UITP ADVANCING PUBLIC TRANSPORT

REPORT

LARGE SCALE BUS ELECTRIFICATION

NEW CHALLENGES FOR IT SYSTEMS

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INTRODUCTION

Public transport is an indispensable component of the mobility needs of people all over the world. In recent years, the issue of sustainability of the modal split has increasingly come to the fore in political objectives. The most important goals here are to reduce fossil fuel consumption and thus reduce greenhouse gas emissions.

Electric drives will play a key role here. Yet while political and public debate is mainly about promoting the conversion of private cars to electromobility switching the operation of buses to electric drives offers a dramatically higher potential for achieving sustainability goals.

In bus transport in particular, the advantages that public transport inherently brings - reductions in fossil fuel use, exhaust fumes, noise, congestion and land consumption - especially in cities - can be significantly enhanced by electric drives. And while rail transport - which is already largely electrically powered - is becoming increasingly widespread, bus transport will still play a highly important role almost everywhere in the future.

With the introduction of electric vehicles, public transport operators have to establish electric energy management. To do so, existing business processes must be reviewed and modified and – in some cases – new processes will need to be defined. As most steps of public transport planning and operation today are usually managed by IT systems, this also means that IT systems need to be adapted to the changing requirements.

The main aim of this report is to discuss this adaption of IT systems. We will look at the major challenges for operators and address the numerous questions raised, complemented by case studies and field reports.

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ACHIEVING SUSTAINABILITY GOALS WITH ELECTRIC BUSES

While politicians and the public debate is mainly about promoting the conversion of private cars to electromobility, switching the operation of buses to electric drives offers a dramatically higher potential for achieving sustainability goals and reducing carbon emission.

Buses normally have operating cycles of 10 - 18 hours a day, have defined operating schedules (routes, topography, passenger volume and so forth) and undergo constant acceleration and braking events at stops. Thus, the buses are ideal for the use of electric drives due to higher uses and fixed duty cycle, as it can help to replace private car trips, which are used for only 30 minutes daily and face constantly changing operating conditions.

The key challenge is that the driving ranges of battery-electric buses are still considerably shorter than those that use internal combustion engines (ICE). This requires new planning processes that can take into account parameters such as route topography, temperature, shorter blocks and charging management, among many others. In addition, there are technical aspects of battery use, such as capacities, charging cycles and ageing processes.

From the onset of the introduction of electric buses, there has been a lively debate as to whether the range limitation is merely a temporary consideration. In other word, the industry will overcome the battery range issue in a relatively short time by the evolution of (battery) technology, meaning that electric buses will ultimately have the same range and usage profile as current diesel buses. This question has not definitely been answered as yet. As many bus operators have already started the transition from diesel buses to limited-range electric buses, it has become clear that for the next decade at least, electric bus operations will have to deal with limited ranges in planning and operation of the actual bus fleet.

Furthermore: even if the impact of range limitation may vanish in the long run, there is another aspect of electric bus operation that will remain and thus permanently change the planning and execution of bus operation. The charging process is more complex and takes more time than classic refuelling. Thus, aspects like charge point occupation, energy (peak) cost, charging curves and battery health have to be taken into account in strategic (infrastructure) planning, operational planning and the management of electric bus operation.

OVERVIEW OF THIS REPORT

The main goal of this report is to discuss the adaption of IT systems when switching to electric vehicles.

We begin with an overview of the relevant technologies on the vehicle and the infrastructure side, namely electric energy distribution and storage technologies. The aim of this part is not to provide an exhaustive and detailed description of each technical variant, but rather to list the main features and their effects on the energy management process.

The main part of the report will then focus on the requirements that energy management for electric vehicles impose on strategic and operational planning, depot management and operations control. It will discuss the effects on the IT systems for timetable, block and duty planning for vehicle and personnel dispatch, depot management, operations control (ITCS) and charge management in the depot, as well as during line operation.

We close with conclusions and an outlook for future developments on the energy management technology side, as well as in the IT domain.

TECHNOLOGY FRAMEWORK

VEHICLES AND INFRASTRUCTURE AND THE REQUIREMENTS FOR IT SYSTEMS

Unlike conventional buses, electric buses have several technical performance parameters that determine their operational capabilities. As driving range is limited, battery size – in particular the net usable battery capacity – and energy consumption are key for operational efficiency. Energy consumption in turn depends on various parameters; not only on the characteristics of the concrete routes and operations and on driver behaviour but also on the vehicle mass and HVAC[1] intensity of use. Another key parameter is charging power. The higher the net effective charging power, the shorter the recharging time and the greater the availability of the bus.

The heart of every electric vehicle is its battery system, which not only defines its technical characteristics such as range and charging speed but also has a significant influence on cost. At more than one-third of the acquisition costs of an electric bus, the battery system is by far the most expensive component. In the example of large battery buses (12m solo buses and larger), the battery capacities (gross capacity, installed/rated capacity) vary significantly between the vehicles currently available on the market, from 150 kWh to almost 900 kWh.

In the future, even higher battery capacities can be expected. Depending on the specific battery technology, ageing state and charging power, only 50 - 90 % of the installed capacity can be exploited. With the usable battery capacity, range also varies.

1 Heating, ventilation, air conditioning

Energy consumption – for the above-mentioned bus sizes – typically varies between 0.8 - 3.8 kWh/km. Here, the technical influencing factors of the vehicle itself (aside from operational and driver-related factors) are its mass, drivetrain configuration and HVAC configuration.[2]

Recharging time usually is unproductive time[3]. The higher the charging power, the shorter the charging time to reach the required State Of Charge (SOC) level. However, after a certain limit, increasing charging power will not reduce the charging time. Due to the fact that the battery cannot be charged with its maximum power from 0% to 100% SOC, doubling the installed power of the electric vehicle supply equipment (EVSE) does not halve the charging time. However, as the dwell time of the vehicles is limited – not only at terminal stops but also in the depot during the day and sometimes even overnight – high charging power can also make sense in the depot and help reduce peak vehicle requirement (PVR). Most of the current battery systems of electric buses limit the charging power to not much more than 400 kW (approx. 1 C charging rate for battery packs with high energy capacity, which means a one-hour charging time from 0% to 100% SOC).

