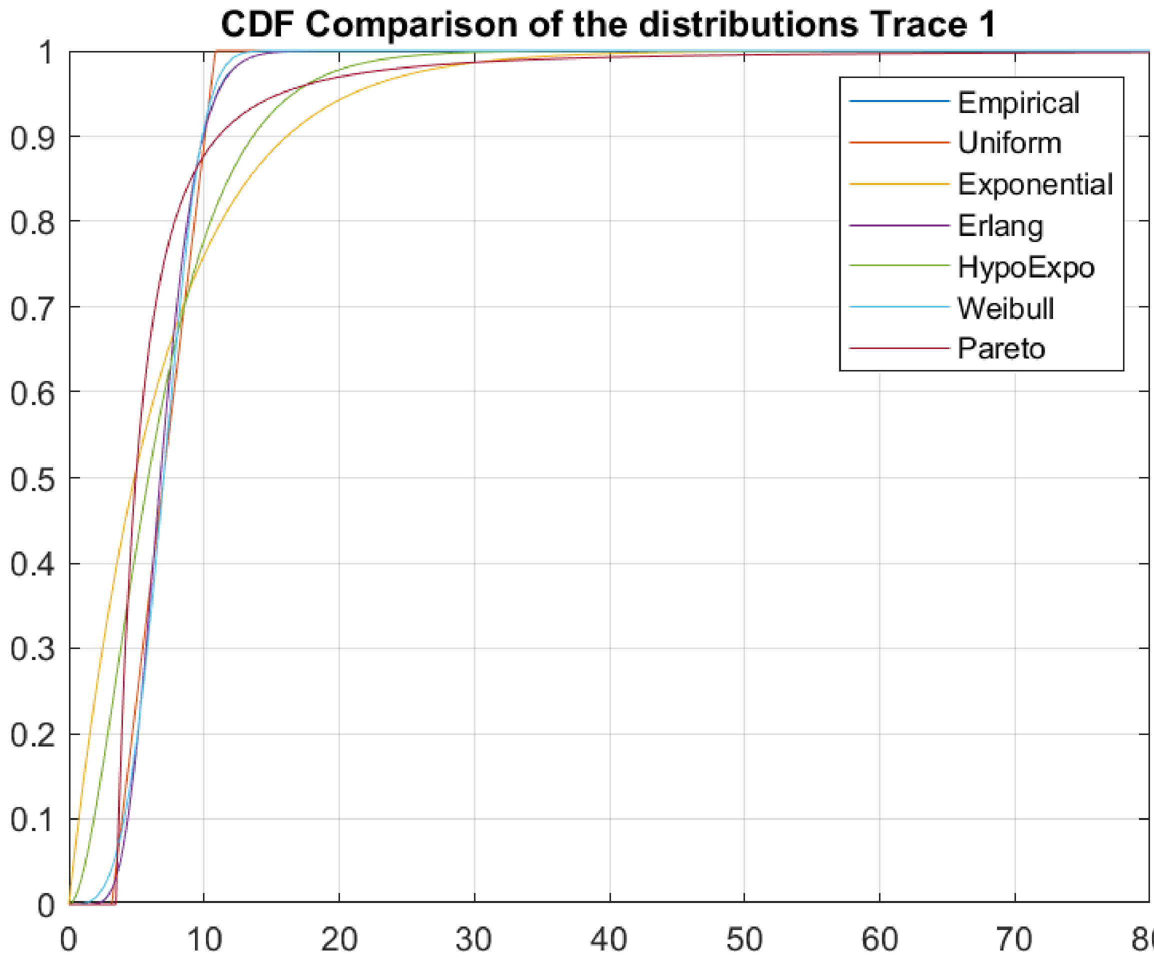
- lambda 1 = 0.285317013770477
- lambda 2 = 0.285316189105212

Weibull:

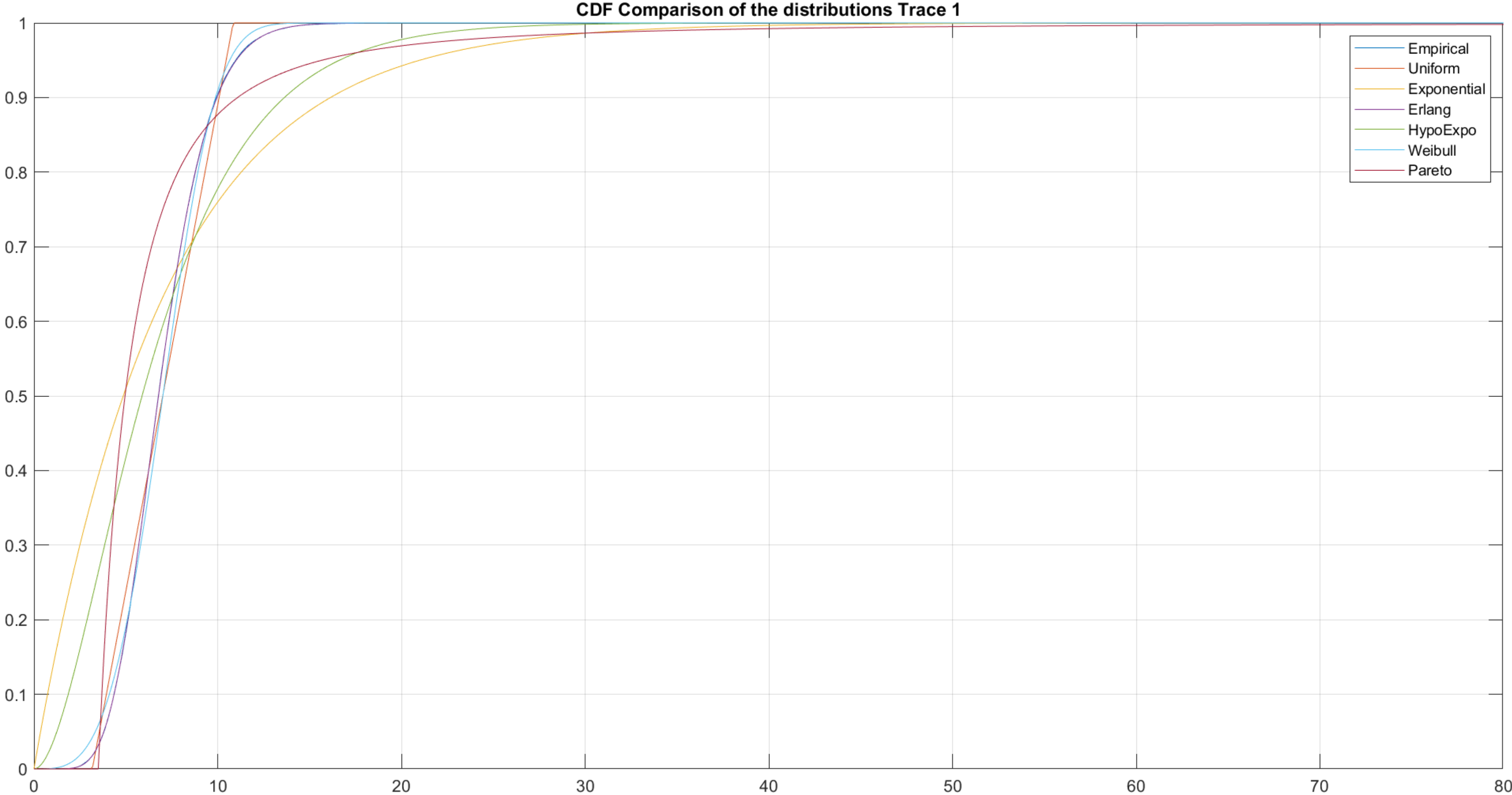
- k = 3.507051598714520
- lambda = 7.789975586826717

Pareto:

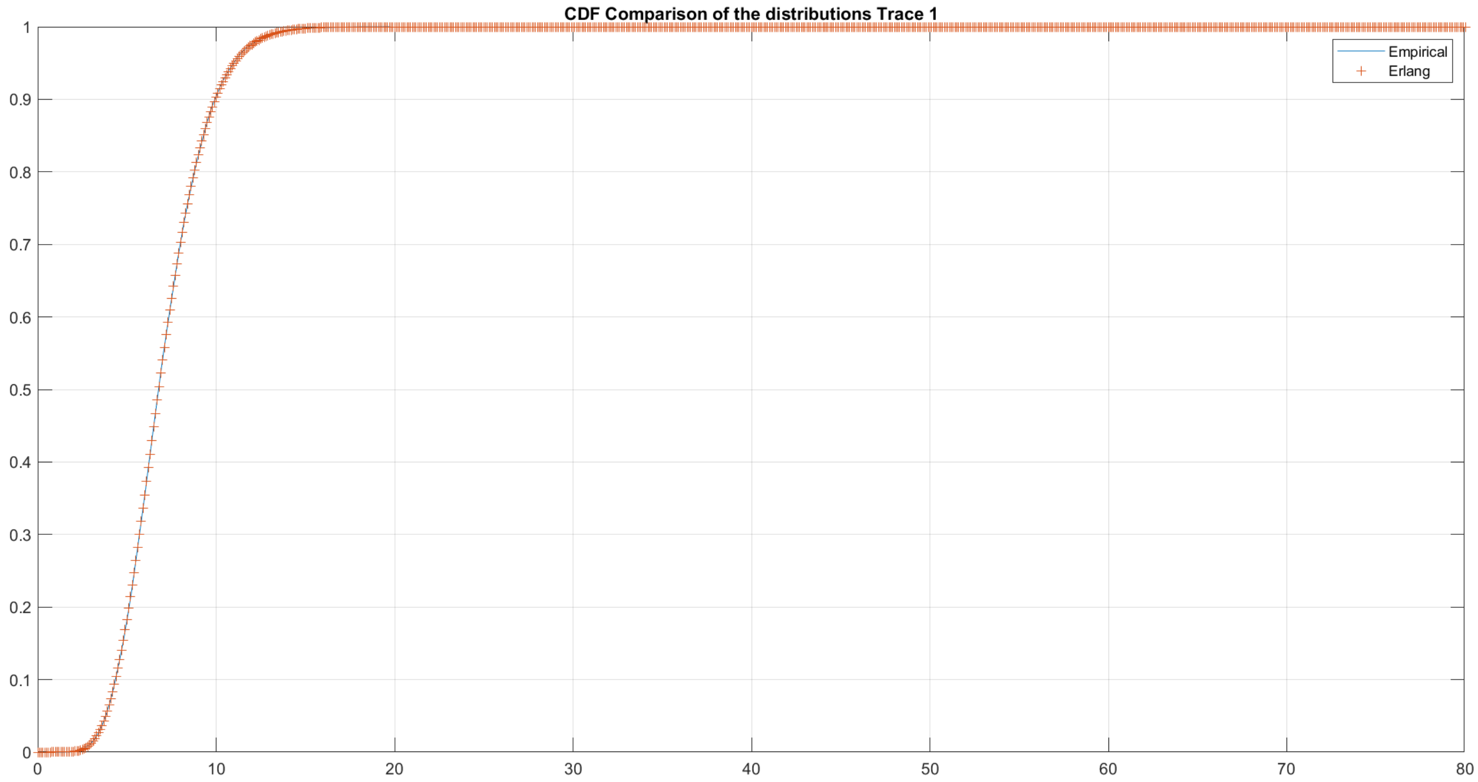
- m = 3.504878421145154
- alpha = 2.00020010001112



Parameters of the distributions in Trace 1:



Parameters of the distributions in Trace 1:



Taking a closer look at the empirical and Erlang, we can see that the Erlang distribution fits the best the samples of Trace 1.

Parameters of Erlang:

- k = 10
- lambda = 1.426582993935715

Project A - Recharging of an electric car on a highway

Parameters of the distributions in **Trace 2**:

Uniform:

- a = 4.032817066619868
- b = 14.972156553780168

Exponential:

- lambda = 0.105235610422168

Erlang:

- k = 9
- lambda = 0.947120493799513

Hypo Exponential:

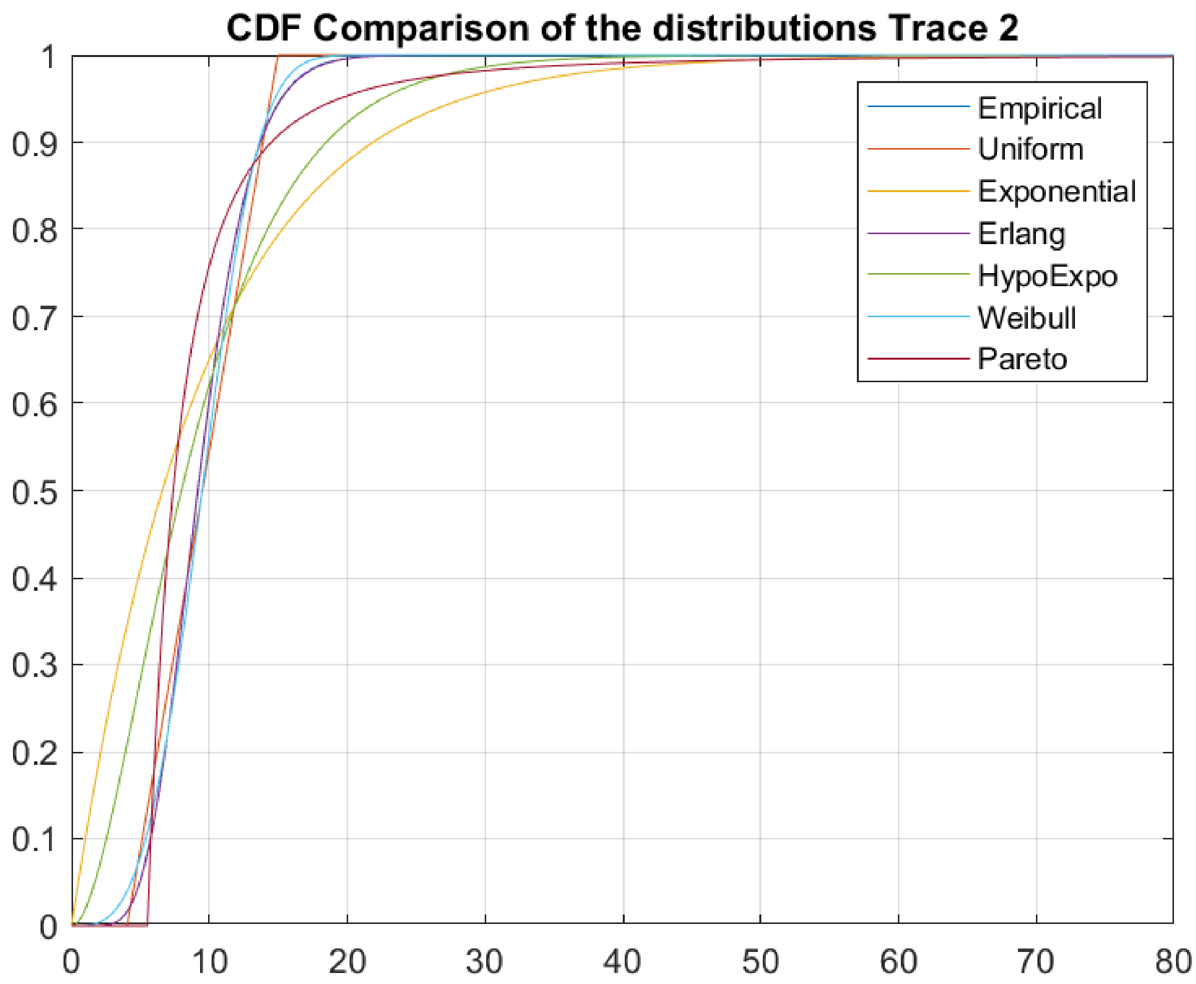
- lambda 1 = 0.210471526967602
- lambda 2 = 0.210470918631789

Weibull:

