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How to Take In Account the New Constraints of Autonomy and Different Charging Methods to Optimize the Scheduling of Battery Electric Buses

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List of Figures

List of Tables

List of Abbreviation:

CNG	Compressed Natural Gas
CO, CO2, NO, NO2	Carbon Oxide, Carbon Di-oxide, Nitrogen Oxide, Nitrogen Di-Oxide
VSP	Vehicle Scheduling Problems
HPC	High Power Charging
OD	Origin – Destination
PIS	Public Information System
LED	Light Emitting Diode
DC	Direct Current
AC	Alternating Current
Km (s)	Kilometre (s)
KwH	Kilo Watt Hour
TFT	Thin Film Transistor

Definitions:

Concept	***Definition***	***Reference***
Scheduling a vehicle	Vehicle scheduling is the process of assigning vehicles to a set of predetermined trips with fixed starting and ending times, while minimizing capital and operating costs.	*[Richard et al., 1995]*
public transportation	A system of vehicles such as buses and trains that operate at regular times on fixed routes and are used by the public	*[Cambridge]*
route	A particular direction or way followed regularly between origin and destination	
vehicle utilization	a measurement typically in hours or mileage to indicate how frequently a vehicle or piece of equipment is used within a given time period	*[Pavement preservation organization]*
Waiting Time	Waiting time is defined as an idling time for bus during operation	
Dwell Time	Time between 2 trips	
Delay time	Delay time is considered as an extra time taken by bus than assigned time for the trip	
Running time	Running time is a time taken by bus between origin and destination.	
Coupling Time	Coupling time is a time taken for coupling or de coupling the pantograph to the power grid or the time to plug-in charger.	
Dead Run	A dead run is when a revenue-gaining vehicle operates without carrying or accepting passengers, such as when coming from a garage to begin its first trip of the day.	*[Wikipedia]*
Commercial run	A commercial run is when a revenue-gaining vehicle operates with carrying or accepting passengers, such as trip between origin and destination.	

Ticketing Dump	Electronic ticket data collected from ticketing machine database	
Sulfation	Sulfation is the failure of the charging process to re-introduce the sulphate radical from the lead plates back into the electrolyte solution.	*[Material Handling Network, 2009]*
One run	One run is defined as total run of a bus in before going for charging	
Capacity of battery unit	Battery unit having the maximum storage in kilo watt hour	
One trip	One trip is called when a bus performs a run between origin and destination	
Peak Hours	Time period hours in which the traffic and load of passengers is maximum within a day of operation	

Abstract

Scheduling vehicles in public transportation is always challenging for planners. This work involves lot of manual interventions and understanding of the ground conditions and becomes a tedious job for the planners to prepare solutions of scheduling route wise. Traditional scheduling for diesel, CNG buses did not had constraints of refuelling during the day of operation. Even if they have to be refuelled, it would be a short time consuming process so had less constraints to schedule. With electric buses, the constraints increases due to non- sufficient power storage. With electric buses stored battery on board, the state of art increases for designing the time table for scheduling due to the constraints of time bound activities such as charging the batteries on board or swapping the batteries, etc. Therefore, it is necessary to consider the electric vehicles for planning and its scheduling constraints in order to cater to new hurdles involved and study how to account these constraints in considerations.

This paper also focuses on considering the different scenarios available in existing practices such as battery swapping technology buses typically used with the slow charging terminals where batteries of the buses will be exchanged during the operation time, every 1-2 hours, depending on the power holding capacity of the batteries and the running time of buses.

It also involves the other type known as fast charging buses where the on board battery unit is typically bigger with larger capacity of storage and can be charged within short time. In this case, the physical location of the battery charging terminals plays an important role in scheduling which will be discussed in this paper. For example, the fast charging infrastructure is installed on the end terminals of the services or fast charging terminals installed only in the depots. Each of the ground operation conditions leads to a new conclusion of the results because of the time management and involvement of critical dead run time or charging time in the scheduling. This paper will present the study of all the above mentioned scenarios and find how to take into account the constraints of autonomy and different charging methods to better plan the scheduling of battery electric buses and reduce the cost of operation by maximizing the vehicle utilization.

Chapter 1. Overview

The world is moving towards an Eco friendly usage of technologies. Air pollution rate is increasing day by day. Few notable factors which involve polluting the environment are the CO, CO2, NO, N2 emissions. Emission of CO is around 75-150 g/Km for cars and public transport buses. In order to reduce the rate of air pollution, governments all over the world are taking initiatives for forming eco- friendly substitutes. One of the major initiatives are the use of electric buses for the public transport. Electric buses for public transportation is a good move in order to reduce the air pollution on the site of operation which will be implemented in coming years all over the world. Some of the cities in China, India, Malaysia, Japan, etc. have already started using electric buses & trams or converting their existing fleet into electric.

Electric buses can store the electricity on board, or can be fed continuously from an external source. Buses storing electricity are majorly battery electric buses, in which the electric motor obtains energy from an on-board battery, although examples of other storage modes do exist, such as the Gyro electric bus which uses flywheel energy storage. In the second case, electricity is supplied by contact with surface power sources.

A battery electric bus is an electric bus that is driven by an electric motor and obtains energy from on-board batteries. Battery buses are equipped for charging with fixed pantographs at bus stops and in the Depot. Super capacitors can be charged rapidly, reducing the time needed to prepare to resume operation. Battery electric buses offer zero-emission from exhaust, quiet operation and better acceleration compared to traditional buses. They also eliminate infrastructure needed for a constant grid connection and allow routes to be modified without infrastructure changes compared to a Trolleybus/TRAM. They typically recover braking energy to increase efficiency by a regenerative brake. With energy consumption of about 1.2 to 2.8 KwH/km, the cost of ownership is lower than diesel buses.

“The vehicle scheduling problem (VSP) is a traditional problem in public transport. One of the main assumptions is that buses can be operated the whole day without any interruption for refuelling etc. Recently, new technological innovations have led to the introduction of electric vehicles (EVs). For these new vehicles, we cannot ignore the need of refuelling during the day, as the range of an electric bus is severely limited, because of the capacity of the batteries.” [Niekerk et al., 2015]. The major challenge is to store the energy in batteries which is a limited source. For example, a fast charging electric buses once fully charged can run between 150-250 kilometres and then has to charge the batteries for another run. Or the battery swapping buses to taking dwell time between the trips for swapping the battery. This is one of the major constraints for the planners and schedulers to achieve a good frequency plan or services for commuters during operating hours. “For a large-scale extension of the use of EVs, a lot of problems have to be solved. One of them is vehicle scheduling. This is mainly because currently batteries in EVs do not have enough capacity for a whole day of driving, so the batteries have to be replaced or recharged during the day.” [Niekerk et al., 2015]. On one side, the engineers are trying to make more efficient buses to run more kilometres in one charge, reduce power charging points and on the other side, planners are trying to find solutions to schedule it better for effective vehicle and crew utilization on the buses.

The thesis is based on taking into account of all constraints for charging the batteries to find the solutions for battery stored electric buses to have better scheduling solutions. Scheduling is a bit technical and tedious job for the planners to do it manually. Also, it has a human limitations for creating the best outputs. The study will help the planners to have possible scheduling solutions for the inputs and constraints put together. It will also reduce the time complexity of the work which increases the productivity of planners.

Placing the right vehicle with the right driver at the right time was never simple in scheduling. Location of buses plays a non-deterministic time polynomial equation which may have infinite possibilities. To optimize the scheduling, a planner has to set the operation in terms of less over time, less dead mileages and on time services. When it comes to battery powered electric buses, it has a limited threshold that impacts traveling time and service arrangements.

There are few more considerations with respect the charging strategies which will be described as use cases in this study.

1.1. State of Art

The state of art is to find all the parameters which are needed to be considered for scheduling electric buses which will be used to find out the solutions for scheduling in considerations of constraints for the battery electric buses. It is necessary to see how the different types of battery powered buses would act on each of the scenario with respect to constraints over places and type of technologies. Battery electric buses neither have a continuous power supply nor generate electricity on-board. Their energy is stored in the battery. The energy density of batteries is rather low compared to diesel or hydrogen. The driving range of battery buses is therefore limited and the charging process requires a certain time. There are mainly two concepts for the charging of the battery, standard and fast charging. Standard charging is performed with a moderate charging power mainly in the bus depot overnight and during long brakes. This requires a high battery capacity and a high weight of the system, when the bus shall be operated the entire day. For the charging infrastructure, there are other factors such as land acquisition, availability and encroachment which may influence the scheduling as per availability of the infrastructure. Fast charging on the track during operation can reduce the required battery capacity and therefore the weight significantly [Matthias et al., 2018]. However, the bus schedule must provide sufficient charging times at certain locations. The researchers in this field so far focus mainly on 1. Adaption of the vehicle scheduling on fixed predetermined charging infrastructure and vehicle configurations or 2. Dimensioning of the battery capacity and charging infrastructure for a single bus route or 3. Standard driving cycle, without considering the vehicle scheduling in detail. This work expands the scope from the secondly mentioned work to the entire bus network taking especially the influence of the vehicle scheduling on the system design into account. It is analysed how and to what extend the entire bus networks can be electrified with fast charging battery bus systems, without changing the existing bus routes and trips.

On the above said, it is important to factories the consequences and methods to determine how the system will work in case of each type.

1.2. Model establishment as case study based on charging types and location [1]

- Fast Charging
  - Fast charging electric Buses with charging terminals at depot only (Scenario 1)

[1] All the scenarios are explained in details in further chapters. Also the case study examples are based on these scenarios.

- Fast charging electric Buses with charging terminals at depot and the OD stations (Scenario 2)
- Standard Charging
    - Battery swapping electric Buses close to OD stations (Scenario 3)
    - Battery swapping electric Buses at Depot (Scenario 4)

1.3. Fast Charging Buses

A fast charging buses are a way of re-charging the battery during the trips of operations. The infrastructure cost of this type goes more expensive but has been more efficient in terms of increasing the performance of capacity of vehicle run and time savings in a day.

Unlike the battery swapping units which are larger infrastructure in terms of space, the overhead installations of fast charging has benefits over time savings to reach to the swapping stations and however, the vehicle utilization is decreased due to the idle state of buses during the charging.

Figure 1 shows a typical infrastructure at the bus station/Stop having fast charging facility.

Fast charging units at the stations/ stops is an effective method of recharging the batteries for few minutes during the trips to gain energy to increase the vehicle run. With the help of the fast charging method, it can be modelled further with respect to the location of the charging points.

Figure 1 Fast Charging at bus Stop

(Source :http://novabus.com/oppcharge-fast-charging-electric-vehicles)

1.3.1. Charging technologies used in fast charging

1.3.1.1. Pantograph

The process of the pantographs works in the sequential way. Described by Siemens as ‘Bus arrives at the charging station and stops under the pantograph – wireless communication between charging station and bus is established. Positioning of the bus: Driver stops at parking reference point and activates the parking break. Sensors check position of the bus; system checks if parking break is activated; if "all ok" charging process is initiated. System checks via 4 pole approach on positive earthing and safe isolation – if "all ok" the main circuit of the HPC is switched on. System sends message to the bus

Figure 2 Pantographs installed in the depot

(Source: Siemens, https://new.siemens.com/global/en/company/stories/home.html)

"all ok/all safe" – bus closes the isolation circuit to the battery system. Charging and battery status are being transmitted to the driver via visual display in the bus cockpit. At "battery status 100 %" or at any point, the driver can release the parking break and by that, initiate the termination of the charging process', as shown in figure 2.

1.3.1.2. Induction

"Inductive charging occurs when an electric current run through a coil, creates a magnetic field, which, in turn, induces current in any nearby conducting loops. When a bus stops at either of the charging stations, its on-board induction loops, lowered to four centimetres above ground, enter the magnetic field. The resulting current tops up its batteries enough to ensure it has enough energy to make it to the other end of the route and its next charge up." [ARUP, Engineering and design company, United Kingdom]. As described by ARUP, the technology at play involves wireless charging where the bus batteries get their charge from underground induction coils positioned at the start and end of a bus driver's route. Charging plates are set into the road, for transferring power to the receiving plates under the bus.

Figure 3 Induction Charging
(Source: ARUP; https://www.intertraffic.com/news/articles/bus-charging-infrastructure)

These kind of infrastructure is very costly but has an innovation. It will be interesting to see how these new technologies are being used in future.

Why is it necessary to consider different type of charging? Every charging infrastructure have different configuration and charging methods. The time of charging will change with different chargers for gaining the power.

1.3.2. Fast charging electric buses with charging terminals at charging depot only (Scenario 1)

Due to the limitations on having larger infrastructure costs, the number of units of fast charging can be limited. In this scenario, time to travel to the charging point increases thus losing the vehicle utilization. Additionally, the charging time will also be accounted in terms of loss in vehicle utilization.

We can define, the loss of time as

$VU_{LOSS} = Time_{CHARGING} + Time_{DEAD\ RUN} + Time_{COUPLING}$. ... (E1)

Where,

VU_{LOSS} = Loss in vehicle utilization
$Time_{CHARGING}$= Time of charging
$Time_{DEAD\ RUN}$= Time of dead run
$Time_{COUPLING}$= Time of coupling and de-coupling time for pantograph/ plugin chargers.

The loss of time has to be accounted in order to understand the maximum vehicle utilization per vehicle throughout the day. Therefore, it can be determined that the fast charging terminals are not sufficient if they are installed only at the depot or far from the OD terminals.

1.3.3. Fast charging electric buses with charging terminals at depot and the OD stations (Scenario 2)

In order to decrease the losses of utilization of vehicles, the fast charging units can be further installed on the OD terminals which would gain a small amount of power on battery at each end of the trip. Here, the dwell time between 2 trips plays an important factor. In case of this, the battery gains power at the end of each trip. Based on this, it can be assumed that

$Time_{Charging} = Time_{Dwell} – Time_{delay} –Time_{Coupling}$. ... (E2)

Where,

$Time_{Charging}$ = Total time of charging
$Time_{Dwell}$= Time between 2 trips.
$Time_{delay}$= Time of bus delay usually considered as buffer time
$Time_{Coupling}$ = Time of coupling and de- coupling of pantograph/ plugin chargers

Still the OD terminal charging times are not enough to make the batteries fully charged. It will be still required to send the bus to the depot or charging stations (Parking) to get sufficient charging for the remaining day.

1.4. Standard Charging Buses

A new charging infrastructure is evolving based on the principle of battery swapping. Conductive charging have disadvantages of having longer charging time at the depot or terminals and reduce its vehicle utilization for the day and battery degrades the performance rapidly in case of fast charging. This problems were solved with the use of battery swapping stations.

“With the difference of the vehicle technical and operating characteristics between battery electric and conventional diesel buses, some new aspects should be taken into account when dealing with the electric bus scheduling problems.” [ZHU and CHEN, 2017]. Mileage of the battery electric buses are limited in current battery technology. It is important to have charging between the operational routes. Vehicle utilization is a major factor as it involves a large amount of cost factor.

Figure 4 Battery swapping station
(Source: https://www.youtube.com/watch?v=FQVx167iYS4)

Maximizing the vehicle utilization will result in reducing the cost of operation. Battery exchanging typically would take less time for replacing the old with new unit but also solves a large amount of investments for fast charging terminal installations. The cost involved in the battery swapping is the infrastructure cost of forming a charging hub and amount of batteries to have a feasibility for swapping with sufficiency during operational day.

1.4.1.Battery swapping electric buses at charging depot (Scenario 3)

The battery swapping unit consists of 3 parts

1. Electric bus with roof top mounted battery exchange mechanism,
2. A battery exchange robot and
3. Storage station with an exchangeable battery pack.

Robots and storage stations are usually located at the depot due to the required infrastructure, but it can be installed along the route of the buses too. The exchange mechanism electric buses run along the route with its capacity. When the battery energy is exhausted, the buses come to these stations to swap the old battery with a new fully charged units. This activity is described as "The discharged battery from the electric bus will be recharged at the battery exchange station using a carefully scheduled battery charging policy to avoid possible overloading of the existing power grid system in the city [Kim et al., 2015] This way, the time loss happened due to the charging time is reduced and the buses have better vehicle utilization.

Still, in this scenario, if the battery swapping unit is installed only in the depot then the travel time from the OD to depot and vice versa would have to be considered as dead run which will result in decreased vehicle utilization.

In order to avoid this consequence of losing the dead run time to travel to place away from the OD stations, we have the scenario 4 as given in 1.4.2.

1.4.2. Battery swapping electric buses at OD stations (Scenario 4)

As seen in the above scenario, if the swapping unit is not close to the OD stations of the operating route then the cost due to non- commercial runs (dead run) increases. This cost can lead as larger cost depending on the distance between OD stations and swapping point. It is important to consider this factor in order to understand how the time-distance of dead run can reduce the vehicle utilization. In this scenario, it can be seen that the battery swapping units are installed close to the OD stations and will have less cost involved due to less dead run distance. "With this integrated approach, the electric buses with the battery exchange system can be optimized for specific bus routes, and the proper locations of battery exchange stations can be optimized to ensure smooth service operation." [Kim et al., 2015]. This can be the most effective way of operating the battery electric vehicles in the context of city operations.

1.5. Impact on scheduling and operational inputs

For the scheduling, the constraints can be factorized in terms of time to produce and evaluate the results. It is important to study the operational inputs to create theoretical approach to the problem. It is also important to understand following factors in scheduling considerations such as

- Autonomy or range which is nothing but modelling battery capacity and consumption rate,
- Modelling for different battery technologies which calculates the charging duration,
- Charging location for understanding charging modes,
- Battery life as to set the limit for fast charging points.

Conclusion: Identified operational inputs -

- Charging time and capacity of the battery unit
- Hours of a day operation for the route
- Number of buses available
- Run Times based on hour of the day
- Buffers/ Dwell Time between trips based on hour of the day
- Dead run time from depot to OD stations
- Charging constraints based on bus configuration and infrastructure availability described as in scenarios.
- Maximum number of trips in one run
- Peak hours of operations

Above all mentioned factors to be considered for scheduling.

Chapter 2. Analytical Methods

The process of validating the resultant output is shown below (See Figure 5). The configuration is a combination of inputs to run a simulation in order to validate the result. It consists of run times (GPS analysis), number of buses available for operation, time to reach from depot to station and vice versa, dwell time, shift hours of bus, charging restriction of terminal, number of trips per charge, restriction to combination of target frequency.

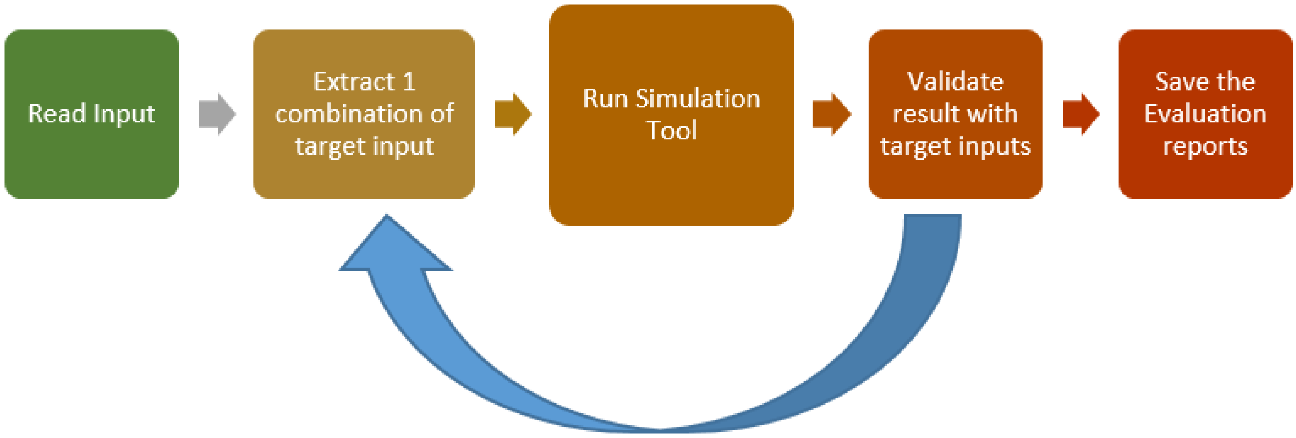


Figure 5 Process of Simulation

The evaluation can be formed by comparing the operational performance with diesel buses. The constraints which are belonging to the limitation of operation will be measured with respect to the parameters mentioned below.

2.1. Scenarios and its evaluation

It is important to know how charging locations affect planning. In order to validate the performance, diesel buses can be considered for comparison. Factors affecting the performance of electric buses are (1) Fast charging electric Buses with charging terminals only at the depot, (2) Fast charging electric buses with charging terminals at the depot and the OD stations, (3) Battery swapping electric buses at depot and (4) Battery swapping electric buses close to the OD stations.

A simulation tool needs to be developed which will evaluate the production result. The simulation tool is nothing but imposed conditions/ constraints of the ground and run as the live operation. The approach to run simulation is a chain of events and checks which will be determined as results and then evaluated with its feasibility. A combination of an input will be provided to simulator for achieving the result. The result may or may not achieve its target which can be determined by evaluation. The non-achieving targets can be ignored from the final results. Validation of the result can be factorised into multiple checks:

2.1.1. Check if Buses are available at origin and destination at specified/targeted time

Buses are the physical entities, that's why location of the buses become critical factor for usage or deployment of the operation. In the beginning, if the targeted frequency requires more number of buses to ply, then it might not be a feasible solution for planners. For example, if the run time between origin and destination is 60 minutes. 5 buses at origin and 5 buses at destination are stationed at the start of the operation then the best frequency which can be achieved by buses will be 12 minutes. This is because, the buses will take minimum 120 minutes to return to its first position to get re-used. There will be few more factors like buffer (dwell time), run time delay, breaks for charging or swapping, etc. which can affect the operation.

2.1.2. Check if the buses are available to perform as targeted frequency

If the targeted frequency is achievable with all the ground constraints, then the solution is acceptable. When using the combination of inputs, several inputs will not be able to satisfy the constraints and generate good results. Frequency is a key factor to rationalize the operation. In the peak hours, it is seen that the demand of the operation is more than non-peak hours. Planners need to keep this phenomena in consideration while planning. In the peak hours, it will be mandatory to provide more frequency of buses as compared to non-peak hours. This is achievable only when the buses are available for performing the trips.

2.1.3. Check if buses have completed the previous trip

To use the buses which are already running on ground conducting a trip, it is necessary to understand its status at time. The buses which are already within their run can notify if the next trip can be finished with sufficient power left in the batteries while running a simulation tool. This can be modelled as how many trips can be conducted in one charge. The simulator has to check if the trip has finished and bus is ready to depart again.

2.1.4. Check if buses have taken dwell time for charging

If the charging mechanism is installed on the station, the buses can be recharged for few minutes during the operation between the trips. This will help the electric buses to operate more distance as well as increase the vehicle utilization for the day operation. The infrastructure cost of installing the overhead charging mechanism is high and would lead to increased cost of establishment. But this will help the electric buses to run flawlessly. For these kind of infrastructure, it will be necessary to check if the buses have enough dwell time to get charge and gain few more kilometres. These infrastructures are typically fast charging points which charges the battery enough to gain kilometres even if it is provided for few minutes.