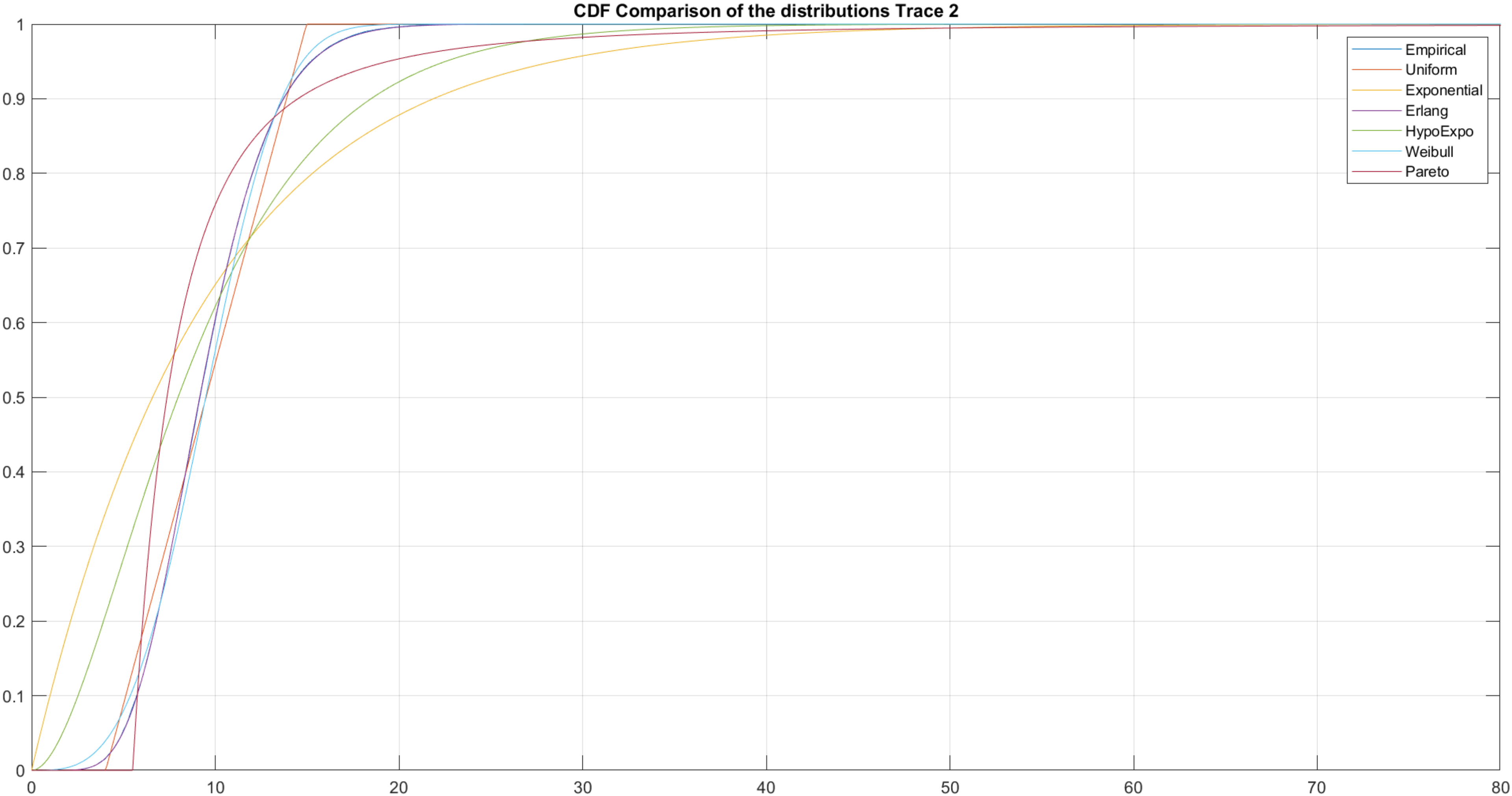
- k : 3.504878421145154
- lambda : 10.591088205750287

Pareto:

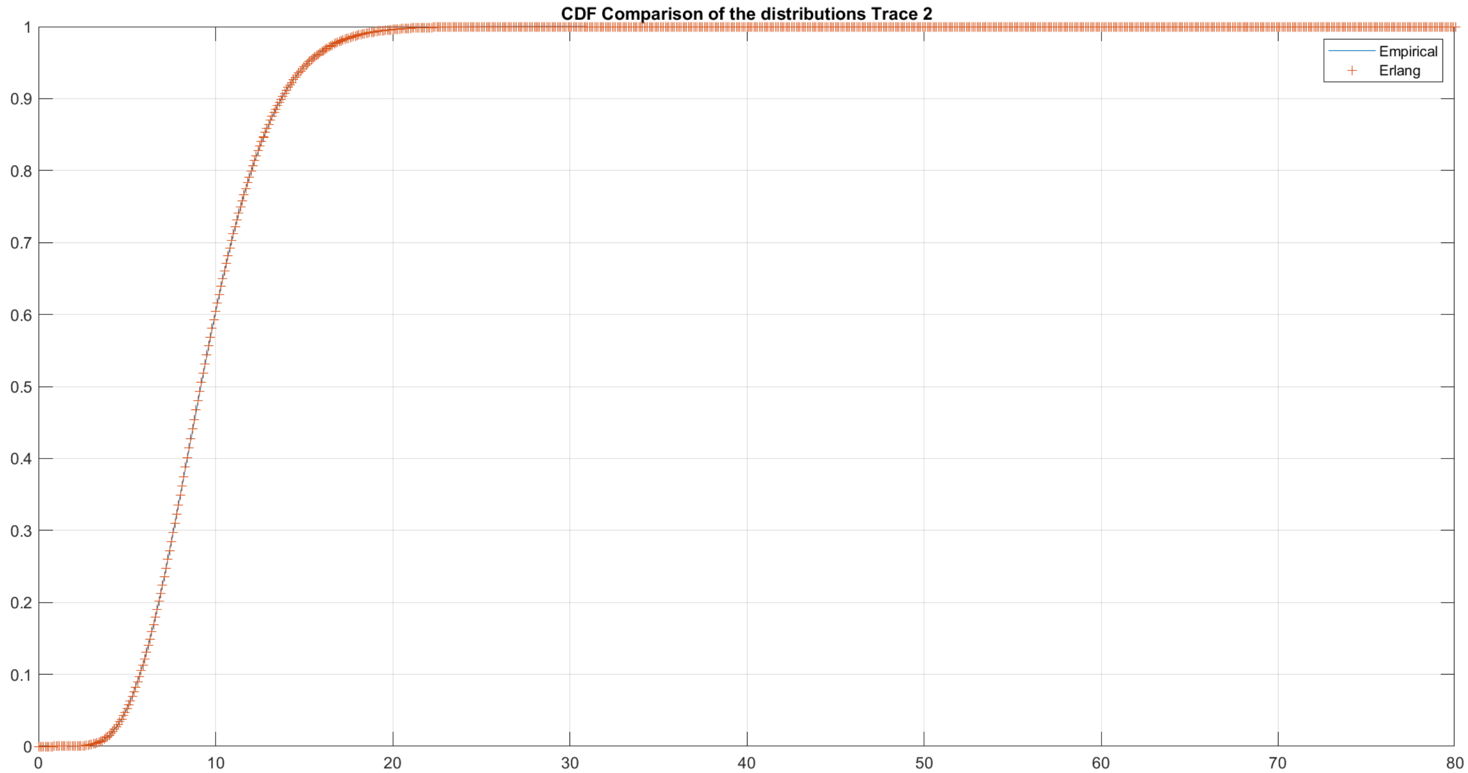
- m : 5.507498933340573
- alpha : 2.378602164287453



Parameters of the distributions in Trace 2:



Parameters of the distributions in Trace 2:



Taking a closer look at the empirical and Erlang, we can see that the Erlang distribution fits the best the samples of Trace 2.

Parameters of Erlang:

- k = 9
- lambda = 0.947120493799513

Parameters of the distributions in **Trace 3** :

Uniform:
- a = 3.782077358611238
- b = 22.163063272988815

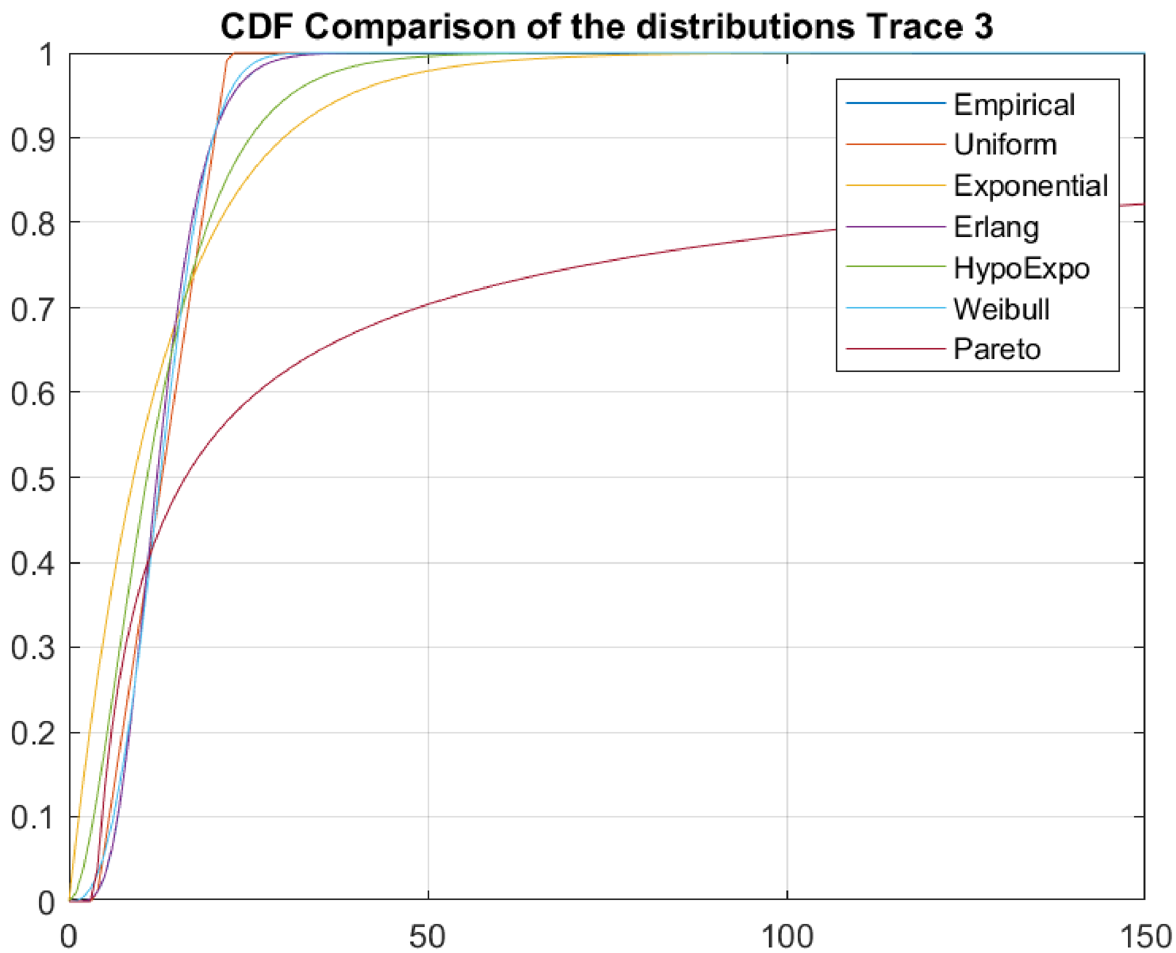
Exponential:
- lambda = 0.077085725932204

Erlang:
- k = 6
- lambda = 0.462514355593221

Hypo Exponential:
- lambda 1 = 0.154171170038689
- lambda 2 = 0.154171721828660

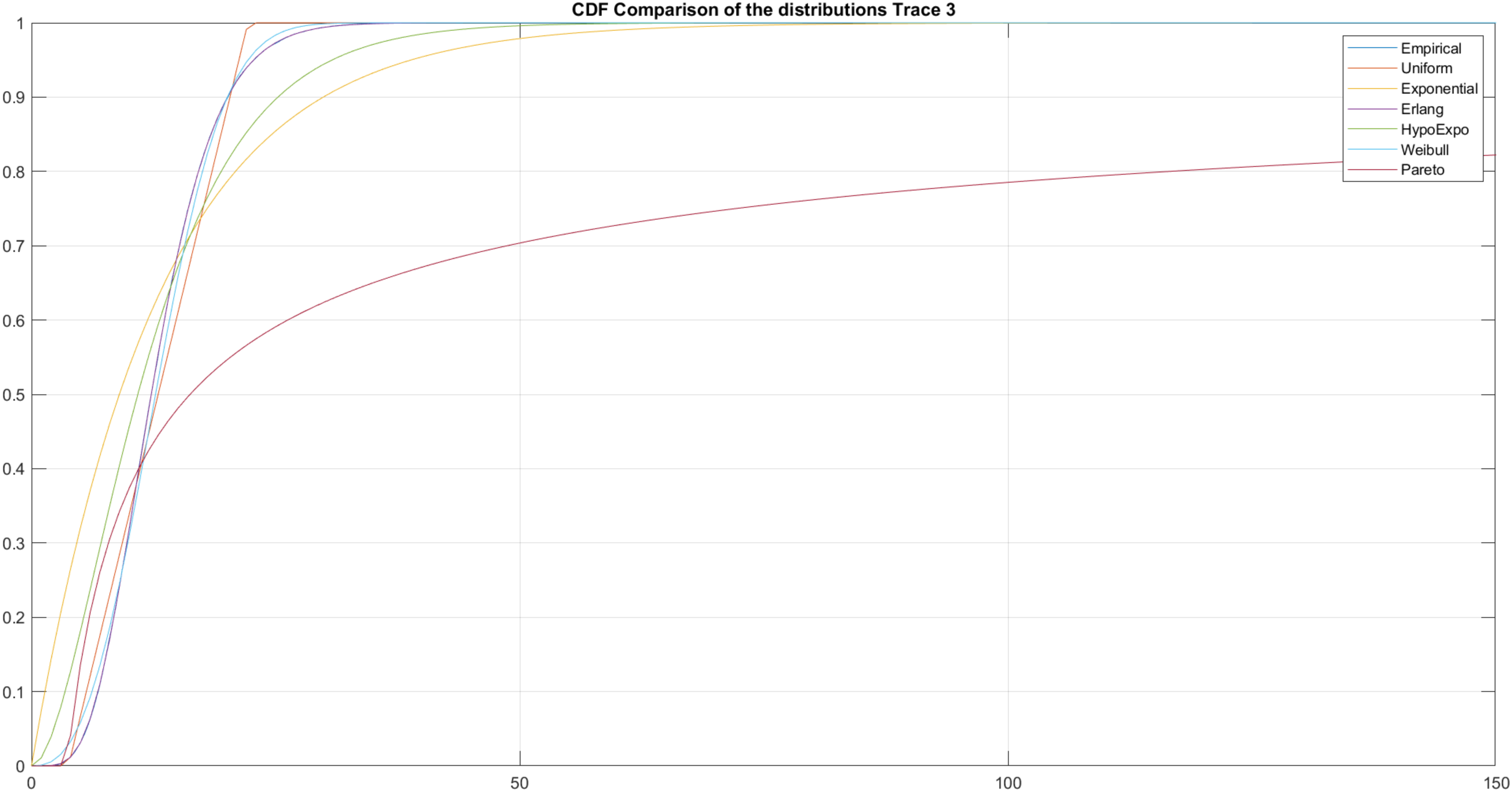
Weibull:
- k : 2.629223203983130
- lambda : 14.600326085310133

Pareto:
- m : 3.656429909416514
- alpha : 0.464976022060314

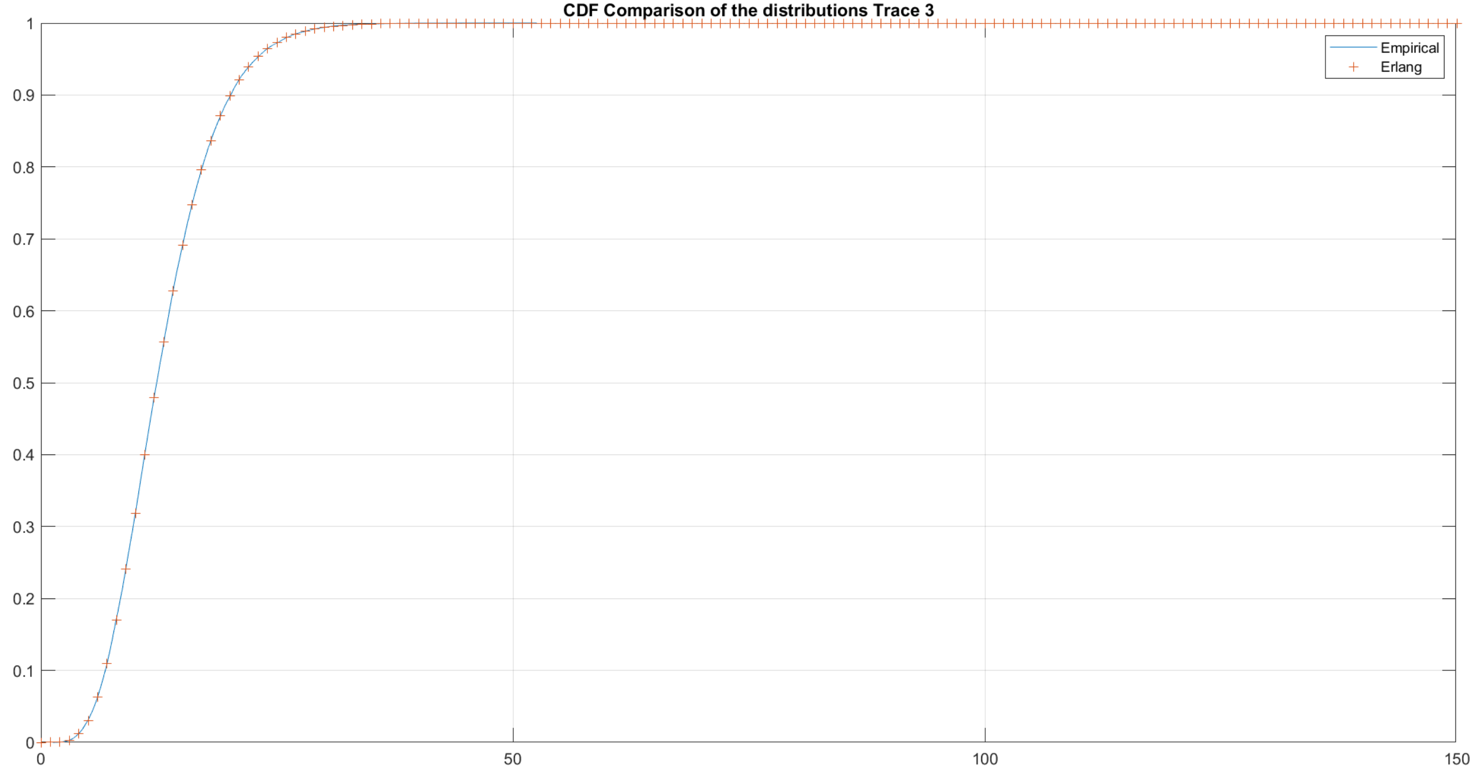


(For the Pareto case, we have an infinite mean because alpha is < 1 and infinite variance. For this reason it's the least appopiate distribution for trace 3).

Parameters of the distributions in Trace 3:



Parameters of the distributions in Trace 3:



Taking a closer look at the empirical and Erlang, we can see that the Erlang distribution fits the best the samples of Trace 3.

Parameters of Erlang:

- k = 6
- lambda = 0.462514355593221

Parameters of the distributions in **Trace 4**:

Uniform:

- a = 3.997730225316182
- b = 12.024779903083825

Exponential:

- lambda = 0.124824386689261

Erlang:

- k = 12
- lambda = 1.497892640271129

Hypo Exponential:

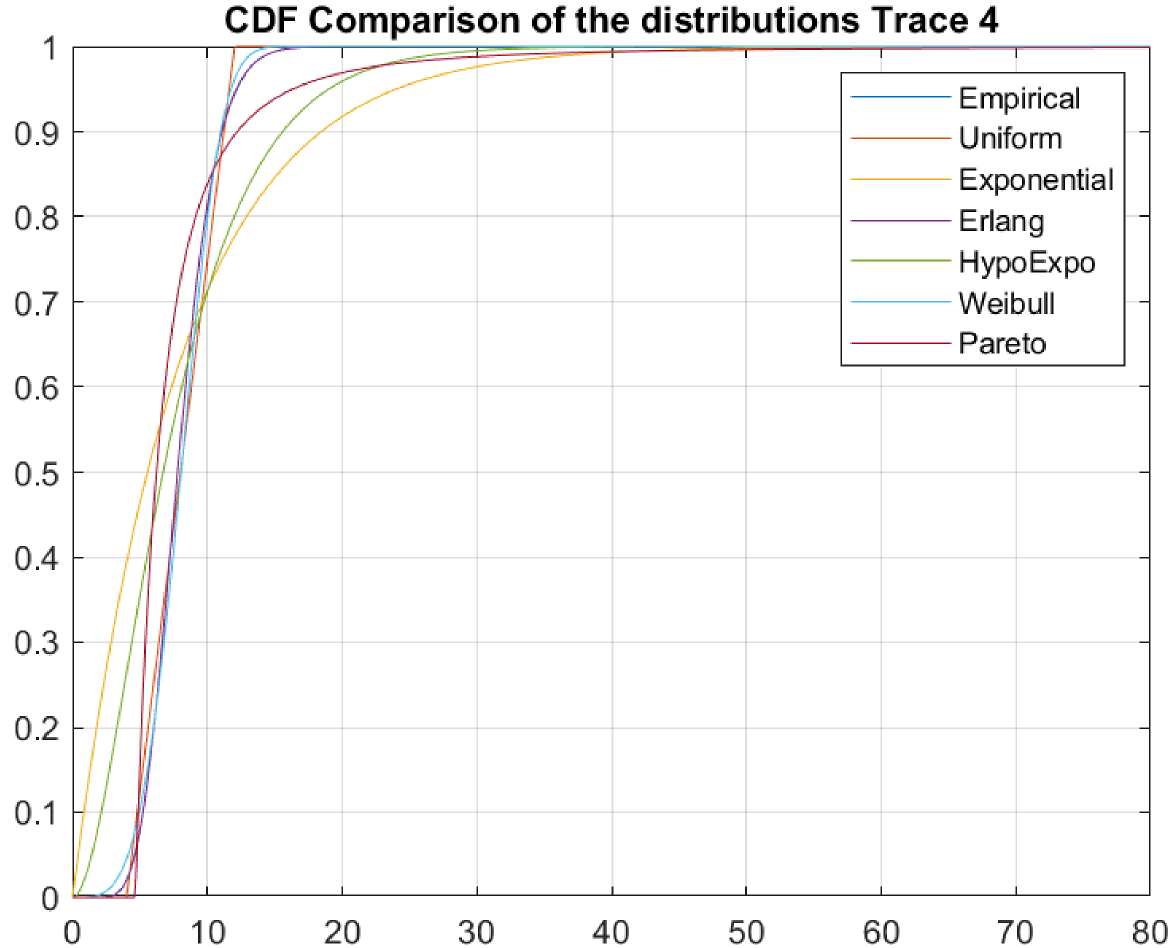
- lambda 1 = 0.249649233800353
- lambda 2 = 0.249648644068338

Weibull:

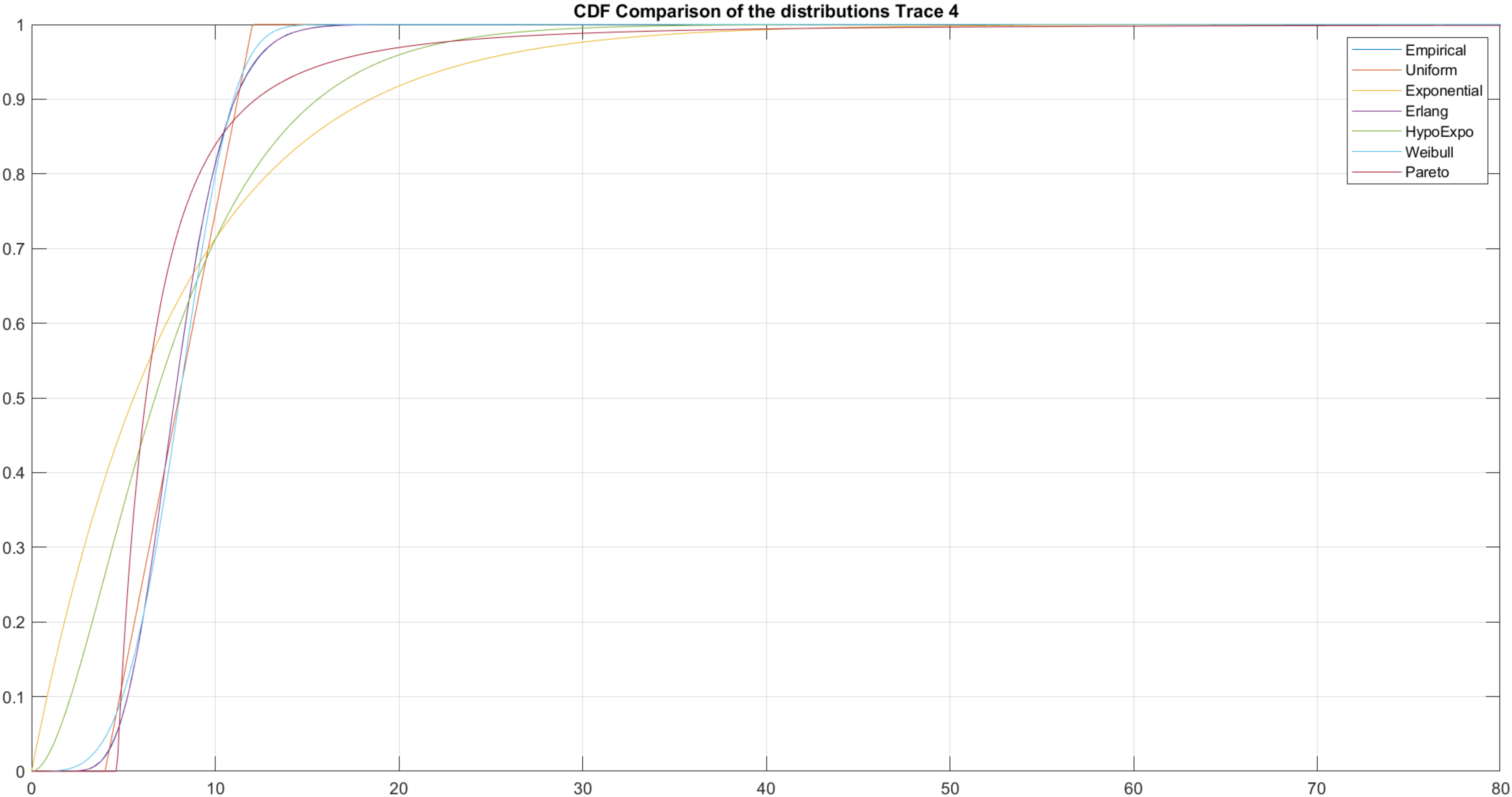
- k : 3.867052192203060
- lambda : 8.855423793450832

Pareto:

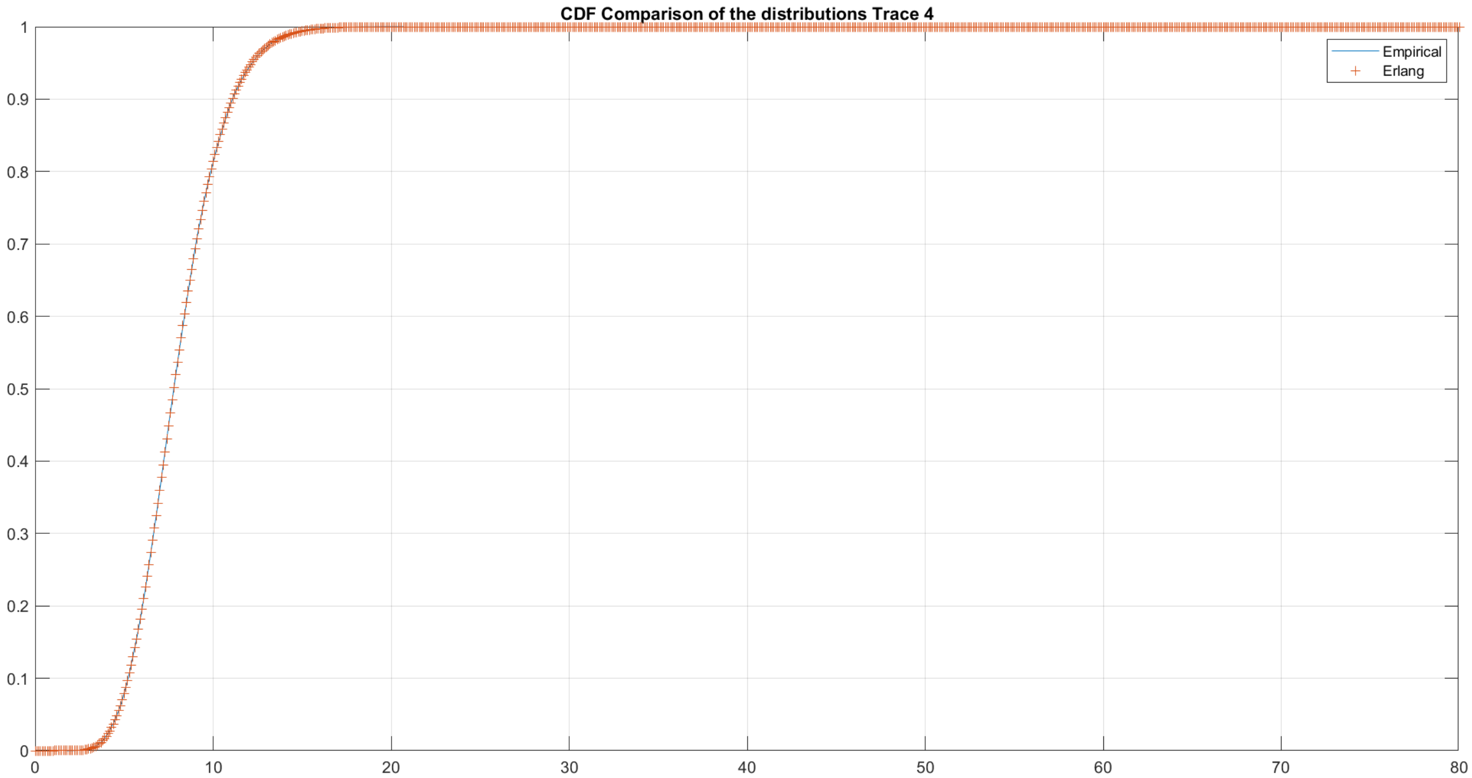
- m = 4.654559759681054
- alpha = 2.386649468426394



Parameters of the distributions in Trace 4:



Parameters of the distributions in Trace 4:



Taking a closer look at the empirical and Erlang, we can see that the Erlang distribution fits the best the samples of Trace 4.

Parameters of Erlang:

- k = 12
- lambda = 1.497892640271129

To sum up, the distributions that fitted the best the samples of the different traces are:

- **Trace 1** → Erlang with: k = 10, lambda = 1.426582993935715
- **Trace 2** → Erlang with: k = 9, lambda = 0.947120493799513
- **Trace 3** → Erlang with: k = 6, lambda = 0.462514355593221
- **Trace 4** → Erlang with: k = 12, lambda = 1.497892640271129

Next, my approach shifted to modeling this problem as a Queuing Network, employing queuing stations.

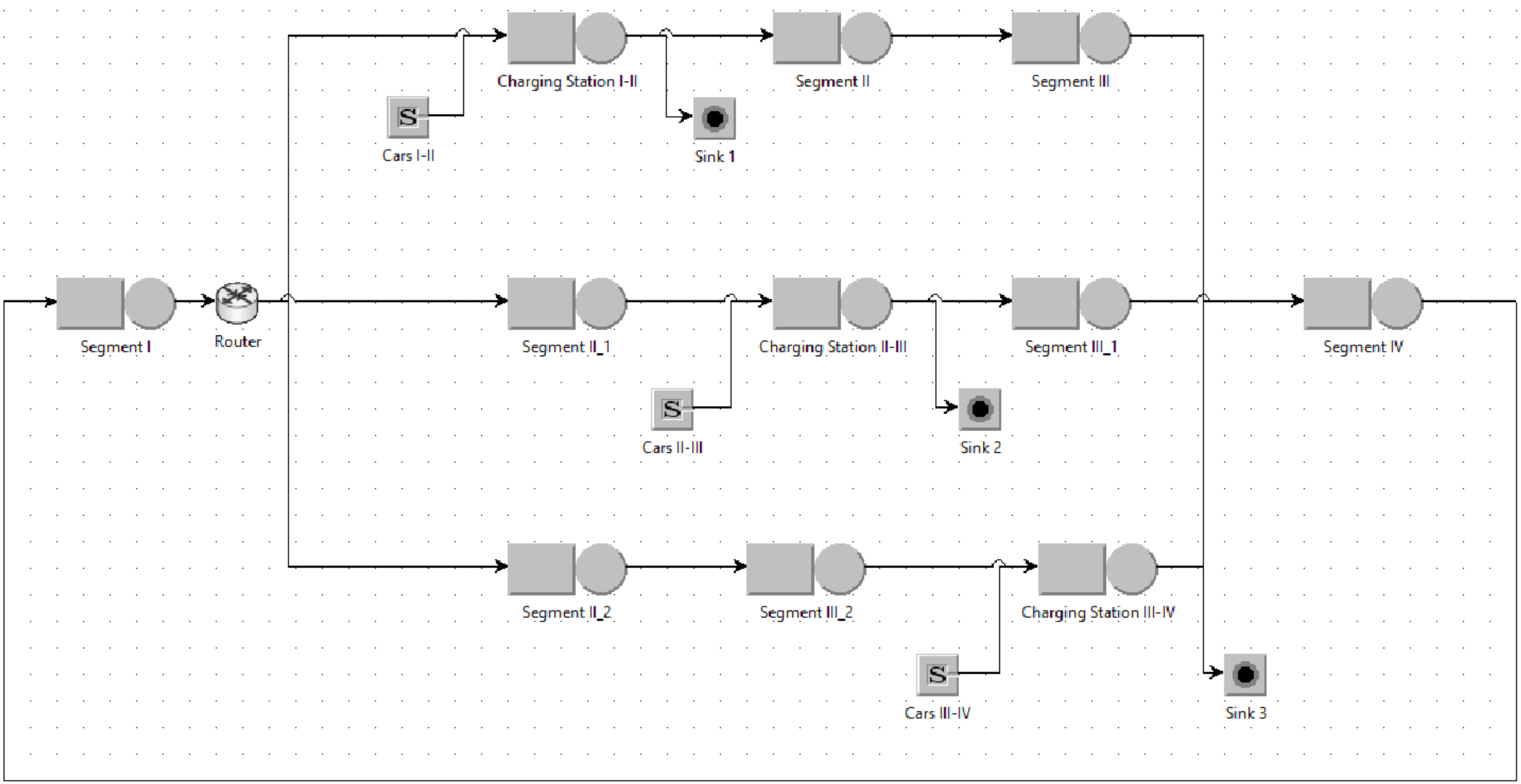
I considered the motion of the electric car as a closed system, with a single job, where the car once it has completed its course, it is teleported back to the initial position to immediately start another trip.