2.1.5. Check if the buses have enough time to charge battery at depot during shift

The method is to find out the solutions which will have enough time to charge sufficiently to conduct a second run. This case is evolved due to the use of fast charging buses having typically two runs per day. If the time for charging is not sufficient, the solution can be rejected by the evaluation.

2.1.6. Check if total duration of dwell time taken during the trips is sufficient to perform the operation

If dwell time is used for charging the batteries then it should have the sufficient time between the trips. In the conduction of an operation, the dwell time can be large. In traditional operation with diesel buses, the dwell time is very less as it doesn't require any activity to be performed. It is usually given as an additional time to give buffer to the driver to complete his trip and bus can start for the next trip on time.

2.1.7. Check if all the buses are used

As a part of the operation, it will be validated if all the buses are equally used. The Equal amount of operation would mean that the buses have a completely rationalized operation. Even if the buses changes their schedule, it will not be affecting the total utilization of buses. The schedules will also have a scope of altering the duty times. The periodic maintenance activity will be easier to manage with spare buses.

Generating equal duties with respect to driving time, dwell time, charging time and duty spread will result in better output and flexibility to play around the duty shuffles.

2.1.8. Check if the buses are ready for the 2nd run after charging

If the buses are considered to be fast charging and having a capacity of running the bus for 100-150 Kilometres, then the buses have to come back to the depot or the charging points where it can charge the battery for 2nd run. This will involve number of factors such as available charging points to understand how many buses can be charged at the same time. Once the buses are stationed for charging, the time of charging will be considered as ideal time and the buses will be ready once fully charged. The operation further to charging will be considered as 2nd shift of bus.

2.1.9. Check if all the trips are performed

In case of electric buses, we have restricted operation in terms of its trips, limitation of charging time during operation, etc. The simulator, if not able to perform all the trips within the duration of the operation, the solution will not considered. The number of trips for the operation can be defined in the inputs and if the bus doesn't able to fulfil all the trips then the solution can be neglected.

2.1.10. In case of not providing buffer time at terminal

In certain cities, it will be difficult to form charging units at the terminals or the charging stations are available at only origin or only at the destination. The difficulties for the planners increase when there are more such constraints. Assume that the charging point is not available on the Outward depot or Origin station, then all the buses have to be planned in such way that they take break/ dwell time or charging time between shifts at only destination or return depot.

2.1.11. Check if the buses have completed the hours of operation as specified

Assume that the buses have to perform for 18 hours of operation per day conducting 20 trips of making 250 kilometres. If the buses are unable to conduct all the trips within the duty durations, the solution can be rejected. This can ensure that all buses will have to finish all the trips assigned based on the inputs provided and is practical to implement on the ground.

2.1.12. Checking all validated frequency patterns

There can be many solutions to one problem input. The simulation will give possible ways of conducting the operation and planners have to choose among those solution which fits the best for bus line operations. Frequency of the trips of the time table need to be validated as to see if the frequency of the buses in day hours is sufficient for commuters. For example, if the frequency of the trips is lesser in peak hours than in nonpeak hours, it is not going to be useful as there won't be buses available during the required hours. The buses might go overcrowded during peak hours, and in non-peak hours, the buses are going to be empty. To balance the load factor of the passengers, the demand of the trips have to be analysed. The solutions which cannot satisfy the need of the frequency would be rejected.

2.1.13. Choosing the operation from results

After evaluating the results, there can be a method of selecting one of the output to implement on ground. The indexing to the evaluation can be given to understand which solution is the best with respect to the inputs provided to the system.

Conclusion: The weight for each activity can be defined depending on the integrity of the impact on result solution based on what was demanded as an input. Analytical methods will help to build an appropriate solution based on the constraints.

2.2. Demand based modelling[2]

In the city operation level, the planners have to schedule the buses according to the frequency required in those respective hours. Demand of the passengers for services is usually higher in peak hours. Usually, it is seen in a day operation that in the morning, peak hours start from 7h45 to 10h30. This is because of the lobby of commuters such as workers, employers, students who are going to their destinations. Similarly, peak hours are seen in the evening 17h to 19h for the same lobby of commuters to come back to their respective place. The demand of the services is needed to be planned for these hours. The solution must consider the factor of peak and non-peak hours of operation and generate result.

For the analysis, we can consider a report showing the targeted frequency and the output frequency after running a simulation test.

2.3. Analysis of run time and bus availability of location

For the planner, the challenge is to achieve a desired frequency for a bus operation. Buses have to be scheduled considering the location of bus at certain time of scheduled trip. Which bus has to perform which trip at what time is determined based on analysed run times and buses locations and scheduling them by assigning each trip to a certain bus. A travel time between the origin and destination is also affected by traffic conditions which can be analysed using GPS loggers which are normally installed in the

[2] The user can modify the input information on the software for peak hours, frequency, run time, break time, charging infrastructure based on the ground conditions.

buses for tracking. Using GPS logs, it is possible to understand the average run time of hour of the day taken from origin to destination. This run time will be utilized to schedule the trips in order to understand the availability of buses at the end terminals. The location of vehicle is very important in order to perform the desired trip. To have the availability, bus needs to complete its previous trip and be ready for departure.

The evaluation of the charging time is a must and is dependent on the type of buses which are used for the operation. If there are buses of battery swapping technology, the buses will be ready for departure for next trip after inclusion of the dwell time of battery swapping.

In order to compare the performance, the frequency will be targeted as a resultant output of the consideration/ inputs.

2.4. Capacity of battery to measure performance

There are different types of buses in battery operated electric buses. They can be broadly classified as fast charging or slow charging buses. The slow charging buses are meant to reduce battery storage but will have battery swapping units. Fast charging buses will have the better capacity of running more distance but still not sufficient to conduct the full day operation.

In order to understand if the buses are needed to be sent back to charging points, this indicator will be very useful. If the capacity of the battery does not qualify to conduct a trip then the simulator has to send the bus back to charging point or end its operation.

2.5. Vehicle utilization

Vehicle utilization is a measure of calculating the total run a bus can conduct within one day of operation. Assume that a buses are planned to perform 200 kilometres in a day and perform it then their vehicle utilization will be 200 kilometres. Here, it is necessary to figure out whether electric buses have equal or reasonably lesser performance than diesel buses. This indication can conclude that the existing operation of diesel buses can be replaced by electric buses.

There can be another way of understanding a good solution with respect to vehicle utilization. For example, if there are 10 buses which are not having same kilometre run in a day, but the average vehicle utilization is around the same what is expected, then the solution can be selected or rejected based on what planners are trying to achieve.

The performance of electric buses will be compared with performances of the diesel buses to understand whether existing operation can be completely changed to electric buses.

2.6. Cost of operation

It is important to understand that Public Transport like any other business module can be effective and efficient only if it understands the market it serves, commuter expectations, and the gap with respect to its current scenario to the expected service aligned with the growing modern day technology. An effective an efficient way to understand operational efficiency is to analyse the operational viability with respect to cost. The cost of operation can be reduced by reducing the trips during operation hours where demand is low or negligible. The required amount of operation will be performed to fulfil demand. When scheduling the electric buses, planners need to consider the type of buses in operation and charging time for those bus type.

Earlier, we have seen the types of buses for electric once, majorly battery swapping and fast charging. The loss of time added in battery swapping buses is after 1 or maximum 2 trips (30 kilometres range). The loss of time will be performed after every trip or 2 trips which will have more dwell time to change the batteries. For example, if 1 trip is of 15 kilometres, then post 2 trips, the bus has to go back to the swapping station where old battery will be replaced by fully charged battery. The time to change the battery will be considered as non-operational time for the bus known as dwell time.

In case of fast charging buses having range of 100 -150 kilometres of driving in a single charge, the planners have to provide 30–90 minutes of charging time for another run. This has to be scheduled such way that the frequency of the trips are not affected due to the charging time of buses. At the same time, it is necessary to consider how many buses can be charged at a time. If the charging point has a limitation of only one bus can charge at a time then it will create difficulties for scheduling. After a full charge, once the bus runs for 100-150 Kilometres, it will be mandatory for the bus to return to charging station and be stationed for 30–90 minutes of time to get charged fully or partially to perform the remaining time for operation. For this, it is possible to consider 2 shifts in a day time to perform the operations. Before leaving the depot, the buses will be fully charged in the morning. The activity can be planned during the ideal hours of operations. Till afternoon, the batteries would exhausted and the buses would return to the depot to re charge the batteries. The process will lose the productivity of the buses during the charging hours but can be manageable if the operation requirement is lesser than other hours of the day.

The operational hours is usually seen at its peak from 7h45 to 10h30 hours in morning. The planners schedule buses according to serve appropriate frequency in the peak hours. Post peak hours, the service requirement is reduced. These hours can be utilized for few buses to go back to depot and re-charge their batteries.

Conclusion: Evaluation will help to compare solutions with each other instead of evaluating it independently. For example, a simple factor of number of buses can be compared by understanding how many buses are been used in solution 1 and solution 2 which can be determine a better solution. A better solution can be the least use of number of buses.

Chapter 3. Data Collection

Public bus services are based on specific timetable giving determined times of departure and arrival at waypoints along the route. These are often difficult to maintain in the event of traffic congestion, breakdowns, on/off bus incidents, road blockages or bad weather condition. Predictable effects such as morning peak and evening peak hour traffic are often accounted for in timetables using existing show-ups of the route. In this document, it is described data to be collected for effective electric bus scheduling and rationalize the existing operations of the city.

Bus scheduling will be tested based on a case study for a city operations. The city of Tours in France has a potential for this study as it is having public bus services spread all over the city and is fully functioning on diesel or hybrid buses. It is important to know what data will be required in order to study appropriately the case.

3.1. Data Sources[3]

There are mainly 3 verticals where the data is required for planning and scheduling the transport service.

- Data required for Planning
- Operational Data for vehicle and crew rostering
- Statistical data for analysis to improve services

To start of planning for rationalization or creation of new bus service, it is important to study the existing operations. Planning mainly includes the existing time tables of schedules. For operational insights, data sources mainly include GPS logs, Ticketing dump, etc. This is a periodic exercise which will be performed according to the operational changes as and when required. The statistical analysis will help to make the operational changes as needed.

The data sources are categorized further for quick insights.

1. Read Network Data set
2. GPS Logs
3. Cost of operation
4. Demand analysis
5. Collection of Revenue (Earnings)
6. Existing Time tables

3.2. Network Data

The geography of the routes is required to be studied in detail. The amount of energy spent to perform the dead runs needs to be calculated to understand how the electric buses will run on ground.

[3] Statistical data which could not be obtained such as cost of operation, Collection of revenue and Crew rostering are assumed based on other project's citing.

3.2.1. Stops and depots

The positions of the stops, stations, depots and parking will be collected from the authority to analyses their positioning and forming the route rationalization to adapt the new constraints of electric bus scheduling. The depots can be studied to understand if the charging infrastructure can be installed. This data can be used to calculate if the depots have the potential location to install charging points and the operative dead run to reach to the starting point of the line. Stops data is also essential to understand the distance between the stops which will give the correct determination of the distances for calculating the usage of the bus.

3.2.2. Lines, routes

The operations are conducted with the lines and routes which would be performing to serve need. It is important to study the existing line and routes network to know whether the network serves the demand. For example, if there is not sufficient service in the area where passengers are moving then it will not be an appropriate scale of planning. The planning has to be rationalized with respect to catering the demand of services by understanding the flow of the passengers within the city.

3.2.3. Charging stations, types and capacity

It is also important to understand what kind of charging points can be installed and their capacity to charge multiple buses simultaneously. The infrastructure which will be used to recharge the batteries or swapping the batteries needs to be located along the route to know the exact loss of kilometres in operations. In most of the cases the run between the depot and the Lines and Routes of operation is considered as non-commercial as it does not generate any revenue from its operation. It will be important to know how the location of these charging station acts in increasing or decreasing the cost of operation.

There are various types of buses and their models. Each will have different configurations and capacity of running and charging. This will be studied to understand what exactly is required to be done in order to maintain the cost of operation and services.

3.3. GPS Logs

Run time data is required to analyses the time needed to travel between two points. The analysis is required for scheduling the buses according to determined run time. The usual approach is to produce the patterns on hourly basis which helps to set up time slots of a particular route.
Run time data analysis can be performed by any of the below given approach.

3.3.1. Run time through GPS systems

Run time through GPS System is the most appropriate method to analysis run times of the route or schedule. GPS loggers are more accurate than any other manual approach. The GPS logger data can be utilized to determine the time taken to reach from one point to another point. GPS data is usually available in Transport organizations.

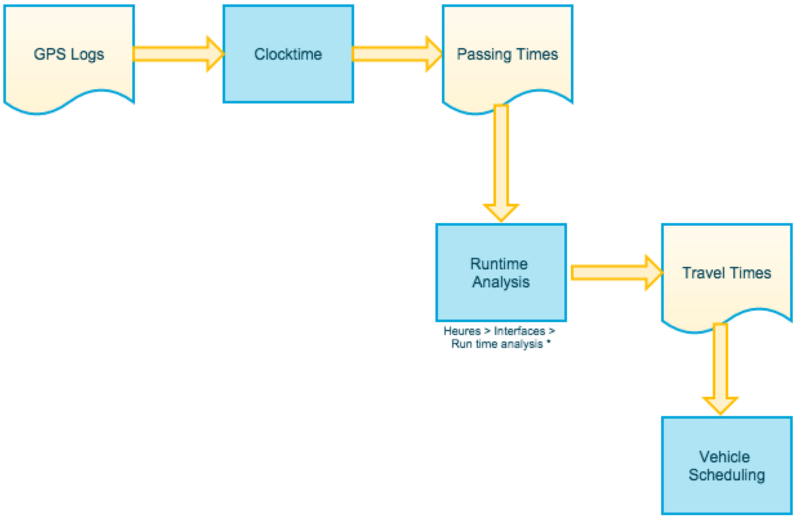


Figure 6 GPS analysis flow chart

Source: Lumiplan internal module; Clock time analysis; Passing time analysis

The flow chart above shows a process which is capable of performing the run time analysis

3.3.2. Run time survey

Conduction of a physical survey on the lines will be beneficial and can determine the run times of a trip. The variation of the hours during the day can be observed and taken into account to analyse run time for hours of the day.

3.4. Cost of operation

3.4.1. Variable and Fixed cost

The cost of operation can be divided in 2 factors, namely, variable cost and fixed cost. The variable cost is a direct cost which varies operation to operation. Variable cost have many contributions such as fuel cost, spares & assemblies, tyres & tubes, lubricants, other consumables, annual maintenance cost, batteries & electric items, depreciation, motor vehicle tax, reconditioning and salaries of operating crew. Fixed cost are the cost involved in operation which is indirect cost of operation such as cost on other Assets, Interest, Central Overheads, Compensation. The cost of operation can be analysed with the help of these all factors mentioned above. However only annual maintenance cost, fuel cost and spare part costs for the study have been considered.

3.4.2. Battery capacity of buses

In order to have the flawless operation, one needs to understand the capacity of the batteries of buses so as to plan for scheduling. According to the route length, the number of trips can be determined to perform before the bus has to rest for its recharging in case of fast charging buses or buses to swap the batteries.

3.5. Demand analysis

For analysing the performance of the schedules requires data such as Collection of revenue, directions of the buses, revenue collected by number of passengers. Revenue ticketing data can be collected with following available source of information. In the city of Tours, the point of sell (POS) of tickets is in the bus. There are services like monthly pass which can be also considered.

3.5.1.Stop wise ticket sale data

Ticketing data analysis mainly includes forming the time slots identifying the peak and non-peak hours of the day. In general scenarios, there are 2 non-peak and 2 peak hours in a day. The slots are defined according to the data show-ups.

3.5.2.Trip wise collection of data of schedules

Trip Wise collection data is easily available in transport organization where the database is centralized. For analysing the performance of the schedules requires data such as Collection of revenue, direction of the bus, revenue collected by number of passengers, kilometres run against one trip or stage. Sample data for trip-wise collection is shown below.

3.5.3.Route-Schedule performance analysis

To get more details on the individual schedules and route, we analysed the trip wise data using Route Schedule performance analysis template to find how the individual schedule or routes are performing hourly, day of the week and direction wise revenue collection per kilometre.
For the route-schedule analysis, the following entities have been considered:

- Number of Trips
- Kilometres travelled
- Number of passengers
- Revenue
- EPKM
- Direction of the trip
- Date of the trip

The above-mentioned entities have been analysed with respect to each of the following time periods:

- Month
- Day of Week
- Quarter
- Day of Week for each Month
- Hour of the day
- Hour of the day for each Day of Week

3.6. KPI (Key Performance Indicators)

3.6.1. Service Reliability - Fleet Efficiency

Fleet efficiency is a key indicator for service reliability. Service reliability is principally determined by vehicle and crew reliability. The crew reliability is mainly related to crew absenteeism. Greater the absenteeism percentage, lesser is the reliability which affect's operation efficiency. Presently, the crew absenteeism is at 5%. It is essential to have the maximum possible number of buses on the road in order to maintain consistent and reliable services for passengers. In order to keep a track of bus availability, it is necessary to keep a tab on bus-days lost due to various reasons. This can be monitored at the depot level.

3.6.2. Cancellation Analysis (Depot wise/week/month)

Cancellations have a pronounced adverse impact on service quality. It is necessary to bring cancellation down to lowest possible level at all times. Cancellations therefore need to be tracked with reference to full and partial schedule cancelled and also trip cancellations in addition to kilometre cancellations.

3.6.3. Service Availability - First and Last Departures

First and Last departures are the key indicators for service availability. The objective of this indicator is to determine the timings of first and last service from bus stations and at the end of routes and the frequency needed to match the commuter needs and check with the existing operations to carry out suitable modifications, periodically, wherever necessary.

This is intended to be a KPI in the sense that the first and last departures of a route/schedule from bus stations and from route ending points needs to be separately monitored as these are the times during which the supervision is slack and the passenger requirement is acute.

3.6.4. Fuel efficiency: Vehicle wise Kilometre per unit (KW-HR -> KMPU)

Kilometres per unit (KMPU) is a key performance indicator which directly impacts a major component of cost and hence needs to be monitored closely for containing costs. KMPU is monitored vehicle – wise for the purpose of control and improvement. However, it is felt necessary to set benchmarks to reduce the limit of KMPU for each type of vehicle. The lower limits for KMPU will be set by analysing the current KMPL/KMPU performance for different types of vehicles and fixing what would be suitable and reasonable. This will help to monitor the performance of each class/type of vehicle on various routes and also give an idea on factors affecting each vehicle type.
Above indicators will help identify the issues or improvement required in operations. Based on the outputs of these indicators, planner can take up some operational changes with more accuracy.

Conclusion: For the planners, reports are very important to improve the services and scheduling. The above KPIs are introduced so that the planners can refer results by these indicators to work out the improvement or corrections.

Chapter 4. States of Vehicle

A simulator is designed to simulate the ground situation finding the best way to ply operations on the ground. As the EV buses have many time constraints over the charging activity, its location and type of infrastructure. The inputs are considered as explained further in this article.

A simulator is a queue based algorithm where a bus performs its life cycle for a one day operation. The algorithm runs for millions of different solutions and checks for better solution by evaluating each solution based on many factors such as number of buses, Maximum Battery capacity required for the operation, number of breaks taken, times of breaks taken during operation, etc.

The simulator is built to try and mirror the ground conduction of operation based on historical data available with transportation operators so that the generated output plan will be able to perform operations practically on ground.

Common parameters for bus scheduling are considered in a simulator shown in the below images.

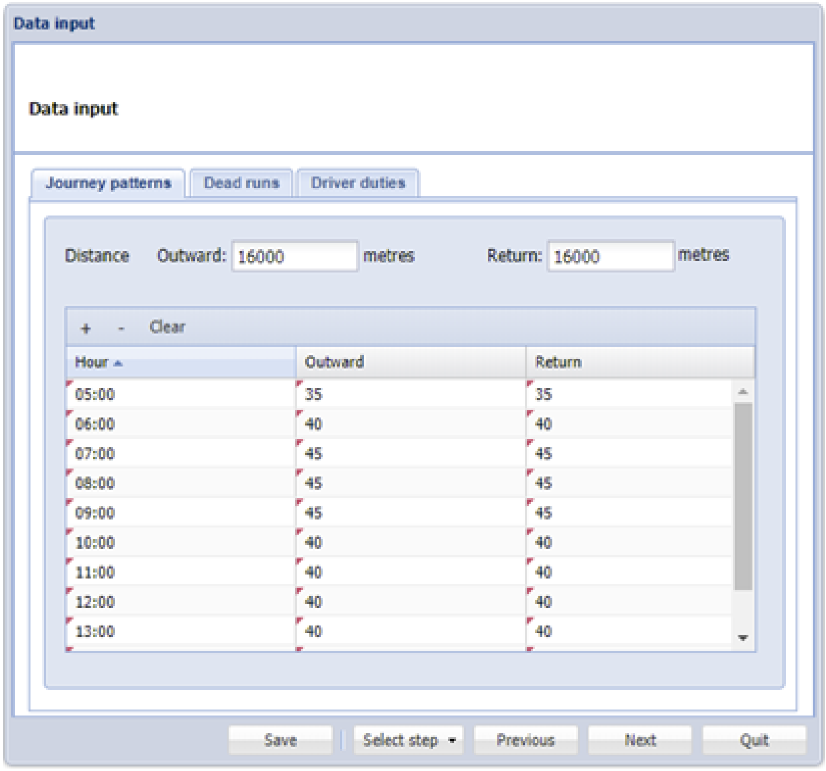


Figure 7 Distance and Run time input of simulator

(Source: Bhushan Kurvey, part of Lumiplan "Heures")

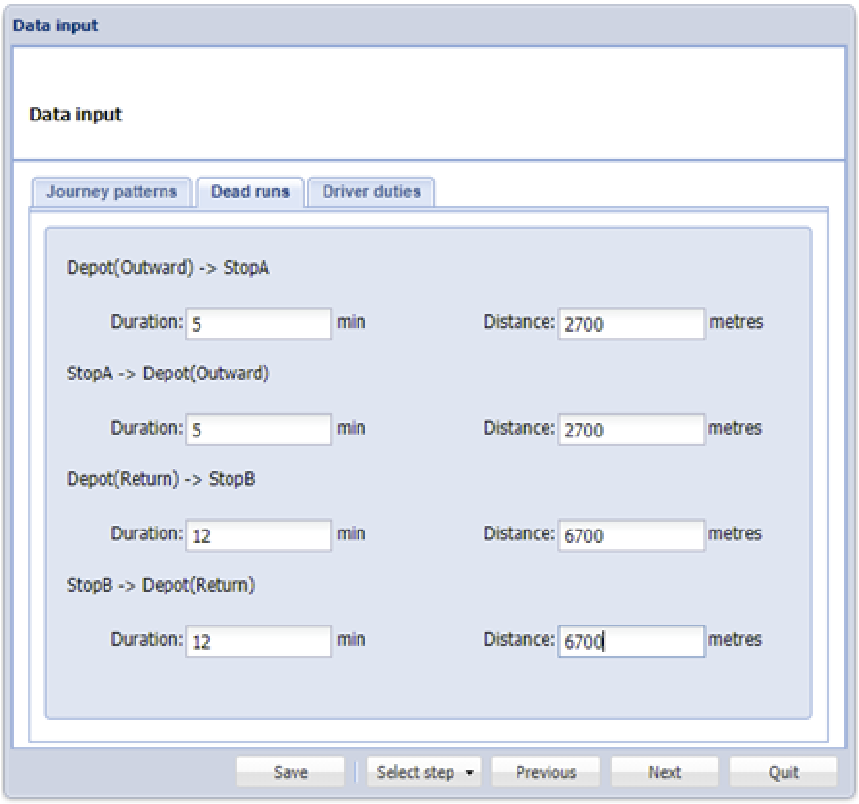


Figure 8 Dead Run Input configuration

(Source: Bhushan Kurvey, part of Lumiplan "Heures")

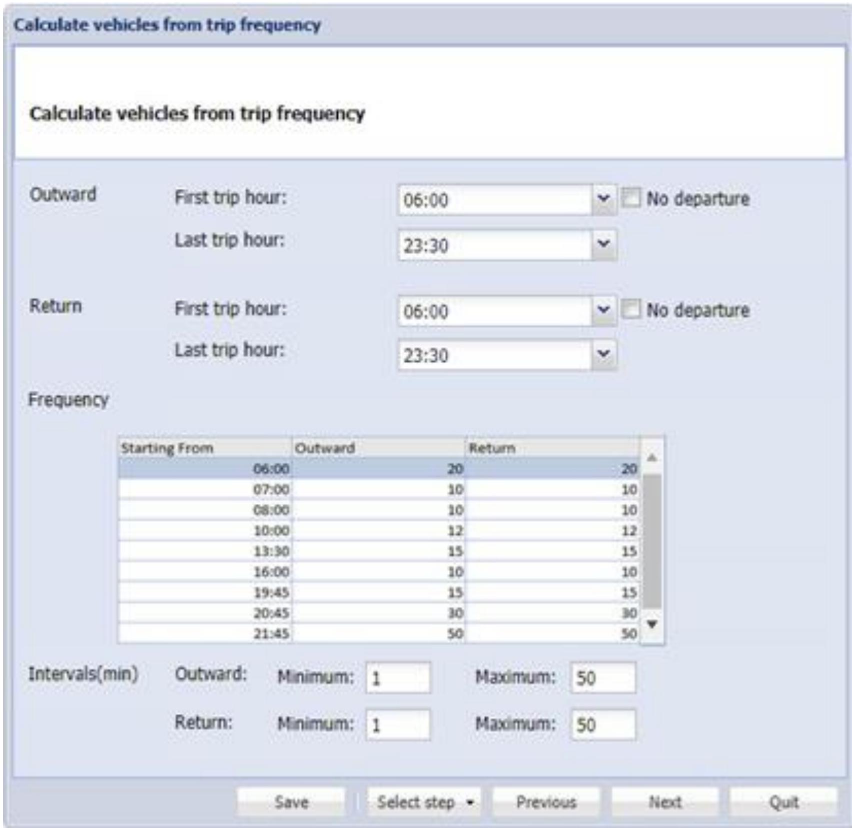


Figure 9 Frequency and operation period configuration

(Source: Bhushan Kurvey, part of Lumiplan "Heures")

The specific parameters for the electric buses and operations has to be taken in account. For that, states of the vehicle have to be studied in detail. Below diagram shows the life cycle of the bus with all the possibilities of having charging infrastructure.