I considered the other cars competing for the charger as an open process.

To visualize and design this model graphically, I utilized a tool within JMT (Java Modelling Tool), specifically **JSimGraph**.

Project A - Recharging of an electric car on a highway

The model of the problem on JSimGraph is the following:



We have 3 possible paths:

- In the first path, the electric car is stopping to recharge in the charging station between Segmet I and II. Then it's continuing its trip until it reaches the destination point.

- In the second path, the electric car is going through the first 2 segments of the highway and it's stopping to charge in the station between Segment II and III. Then it's continuing its trip until it reaches the destination point.

-In the third path, the electric car is going through the first 3 segments of the highway and it's stopping to charge in the station between Segment III and IV. Then it's going through the last segment (Segment IV) and it reaches its destination.

By having a router after Segment I, we can test different probabilities of stopping at each station, and for each scenario we can determine the average travelling time, in order to determine the best stopping probability distribution.

Project A - Recharging of an electric car on a highway

I considered the motion of the car as a closed system, with a single job, and the other cars competing for the process as 3 open models, one for each charging station.

The Interarrival Time Distributions of the other traffic cars are:

- lambda = 6/60 = 0,1 cars/minute (for the first charging station)
- lambda = 4/60 = 0,067 cars/minute (for the second charging station)
- lambda = 5/60 = 0,0833 cars/minute (for the third charging station)

Define customer classes

Classes Characteristics

Add Class

Classes: 4

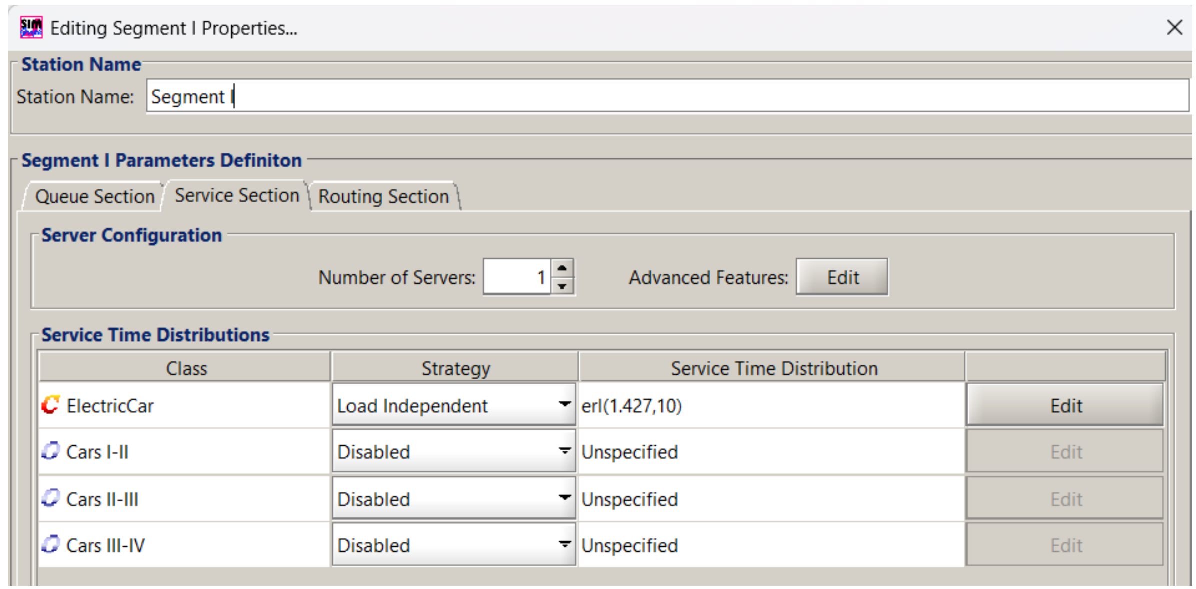
Define type (Open or Closed), name and parameters for each customer class.
Closed Classes: If a **ClassSwitch** is in the model, then **all** the closed classes must have the **same** reference station.
Open Classes: An open class that has **Fork**, **ClassSwitch**, **Scaler** or **Transition** as the reference station is **not** generated by **any** Source.
Priorities: A larger value implies a higher priority.

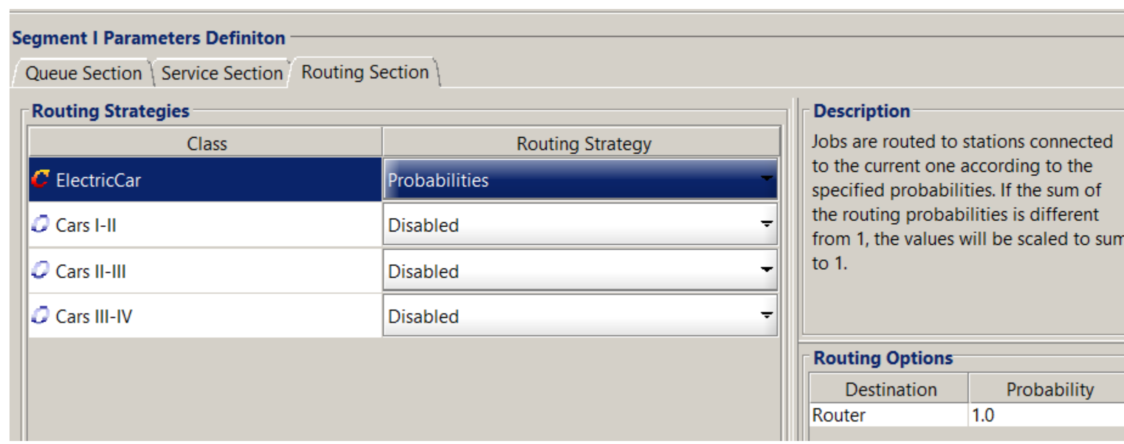
Color	Name	Type	Priority	Population	Interarrival Time Distribution		Soft Deadline	Reference Station
	ElectricCar	Closed	0	1			0.0000	Segment I
	Cars I-II	Open	0		exp(0.1)	Edit	0.0000	Cars I-II
	Cars II-III	Open	0		exp(0.067)	Edit	0.0000	Cars II-III
	Cars III-IV	Open	0		exp(0.083)	Edit	0.0000	Cars III-IV

Segment I :

The parameter used for the Service Time Distribution are the ones found in Matlab doing the fitting.

The Routing sections of all the queues were used with probability = 1 for the electric car.

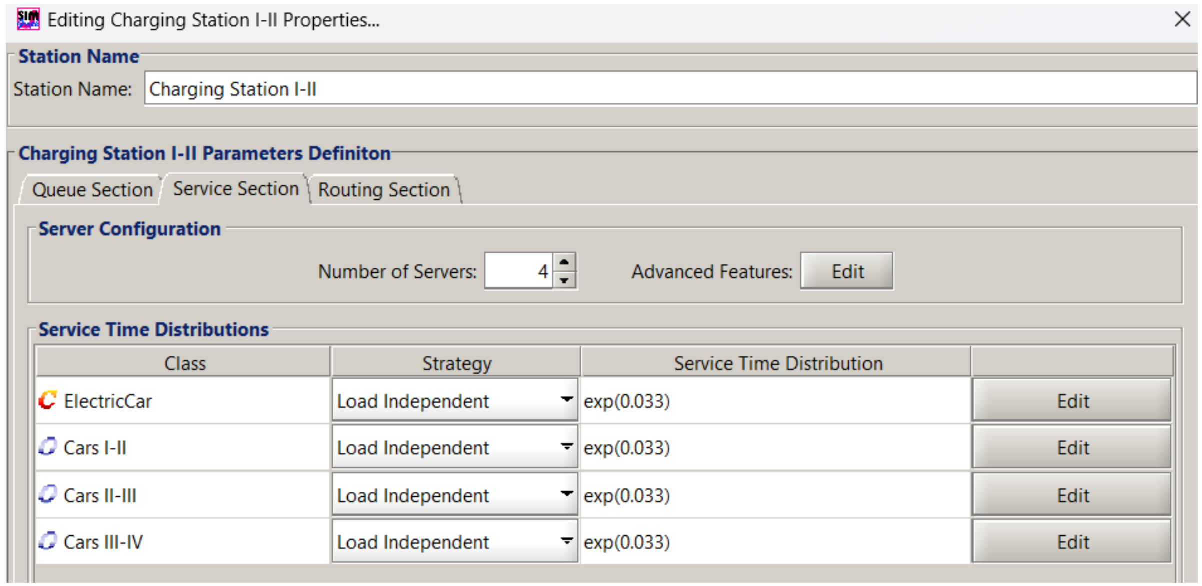


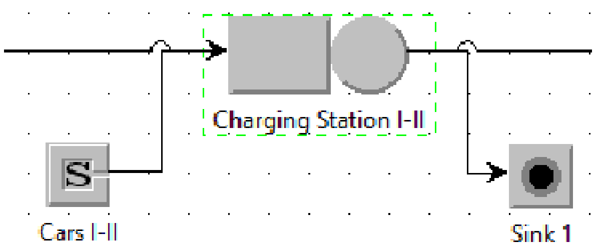


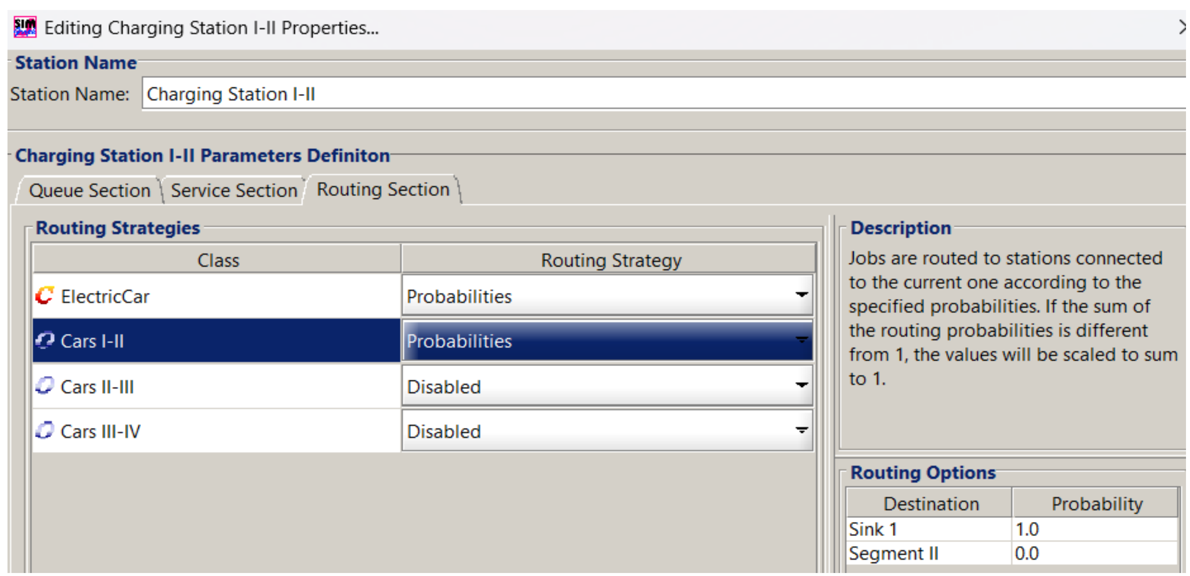
Charging Station I-II :

The parameter used for the Service Time Distribution are exponential with mean = 30 minutes (the average charging time of a car).

As there are 4 chargers in the station, I set the Number of Servers equal to 4.

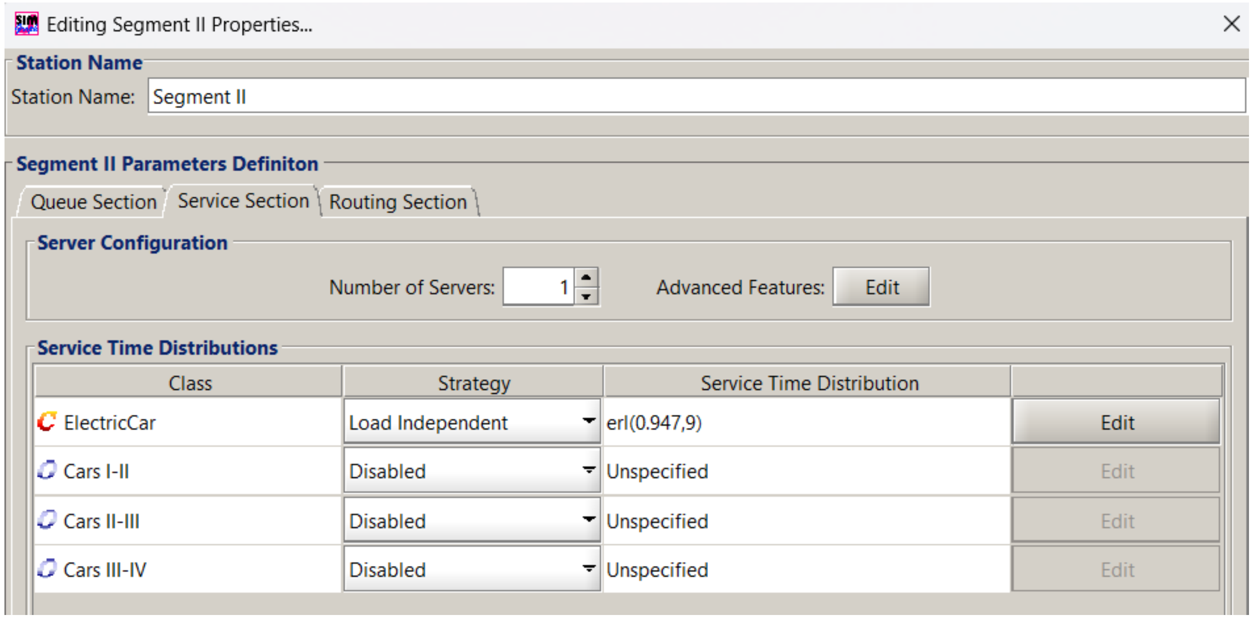




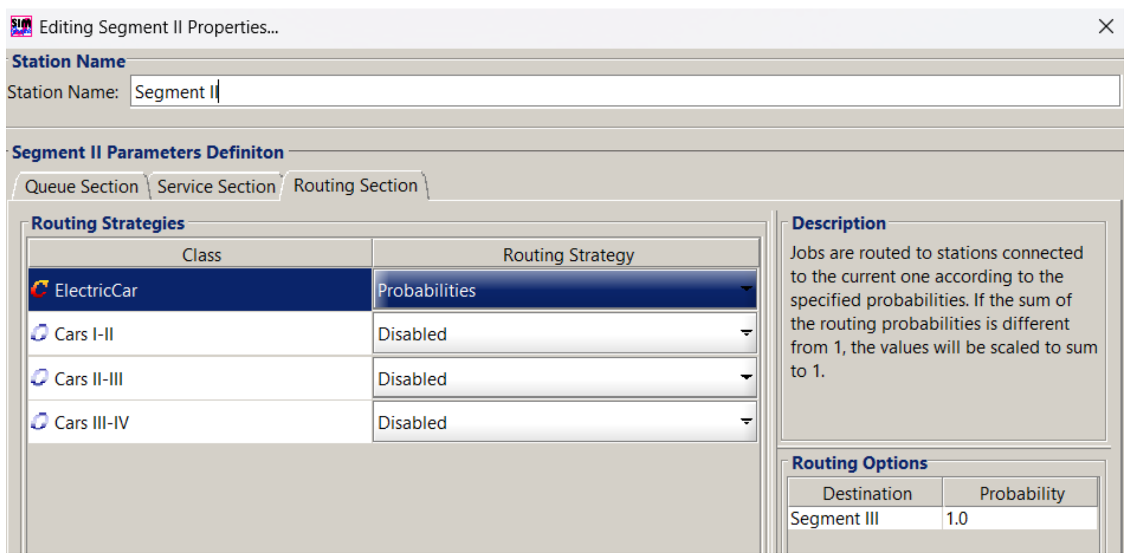


I generated the traffic of the other cars from a source and I directed all to a sink after the charging station (probability to go to the sink1 = 1).

Segment II :



Editing Segment II Properties...
Station Name
Station Name: Segment II
Segment II Parameters Definiton
Queue Section
Service Section
Routing Section
Server Configuration
Number of Servers: 1
Advanced Features: Edit
Service Time Distributions
Class | Strategy | Service Time Distribution
ElectricCar | Load Independent | erl(0.947,9) | Edit
Cars I-II | Disabled | Unspecified | Edit
Cars II-III | Disabled | Unspecified | Edit
Cars III-IV | Disabled | Unspecified | Edit

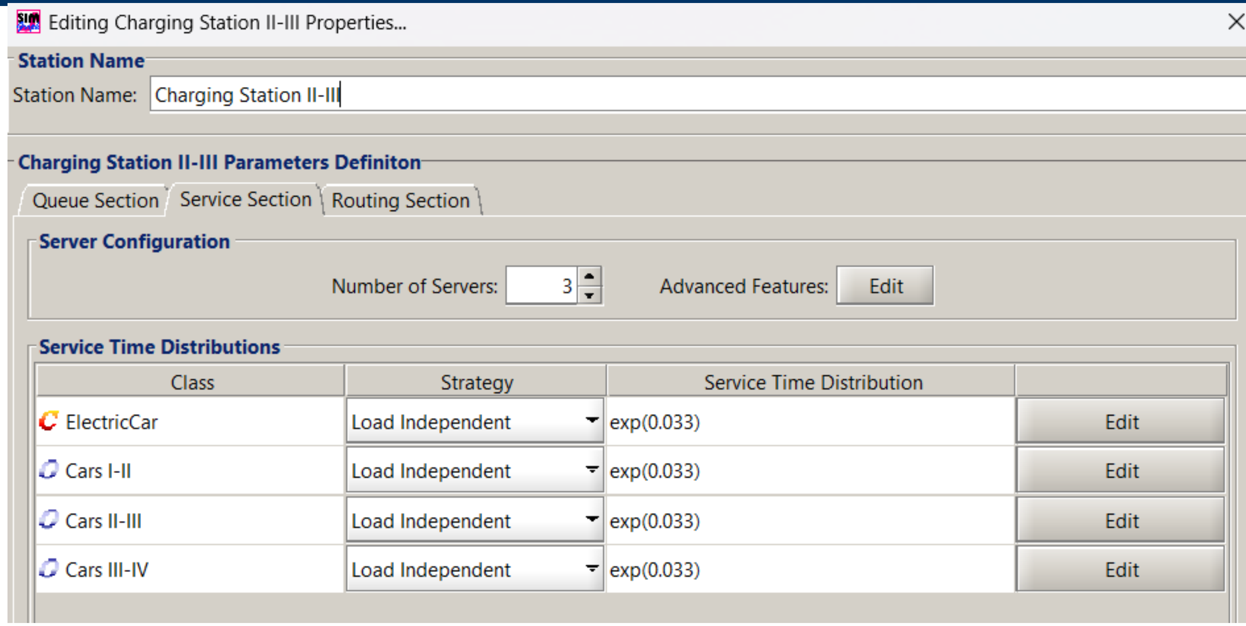


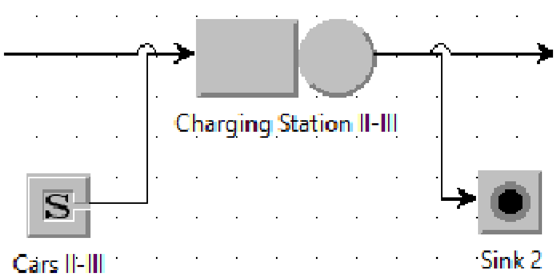
Editing Segment II Properties...
Station Name
Station Name: Segment II
Segment II Parameters Definiton
Queue Section
Service Section
Routing Section
Routing Strategies
Class | Routing Strategy
ElectricCar | Probabilities
Cars I-II | Disabled
Cars II-III | Disabled
Cars III-IV | Disabled
Description
Jobs are routed to stations connected to the current one according to the specified probabilities. If the sum of the routing probabilities is different from 1, the values will be scaled to sum to 1.
Routing Options
Destination | Probability
Segment III | 1.0

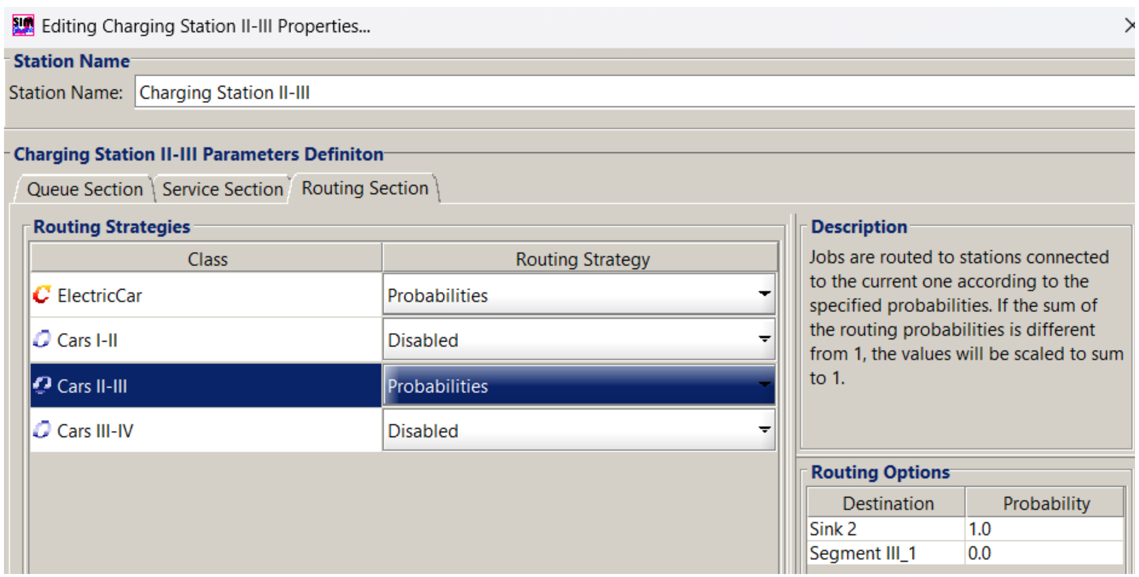
Project A - Recharging of an electric car on a highway

Charging Station II-III :

As there are 3 chargers in the station, I set the Number of Servers equal to 3.

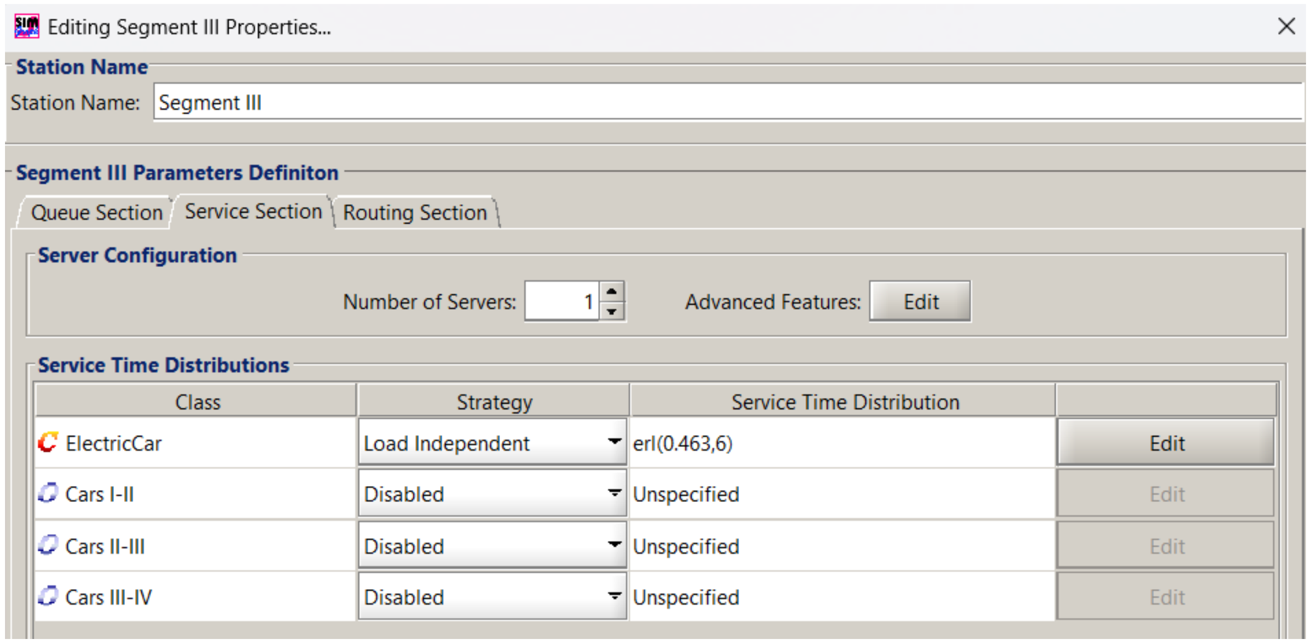


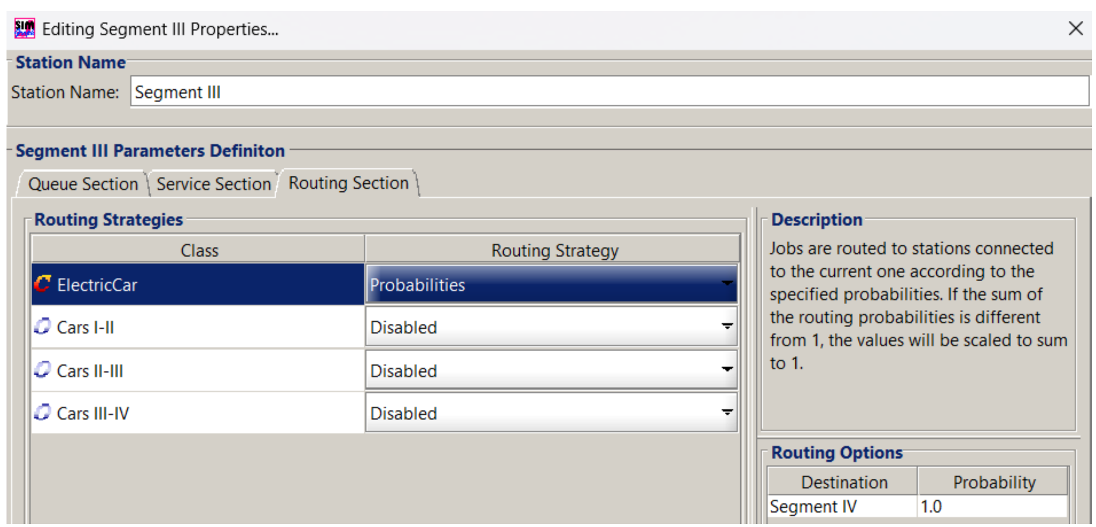




Also in this case the traffic of the other cars, generated from a source, was directed entirely to a sink after the charging station (probability to go to the sink2 = 1).

Segment III :

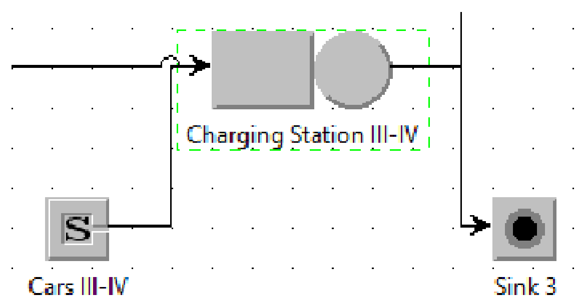

Editing Segment III Properties...
Station Name
Station Name: Segment III
Segment III Parameters Definiton
Queue Section
Service Section
Routing Section
Server Configuration
Number of Servers: 1
Advanced Features: Edit
Service Time Distributions
Class
Strategy
Service Time Distribution
ElectricCar
Load Independent
erl(0.463,6)
Edit
Cars I-II
Disabled
Unspecified
Edit
Cars II-III
Disabled
Unspecified
Edit
Cars III-IV
Disabled
Unspecified
Edit

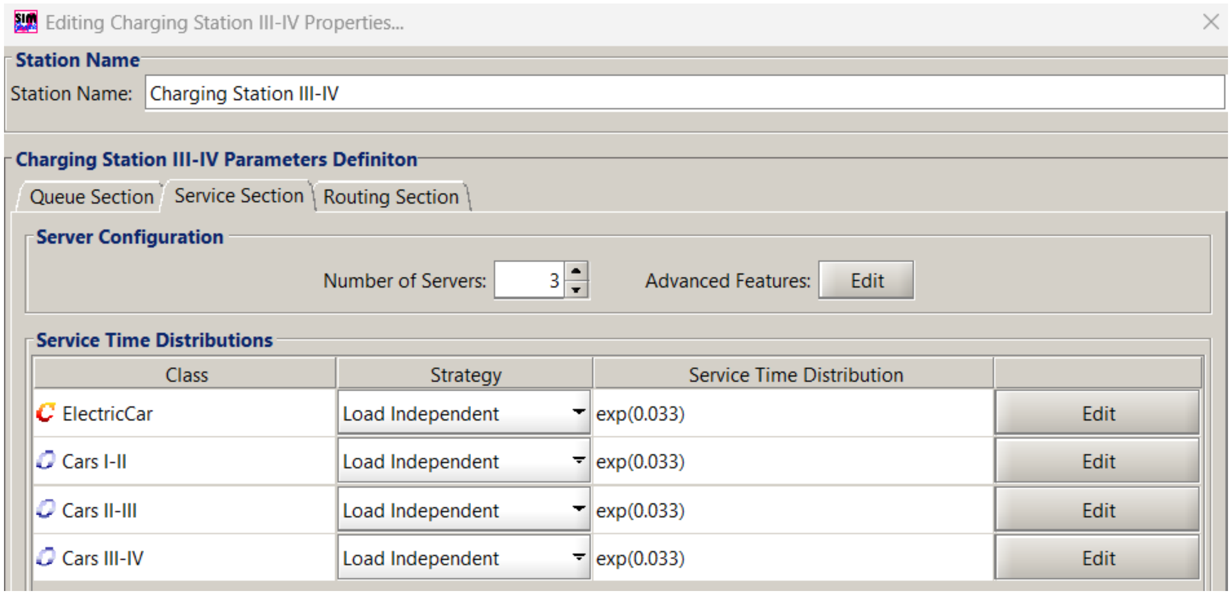

Editing Segment III Properties...
Station Name
Station Name: Segment III
Segment III Parameters Definiton
Queue Section
Service Section
Routing Section
Routing Strategies
Class
Routing Strategy
ElectricCar
Probabilities
Cars I-II
Disabled
Cars II-III
Disabled
Cars III-IV
Disabled
Description
Jobs are routed to stations connected to the current one according to the specified probabilities. If the sum of the routing probabilities is different from 1, the values will be scaled to sum to 1.
Routing Options
Destination
Probability
Segment IV
1.0

Project A - Recharging of an electric car on a highway

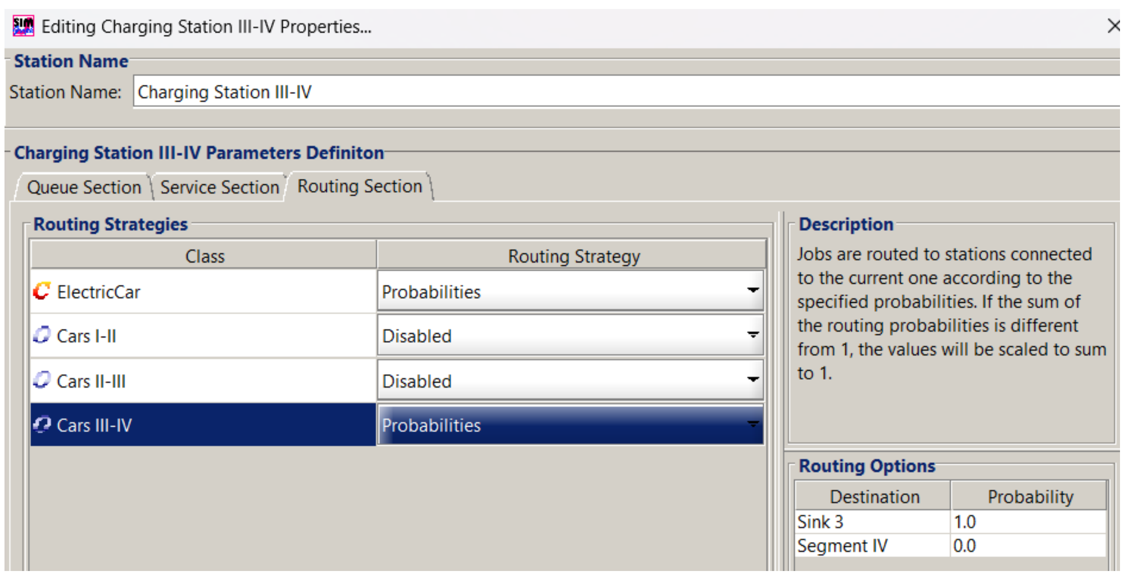
Charging Station III-IV :

As there are 3 chargers in the station I set the Number of Servers equal to 3.