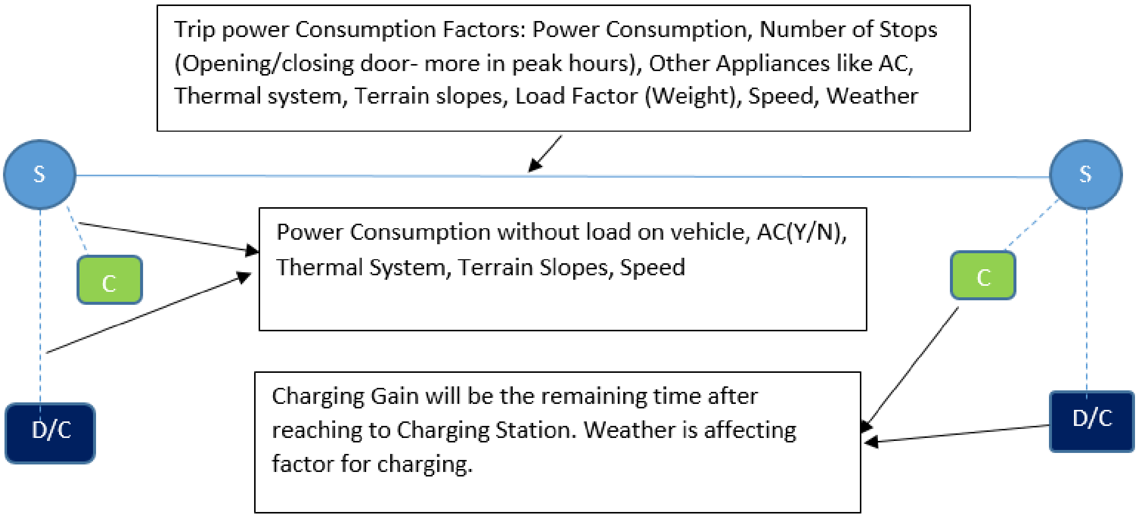


Figure 10 States of Vehicle

Source: Bhushan Kurvey

A Vehicle will have to go through different states during the operation. The activities of these states are broadly classified in **running, waiting and charging**. The below states are either responsible for either gaining the power by charging activity or losing the power by the activities performed in those states.

1) Running a dead run trip
    a. driving consumption based on distance (KwH/km)
    b. does not lose energy on opening/ closing doors
    c. speed of the vehicle considerably higher
    d. air conditioner, thermal system(to keep the battery unit warm), lights (optional additional consumption) depends on weather and time of operation (KwH/minute)
    e. terrain slopes considered
2) Waiting at the terminal at idle
    a. lose energy on opening/closing doors- (KwH/ opening-closing door)
    b. vehicle is stationary so no loss of energy due to driving consumption
    c. air conditioner, thermal system(to keep the battery unit warm), lights (optional additional consumption) (KwH/minute)
3) Running a commercial trip
    a. lose energy on opening/ closing doors based on number of stops and peak hours- ((KwH/ opening-closing door)*no of stops)
    b. Speed of the vehicle depends on the hour of the day and traffic conditions of the route.
    c. air conditioner, thermal system(to keep the battery unit warm), lights (optional additional consumption) depends on weather and time of operation(KwH/minute)
    d. terrain slopes considered
4) Running a dead run if charging station at a short distance

   a. does not lose energy on opening/ closing doors
   b. speed of the vehicle considerably higher
   c. air conditioner, thermal system(to keep the battery unit warm), lights (optional additional consumption) depends on weather and time of operation
   d. terrain slopes considered
5) Waiting for coupling for charging
   a. energy consumption for coupling and de coupling
   b. air conditioner, thermal system(to keep the battery unit warm), lights (optional additional consumption) depends on weather and time of operation
6) Coupling – de coupling
   a. energy consumption due to coupling and de coupling
7) Charging methods
   a. Gain of energy can be described as KwH per minute, as per the configuration of charger.

From the above states, it can be determined that the EV buses have an additional factor of battery consumption and gain. The consumption and gain will depend on the configuration and the type of infrastructure available on the site. In the further chapters, it is explained that how we can take in account all the parameters for charging methods, Power consumptions and gain as an input to the simulator.

Chapter 5. Batteries, Chargers and Charging Methods

Battery electric buses has been conventional associate of bus public transport in this new era due to which new terminologies are evolving specially factors related to range of a run. As it is a new technology, the terms are not been clearly defined to establish a definition for range. Today, each manufacturer defines range by their respective purpose, usability and perception. Due to this, it gets difficult to understand the range in one charge while not burdening batteries to obtain better life.

5.1. EV's Batteries

The batteries have been used commercially and domestically from seven decades. EV batteries can be determined and differentiated by their properties such as its composition currently available in market such as Nickel cadmium, Nickel Metal Hydride, Lead acid, Lithium Ion (Cobalt), Lithium Ion (Manganese), Lithium Ion (Phosphate) and Lithium Ion (Titanate). Based on their properties, the batteries performances can be described as below. However, the presented value may change among manufactures and their claims.

5.1.1. C-rate

Charge and discharge rates of a battery are governed by C-rates. The capacity of a battery is commonly rated at 1C, meaning that a fully charged battery rated at 1Ah should provide 1A for one hour. The same battery discharging at 0.5C should provide 500mA for two hours, and at 2C it delivers 2A for 30 minutes. Losses at fast discharges reduce the discharge time and these losses also affect charge times [Buchmann 2016].

A C-rate of 1C is also known as a one-hour discharge; 0.5C or C/2 is a two-hour discharge and 0.2C or C/5 is a 5-hour discharge. Some high-performance batteries can be charged and discharged above 1C with moderate stress. Below table illustrates typical times at various C-rates [Buchmann 2016].

Specification	Nickel Cadmium	Nickel Metal Hydride	Lead Acid	Lithium Ion Cobalt	Lithium Ion Manganese	Lithium Ion Phosphate
Year of Commercial use	1950	1990	1970	1991	1996	2006
Composition Toxicity	Very High	Low toxic	Very High	Low	Low	Low
Gravimetric energy (Wh/Kg)	45-80	60-120	30 -50	150-190	100-135	90-120
Internal resistance	100 mΩ to 200 mΩ for 6V	200 to 300 mΩ for 6V pack of cell	less than 100 mΩ for 12V	100 mΩ to 130 mΩ per Cell	25 mΩ to 75 mΩ per Cell	25 mΩ to 50 mΩ per Cell

	pack of Cell		pack of Cell			
Life Cycle	1500	300-500	200-300	300-500	300-500	greater than 1000
Tolerance on Overcharging	Moderate	Low	High	Low	Low	Low
Self-discharging (per Month)	20%	30%	5%	10%	10%	10%
Nominal average cell voltage	1.25V	1.25V	2V	3.6V-3.7V	3.6 -3.8V	3.3V
Load current	20C at peak, best results 1C	5C at peak, 0.5C for best results	5C at peak, 0.2C for best results	3C at peak, 1C for best results	30C at peak, less than 10C for best results	30C at peak, less than 10C for best results
Range of operating temperature at discharging	- 40 to 60 ^{0}C	- 20 to 60 ^{0}C	- 20 to 50 ^{0}C	- 20 to 60 ^{0}C	- 20 to 60 ^{0}C	- 20 to 60 ^{0}C
Range of operating temperature at charging	0 to 45 ^{0}C	0 to 45 ^{0}C	- 20 to 50 ^{0}C	0 to 45 ^{0}C	0 to 45 ^{0}C	0 to 45 ^{0}C
Maintenance	30 to 60 days	60 to 90 days	90 to 180 days	Not required	Not required	Not required
Safety	Thermally Stable without protection circuit		Thermally Stable without protection circuit	Thermally not stable hence Protection circuit required	Thermally not stable hence Protection circuit required	Thermally not stable hence Protection circuit required

Table 1 Types of batteries and their specification

Source: Battery University, https://batteryuniversity.com/learn/

5.1.2.Advantages and disadvantages of Nickel-Cadmium Batteries

If the charging cycles are properly maintained, it will have better life than other batteries and also supports ultra-fast charging with little stress. The batteries have a good load performance. The shelf life is longer and can be stored in discharge state. The battery shows good performance on low as well as high temperature conditions. The Ni-Cad batteries have the lowest cost among all the types. They are widely available in size and performance option in the market.

However, it has a low specific energy compared to newer battery types. It is prone to memory effects. So the batteries must be fully discharged periodically. As cadmium is a toxic metal and hence can be disposed-off. It has a high self-discharge and hence needs recharging after storage.

5.1.3.Advantages and disadvantages of Nickel- Metal Hydride Batteries

Nickel- Metal Hydride batteries are less prone to memory effect than Nickel- Cadmium batteries which cause them to hold less charge. They are less toxic so are environment friendly. The batteries can be recycled which makes them more cost effective. It has typically 30 to 40 % higher capacity than Ni-Cad batteries. They are easy to store and transport.

However the batteries have a limited service life and deep cycling would reduce the life cycle. It requires complex algorithm for charging strategy. It does not absorb the overcharge well and trickle charge has to be kept as low as possible. It generates heat while fast charging and also at a high load discharge. It has a high self- discharge.

5.1.4.Advantages and disadvantages of Lead Acid Batteries

Lead Acid are not expensive and simple to manufacture. It has a low cost per Watt- Hour. The batteries have a low self-discharge rate which lowest among other rechargeable batteries. It has high specific power and is capable of high discharge currents. Performance is good in low and high temperatures [Ronald et al., 2014].

The disadvantage with these batteries is low specific energy and poor weight to energy ratio. It supports slow charging and takes around 14-16 hours for fully saturated charging. To prevent from sulfation, the batteries need to be kept in charged state. The life cycle is limited and reduces its life by deep – cycling. The battery is not environment friendly.

5.1.5.Lithium Ion Batteries

Lithium is the lightest of all metals, has the greatest electrochemical potential and provides the largest specific energy per weight. Rechargeable batteries with lithium metal on the anode (negative electrodes) could provide extraordinarily high energy densities, however, cycling produced unwanted dendrites on the anode that could penetrate the separator and cause an electrical short. The cell temperature would rise quickly and approaches the melting point of lithium, causing thermal runaway, also known as "venting with flame." [Ian Poole, 2012].

5.1.5.1. Lithium ion battery advantages

There are many advantages for using a Li-ion cell of battery as described below.

High energy density

One of the great advantage of using a Li-Ion batteries is the high energy density. With the interest of EV buses, the buses are required to operate longer time expected to perform for a full day of operation while the power consumption is high by all equipment.

Self-discharge

Self-discharge is a discrete issue for all the batteries. Li-Ion batteries have much lesser self-discharge rate than other rechargeable batteries such as Nickel and Lead based batteries.

Low maintenance

Li-Ion batteries do not require periodic maintenance to have the desired performance. They do not need periodic discharge to ensure that batteries do not show the memory effects. It will not comprise the cost of maintenance and resource engagement for this activity.

Variety of types available

There are several types of lithium ion cell available in the market as per its application. The variety is an advantage for type cast to ensure the requirement.

5.1.5.2. Lithium ion battery disadvantages

Protection Circuit

Li-Ion batteries are not robust batteries in rechargeable technology. A protection circuit is required to stabilize for being overcharged or discharged. The load current needs to be stable or maintained within the range of safety [Tarascon and Armand, 2001].

Aging

The life cycle of Li-Ion batteries is around 500-1000 charge/discharge cycles until the capacity reaches 80% of its original capacity. These have less life when it is compared to Ni-Cad batteries. If the batteries are embedded in the equipment itself, it will be difficult to replace the batteries [Haibo et al., 2017].

Transportation

There are limitations of transporting the batteries as per norms formed by the airlines and shipping corporations under the safety regulation. The transportation of the batteries also involves covering with protection against short circuit. However, these regulation may change over a period of time after risks with these batteries are confined [Haibo et al., 2017].

Cost

Lithium Ion batteries are around 20-40% costlier than other type of batteries. The cost increases when there is a mass fleet use such as in EV buses. The production is limited which impacts on its cost as well.

Niche technology

Lithium Ion batteries are not new technologies but are still improving their technology to reduce the disadvantages. Technology is changing constantly which makes it difficult to industrialize on one.

5.1.6. How to determine the Battery Capacity?

When the range issue is addressed based on its application for planning and scheduling, the battery capacity has to be determined keeping in mind that the batteries are expensive and heavy to carry on board.

5.1.6.1. Covering full range in one charge

One of the solution is to install number of batteries required to conduct the full operation by understanding the drive range for a day. This will require more battery capacity to perform a full day operation without any charging events in middle of operation. Typically, a public transportation buses have a vehicle utilization between 250 – 400 kilometres per day which may require a large set of batteries. Larger the batteries, more weight to be carried on board. This makes an additional power requirement to carry extra weight on board leading to more consumption. In the current era, it can be observed that if the battery capacity is designed as per above example, the cost of buses will go higher. Another way is to increase the number of fleet on the ground to perform same operation and by giving charging events in the middle of operation. The vehicle utilization of each bus reduces in this case as the buses are on charging during the operation hours.

5.1.6.2. Analysing Peak and Non-peak hours for battery capacity

Usually, it is seen that the rush hours are typically in the mornings and evenings lasting between 2-3 hours. This rush is due to crowd moving from home to work in morning and from work to home in the evening. Apart from these rush hours, non-rush hours will have a reduced operation based on the demand analysis of services. These non-peak hours will have reduced operation and will have sufficient but lesser buses running on ground. Utilizing these gaps of non-peaks hours would be useful in reducing the additional fleet on ground while converting diesel operations to EV.

5.2. Chargers

“A good battery charger provides the base for batteries that are durable and perform well. In a price-sensitive market, chargers often receive low priority and get the “after-thought” status. Battery and charger must go together like a horse and carriage. Prudent planning gives the power source top priority by placing it at the beginning of the project rather than after the hardware is completed, as is a common practice. Engineers are often unaware of the complexity involving the power source, especially when charging under adverse conditions” [Buchmann 2016]. Charging speed is a quantified unit for consideration. Chargers work well in idle condition scenarios. Having adequate weather is one of the key issue to be addressed. The industrial chargers include features to charge batteries in a contrary weather conditions as well. Many manufacturers offer additional specification such as thermal systems to warm the batteries and isolation at charging station units [CADEX 2019]. However, different types of batteries have different impact of weather temperature. For example, considering the chemistry with Lithium-Ion batteries, most of this type of batteries can operate even below the freezing point but cannot be charged unless provided with a thermal unit. Lead and Nickel based batteries accept charging when cold but at a lower rate.

5.2.1. Types of Chargers

Various types of chargers have been developed by international industries as follows.

5.2.1.1. Nickel-based battery's charger

NiCad and NiMH batteries are harder to charge than Lithium Ion and lead acid batteries. The charging is based on forcing electric current through the batteries and the voltage is not fixed unlike Lithium Ion or lead acid batteries where the voltage can be controlled to avoid overcharging by setting up the voltage to maximum. Parallel charging is difficult with Nickel based batteries because it is not certain whether all cells of the battery are having same resistance to charge further. Cells may take more current even if the cells are fully charged. For this, separate circuits need to be used for each cells in parallel charging or by using a current resistance controller (resistors).

Charging efficiency of NiCad and NiMH is around 83% for fast charge at the rate of C/0.25 to C/1. For C/5, the efficiency is around 63%. With C/10, it further decreases to 55%, and C/20 below 50% [PowerStream 2019]. Thus, it can be determined that slow charging decreases the efficiency for Nickel based batteries. However, the presented value may change manufacture to manufacture and their claims. The temperature rises with the rise of charging especially when reaches 70% of its charged state. The current has to be lowered to its maximum stress limit.

5.2.1.2. Lead Acid battery's Charger

Lead Acid batteries are primordial method and lot of methods of charging are been developed to use. In the era where it was difficult to regulate the voltage, flooded lead acid batteries were used because the water could be replaced. Lead acid chemistry is capable to tolerate overcharging. Even the sealed batteries can be recycled. So, these batteries are widely used because there are varieties of chargers been developed ranging from cheap to robust, based on the requirement of equipment. With the latest development, chargers are sophisticated to avoid overcharging.

The efficiency of battery charging is based on how many electrons are inserted in batteries. The battery charging voltage has to be kept always higher than the discharging voltage to make batteries charge. For example, flooded lead acid batteries have a charging efficiency of 70%. If a battery of 100 amp hour needs to be charged then, the battery has to be charged on 142.8 amp hour as shown below.

- ⇨ 70/100 = 100/X
- ⇨ X = 142.8 amp hour

This can vary by charger's configuration, battery type and capacity, temperature, etc. A sealed battery has a higher charging efficiency up to 95% depending on charging voltage.

Minimum voltage is an important part in these batteries. Lead acid batteries charge on voltage above 2.15 volts per cell. For 12V batteries, it will require 12.9V to gain any energy in batteries. However, the above values are the minimum voltage requirement whereas the batteries are charged with higher voltage than this to have higher charging rate. Charging at minimum voltage will typically take longer time. But gassing voltage has to be avoided to restrict undesirable chemical reactions in the battery which can be achieved by limiting maximum voltage.

The typical charging voltage is between 2.15 volts per cell (12.9 volts for a 12V 6 cell battery) and 2.35 volts per cell (14.1 volts for a 12V 6 cell battery). These voltages are appropriate to apply to a fully charged battery without overcharging or damage. If the battery is not fully charged you can use much higher voltages without damage because the charging reaction takes precedence over any over-charge chemical reactions until the battery is fully charged. This is why a battery charger can operate at 14.4 to 15 volts during the bulk-charge phase of the charge cycle [Buchmann 2016].

5.2.1.3. Lithium Based Battery's Charger

Lithium batteries are to be charged at a cool temperature state. Whenever the battery temperature rises by 10 0C above the normal temperature, the charging has to be stopped immediately. These batteries do not absorb the overcharging and also do not support trickle charging. It is not necessary to remove the batteries from charging but if the batteries are not been used for more than a week, it's better to keep it in a cool place and charge before re using [Tarascon and Armand, 2001].

One of the issue is that if the batteries being over charged and fallen asleep, then a wake up or boost mechanism is used to allow recharging the batteries again. A sleep condition can happen when the batteries are been stored in a discharged state or the batteries are self-discharged to its cut off voltage. A safety circuit is required to regulate the charging with respect to battery temperature and charging rate.

Lithium Ion batteries charge on constant current and voltage is capped to its limitation. When the battery reaches its voltage limits, the battery starts saturating and the current drops till the battery can again start accepting the charge. Every battery assembly will have their own low current threshold and prevention from sulfation. A charging strategy is one of the most important part of charging when using Lithium Ion batteries.

5.2.2. Charging Power Types

In the current generation of the chargers, there are 2 types of chargers offered by the international market. AC chargers and DC chargers.

For the batteries to be charged, the power has to be converted from alternating current (AC) to direct current (DC). The power that comes from the grid is always AC power. This is done by a converter. In the case of electric vehicles, this converter is inside the vehicle. In the case of DC chargers for fast charging of electric vehicles, this converter can be found inside the charger itself. In this case the converter inside the charger takes care of the conversion. As a result, DC chargers are usually larger and more expensive.