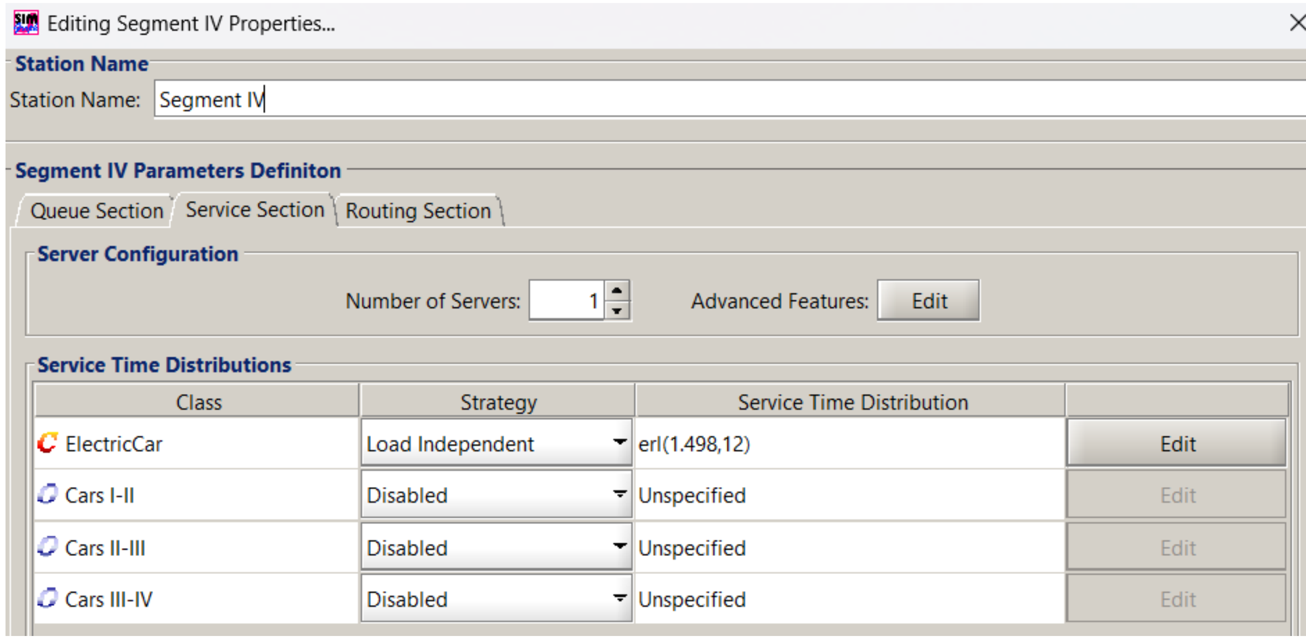


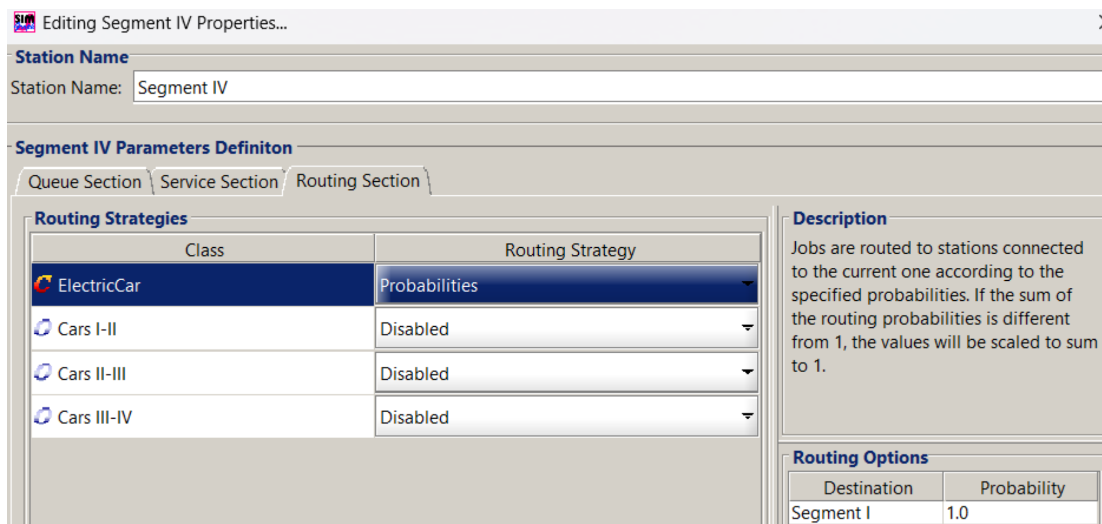
Also in this case the traffic of the other cars, generated from a source, was directed entirely to a sink after the charging station (probability to go to the sink3 = 1).



Project A - Recharging of an electric car on a highway

Segment IV :





I set the probability of the electric car, in the routing section of Segment IV, equal to 1 so the electric car is teleported back to the initial position to immediately start another trip.

Project A - Recharging of an electric car on a highway

Performance indices collected and plotted by the simulation engine:

- System Response Time for ElectricCar class
- Charging Station I-II Response Time of All classes
- Charging Station I-II Response Time of All classes
- Charging Station I-II Response Time of All classes

Define performance indices

Performance Indices

Define performance indices to be collected and plotted by the simulation engine.

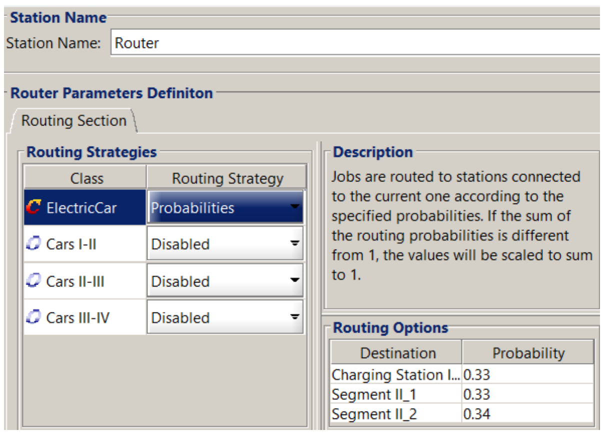
------ Select an index ------

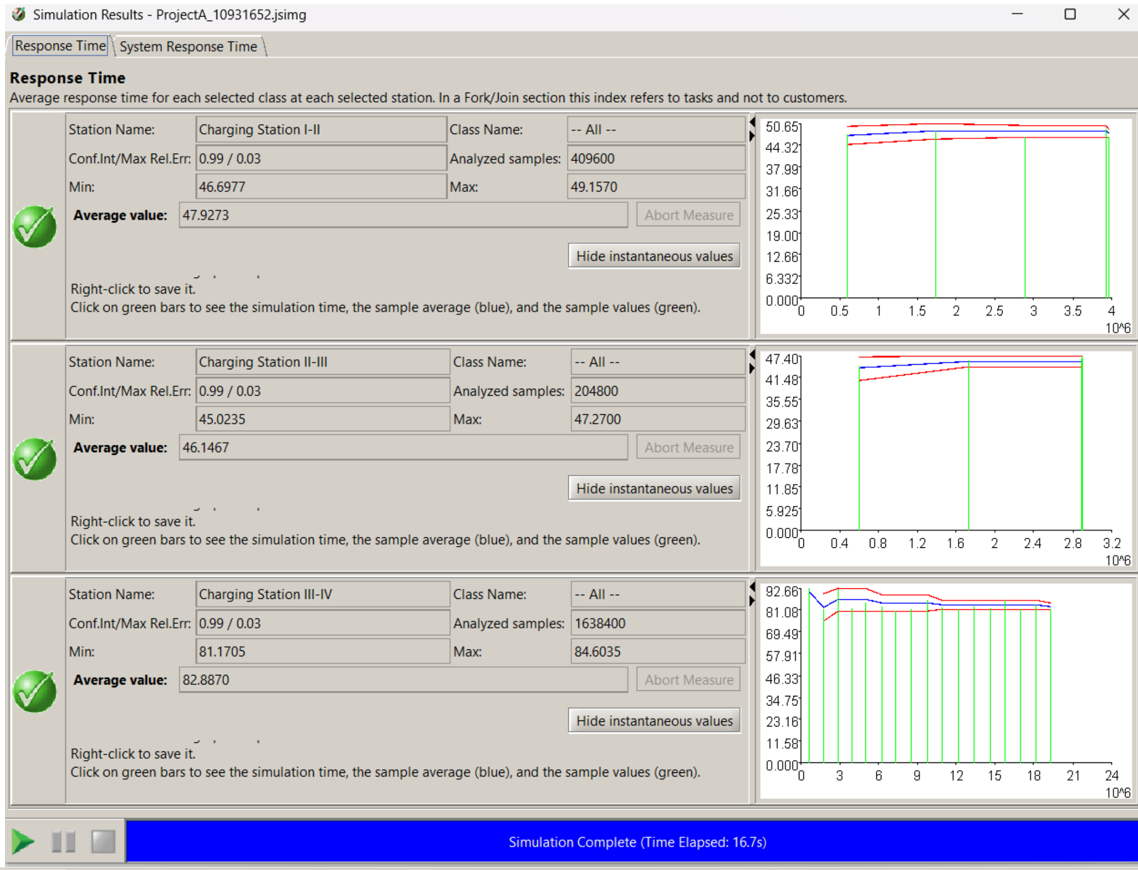
Performance Index	Class/Mode	Station/Region/System	Save Stats	Conf.Int.	Max Rel.Err.
Response Time	ElectricCar	System	☐	0.99	0.03
Response Time	--- All Classes ---	Charging Station I-II	☐	0.99	0.03
Response Time	--- All Classes ---	Charging Station II-III	☐	0.99	0.03
Response Time	--- All Classes ---	Charging Station III-IV	☐	0.99	0.03

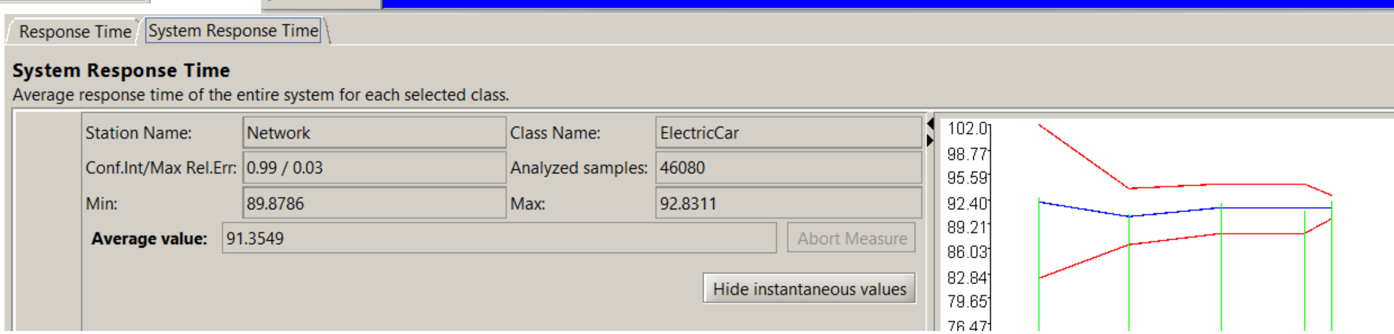
SIMULATION 1)

Simulation having routing probabilities:
prob(path 1) = 0,33
prob(path 2) = 0,33
prob(path 3) = 0,34

In this scenario we obtain an Average Travelling Time of 91,3549 minutes.





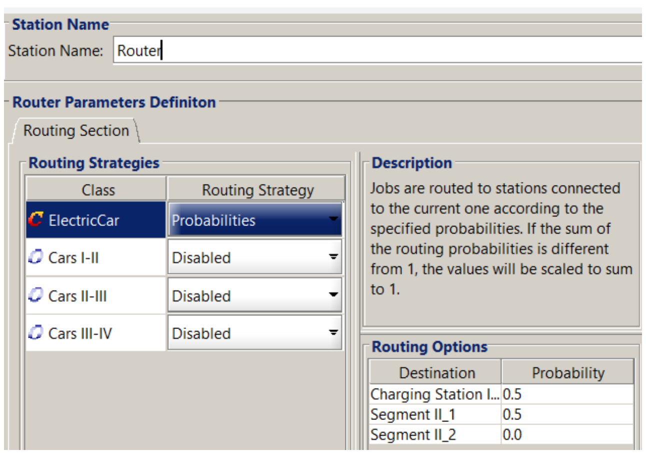


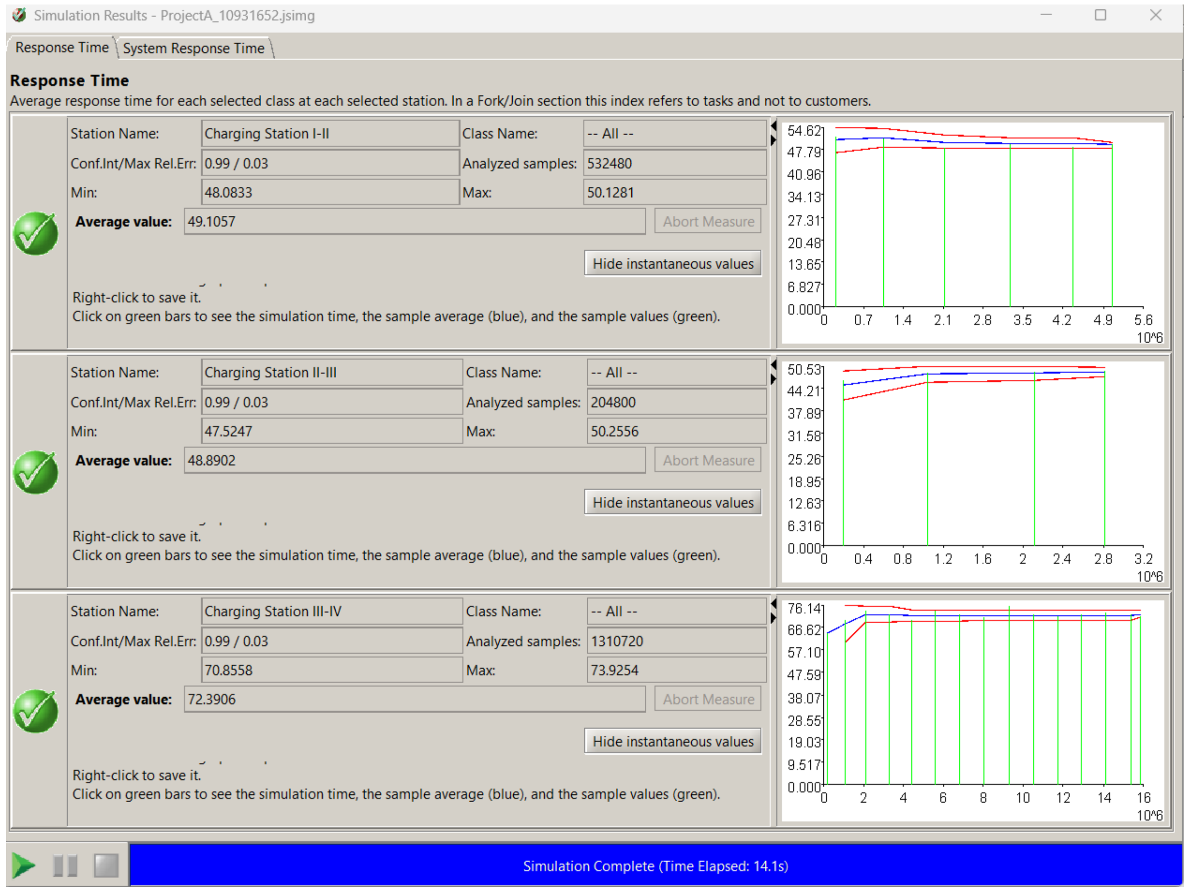
Project A - Recharging of an electric car on a highway

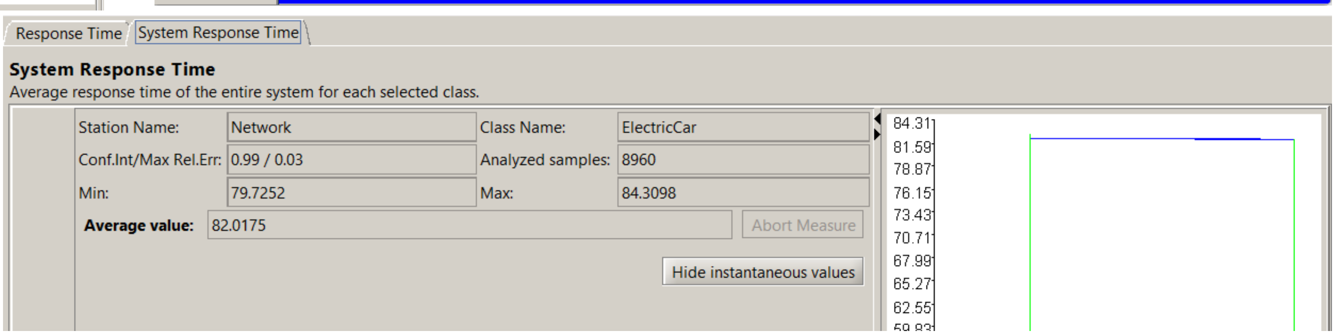
SIMULATION 2)

Simulation having routing probabilities:
prob(path 1) = 0,5
prob(path 2) = 0,5
prob(path 3) = 0

In this scenario we obtain an Average Travelling Time of 82,0175 minutes.