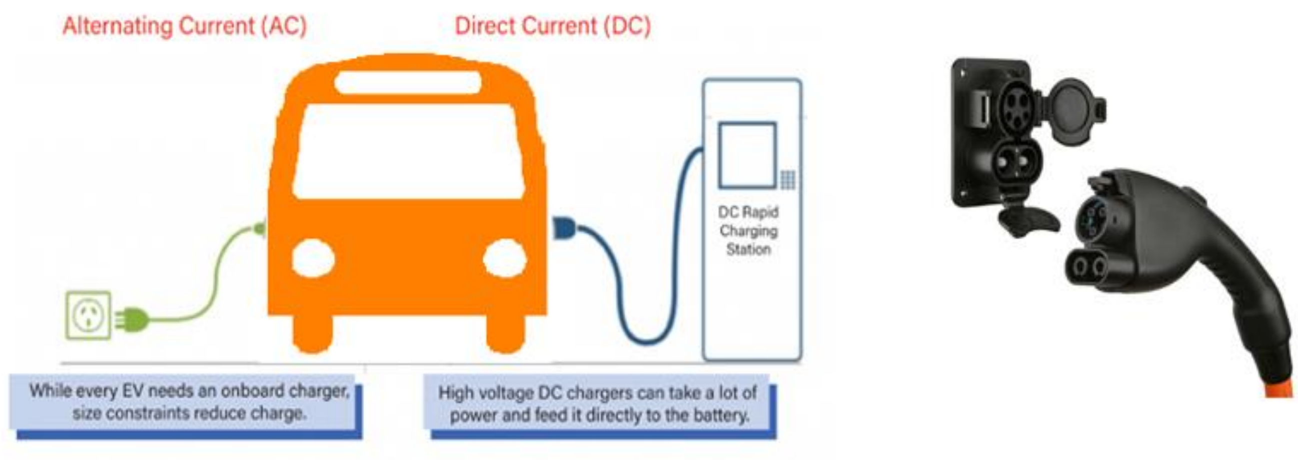


Figure 11 AC and DC plug-in Charging
Source: Protera Inc., edited by Bhushan Kurvey

5.2.2.1. AC Chargers [PROTERA]

This is the most common charging method for electric vehicles with a plug-in technology. When plugging an electric vehicle into a normal charge point, the power gets converted inside the vehicle, then moves into the bus's battery. Charging speeds depend on the output power of the charge point as well as the convertor's capabilities to convert the power to DC.
The required power for AC chargers ranges between 16A (3.7 KwH) and 63A (43 KwH). This charging method is the most suitable for parking spots where the EV buses will stay parked for 20 minutes or longer. Due to the low costs (production, installation and operation), these are preferred and installed. Also, due to these low costs, it is usually cheaper to charge at AC chargers, making them more popular for general day to day charging.
Plug in chargers are most widely used chargers in the depot parallel charging or charging station with larger capacity of charging vehicles in parallel.
Fast chargers for electric vehicles make use of DC charging; they convert the power before it enters the vehicle. After conversion, the power goes directly into the car battery, bypassing the car's converter.

5.2.2.2. DC Chargers

A DC installation requires a lot of power from the grid (around 125 A). This makes its costs (production, installation and operation) quite high, resulting in higher tariffs for charging. However, as it usually allows for much faster charging, it is the preferred charging method to quickly recharge during trips for buses that support DC charging. This type of chargers is mostly found along route, at the bus terminals rather than at a far distance or depot.

5.3. Charging infrastructure

It is important to understand what kind of charging infrastructure is available on the site as to understand strategy for charging.

5.3.1. Plug-In Chargers

Four modes in EV Charging Stations for plug-in chargers are explained as per the International Electro technical Commission modes definition (IEC 62196):
Mode 1 is a slow charging from a regular electrical socket (single- or three-phase)

Mode 2 is a slow charging from a regular socket but which equipped with some EV specific protection arrangement

Mode 3 is slow or fast charging using a specific EV multi-pin socket with control and protection functions (e.g., SAE J1772 and IEC 62196)

Mode 4 is a fast charging using some special charger technology

There are three connection cases based on the above modes:

• Case A is any charger connected to the mains (the mains supply cable is usually attached to the charger) usually associated with modes 1 or 2.

• Case B is an on-board vehicle charger with a mains supply cable which can be detached from both the supply and the vehicle – usually mode 3.

• Case C is a dedicated charging station with DC supply to the vehicle. The mains supply cable may be permanently attached to the charge-station such as in mode 4.

5.3.2. Types in EV Charging Station plugs

	Type 1: SAE J1772 (Level 1 and 2) – Adapted North American Standard – 2 AC power lines, ground pin, proximity detection, and control pilot signals – Uses +/-12V Pilot interface
	Type 2: VDE-AR-E 2623-2-2 (Level 1 and 2) European Plug Standard – Additional pins for three phase connections – Signalling aligns with J1772

	Type 3: Combined Charging System-CCS (Level 3) – Additional DC pins for level 3 charging added to J1772 and Type 2 – HomePlug GreenPHY communication protocol
	Type 4: CHAdeMO (Level 3) – Adopted in Japan and France – CAN interface to vehicle

Table 2Type of Charging Station Plugs designed by Protera
Source: Protera Electric buses Chargers, https://www.proterra.com/technology/chargers/

5.3.3.Overhead Chargers

The charger's overhead design helps to maintain a safe environment. Installed on the ceiling of the garage, the Overhead Charger keeps the system's charging cable and connector a safe distance away from hazards such as water, other automobiles and salt. Additionally, the system's retractable cable prevents tripping hazards and inhibits vandals from easily accessing the unit. The design meets regulatory standards that mandate live cables must be off the ground.
Power is continually monitored during charging. If the voltage deviates from the acceptable range, or if the load current exceeds the maximum level, the charger disconnects power to the vehicle. When the driver removes the connector from the vehicle, the connector and cable retract to the original overhead position within the charging station and are locked in place.

5.3.4.Roof Mounted Pantograph

This type of pantographs are installed on-board. The pantographs consumes power from the battery unit of the buses. Roof mounted pantographs are usually installed where there is a possibility of continuous charging during the run or the charging stations.

The roof mounted pantographs works on the principle of air pressure. The pantograph connects the power grid by the air pressure and returns to its original position by gravitational force. As the power grid unit does not have pantograph, it must be installed on every bus to use the charging infrastructure of such types.

5.3.5. Inverted Pantograph

This type of pantographs are installed on the grid of the power infrastructure. The buses arriving to these charging stations are placed at a certain position to have a successful connection between the pantograph and charging connectors.

In this type, the buses do not need to have a pantograph installations but a connector. Multiple installations of pantograph on the buses are avoided due to this technology.

5.3.6. Wireless Induction Chargers

Wireless Induction chargers are also called as "Opportunity Charging". The coil are installed on the road as well as at the bottom of the bus. Once the bus is parked at a certain position above the coil on the road, the wireless charging activates to charge the battery.

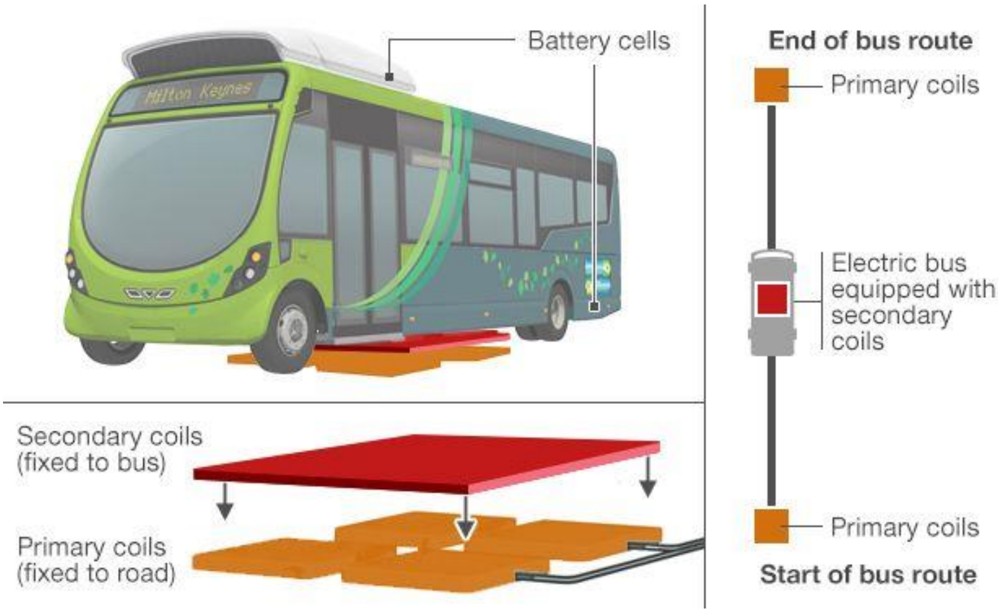


Figure 12 Wireless Induction Charging

Source: https://www.bbc.com/news/technology-25621426

These type of chargers are new and expensive at the current era. It will be interesting to evolve this technology for future propositions of fast charging.

5.4. Charging Methods

It is important to consider charging parameters as it impacts on both consumption and gain of energy operations.

5.4.1. Charging Parameters

To calculate the charging time for the buses, it is important to understand parameters of the battery and charging infrastructure. The required time for charging can be calculated as

Time for Charging Tc = Capacity of battery (KwH)/ Load Power P (KW)

Where,

P = V*I; … (E3)

Where

P = Load Power in Watt

V = Voltage in volts

I = Current in Amps

For example: P = 32A x 230V = 7360 W = 7360/1000 = 7.36 KW

Assume that, the capacity of the battery is 100 KwH then using (E3),

Tc = Capacity of battery (KwH)/ Load Power P (KW) .. (E4)

Where,

Tc = Time for Charging

Tc = 100 KwH/ 7.36 KW = 13.5 Hours

Charging rate per minute Cr = P/ time = 7.36 KW/ 60 minutes = 0.123 KW/ minute

Note: Charging Rate will varry depending on the model of buses as well.

5.4.2. Charging Efficiency

1. Maximum charging rate of charger
2. Maximum acceptance charging rate of the vehicle

Both the above factors are considered to understand the minimal value between them to configure the charging rate at a location.
The simple equation to calculate the Charge time demand can be defined as
Charge Time = Vehicle Battery Capacity (KWH)/ Charging Station Delivery Rate (KW) .. (E5)

Actually, the charging duration depends on a number of factors, such as temperature, state of health of the battery and charging strategy. The maximum power output is used only in the very beginning of the charge cycle. (Constant current mode + constant voltage mode.) At the very end (when the battery is nearly fully charged, the controller usually switches to "trickle mode", which is why charging the battery from 90% to 100% takes a lot longer than going from 50% to 60% for instance.
Due to the weather conditions, the charging efficiency is affected. It is important to take in account the factor of efficiency into consideration.

The charging rate can be represented as

Actual Charging Rate $C_{rA} = Cr * E_f$ .. (E6)

Where,

C_{rA} = Actual charging rate

C_r = Charging rate of charger

E_f = efficiency factor in percentage (%).

5.4.3. Charging Strategies parameters

To parameterize the charging strategy, a coefficient of efficiency has to be defined. It can be represented in percentage.

For example,

Charging strategy at SoC	Charging Efficiency*	Charging efficiency in %
0%	1.0	100%
20%	0.95	95%
40%	0.7	70%
75%	0.6	60%
90%	0.5	50%

Table 3 Charger's efficiency Configuration

*****Efficiency may vary depending on type of battery, temperature, etc. Values may differ case to case.

A screen from the simulator is shown below explains how the parameters are considered as input to the system.

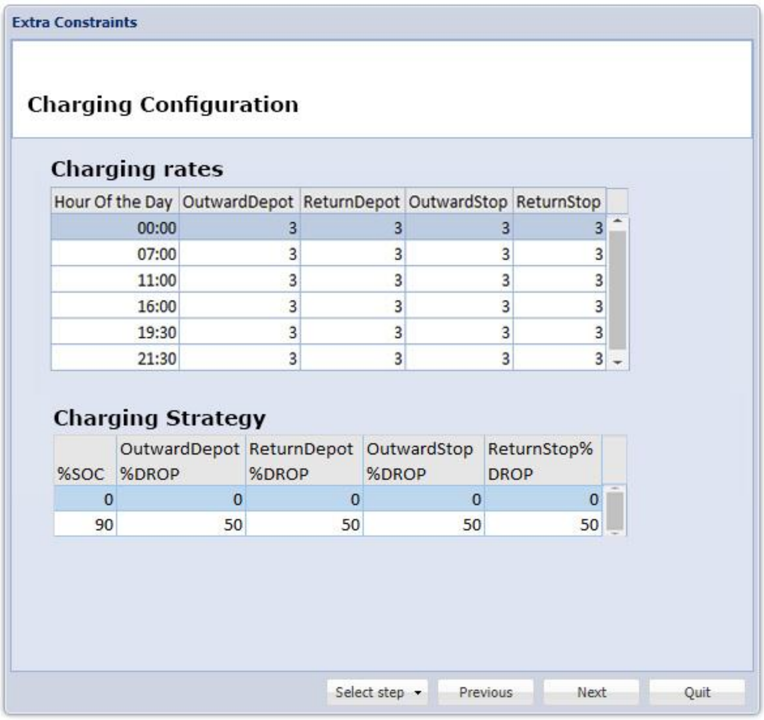


Figure 13 Charging configuration

(Source: Bhushan Kurvey, part of "Heures" Lumiplan)

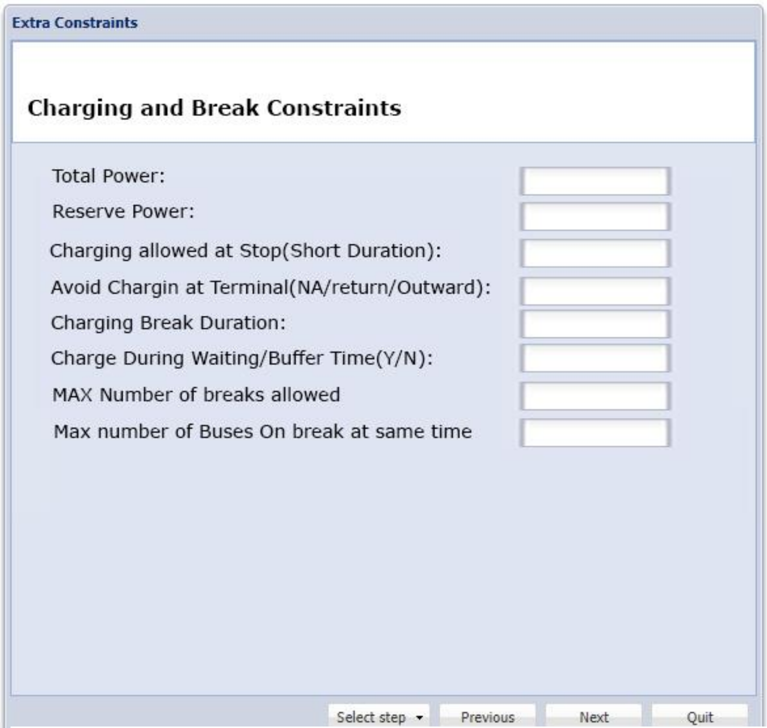


Figure 14 Power, charging and Break Configuration

(Source: Bhushan Kurvey, part of "Heures" Lumiplan)

Conclusion: A charging profile has to be defined for each charger to calculate charging gain accurately. A table of charging strategy efficiency can be considered as a parameter to calculate exact power gain within certain time during the charging activities. The charging strategy mechanism is setup by charger manufacturers and can be obtained from them based on the configuration of charger.

Chapter 6. Energy Consumptions

6.1. EV Power Consumption

The Power required for a bus can be determined by understanding bus mass and passenger load, speed and acceleration, front area and shape, road elevation and power demand from accessories such as air conditioning or thermal unit, public information system (PIS) displays, opening closing door and additional devices. There is also an impact on some of the factors on consumption of energy due to weather conditions. For example, the air conditioning unit or thermal unit will likely consume more energy when the climate temperature is above or below the adequate settings. The more difference it will have, more consumption may occur for larger difference between outside temperature and adequate temperature set inside the bus. The major power is consumed by the traction motor and accessories consequence additional power consumption. The power requirement is based on the forces acting on the wheels to push the vehicle forward. The total power required is to overcome resistance forces, to run the vehicle and to overcome internal engine friction [Caixia et al. 2012]. The total required power can be equated as

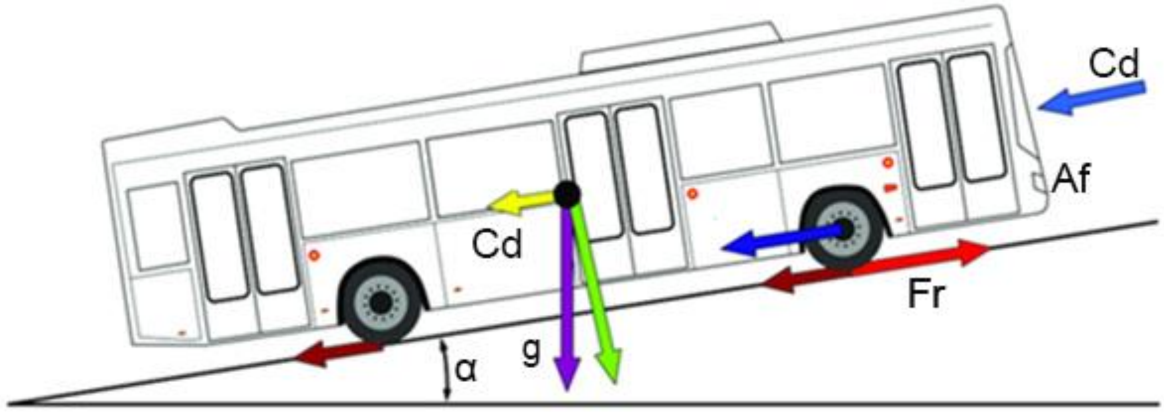


Figure 15 Forces acting on bus while in run

$$P_{Total} = P_{TractionMotor} + P_{Accessories}$$ .. (E6)

Where Power consumed by traction motor based on all resistances acting on it is,

.. (E7)

$$P_{TractionMotor} = V(M \cdot g \cdot F_r + \frac{1}{2}\rho_a \cdot V^2 \cdot A_f \cdot C_d + M \cdot g \cdot \sin\alpha)$$ Where,

V = Vehicle speed
M = Total mass of vehicle
g = Gravitational force
P_a = Air density
A_f = Front area of vehicle
C_d = Aerodynamic drag coefficient
F_r = Rolling resistant force

External factor of Road Elevation (Slopes)

There is an additional power required for the elevation of the roads as it takes more energy to push the bus forward against the gravitational forces. In the above equation, this additional power is equated as

$$PowerElevation = M \cdot g \cdot \sin \alpha \quad \text{.. (E8)}$$

Where,

M = mass of the vehicle
g = gravitational force
α = angle of elevation.

External factor of Load factor of passengers

As the mass of the vehicle will increase with increase in the number of passengers in the bus. The mass is directly proportional to the consumption as it acts on rolling resistance force and the gravitational forces. The Vehicle consumes energy to overcome with these forces acting against it to move forward.

According to the study by [Vepsäläinen, et al. 2019], a city bus with a light-weight aluminium frame bus is with a curb weight of 8500 kg. The maximum load for the vehicle is 6500 kg, resulting in a maximum total mass of 15 000 kg.

So, based on the total mass, the energy will be amounted more.

Headwind

The wind speed and direction are factors increasing or decreasing the resistance against the push of the bus. The nature of the wind is ever-changing and in the worst-case scenario the wind could be facing the bus throughout the route in which the consumption will be higher.

Rolling resistance coefficient

The rolling resistance coefficient is determined by tire wear and pressure, terrain and ambient temperature [Jazar 2014]. In the best-case the rolling resistance is 0.006 with a smooth tar roads and new tires during summer time. In the worst-case there is shallow snow on the road and the tires are worn, represented with a rolling resistance coefficient of 0.02.

Ambient Temperature

The air density is increased at low temperatures, which also increases aerodynamic drag. The air density fluctuates 25% because of the ambient temperature variation.

Battery resistance

Internal resistance generates heat thus creating the loss of energy. The variation of internal resistance for Lithium Ion batteries varies from 100% to 200% of its original value. As the temperature decreases, the internal resistance increases exponentially. The rise in temperature may occur due to high current flow to the batteries.

Battery Life cycle

If the batteries capacity is reduced by 20% then it is no longer be useful for operation. To maintain the health of the batteries, a good configuration of charger must be provided to reduce the effect of deterioration.

6.2. Air Conditioner/ Thermal System

For the accessories, let us consider only Air conditioning and PIS to equate it as:

$$P_{Accessories} = P_{AC/Thermal} + P_{PIS}$$ .. (E9)

Power required by AC thermal unit is directly proportional to the outside temperature of the bus. Assuming that if the maximum power required by the Air conditioner is 10 KwH then it will consume 166.66 Watts of energy per minute. If the compressor of the AC shuts down after reaching the adequate temperature, the power consumption will be tending towards zero (A blower may consume some energy even if compressor is off). Similarly, thermal system will also consume power based on the outside temperature. In public transportation in the current era, the buses require 25 KW to 50 KW energy for cooling or heating unit. The energy requirement is based on how much time the compressor is in the active state. For example,

E = P * T .. (E10)

Where

E = Energy consumption in KwH
P = Power in Kilo Watt
T = time in hours
E=30*1
E= 30 Kilo Watt-hour.

If the compressor is ON for 30 minutes then

E = 30*(30/60)
E = 15 Kilo Watt hour
The below figure is referred from a study given by Dr.-Ing. Robert Basile, Director R&D, SPHEROS on the challenges of air conditioning and heating solution of electric buses.

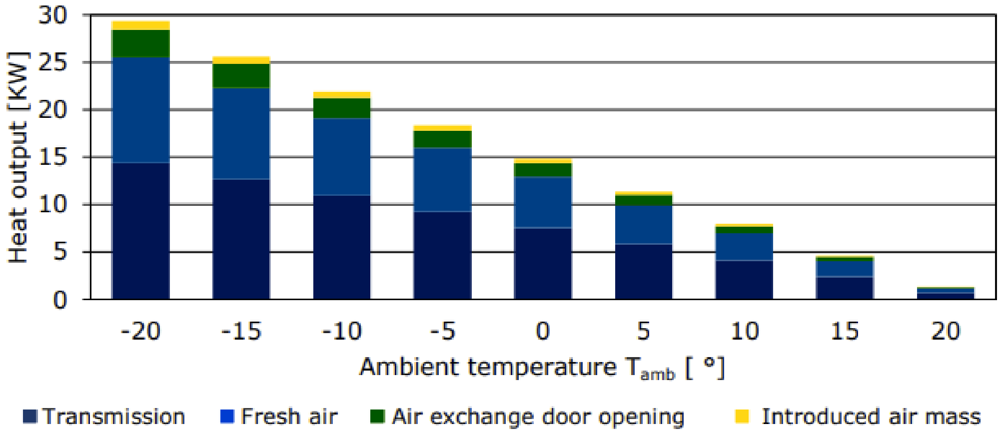


Figure 16 Heating unit consumption of a bus based on ambient temperature

Source: Dr.-Ing. Robert Basile, Director R&D, SPHEROS

There is a major impact of outside cabin temperature. The climate plays an important role in consumption requirement.

A similar graph will be projected for the air conditioning consumption. Still it will be a question that how to account this factor into the system so that the impact on consumption of variation in weather will be projected accurately.

6.3. Public Information System (PIS)

PIS displays are installed on board and consume power from the batteries directly. Usually, it is seen that buses are installed with Front, Rear and Side PIS. Some buses are seen with additional PIS inside the bus showing the upcoming stops. Each of the PIS will consume certain amount of energy depending on the type display it has.

Here is an example of a typical bus installed with "Groupe Lumiplan's PIS" with LED and TFT screen display.