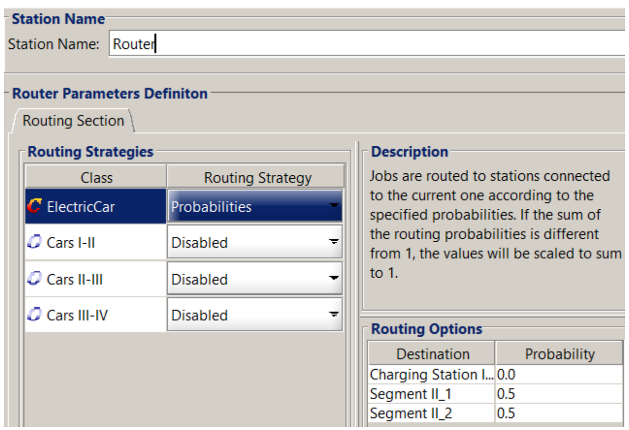


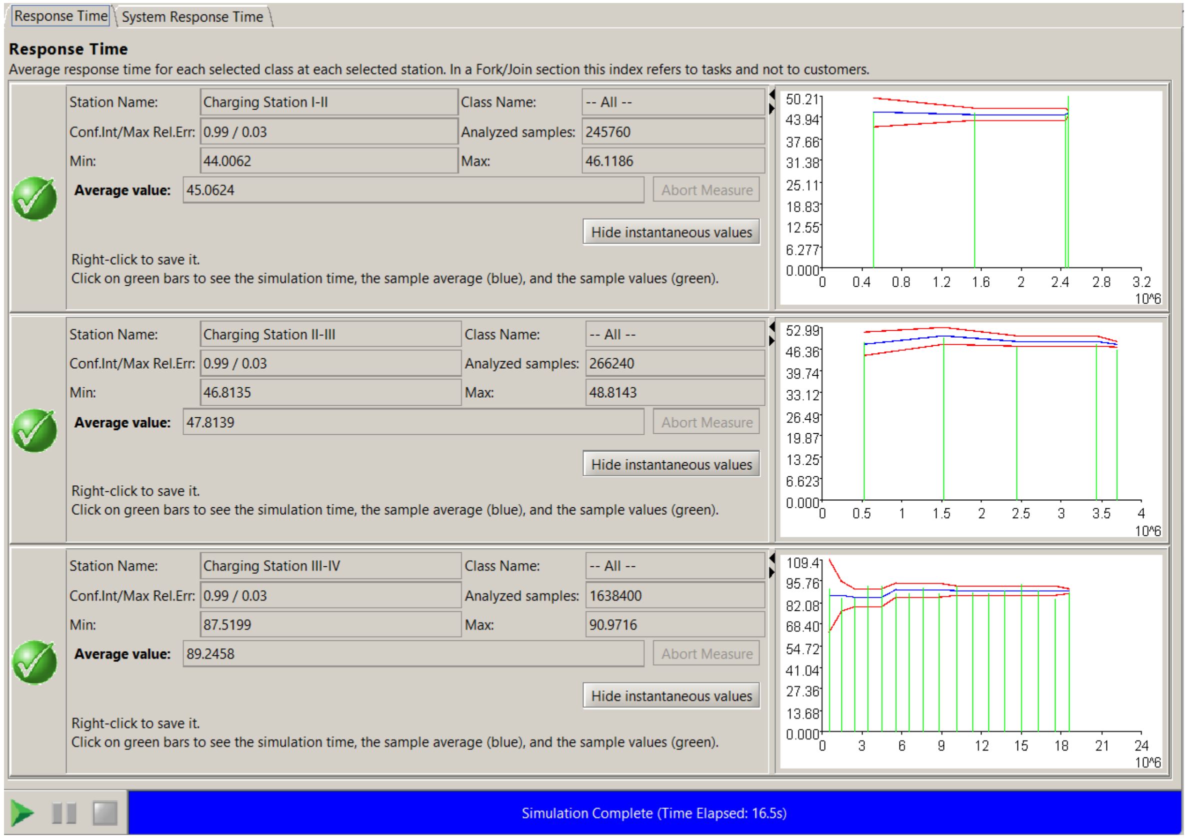
Project A - Recharging of an electric car on a highway

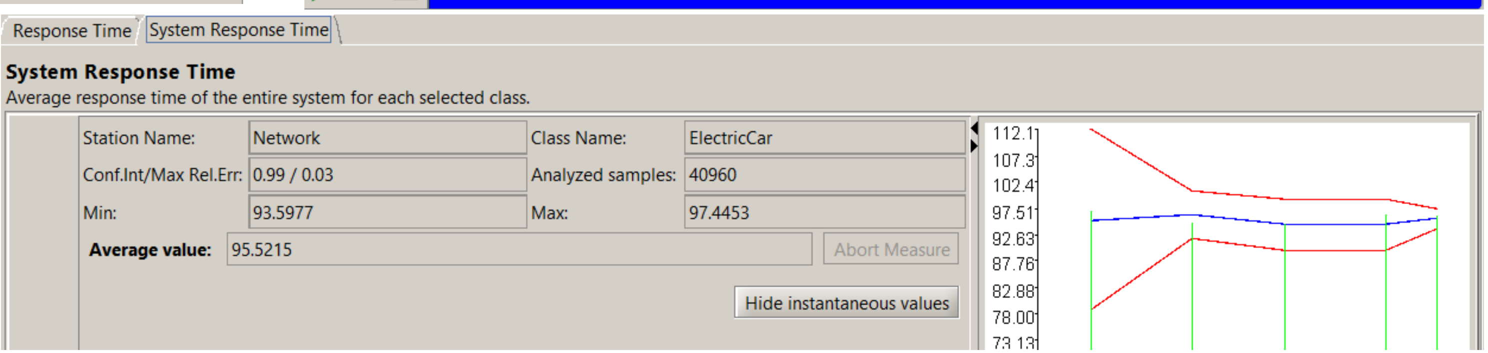
SIMULATION 3)

Simulation having routing probabilities:
prob(path 1) = 0
prob(path 2) = 0,5
prob(path 3) = 0,5

In this scenario we obtain an Average Travelling Time of 95,5215 minutes.



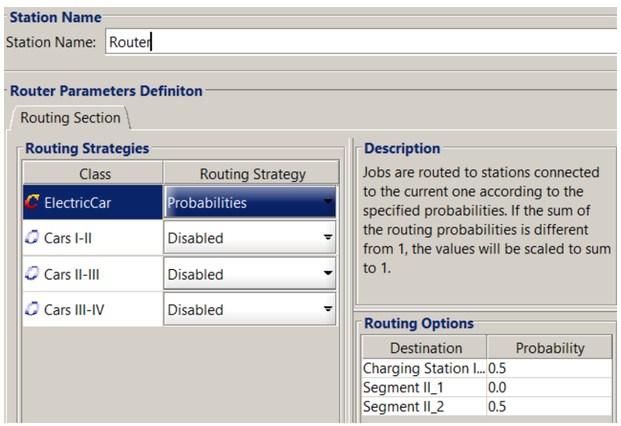


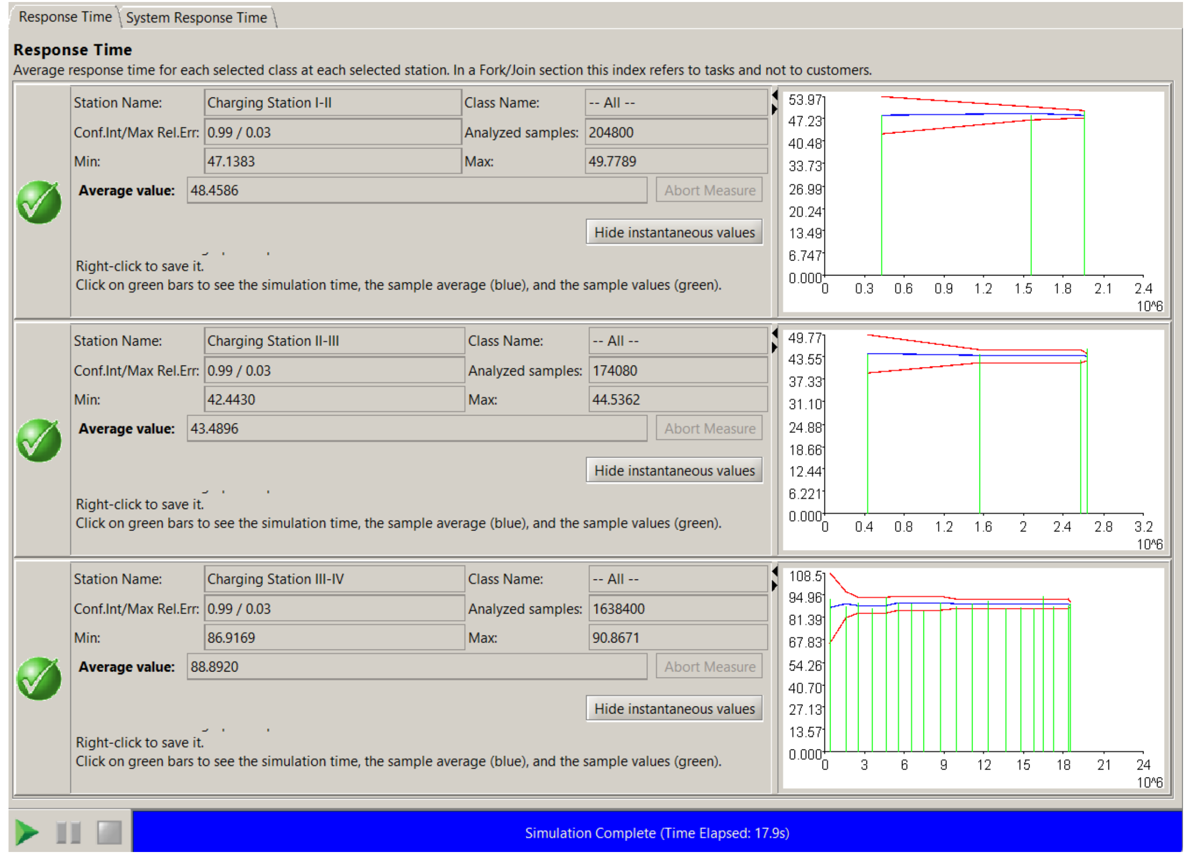


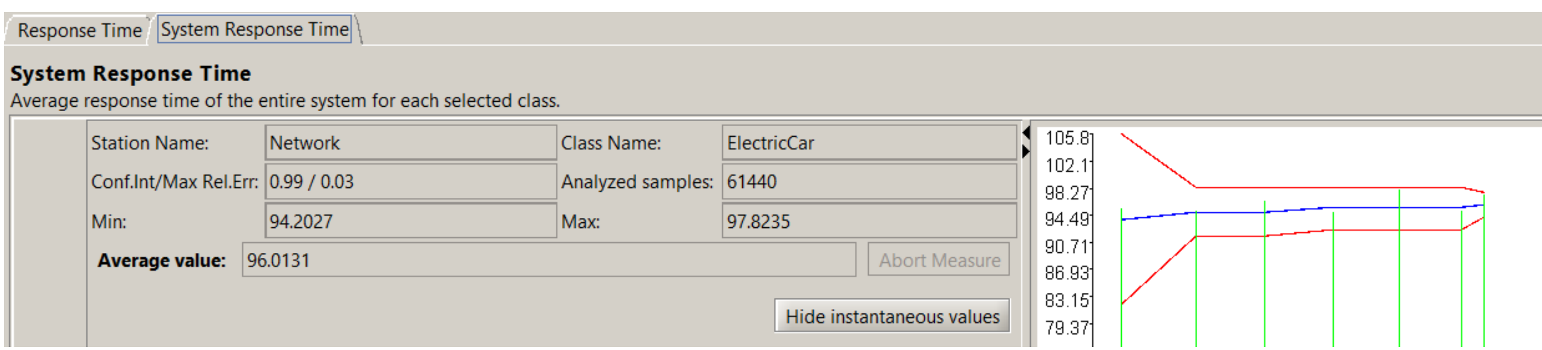
SIMULATION 4)

Simulation having routing probabilities:
prob(path 1) = 0,5
prob(path 2) = 0
prob(path 3) = 0,5

In this scenario we obtain an Average Travelling Time of 96,0131 minutes.