PIS displays in the bus	Consumption
RGB + monochrome front weathervane	70W
Side weathervane	40W
RGB rear weathervane	40W
UC announcement sound	10W
TFT screen type 29 '' double sided	70W
TOTAL	**230W**
For double decker buses, additional displays	
Side weathervane	40W
TFT screen type 29 '' single-sided	30W
TOTAL	**300W**

Table 4 PIS power consumption

Source: Lumiplan, Nantes, France

In this case, the amount of total power required for PIS is 300 W. So, if the bus is operational for 18 hours

> Conclusion: Consumption by PIS and effect of extra Load of passengers can be **neglected** for power consumption calculations as it results a minor percentage of total available power of battery capacity.

of the day then, it will consume 5.4 KW energy. This value is negligible compared to buses having capacity more than 100 KW.

6.3.1. Weather impact on Air conditioning and Thermal system

Previously in this chapter, it is seen that the weather temperature has a large impact on the accessories which leads to greater consumption for the buses.

6.3.2. Affectation of weather temperature by seasons

The graph below shows a weather statistics of France. It is clear that the scheduling has to be performed for different seasons as the weather temperature varies significantly. For the city "Tours", the average low temperature is between 2^0C to 13^0C wherein the average high temperature is between 8^0C to 25^0C within the year. It can be further split to different seasons. For example, July to September, the weather shows an average low temperature between 11^0C to 14^0C and average high between 22^0C to 25^0C. The Air conditioner or a thermal system will consume less energy as the temperature range is close the ambient temperature to be maintained in the bus. In this way, there can be a seasonal plan to have the accurate predictions of range for EV buses.

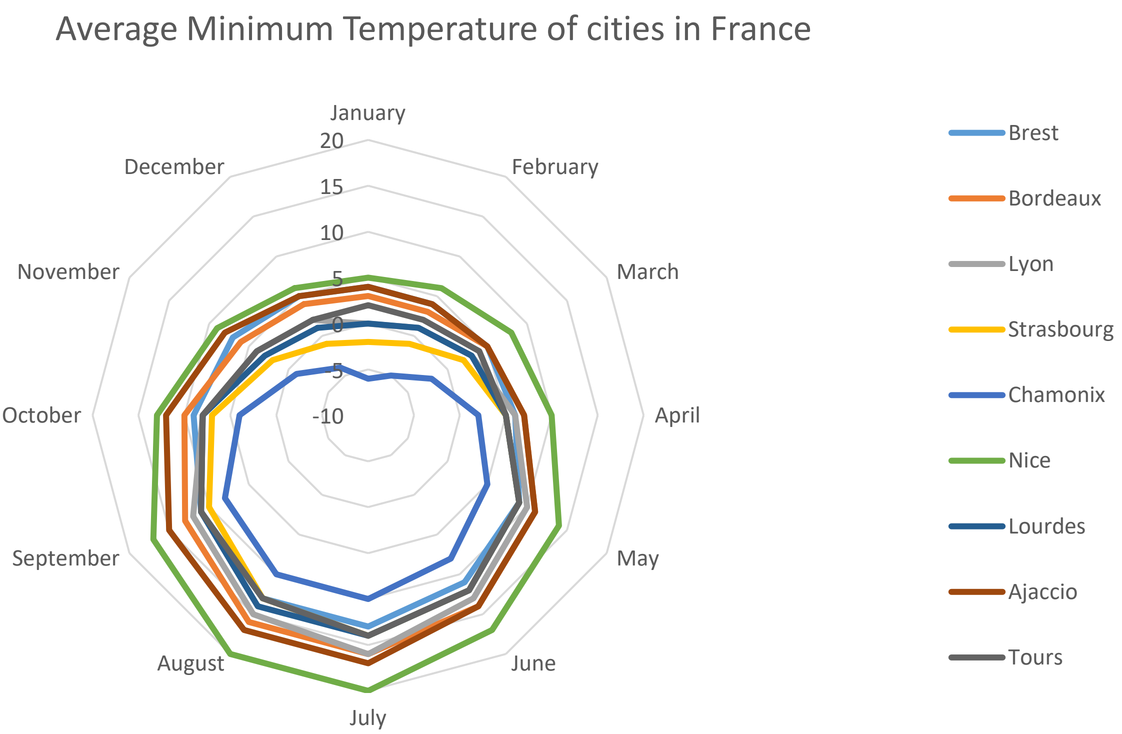


Figure 17 Average Minimum monthly temperature of cities of France Source: http://www.meteofrance.com/

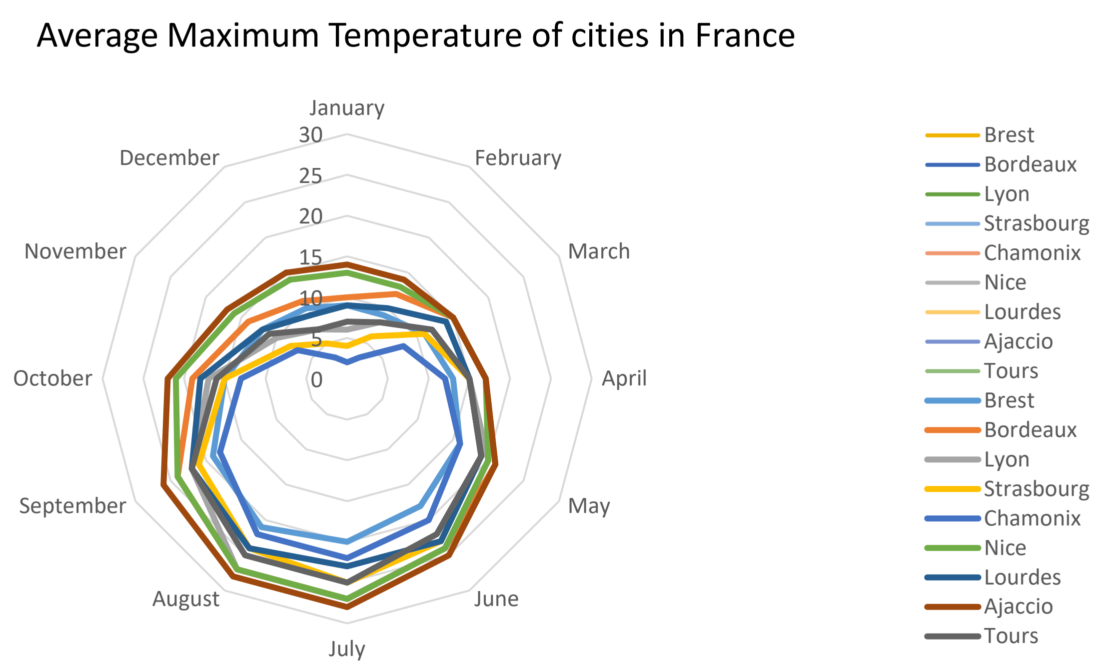


Figure 18 Average Maximum Monthly Temperature of cities of France *Source: http://www.meteofrance.com/*

6.3.3. Affectation of weather temperature within the day

Having different plans for different season is not enough as there are variation observed throughout the day as well. The temperature in the morning time between 5h to 9h are overserved to have lowest temperature of the day where in 17h to 19h have the highest temperature of the day. As both of the hours slots are the operational hours, the scheduling must take care of the variation or loss of energy. For example, the data from City "Paris" is shown below. The power consumption for the hours having lowest and highest temperature will have different consumption as explained above.

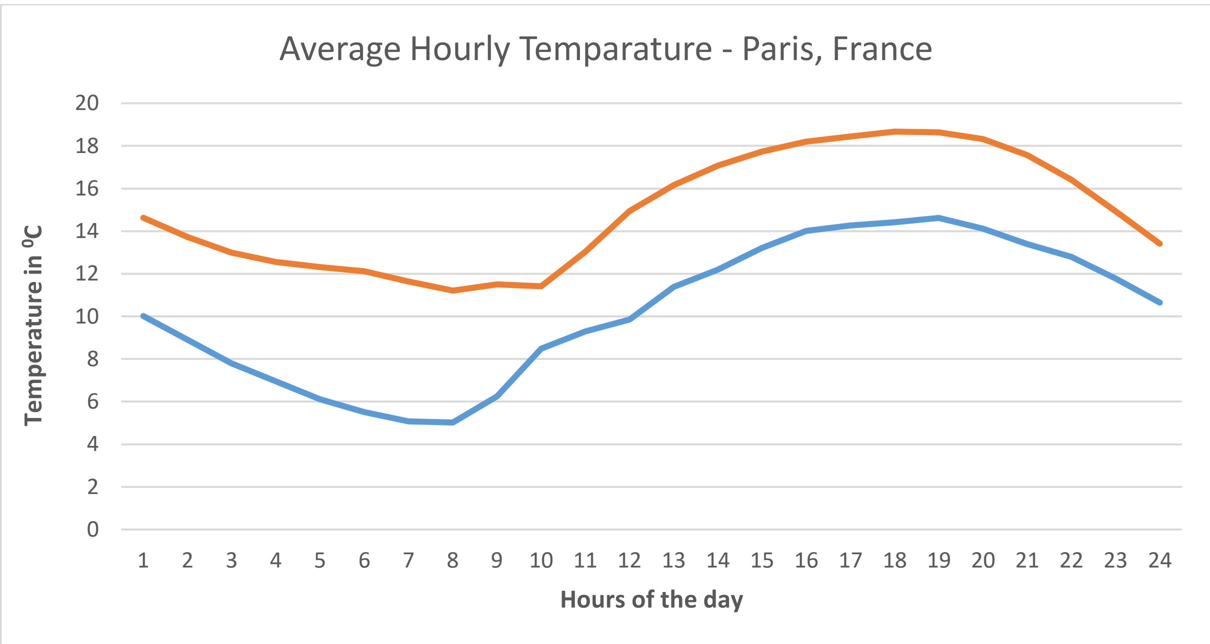


Figure 19 Average Hourly Temperature - Paris, France *Source: http://www.meteofrance.com/*

6.4. Auxiliary Power - Uncertain Factor affecting consumption

The doors of the bus are operated with approximately 6 kW air compressor. In addition, hydraulic power is needed for power steering and braking systems which consume approximately 1.5 kW continuously. Other auxiliary devices have an estimated average power of 1 kW. Given these characteristics, the best possible situation is estimated as average continuous auxiliary power of 2 kW. In the worst-case the doors are opened frequently and the auxiliary device power is maximum, leading to an estimate of 7 kW power Consumption in the worst-case scenario.

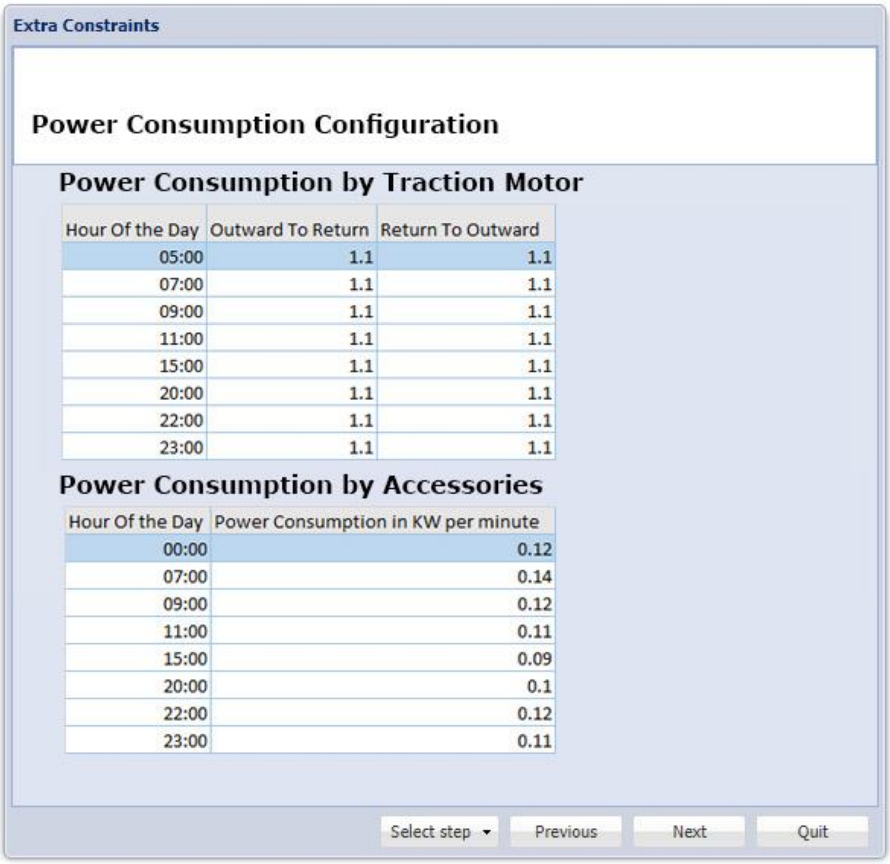


Figure 20 Configuration of Power consumption

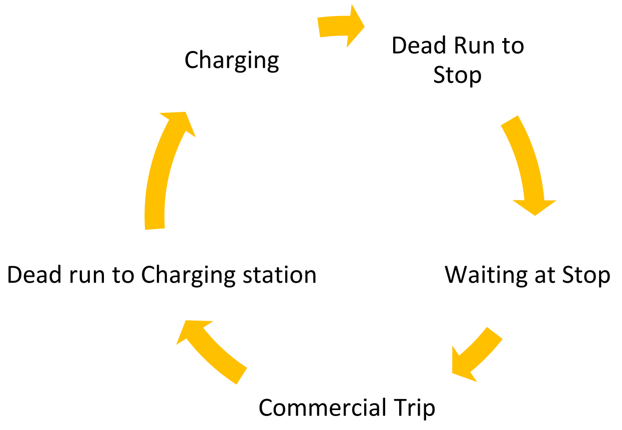
(Source: Bhushan Kurvey, part of "Heures" Lumiplan)

Conclusion: Weather is an important factor for consideration as its impact on consumption and charging due to its variation. It is also important to note that the weather changes season to season and should have different planning and scheduling for different seasons. Weather also shows a variation within the day time. So, the impact of weather factor must be considered for the hour of the day as well.

6.5. Bus Life Cycle

A. Bus Life Cycle: In case of Charging at the depot

The bus life cycle starts from the depot at the beginning of its operation. The bus performs a dead run to reach to the first point of the operation. The energy consumption for this trip is without the bus load of passengers but has a thermal system, AC and terrain slope acting on consumption.



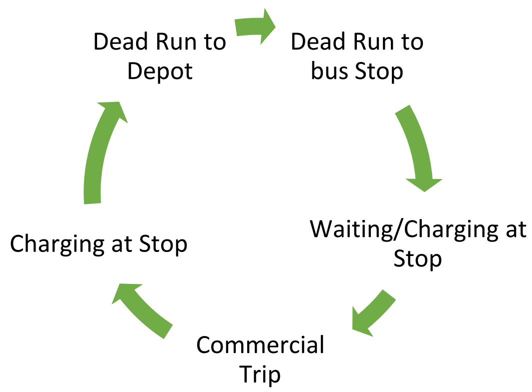
The commercial trip consumption will depend on the number of stops (opening/closing door - more in peak hours), other appliances like ac, thermal system, terrain slopes, load factor (weight) speed and weather. The contribution of having more consumption of energy is due to the external factors as mentioned above. The impact is an extra consumption. This factor can be defined as efficiency factor (0-1). For example, 0 → 0.95→1, if the efficiency is 95%.

When the charge in the battery is remaining close to reserve power, the bus needs to go for charging. If the charging infrastructure is installed only in the depot, the bus has to go back to depot. In this case, a bus has to perform a dead run. The energy consumption for this trip is without the load on bus of passengers but has a thermal system, AC and terrain slope acting on consumption.

Charging Efficiency: Charging efficiency here can be affected by the Weather factor. If the temperature is lower than the idle the temperature then the charging rate will be varied.

B. Bus Life Cycle: In case of Charging at Stop

The bus life cycle starts from the depot at the beginning of its operation. The bus performs a dead run to reach to the first point of operation. The energy consumption for this trip is without the bus load of passengers but has a thermal system, AC and terrain slope acting on consumption.



The commercial trip consumption will depend on the number of stops (opening/closing door - more in peak hours), other appliances like ac, thermal system, terrain slopes, load factor (weight) speed and weather. The contribution of having more consumption of energy is due to the external factors as mentioned above. The impact is an extra consumption. This factor can be defined as efficiency factor (0-1). For example, 0 → 0.95→1, if the efficiency is 95%.

Charging during the waiting time will be possible in case of the chargers are installed on the stop itself. The waiting time could be the time between the end time of last trip and the next trip to be performed.

Waiting at the bus stop before operation will have an idle consumption of the energy due to activities such as opening and closing of doors, air conditioner in operation, thermal system to keep the battery unit warm for better performance, etc. will make an impact on energy consumption.

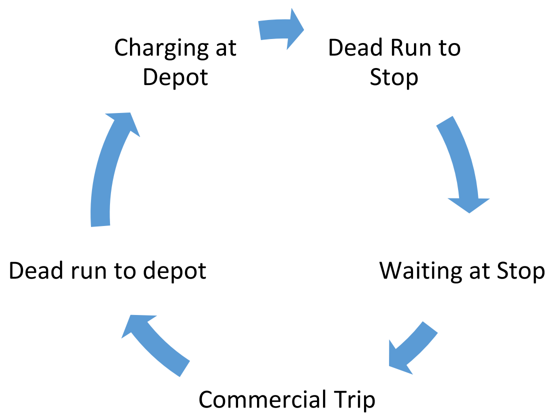
When the charge in the battery is remained close to reserve power, the bus needs to go for charging. If the charging infrastructure is installed at the stop, the buses can charge the battery at the stop according to the number of parallel charger capacity, the installation has. For this, a bus has does not have to perform a dead run.

Charging Efficiency: Charging efficiency here can be affected by the Weather factor. If the temperature is lower than the idle the temperature then the charging rate will be varied.

C. Bus Life Cycle: In case of Charging at Stop but at a short distance

The bus life cycle starts from the depot at the beginning of the operation. The bus performs a dead run to reach to the first point of the operation. The energy consumption for this trip is without the load on bus of passengers but has a thermal system, AC and terrain slope acting on consumption.

The commercial trip consumption will depend on the number of stops (opening/closing door- more in peak hours), other appliances like ac, thermal system, terrain slopes, load factor (weight) speed and weather. The contribution of having more consumption of energy is due to the external factors as mentioned above. The impact is an extra consumption. This factor can be defined as efficiency factor (0-1). For example, 0 → 0.95→1, if the efficiency is 95%.



Waiting at the bus stop before operation will have an idle consumption of the energy due to activities such as opening and closing of doors, air conditioner in operation, thermal system to keep the battery unit warm for better performance, etc. will make an impact on energy consumption.

Dead Run to Charging Station will be performed in case the charger station is installed at a considered distance from the end stops. A dead run will have an energy consumption based on the driving consumption, air conditioner, thermal system and other appliances like lights etc. will have consumption. The driving speed during the dead run is expected to be more than the driving speed at the commercial trip. The consumption of the dead run trip and commercial trip to be considered separately.

When the charge in the battery is remained close to reserve power, the bus needs to go for charging. If the charging infrastructure is installed at a close distance to the stop, the buses can charge the battery at the depot according to the number of parallel charger capacity, the installation has. In this case, a bus does not have to perform a dead run.

Dead run to commercial stop will be performed after the battery is recharged at the charger station and the bus can be ready to perform the commercial trip from the stop.

Conclusion:

Considering the variable parameters

I. Driving consumption without load (Route condition, driver behaviour)
II. Driving consumption with Load (0 - 12.5% more) (Route condition, driver behaviour)
III. Consumption of PIS, lights, duct. fans, card readers and other accessories
IV. Consumption on air conditioner, thermal system
V. Consumption of opening and closing doors
VI. Consumption of coupling and de-coupling for charging

Chapter 7. Cost of Operation

The cost factor has a greater contribution in choosing a type of fleet for the operation as it involves a large amount of initial cost. The return on investment depends on the usability of public transportation moreover demand verses services provided by the operator. Through, the initial cost of the EV buses are much higher than the diesel buses, there are many factors which needs to be studied to have better understanding over the long term period cost incurred.

In this chapter, the cost for the bus operation is compared based on 2 factors:

- Initial Cost of the bus and infrastructure
- Operation and maintenance Cost

7.1. Initial Investment

When it comes to the initial purchase cost of bus and required infrastructure for the EV buses, it is higher than the diesel bus & its required infrastructure purchase cost. A diesel bus model MERCEDES - BENZ, Merkavim Pioneer costs around 234000 euros compared to a similar configuration model of EV bus model SOR-NS-12-electric which costs almost 2.5 times more than diesel bus around 577000 euros The diesel buses have a life of 10 years and EV around 12-15 years. For the ease of calculation, life of buses are considered to be the same as 10 years. There is an additional cost of infrastructure for charging and chargers associated to EV buses which is included in the table below.

7.2. Operation and Maintenance

Cost of maintenance involves periodic part replacement of wear and tear parts of engines such as filters, assemblies, etc. Diesel buses persist an additional cost as it has engine to generate power. In electric buses the power is stored in batteries and with drowned from it for the motor. So the maintenance cost of the EV buses are lesser than diesel. But EV buses have an additional cost of batteries to be replaced in every 5 years.

In the below example, the average cost of operation for diesel and EV buses is considered under 2 factors.

1. Cost of the spare parts, assemblies, periodic maintenance
2. Cost of fuel

Periodic maintenance is considered in average cost per kilometre as it is directly proportional to vehicle run and multiplied with kilometres run in 1 year. Similarly, the average fuel cost is considered by calculating the cost per kilometre.

Cost Factors	Diesel Bus (Standard)	EV Bus (Comparable Model with Diesel)
Average Initial purchase Cost of Bus	€234,000.00	€577,000.00
Life in years	10	10
Average Cost of Bus per year	**€23,400.00**	**€57,700.00**
Average driving distance per year	100000	100000
Cost of O&M (Cost per kilometre)	€0.31	€ 0.05
Battery unit	€-	€7,500.00
Average Total Cost of O&M per year	**€31,250.00**	**€ 12,187.50**
Average Cost of fuel (per litre) or Electricity(per KwH)	€1.49	€0.15
Mileage (Litres per Kilometre) or (KwH per kilometre)	0.42	2.2
Total Cost of fuel per year	**€62,580.00**	**€33,000.00**
Cost of Charger unit and infrastructure	€-	€14,000.00
Cost per Year	**€117,230.00**	**€116,887.50**

Table 5 Comparison of cost of operation (Diesel Vs EV buses)
Source: [Marek et al., 2018] and Protera EV buses

In the above example, it can be determined that the cost per year to operate EV buses is lesser than the diesel car. However, the calculation will vary based on the specifications and performance of the vehicle. Though the cost of operation and maintenance for EV buses will always be lesser than diesel buses.

Diesel buses have lesser life than the EV buses due to engine on board. The engine create a vibration which results in deteriorating the life of the body. In EV buses, there is only motor which is not an expensive part and can be replaced and body shows up better life as there is no vibration in the bus.

However, the infrastructure cost may vary depending on many factors with respect to land availability, distance from the OD stations, and land acquisition and cost, Infrastructure material and type.

Chapter 8. Is Electric Bus a move to save the Planet?