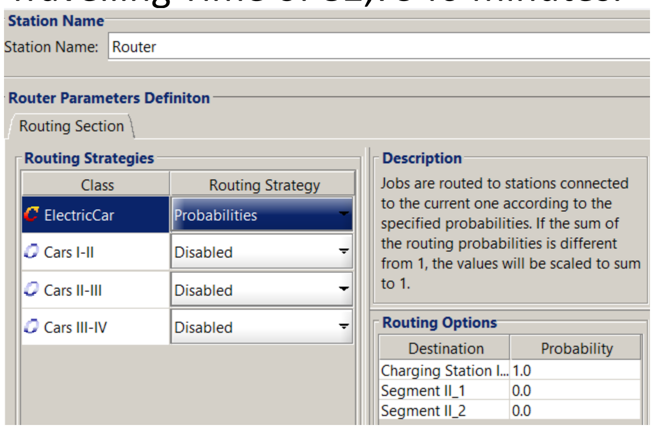


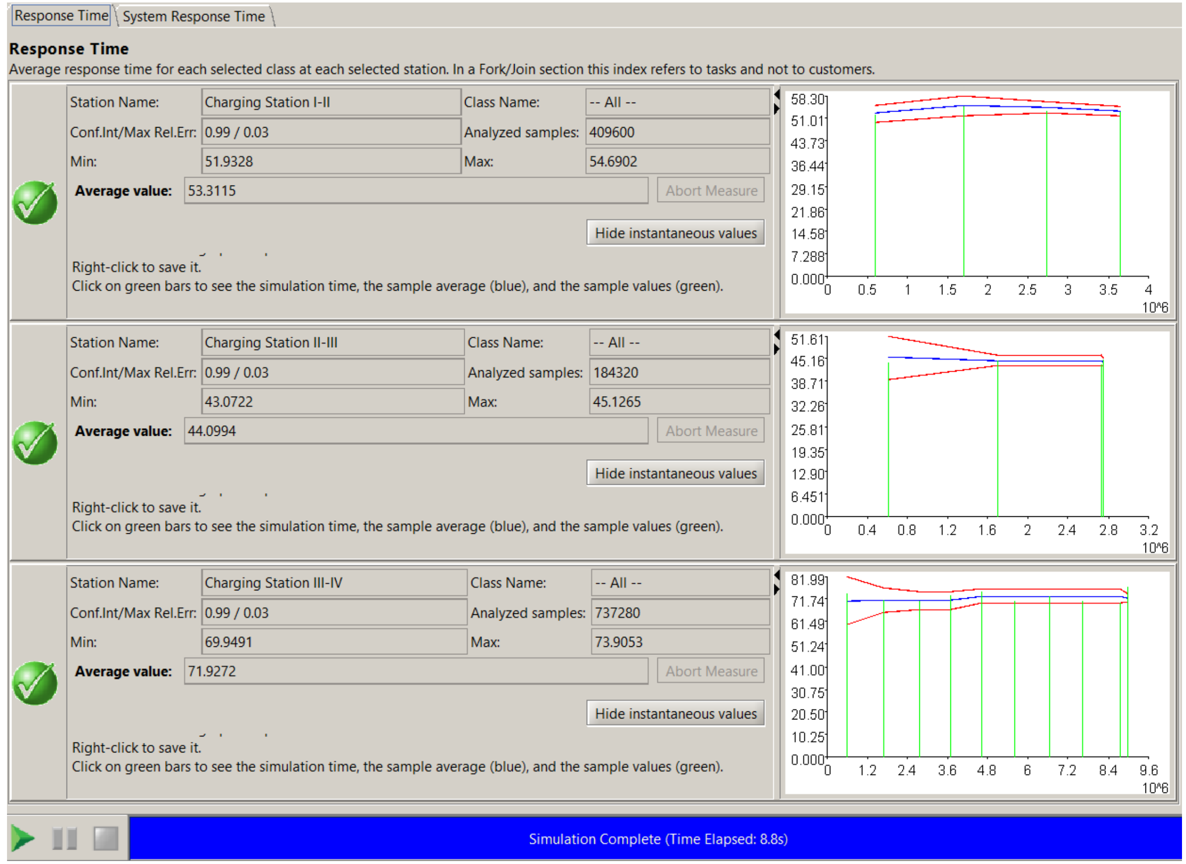
Project A - Recharging of an electric car on a highway

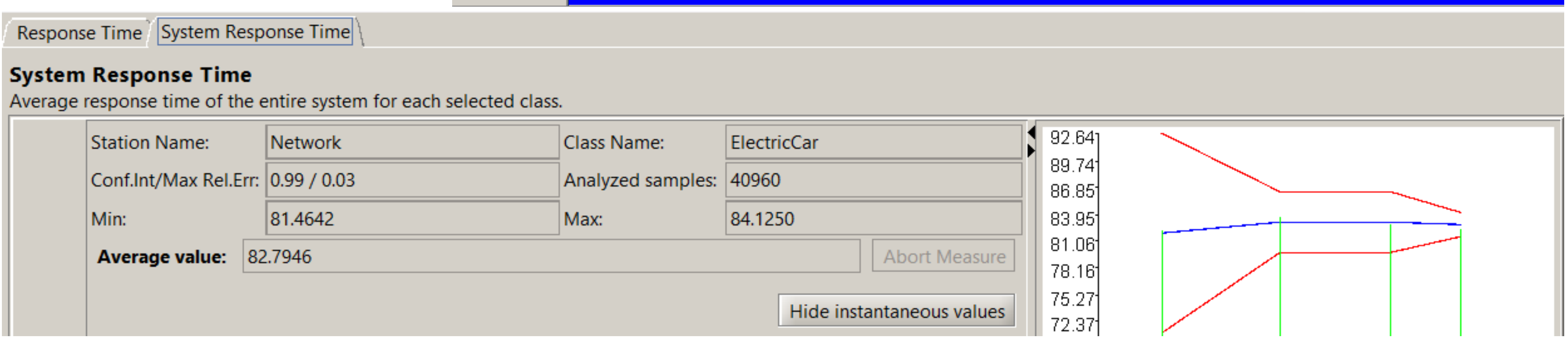
SIMULATION 5)

Simulation having routing probabilities:
prob(path 1) = 1
prob(path 2) = 0
prob(path 3) = 0

In this scenario we obtain an Average Travelling Time of 82,7946 minutes.





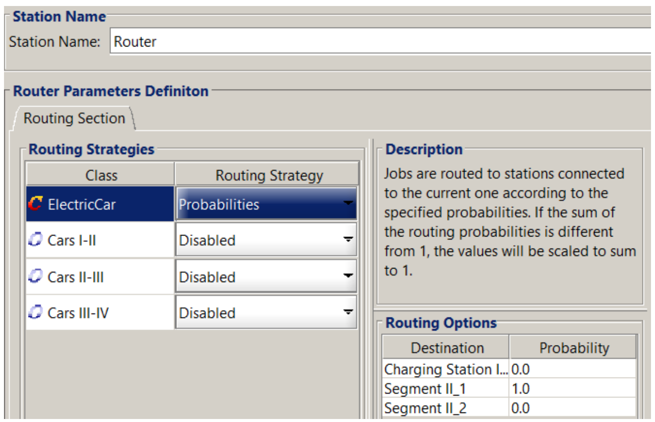


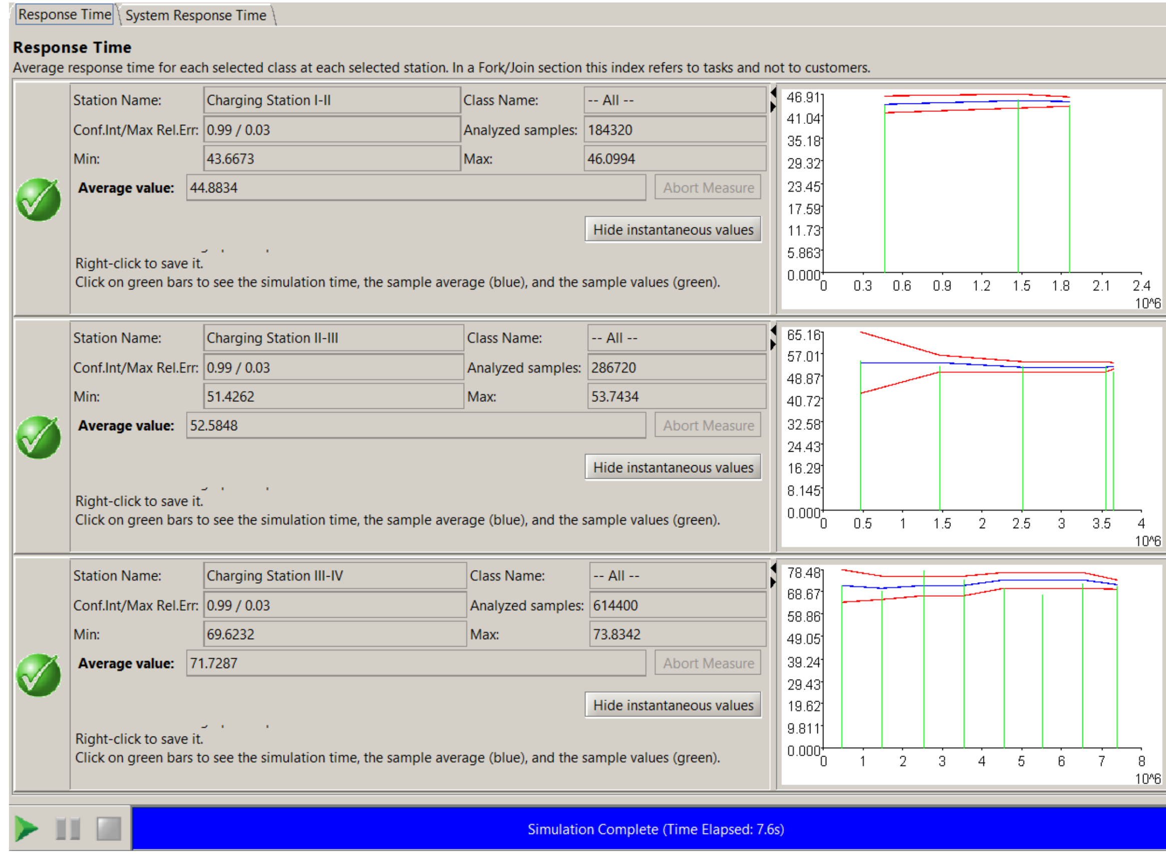
Project A - Recharging of an electric car on a highway

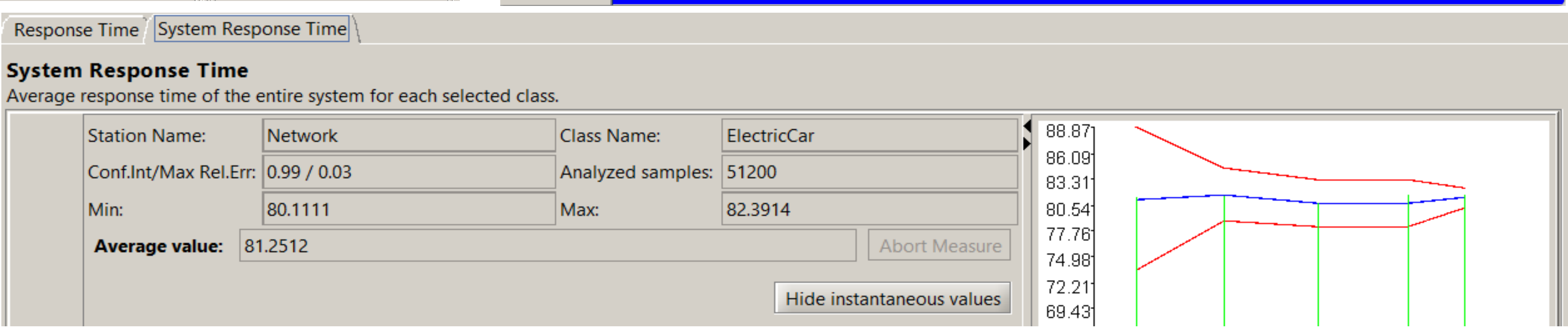
SIMULATION 6)

Simulation having routing probabilities:
prob(path 1) = 0
prob(path 2) = 1
prob(path 3) = 0

In this scenario we obtain an average Travelling time of 81,2512 minutes.



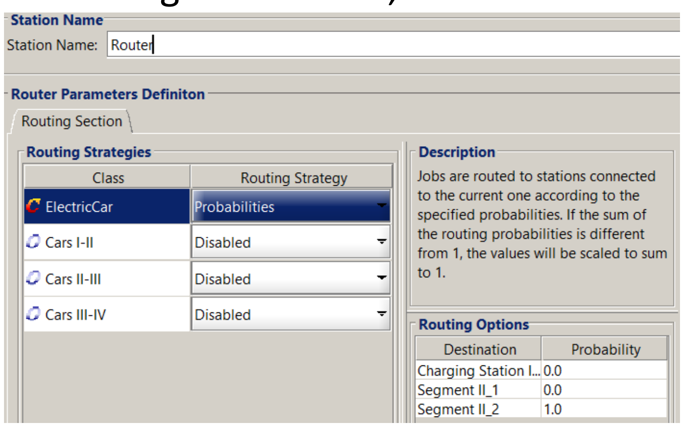


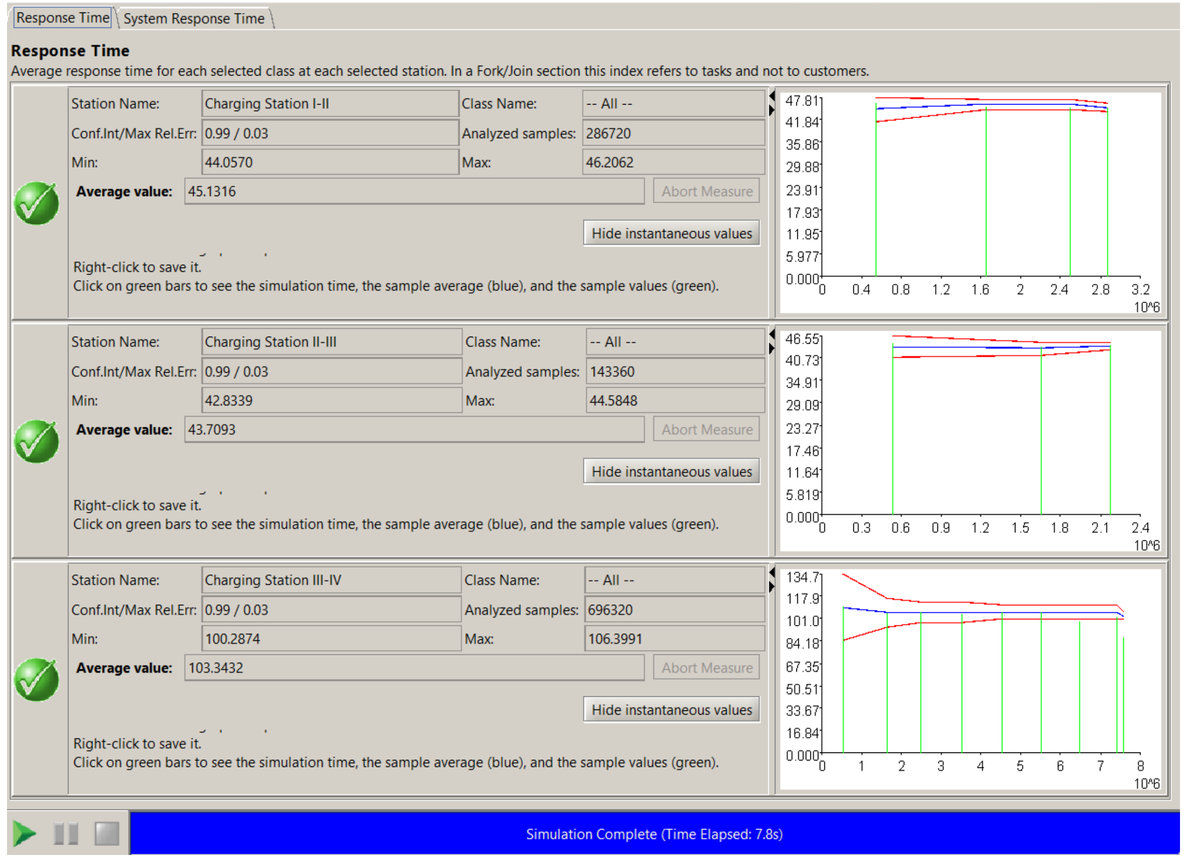


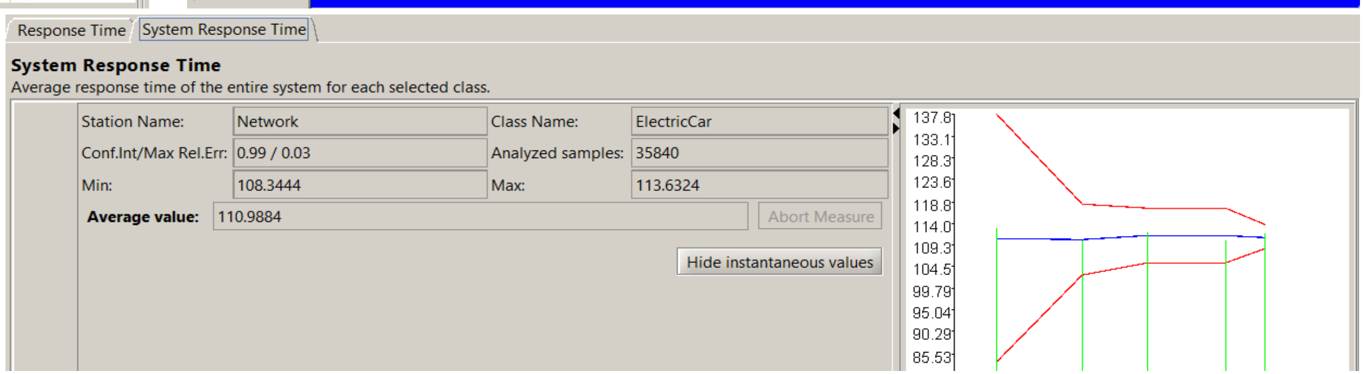
SIMULATION 7)

Simulation having routing probabilities:
prob(path 1) = 0
prob(path 2) = 0
prob(path 3) = 1

In this scenario we obtain an average travelling time of 110,9884 minutes







Project A - Recharging of an electric car on a highway

The best stopping probability distribution, between the 7 different scenario tested is:

prob(path 1) = 0

prob(path 2) = 1

prob(path 3) = 0

So the best stopping probably is to stop at Charging Station II-III with prob = 1.

With these stopping probabilities, the average travelling time is 81,2512 minutes (1 hour and 35 minutes) and its confidential interval is [min: 80,1111, max:82,3914].