Greenhouse gas emissions are the serious concern in front of the societies. The environment is getting affected everyday due to the use of greenhouse gas emitting equipment. This has led to a global warming and would contribute more in future. EV buses have larger short and long term benefits over diesel buses.

- It drastically reduces Nitrogen Oxide and smog present on ground level which protects our health and environment.
- It also significantly reduces CO2 and other greenhouse gas (GHG) emissions.
- It reduces long-term fuel consumption, maintenance and operation costs of public fleet vehicles.
- It increases public awareness and adoption of EVs as cleaner alternatives to traditional gas-powered vehicles.

In the context of transportation, the total gas emission can be determined by understanding emission during the power generation and emission during the vehicle operation. Power generation industries world-wide use limited source of coal, natural gas, nuclear and oil as the primary source to generate electricity. There are also industries for generating electricity by renewable sources such as solar (Thermal & Photovoltaics), wind, Hydro, geo thermal and Tide.

Source of Electricity (World total year 2008)

-	Coal	Oil	Natural Gas	Nuclear	Renewables	other	Total
Average electric power (TWh/year)	8,263	1,111	4,301	2,731	3,288	568	20,261
Average electric power (GW)	942.6	126.7	490.7	311.6	375.1	64.8	2311.4
Proportion	41%	5%	21%	13%	16%	3%	100%

Figure 21 Source of Electricity by technologies
Source: Wikipedia, IEA/OECD

It will not be appropriate to say that the EV buses eliminates 100% pollution but definitely, the emission on the operation's site is eliminated. The part of pollution caused during electricity generation has to be accounted. It is known that the fossil fuels are the limited source of energy. In coming years, these sources will have limitations on their supply verses demand. There is a need of finding new source of energy. At the same time, it is important to look after the environmental factors to avoid hazardous effects on it.

Use of renewable source of energies can reduce the risk of rising pollution and also reduce the use of fossil fuels for energy productions. Below is a table referred from Wikipedia describing CO2 emissions due to technology used for producing electricity.

Technology	Description	50th percentile (g CO2/kWh$_e$)
Hydroelectric	reservoir	4
Wind	onshore	12
Nuclear	various generation II reactor types	16
Biomass	various	18
Solar thermal	parabolic trough	22
Geothermal	hot dry rock	45
Solar PV	Polycrystalline silicon	46
Natural gas	various combined cycle turbines without scrubbing	469
Coal	various generator types without scrubbing	1001

Figure 22 CO2 emission by use of technologies

Source: Wikipedia, IEA/OECD

However, there can be alternatives to generate electricity with which the pollution will reduce. However in case of diesel buses, the combustion will happen on the site of operation and will create pollution. But the pollution on the site of the operation will be absolutely reduced when EV buses are used. Assuming that an EV bus runs 100,000 kilometres in 1 year.

CO2 emission for diesel buses being 69 Grams/ KM [source].

Then the bus will generate 6900 KGs of CO2 in 1 year which will be on the site.

Chapter 9. Case Study

9.1. Scenario 1: Charging at Depot Only

9.1.1. Input:

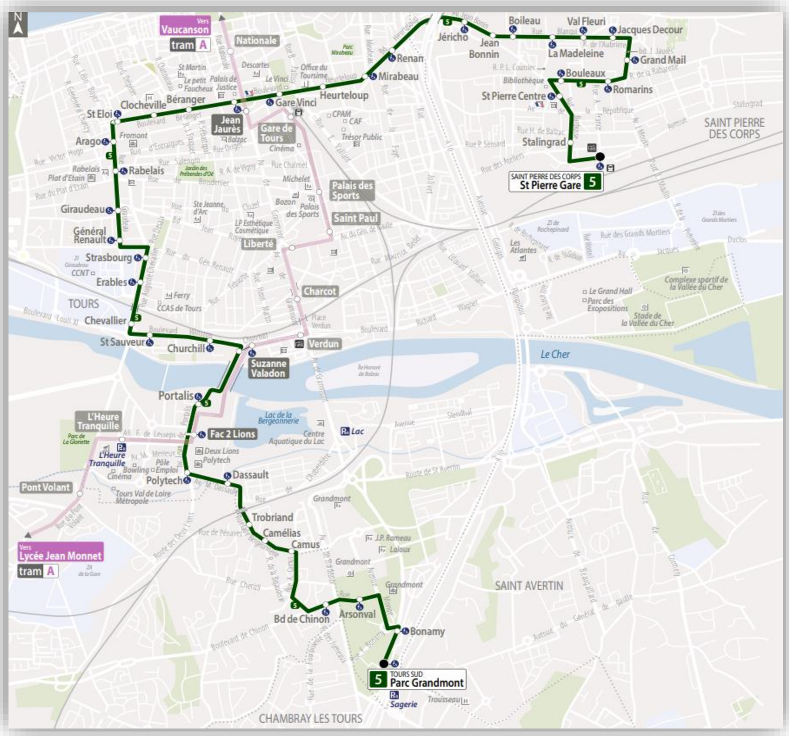


Figure 23 Line 5 Fil bleau, Tours, France *Source: Fil Beau, tours, France*

City	Tours, France
Line No	5
From	St Pierre Gare
To	Parc Grandmont
Operation Time	6h to 23h30

9.1.1.1. Distances required for calculating power consumption by Traction Motor:

Distance Outward trip (meters) = 16000

Distance Return trip (meters) = 16000

Distance Outward stop to depot dead Run trip (O-D) (meters) = 2700

Distance Depot to Outward stop dead Run trip (D-O) (meters) = 2700

Distance Return stop to depot dead Run trip(R-D) (meters) = 6700

Distance Depot to Return stop dead Run trip (D-R) (meters) = 6700

Distance Outward to Charging (meters) = 2700

Distance to Charging to Outward (meters) = 2700

Distance Return to Charging (meters) = 6700

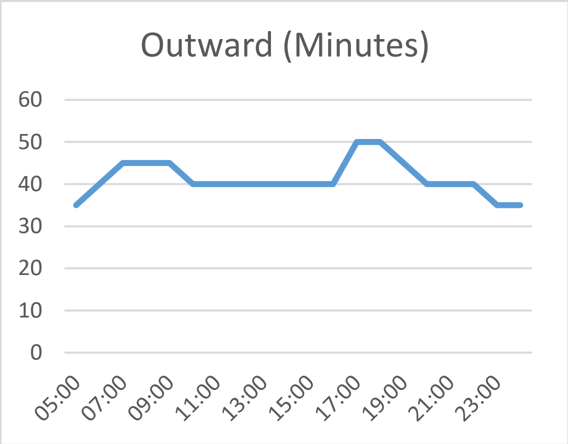
Distance to Charging to Return (meters) = 6700

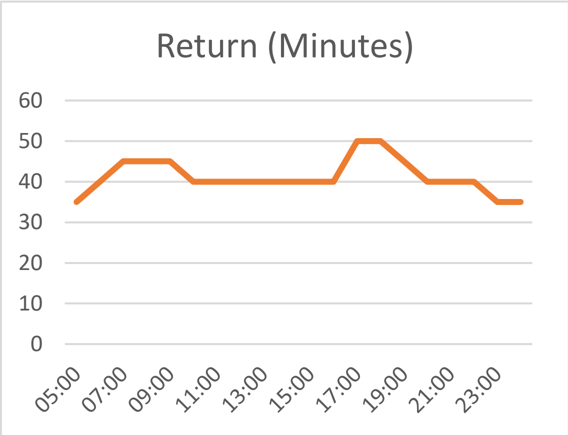
Turn Around distance at Outward Stop (meters) = 20

Turn Around distance at Return Stop (meters) = 20

9.1.1.2. Run Time Table:s

Hour of Day	Outward (Minutes)	Return (Minutes)
05:00	35	35
06:00	40	40
07:00	45	45
08:00	45	45
09:00	45	45
10:00	40	40
11:00	40	40
12:00	40	40
13:00	40	40
14:00	40	40
15:00	40	40
16:00	40	40
17:00	50	50
18:00	50	50
19:00	45	45
20:00	40	40
21:00	40	40
22:00	40	40
23:00	35	35
00:00	35	35





9.1.1.3. Dead Run to Depot in minutes

Hour of the Day	Depot to Outward	Depot to Return	Outward to Depot	Return to Depot
For whole day	5	12	5	12

9.1.1.4. Dead Run to Charging Stop in minutes

Hour of the Day	Charging Stop to Outward	Charging Stop to Return	Outward to Charging Stop	Return to Charging Stop
For whole day	5	12	5	12

9.1.1.5. Charging Configuration in KwH/Minute-

Hour Of the Day	Outward Depot	Return Depot	Outward Stop	Return Stop
For whole day	3.0	3.0	3.0	3.0

9.1.1.6. Charger's Charging Strategy

%SOC	Outward Depot%	Return Depot%	Outward Stop%	Return Stop%
0	0	0	0	0
90	50	50	50	50

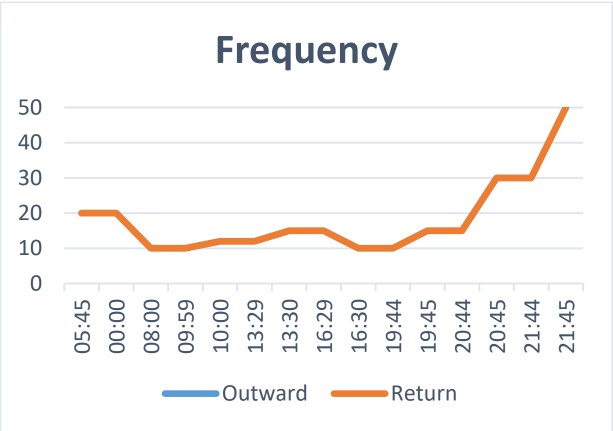
*% Drop in charging rate after State of charge reaches

9.1.1.7. Charging & infrastructure Constraints considered as:

Use Charging at Stops during Short Break time = Yes
Short Charging Break Minutes Start time = 50
MAX Short Charging Break duration = 30
Max number of Buses On short charging break at a given time = 4
Avoid Charging at Terminal (Outward/Return/NA) = NA
Window_1 start when Charging break not to be taken (in min) = 8:00
Window_1 end when Charging break not to be taken (in min) = 10:00
Window_2 start when Charging break not to be taken (in min) = 17:00
Window_2 end when Charging break not to be taken (in min) = 20:00
Charge During Waiting/Buffer Time (Yes/No) = No
Total Power KwH = 300
Reserve Power KwH = 30
MAX Number of breaks to be taken by each bus= 5

9.1.1.8. Frequency Requirement Table:

Hour of the Day	Outward	Return
05:45	20	20
07:00	10	10
08:00	10	10
10:00	12	12
13:30	15	15
16:30	10	10
19:45	15	15
20:45	30	30
21:45	50	50



9.1.1.9. Energy Consumption Parameters:

Commercial:

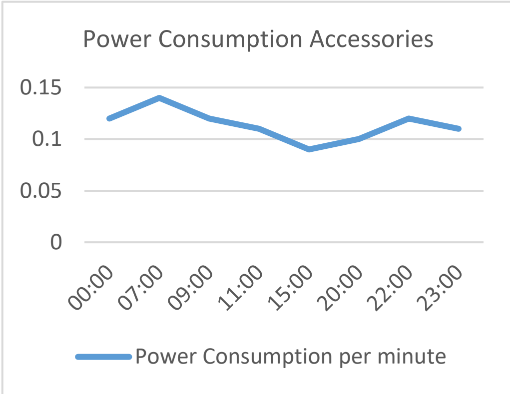
Hour Of the Day	Outward To Return(KwH/Km)	Return To Outward(KwH/Km)
For whole day	1.1	1.1

Dead Run:

Hour Of the Day	Outward To Return (KwH/Km)	Return To Outward(KwH/Km)
For whole day	1	1

9.1.1.10. Accessories (Air Conditioning/ Thermal System/PIS/OBD):

Hour Of the Day	AC power Consumption per minute
00:00	0.12
07:00	0.14
09:00	0.12
11:00	0.11
15:00	0.09
20:00	0.1
22:00	0.12
23:00	0.11



The above table is considered under a specific season climate.

The table represents 00h to 07h, the AC consumption takes 0.12 KwH/Minute and further 7h to 9h takes 0.14 KwH/Minute. The consumption is majorly because of thermal and air-conditioning unit which is dependent on the weather and climate conditions

9.1.1.11. Operation Start and End Time

Direction	Start Time	End Time
Outward	06:00	23:30
Return	06:00	23:30

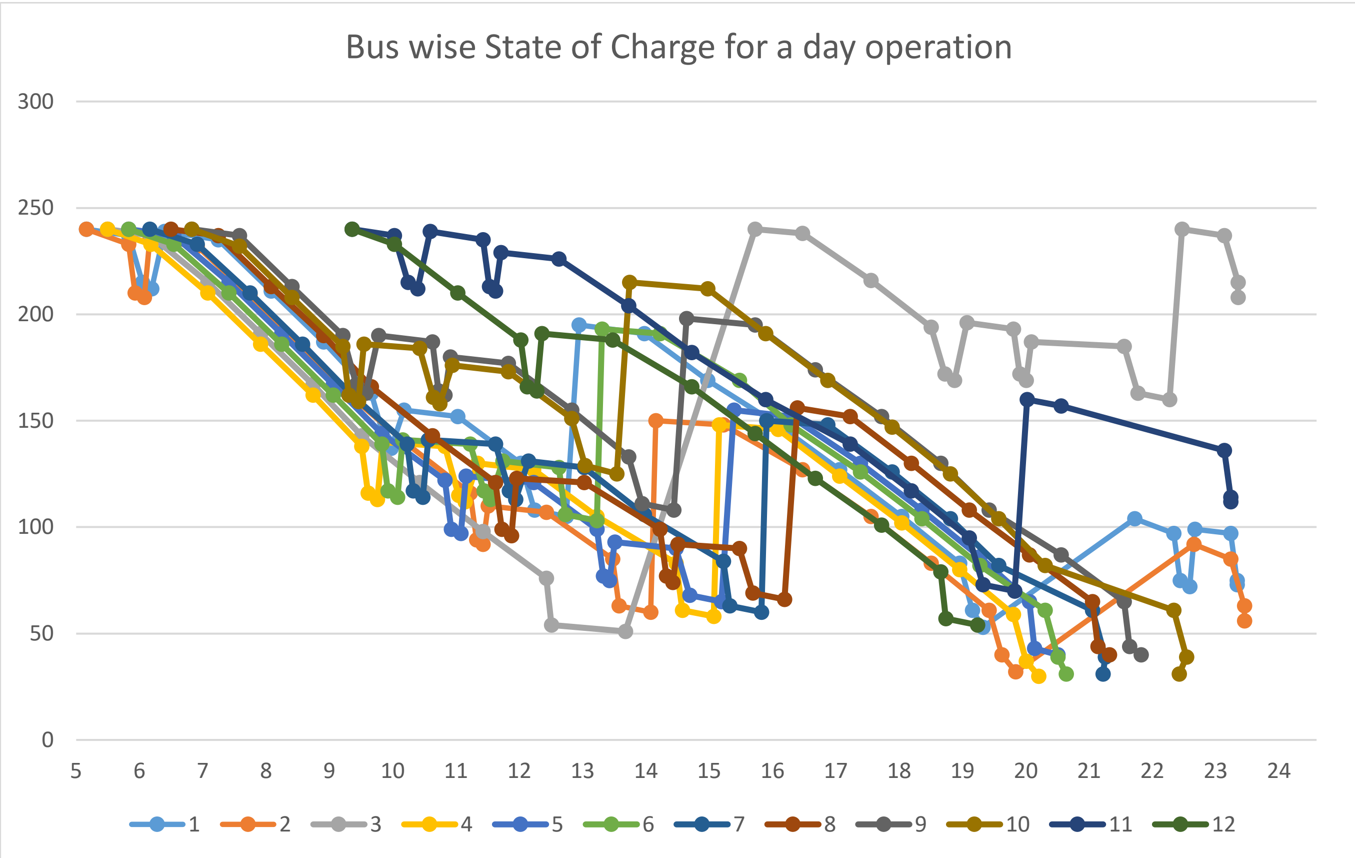
The operation requires 12 buses to perform with diesel buses. This result has the minimum buses needed for required operation.

9.1.2.Result:

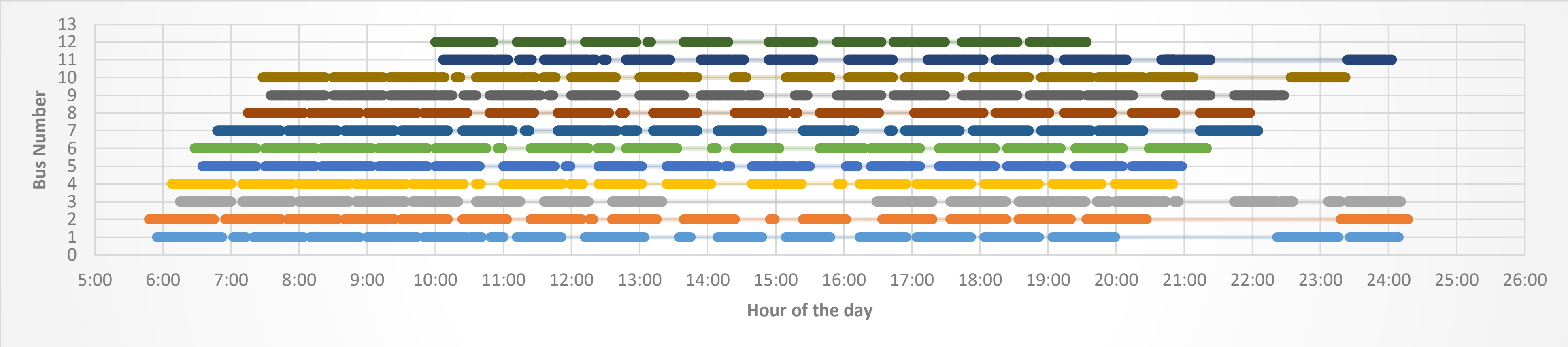
When the simulation was run under the above configuration. Below result is found to be the best among other solutions generated by simulator.

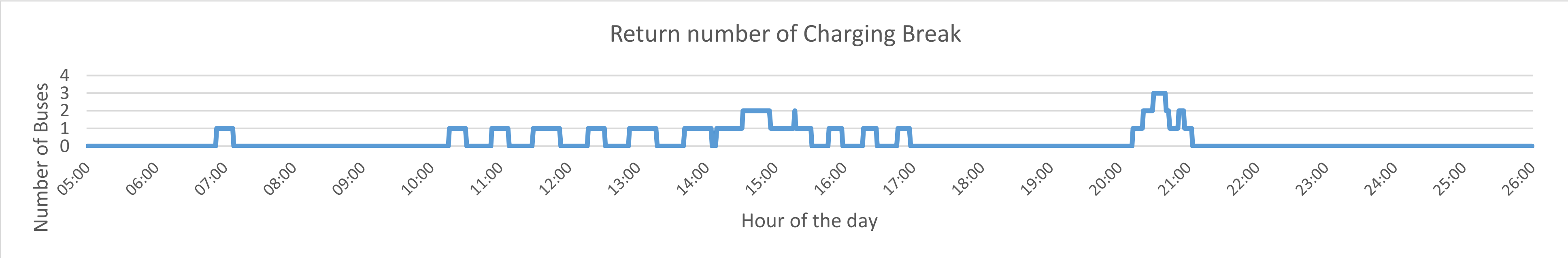
Number of buses required	12
Total Power	240
Minimum Reserve Power	30
Maximum number of short breaks taken by bus	3
Maximum Parallel break at same time	3
Charging at Outward Depot	Yes
Charging at Return depot	Yes
Charging at Outward Stop or Charging Station close by	No
Charging at Return Stop or Charging Station close by	No
Minimum number of parallel charging ports required at Outward Stop	0
Minimum number of parallel charging ports required at Return Stop	0
Total Consumption of 1 day operation (KWH)	3965

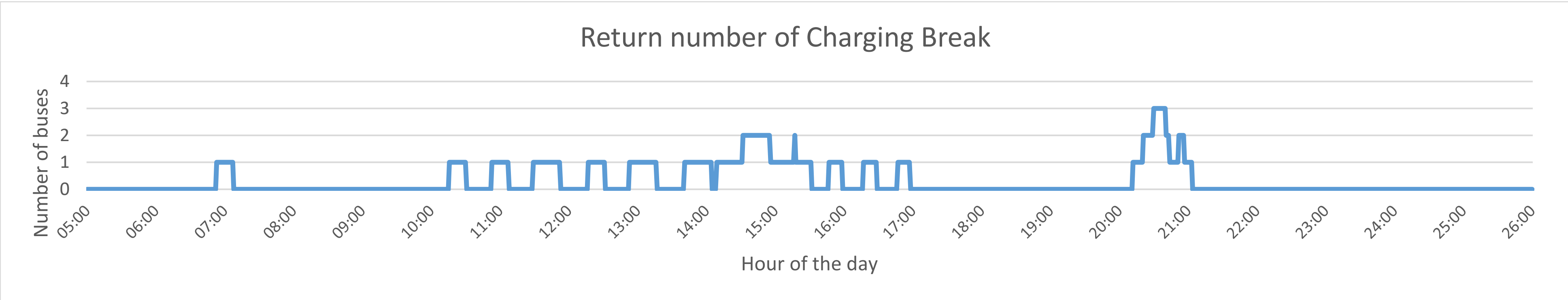
9.1.2.1. State of charge for each bus throughout the day operation:



9.1.2.2. Vehicle Scheduling Plan:







9.1.3.Conclusion:

12 buses plan is able to perform the whole day operation based on the frequency of services given as input.

In the above result, it can be seen that the operation can be replaced with EV buses having 12 buses only. The charging events are arranged such way that there are sufficient buses on the ground to perform each trip and all the trips are performed as per the input.

The evaluation of the solution is carried out based on 2 major factors, number of buses and total power consumption of each generate solution wherein the presented output has the best plan to be practically implemented on ground.

9.2. Scenario 2: Charging at Depot and OD stations

9.2.1. Input:

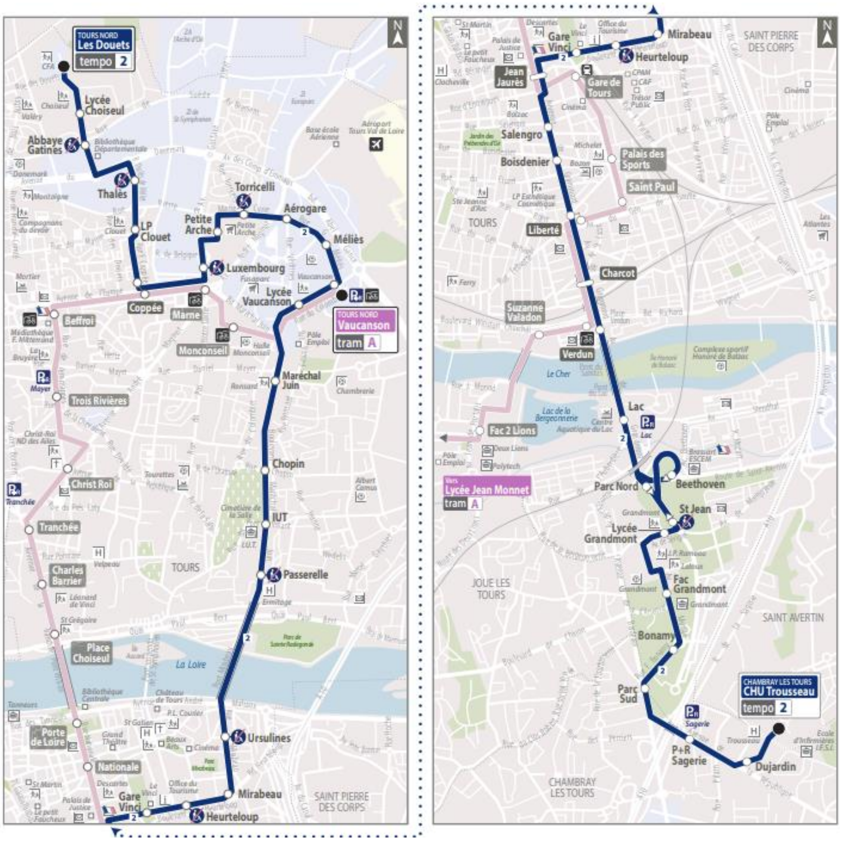


Figure 24 Line 2 Fil Bleau, Tours, France *Source: Fil Bleau, Tours France*

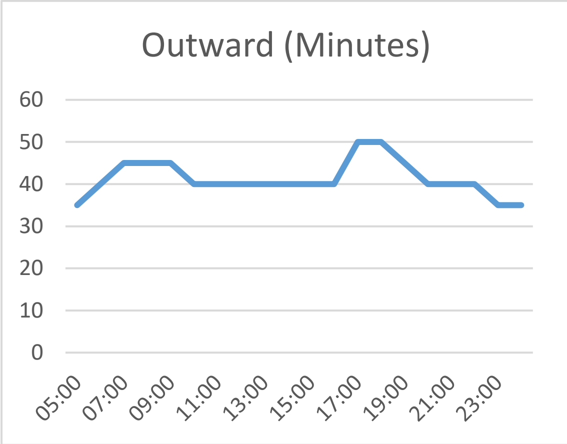
City	Tours, France
Line No	2
From	Les Douets
To	CHU Trousseau
Operation Time	5h to 23h30

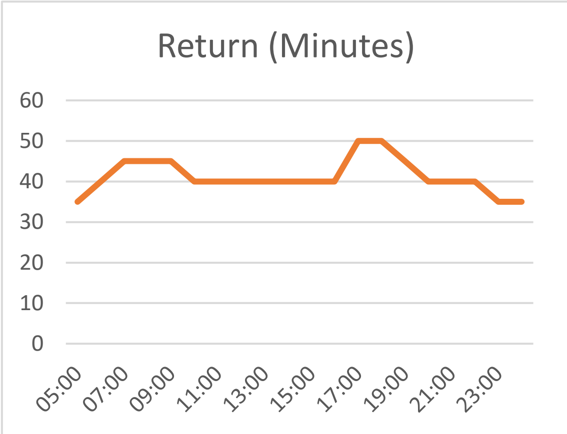
9.2.1.1. Distances required for calculating power consumption by Traction Motor:

Distance Outward trip (meters) = 15900
Distance Return trip (meters) = 15900
Distance Outward stop to depot dead Run trip (O-D) (meters) = 11000
Distance Depot to Outward stop dead Run trip (D-O) (meters) = 11000
Distance Return stop to depot dead Run trip(R-D) (meters) = 7600
Distance Depot to Return stop dead Run trip (D-R) (meters) = 7600
Distance Outward to Charging (meters) = 1000
Distance to Charging to Outward (meters) = 1000
Distance Return to Charging (meters) = 1000
Distance to Charging to Return (meters) = 1000
Turn Around distance at Outward Stop (meters) = 10
Turn Around distance at Return Stop (meters) = 10

9.2.1.2. Run Time Table:

Hour of Day	Outward (Minutes)	Return (Minutes)
05:00	39	39
06:45	40	40
07:00	43	43
08:00	43	43
09:00	43	43
10:00	42	42
11:00	42	42
12:00	42	42
13:00	42	42
14:00	42	42
15:00	42	42
16:00	42	42
17:00	48	48
18:00	48	48
19:00	45	45
20:00	45	45
21:00	44	44
22:40	42	42
23:00	42	42





9.2.1.3. Dead Run to Depot in minutes

Hour of the Day	Depot to Outward	Depot to Return	Outward to Depot	Return to Depot
For whole day	20	15	20	15

9.2.1.4. Dead Run to Charging Stop in minutes

Hour of the Day	Charging Stop to Outward	Charging Stop to Return	Outward to Charging Stop	Return to Charging Stop
For whole day	3	3	3	3

9.2.1.5. Charging Configuration in KwH/Minute-

Hour Of the Day	Outward Depot	Return Depot	Outward Stop	Return Stop
For whole day	3.0	3.0	3.0	3.0

9.2.1.6. Charger's Charging Strategy

%SOC	Outward Depot%	Return Depot%	Outward Stop%	Return Stop%
0	0	0	0	0
90	50	50	50	50

*% Drop in charging rate after State of charge reaches

9.2.1.7. Charging & infrastructure Constraints considered as:

Use Charging at Stops during Short Break time = Yes
Short Charging Break Minutes Start time = 30
MAX Short Charging Break duration = 40
Max number of Buses On short charging break at a given time = 8
Avoid Charging at Terminal (Outward/Return/NA) = NA
Window_1 start when Charging break not to be taken (in min) = 6:45
Window_1 end when Charging break not to be taken (in min) = 10:00
Window_2 start when Charging break not to be taken (in min) = 17:00
Window_2 end when Charging break not to be taken (in min) = 20:00
Charge During Waiting/Buffer Time (Yes/No) = No
Total Power KwH = 200
Reserve Power KwH = 30
MAX Number of short breaks to be taken by each bus= 5

9.2.1.8. Frequency Requirement Table:

Hour of the Day	Outward	Return
05:00	30	30
06:00	15	15
06:45	7	7
10:00	10	10
17:00	7	7
19:00	11	11
20:15	15	15
21:00	22	22
22:30	30	30

9.2.1.9. Energy Consumption Parameters:

Commercial:

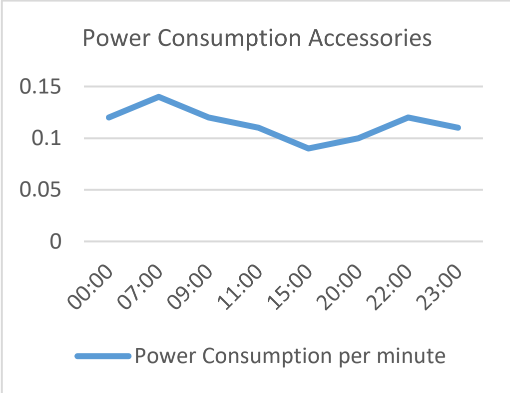
Hour Of the Day	Outward To Return(KwH/Km)	Return To Outward(KwH/Km)
For whole day	1.1	1.1

Dead Run:

Hour Of the Day	Outward To Return (KwH/Km)	Return To Outward(KwH/Km)
For whole day	1	1

9.2.1.10. Accessories (Air Conditioning/ Thermal System/PIS/OBD):

Hour Of the Day	AC power Consumption per minute
00:00	0.12
07:00	0.14
09:00	0.12
11:00	0.11
15:00	0.09
20:00	0.1
22:00	0.12
23:00	0.11



The above table is considered under a specific season climate.

The table represents 00h to 07h, the AC consumption takes 0.12 KwH/Minute and further 7h to 9h takes 0.14 KwH/Minute. The consumption is majorly because of thermal and air-conditioning unit which is dependent on the weather and climate conditions

9.2.1.11. Operation Start and End Time

Direction	Start Time	End Time
Outward	06:00	23:30
Return	06:00	23:30

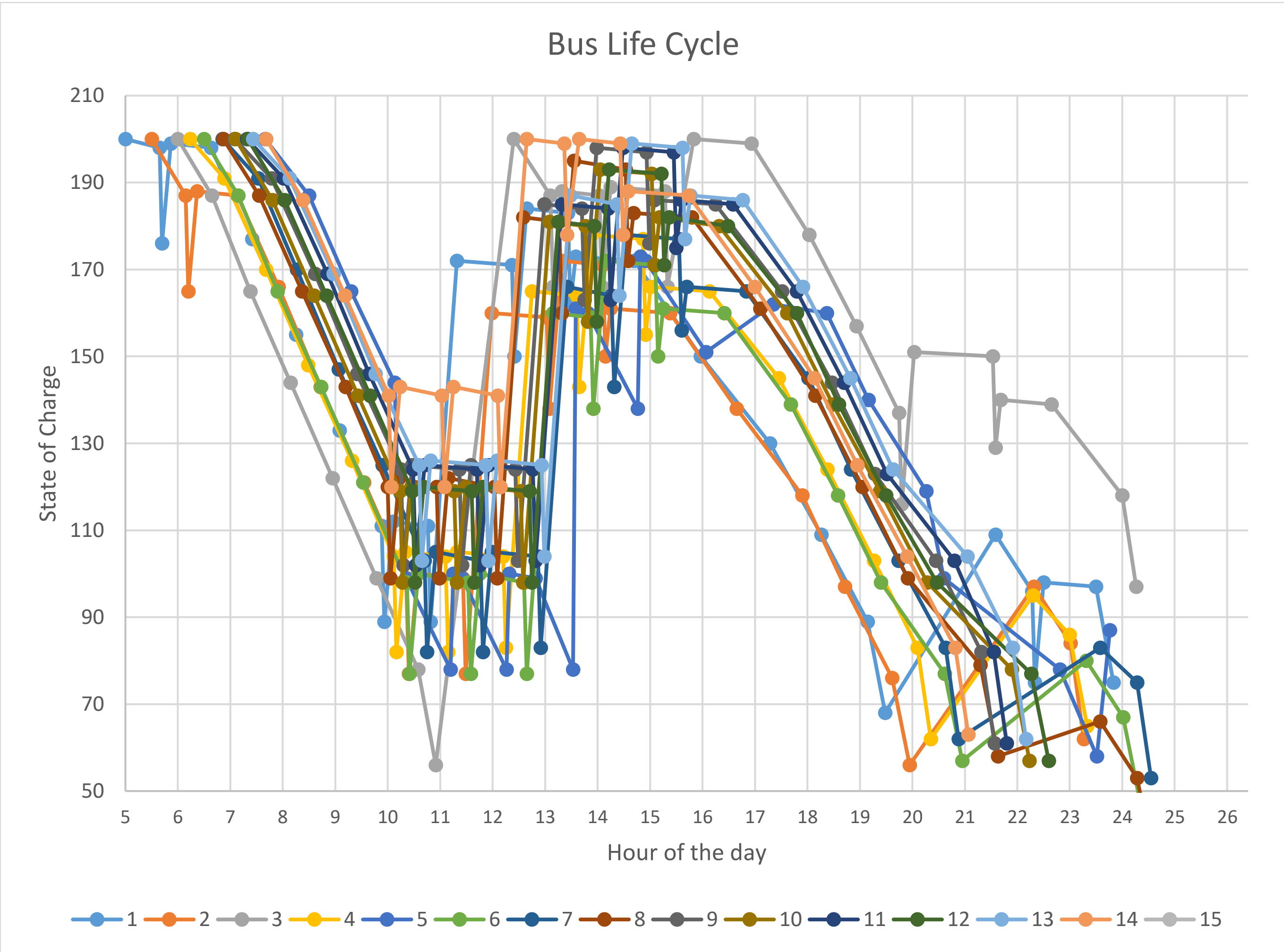
The operation requires <u>15 buses</u> to perform with diesel buses. This result has the minimum buses needed for required operation.

9.2.2. Result:

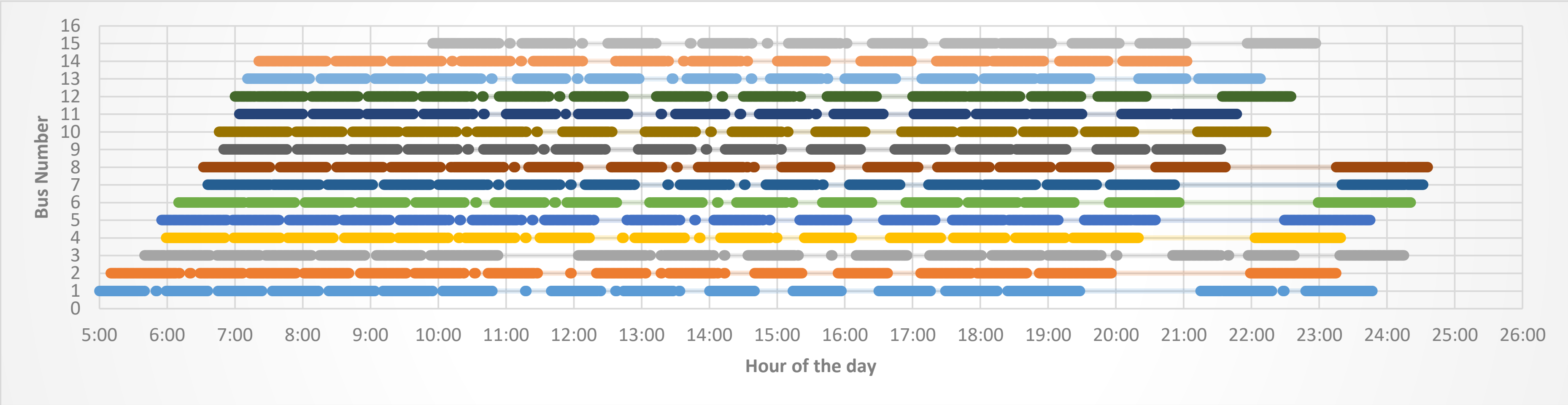
When the simulation was run under the above configuration. Below result is found to be the best among other solutions generated by simulator.

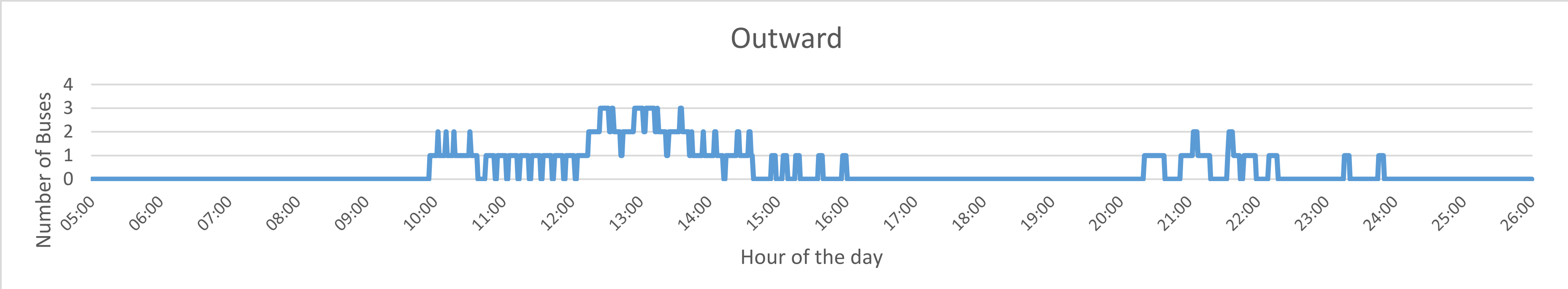
Number of buses required	16
Total Power	200
Minimum Reserve Power	33
Maximum number of short breaks taken by bus	3
Charging at Outward Depot	No
Charging at Return depot	No
Minimum number of parallel charging ports required at Outward Stop	3
Minimum number of parallel charging ports required at Return Stop	3
Total Consumption of 1 day operation	5260 KwH

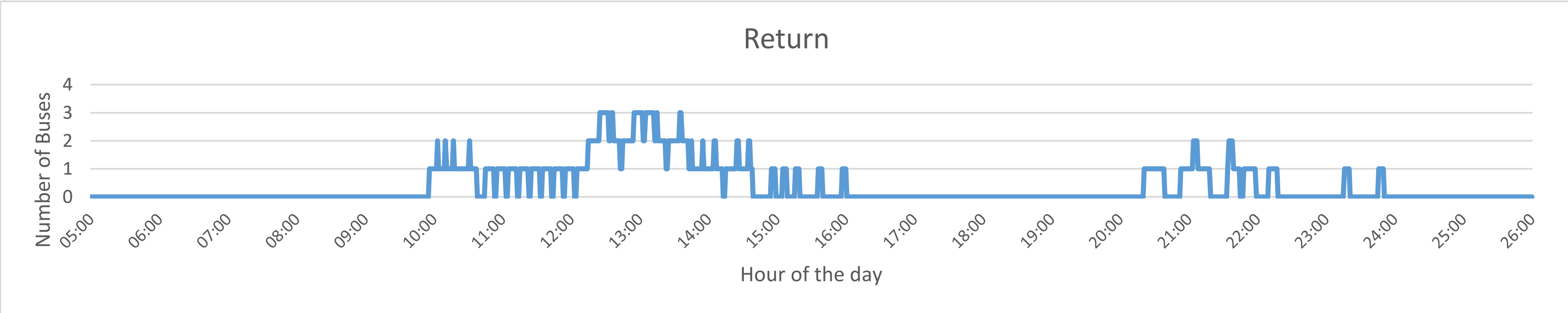
9.2.2.1. State of charge for each bus throughout the day operation:



9.2.2.2. Vehicle Scheduling Plan:







9.2.3.Conclusion:

As it’s a flat frequency around 7 to 10 min throughout day, there is no gap for buses to have break for charging. At the same time, the depot is very far from the stops. So, to have the minimal number of buses for operation as of diesel operation which is 15 buses, an additional infrastructure for charging has to be installed close to the both end points of operation within 1 kilometre of vicinity

A proposed solution determines that if there are fast charging stations within the close vicinity, it will be possible to operate the required schedules with the same number of buses. Still, the cost of infrastructure of charging and cost of bus has to be compared to understand which is cost effective

9.3. Scenario 3: Battery Swapping at Depot only

9.3.1. Input:

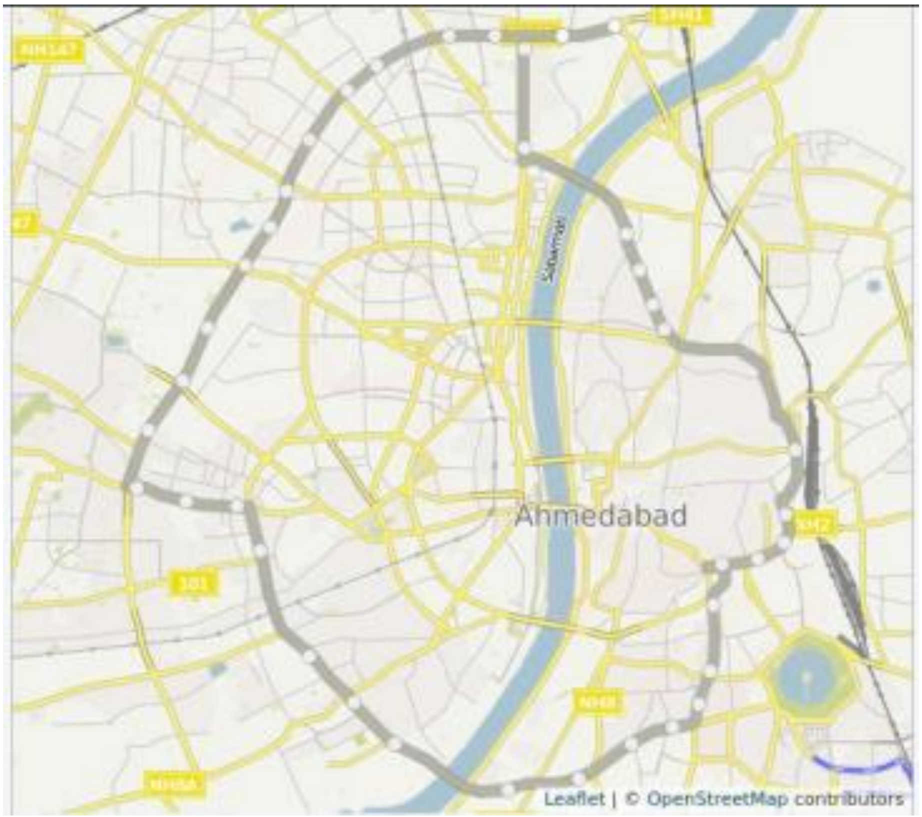


Figure 25 Line 101 Ahmedabad Janmarg Limited, India *Source: Leaflet*

City	Ahmedabad, Gujrat, India
Line No	101 (Circular Line)
From	R.T.O Circle
To	R.T.O Circle
Operation Time	6h30 to 22h30

9.3.1.1. Distances required for calculating power consumption by Traction Motor:

Distance Outward trip (meters) = 26900
Distance Return trip (meters) = 26900
Distance Outward stop to depot dead Run trip (O-D) (meters) = 1576
Distance Depot to Outward stop dead Run trip (D-O) (meters) = 1576
Distance Return stop to depot dead Run trip(R-D) (meters) = 1576
Distance Depot to Return stop dead Run trip (D-R) (meters) = 1576
Distance Outward to Charging (meters) = 1576
Distance to Charging to Outward (meters) = 1576
Distance Return to Charging (meters) = 1576
Distance to Charging to Return (meters) = 1576
Turn Around distance at Outward Stop (meters) = 10
Turn Around distance at Return Stop (meters) = 10

9.3.1.2. Run Time Table:

Hour of Day	Outward (Minutes)	Return (Minutes)
05:00	49	49
06:45	50	50
07:00	53	53
08:00	53	53
09:00	53	53
10:00	52	52
11:00	52	52
12:00	52	52
13:00	52	52
14:00	52	52
15:00	52	52
16:00	52	52
17:00	58	58
18:00	58	58
19:00	55	55
20:00	55	55
21:00	54	54
22:40	52	52
23:00	52	52

9.3.1.3. Dead Run to Depot in minutes

Hour of the Day	Depot to Outward	Depot to Return	Outward to Depot	Return to Depot
For whole day	3	3	3	3

9.3.1.4. Dead Run to Charging Stop in minutes

Hour of the Day	Charging Stop to Outward	Charging Stop to Return	Outward to Charging Stop	Return to Charging Stop
For whole day	3	3	3	3

9.3.1.5. Charging Configuration in KwH/Minute-

Hour Of the Day	Outward Depot	Return Depot	Outward Stop	Return Stop
For whole day	NA	NA	NA	NA

9.3.1.6. Charger's Charging Strategy

%SOC	Outward Depot%	Return Depot%	Outward Stop%	Return Stop%
0	NA	NA	NA	NA
90	NA	NA	NA	NA

*% Drop in charging rate after State of charge reaches

9.3.1.7. Charging & infrastructure Constraints considered as:

Use Charging at Stops during Short Break time = NA
Short Charging Break Minutes Start time = NA
MAX Short Charging/Swapping Break duration = 5
Max number of Buses On short Charging/Swapping break at a given time = 8
Avoid Charging at Terminal (Outward/Return/NA) = NA
Window_1 start when Charging break not to be taken (in min) = NA
Window_1 end when Charging break not to be taken (in min) = NA
Window_2 start when Charging break not to be taken (in min) = NA
Window_2 end when Charging break not to be taken (in min) = NA
Charge During Waiting/Buffer Time (Yes/No) = No
Total Power KwH = 60
Reserve Power KwH = 0
MAX Number of short breaks to be taken by each bus= NA

9.3.1.8. Frequency Requirement Table:

Hour of the Day	Outward	Return
06:00	15	15
08:00	12	12
12:00	15	15
17:00	12	12
20:00	15	15

9.3.1.9. Energy Consumption Parameters:

Commercial:

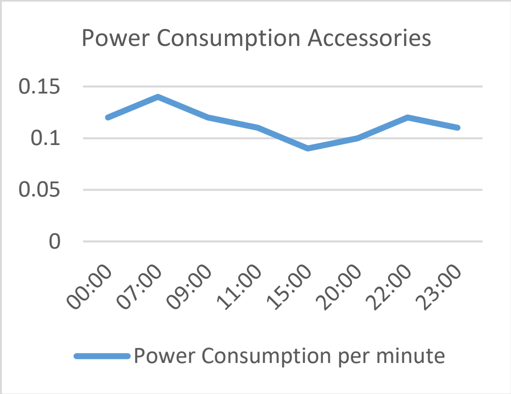
Hour Of the Day	Outward To Return(KwH/Km)	Return To Outward(KwH/Km)
For whole day	1.1	1.1

Dead Run:

Hour Of the Day	Outward To Return (KwH/Km)	Return To Outward(KwH/Km)
For whole day	1	1

9.3.1.10. Accessories (Air Conditioning/ Thermal System/PIS/OBD):

Hour Of the Day	AC power Consumption per minute
00:00	0.12
07:00	0.14
09:00	0.12
11:00	0.11
15:00	0.09
20:00	0.1
22:00	0.12
23:00	0.11



The above table is considered under a specific season climate.

The table represents 00h to 07h, the AC consumption takes 0.12 KwH/Minute and further 7h to 9h takes 0.14 KwH/Minute. The consumption is majorly because of thermal and air-conditioning unit which is dependent on the weather and climate conditions

9.3.1.11. Operation Start and End Time

Direction	Start Time	End Time
Outward	06:30	22:30
Return	06:30	22:30

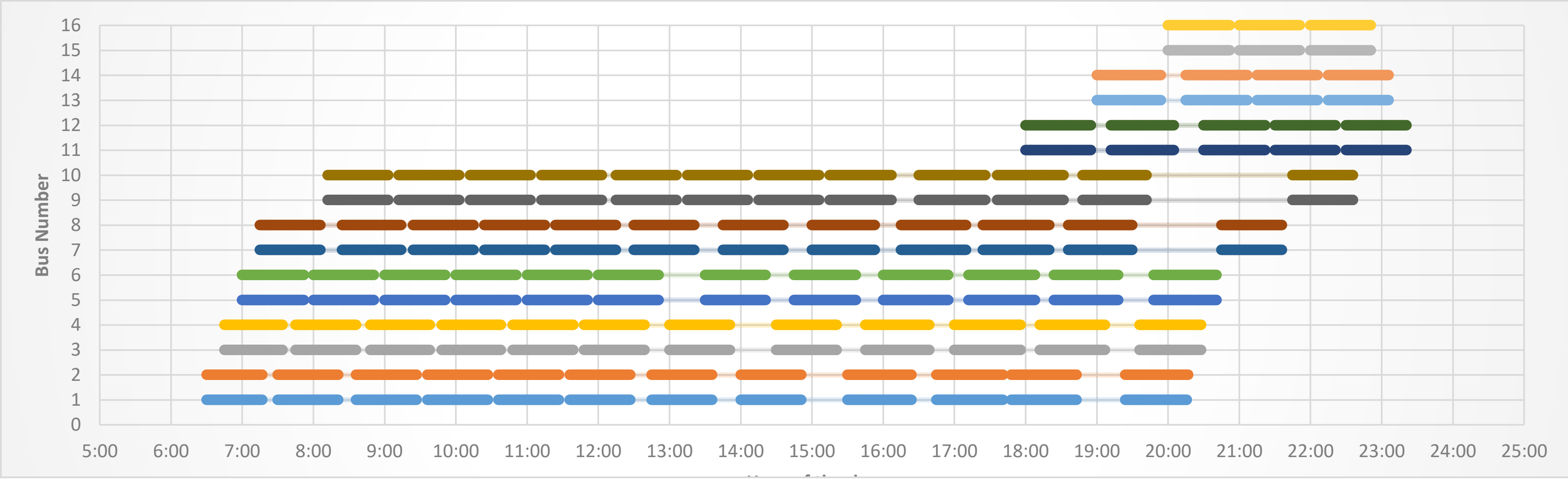
The operation requires <u>10 buses</u> to perform with diesel buses. This result has the minimum buses needed for required operation.

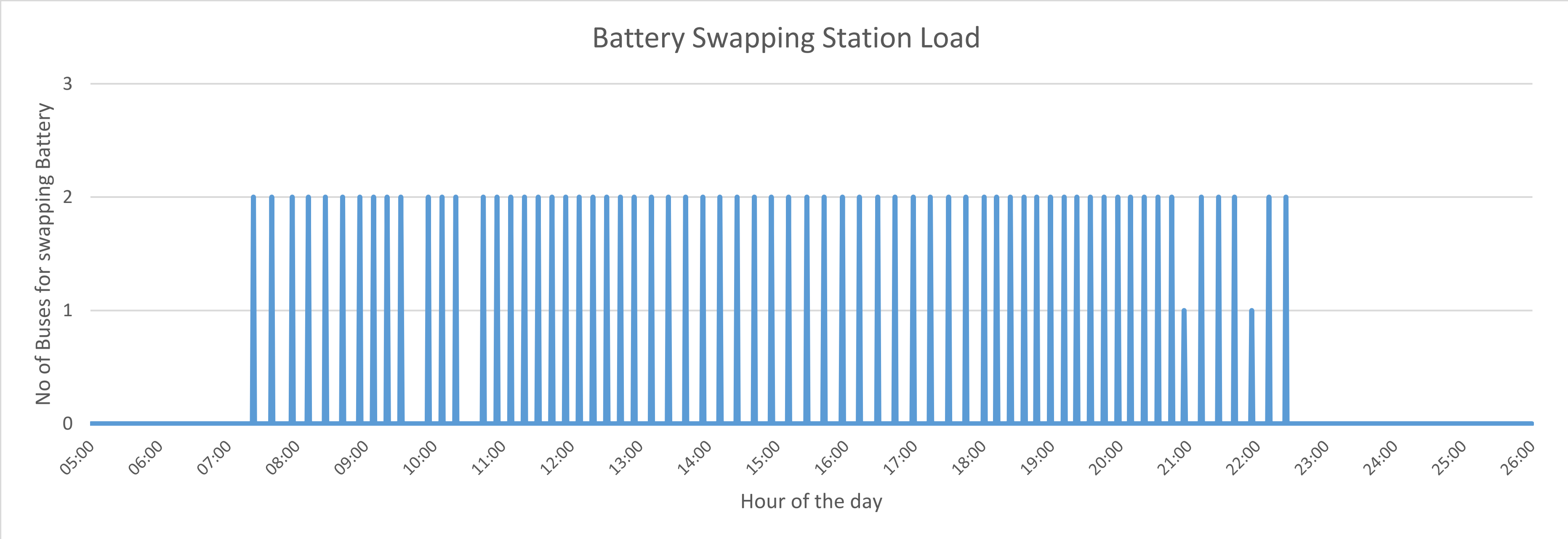
9.3.2.Result:

When the simulation was run under the above configuration. Below result is found to be the best among other solutions generated by simulator.

Number of buses required	16
Total Power	60
Minimum Reserve Power	0
Maximum number of short breaks taken by bus	NA
Charging at Outward Depot	NA
Charging at Return depot	NA
Minimum number of parallel charging ports required at Outward Stop	NA
Minimum number of parallel charging ports required at Return Stop	NA

9.3.2.1. Vehicle Scheduling Plan:





9.3.3.Conclusion:

2 battery swapping robots required as the Line is operated by only 1 depot and have only 1 battery swapping point.

As the depot is not very close to the operating stations, the loss of time is more due to which it required more number of buses to operate the required frequency of services.

9.4. Scenario 3: Battery Swapping at OD Stations

9.4.1. Input:

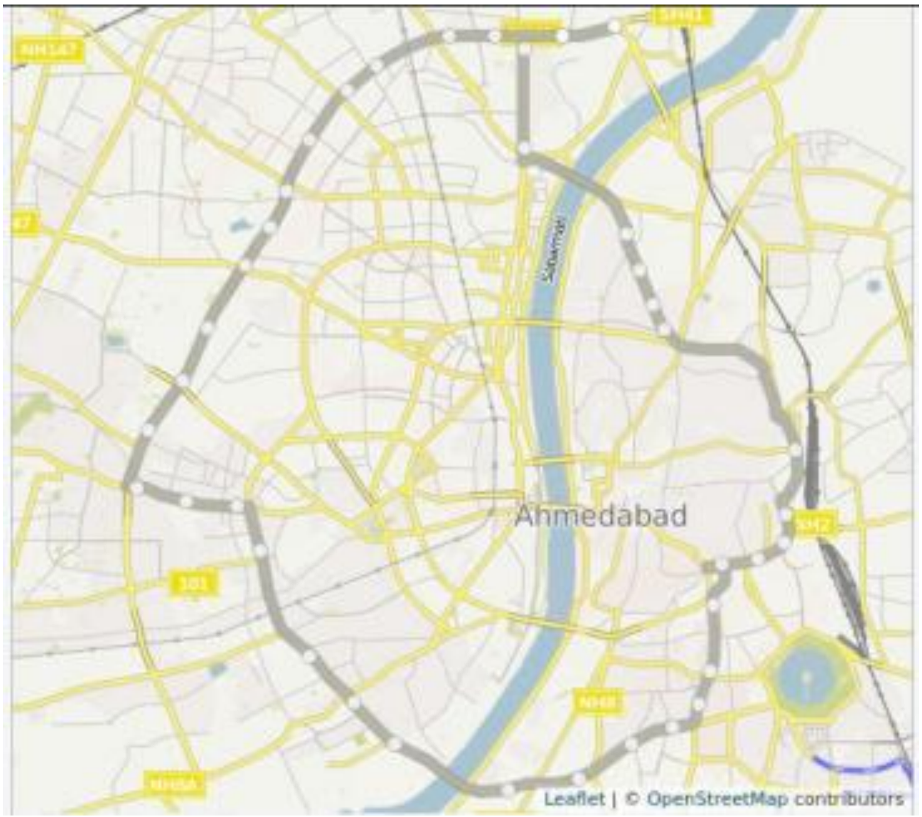


Figure 26 Line 101 Ahmedabad Janmarg Limited, India *Source: Leaflet*

City	Ahmedabad, Gujrat, India
Line No	101 (Circular Line)
From	R.T.O Circle
To	R.T.O Circle
Operation Time	6h30 to 22h30

9.4.1.1. Distances required for calculating power consumption by Traction Motor:

Distance Outward trip (meters) = 26900
Distance Return trip (meters) = 26900
Distance Outward stop to depot dead Run trip (O-D) (meters) = 1576
Distance Depot to Outward stop dead Run trip (D-O) (meters) = 1576
Distance Return stop to depot dead Run trip(R-D) (meters) = 1576
Distance Depot to Return stop dead Run trip (D-R) (meters) = 1576
Distance Outward to Swapping (meters) = 500
Distance to Swapping to Outward (meters) = 500
Distance Return to Swapping (meters) = 500
Distance to Swapping to Return (meters) = 500
Turn Around distance at Outward Stop (meters) = 10
Turn Around distance at Return Stop (meters) = 10

9.4.1.2. Run Time Table:

Hour of Day	Outward (Minutes)	Return (Minutes)
05:00	49	49
06:45	50	50
07:00	53	53
08:00	53	53
09:00	53	53
10:00	52	52
11:00	52	52
12:00	52	52
13:00	52	52
14:00	52	52
15:00	52	52
16:00	52	52
17:00	58	58
18:00	58	58
19:00	55	55
20:00	55	55
21:00	54	54
22:40	52	52
23:00	52	52

9.4.1.3. Dead Run to Depot in minutes

Hour of the Day	Depot to Outward	Depot to Return	Outward to Depot	Return to Depot
For whole day	2	2	2	2

9.4.1.4. Dead Run to Charging Stop in minutes

Hour of the Day	Charging Stop to Outward	Charging Stop to Return	Outward to Charging Stop	Return to Charging Stop
For whole day	2	2	2	2

9.4.1.5. Charging Configuration in KwH/Minute-

Hour Of the Day	Outward Depot	Return Depot	Outward Stop	Return Stop
For whole day	NA	NA	NA	NA

9.4.1.6. Charger's Charging Strategy

%SOC	Outward Depot%	Return Depot%	Outward Stop%	Return Stop%
0	NA	NA	NA	NA
90	NA	NA	NA	NA

*% Drop in charging rate after State of charge reaches

9.4.1.7. Charging & infrastructure Constraints considered as:

Use Charging at Stops during Short Break time = NA
Short Charging Break Minutes Start time = NA
MAX Short Charging/Swapping Break duration = 5
Max number of Buses On short charging break at a given time = 1
Avoid Charging at Terminal (Outward/Return/NA) = NA
Window_1 start when Charging break not to be taken (in min) = NA
Window_1 end when Charging break not to be taken (in min) = NA
Window_2 start when Charging break not to be taken (in min) = NA
Window_2 end when Charging break not to be taken (in min) = NA
Charge During Waiting/Buffer Time (Yes/No) = No
Total Power KwH = 60
Reserve Power KwH = 0
MAX Number of short breaks to be taken by each bus= NA

9.4.1.8. Frequency Requirement Table:

Hour of the Day	Outward	Return
06:00	15	15
08:00	12	12
12:00	15	15
17:00	12	12
20:00	15	15

9.4.1.9. Energy Consumption Parameters:

Commercial:

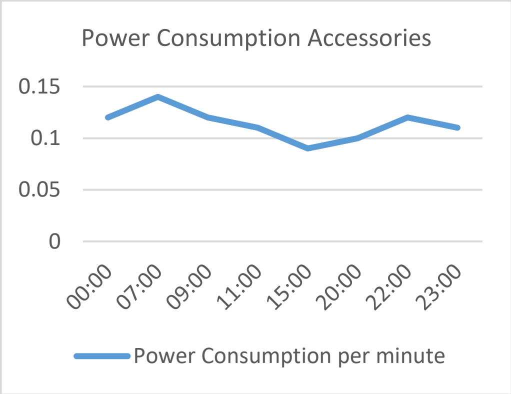
Hour Of the Day	Outward To Return(KwH/Km)	Return To Outward(KwH/Km)
For whole day	1.1	1.1

Dead Run:

Hour Of the Day	Outward To Return (KwH/Km)	Return To Outward(KwH/Km)
For whole day	1	1

9.4.1.10. Accessories (Air Conditioning/ Thermal System/PIS/OBD):

Hour Of the Day	AC power Consumption per minute
00:00	0.12
07:00	0.14
09:00	0.12
11:00	0.11
15:00	0.09
20:00	0.1
22:00	0.12
23:00	0.11



The above table is considered under a specific season climate.

The table represents 00h to 07h, the AC consumption takes 0.12 KwH/Minute and further 7h to 9h takes 0.14 KwH/Minute. The consumption is majorly because of thermal and air-conditioning unit which is dependent on the weather and climate conditions

9.4.1.11. Operation Start and End Time

Direction	Start Time	End Time
Outward	06:30	22:30
Return	06:30	22:30

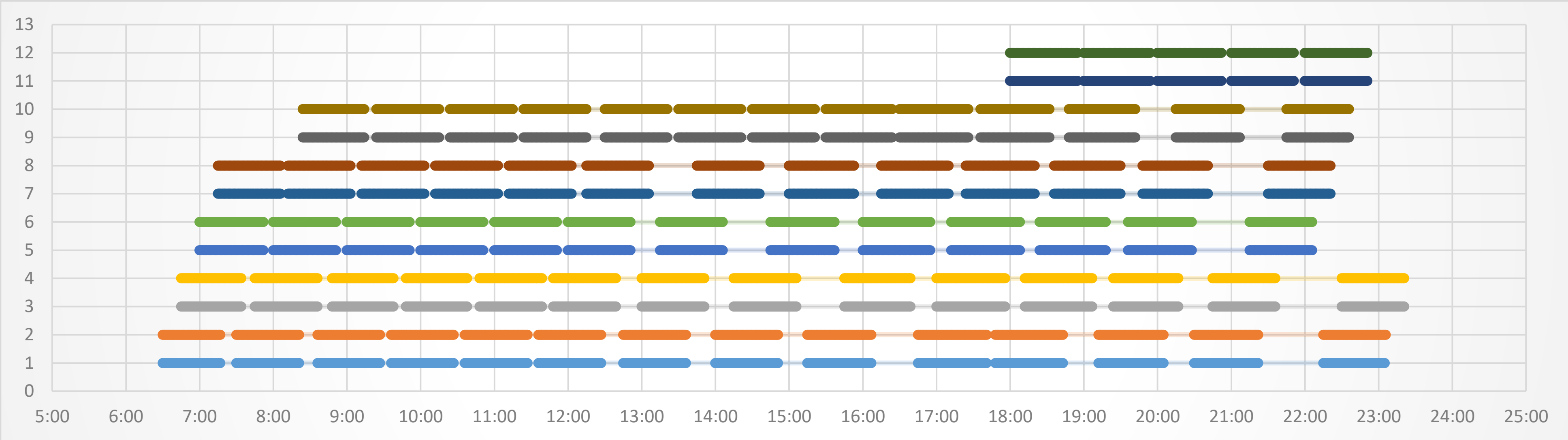
The operation requires <u>10 buses</u> to perform with diesel buses. This result has the minimum buses needed for required operation.

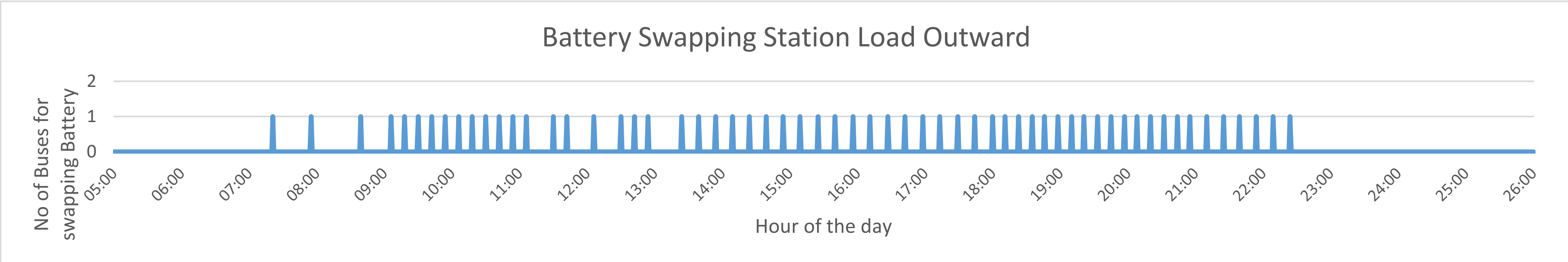
9.4.2.Result:

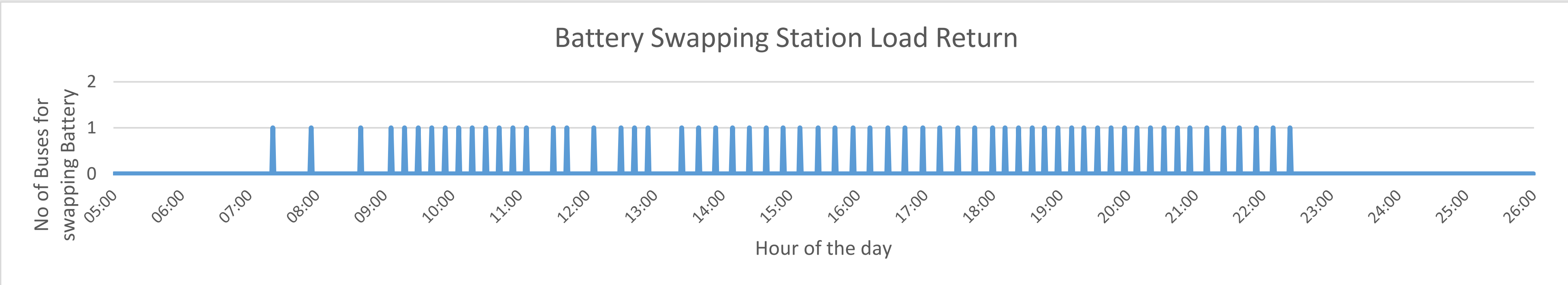
When the simulation was run under the above configuration. Below result is found to be the best among other solutions generated by simulator.

Number of buses required	12
Total Power	60
Minimum Reserve Power	0
Maximum number of short breaks taken by bus	NA
Swapping at Outward Depot	NA
Swapping at Return depot	NA
Swapping at Outward Stop	Yes
Swapping at Return Stop	Yes
Minimum number of parallel Swapping required at Outward Stop	NA
Minimum number of parallel Swapping required at Return Stop	NA

9.4.2.1. Vehicle Sched uling Plan:







9.4.3. Conclusion:

Only 1 battery swapping robot at each end is required. However, in this example, it is considered that the swapping station is 500 metres away from the OD stops.

Minimum 12 buses are required for the operation which can serve the purpose of performing all the trips as given in inputs.

It is to be noted that there is definitely a loss of time for swapping the batteries. The technology is suitable for short distance routes where there is possibility of installing infrastructure for swapping close to the operating stations.

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Detailed Table of content

How to Take In Account the New Constraints of Autonomy and Different Charging Methods to Optimize the Scheduling of Battery Electric Buses

Abstract:

Scheduling vehicles in public transportation is always challenging for planners. This work involves lot of manual interventions and understanding of the ground conditions and becomes a tedious job for the planners to prepare solutions of scheduling route wise. Traditional scheduling for diesel, CNG buses did not had constraints of refuelling during the day of operation. Even if they have to be refuelled, it would be a short time consuming process so had less constraints to schedule. With electric buses, the constraints increases due to non- sufficient power storage. With electric buses stored battery on board, the state of art increases for designing the time table for scheduling due to the constraints of time bound activities such as charging the batteries on board or swapping the batteries, etc. Therefore, it is necessary to consider the electric vehicles for planning and its scheduling constraints in order to cater to new hurdles involved and study how to account these constraints in considerations.

This paper also focuses on considering the different scenarios available in existing practices such as battery swapping technology buses typically used with the slow charging terminals where batteries of the buses will be exchanged during the operation time, every 1-2 hours, depending on the power holding capacity of the batteries and the running time of buses.

It also involves the other type known as fast charging buses where the on board battery unit is typically bigger with larger capacity of storage and can be charged within short time. In this case, the physical location of the battery charging terminals plays an important role in scheduling which will be discussed in this paper.

Keywords:
Electric Bus, Planning and Scheduling, Constraints of electric buses, power consumption, chargers, charging methods, battery.

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