All of these dependencies, along with the variability of the energy consumption and the driving range, lead to the need to match vehicle and operational characteristics by software in order to predict energy consumption as well as charging behaviour. This is needed when (a) strategically designing the system upfront, as well as for (b) the regular resource planning and monitoring, daily, weekly, monthly or annually. Here, strategically designing the systems means developing a transition concept for the electrification of the bus fleet, including identifying the requirements for the vehicles, charging locations and designing the charging infrastructure (power level, number of chargers). Regular resource planning and monitoring comprises block scheduling, vehicle dispatch (assignment of vehicles to blocks and parking positions with their EVSE), charging management (planning and monitoring of charging phases) and fleet control (ITCS, monitoring vehicles, and their driving range).

Charging management systems for electric buses in public transport differ significantly from those for other use cases, such as freeway service stations and parking garages. The system knows in advance about arrival and departure times of the vehicles and about the amount of energy that must be recharged in this time window. Further, it must initiate preconditioning of the vehicles (for example heating the battery and heating/cooling the passenger cabin of the bus prior to pull-out) and instruct the EVSE (for example via OCPP communications protocol) to provide sufficient power for this purpose.

ENERGY PROCUREMENT

Energy procurement is a key consideration in the process of minimising energy costs. As electricity prices are largely affected by the local ecosystem and regulatory conditions, the aim of this section is to list the topics that most often affect electricity prices (particularly those that are typically negotiated in the electricity supply agreement).

There are several factors that affect electricity prices over which the costumer typically has no control, such as the cost of power generation, government taxes, weather conditions and transmission and distribution line costs.

However, other factors – ones that need to be defined in the electricity supply agreement - have an impact on energy costs and can be mitigated with the correct infrastructure. Although prices and factors vary from country to country (or even within the same country), there are several items that are consistent.

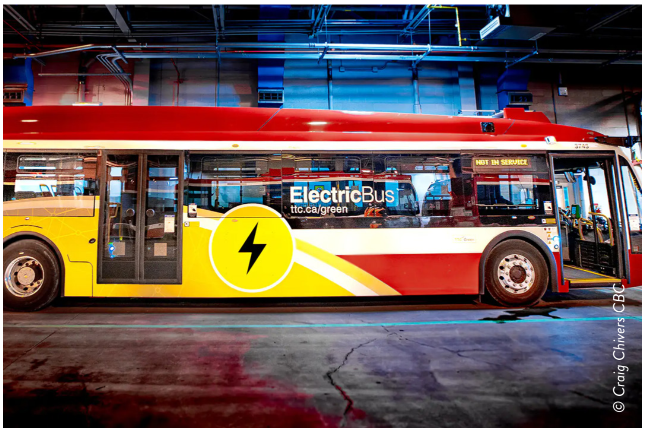
- Type of rate:
  a. Flat or fixed
  b. Time of use-dependant
  c. Amount-dependant
- Peak power demand required:
  a. Without restrictions
  b. With restrictions
- Redundancy (availability of the service):
  a. One (1) single utility feeder
  b. Two (2) redundant utility feeder (N+1)
- Outage restoration:
  a. Priority
  b. Non-priority

2 Please note that the aging state of the battery system resp. the fuel cell system also impact energy consumption as aging reduces efficiency of these components.
3 An exception are trolley hybrid buses, which can also recharge their batteries when driving connected to catenary.

As a general rule, electricity prices are directly related to the power capacity of the utility supply, the time at which it is consumed and the power availability required to the utility supply feeders.

It is possible to reduce dependency on the utility grid by including the necessary elements into the infrastructure, such as Battery Energy Storage Systems (BESS), which enables energy to be stored for later use. A BESS within a depot will provide the following benefits:

1. Reduce load – Peak Shavings
2. Energy arbitrage – battery dispatch during peak periods when energy costs are high
3. Resilience – battery dispatch to provide power during utility grid outage



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Toronto Transit Commission (TTC) is operating a fleet of 1,665 buses, including 60 all-electric buses. TTC procured its electric buses from three manufacturers to carry out the pilot and has floated a tender for 240 electric buses in April 2022.

To manage the charging costs for electric buses, TTC implemented an energy management system to ensure electric buses are fully charged for the route, as well as minimising infrastructure requirements and electricity costs. The agency procured a 'smart charge' system in 2021. This can control the ABB chargers using a common, open communication standard known as Open Charge Point Protocol (OCPP), which is widely supported by many charger vendors. During the testing phase, TTC found some problems in the charger-side implementation of OCPP.

(Source: TTC's Green Bus Program: Final Results of TTC's Head-to-Head electric bus Evaluation)

Another aspect to be considered in the purchase energy equation is the possibility of back-feeding the grid with energy stored in the vehicles (vehicle-to-grid – 'V2G'). V2G goes a step further than regular smart charging. Smart charging enables control of the charging process based on specific aspects, which are normally time-dependent. V2G permits the charger power to also be momentarily pushed back into the grid from the vehicle to balance fluctuations in energy production and consumption. The following key aspects shall be considered with this technology:

- Vehicle charging should be bidirectional, allowing the vehicle battery to receive energy from the grid and also allowing the vehicle battery to supply energy back to the grid.
- Grid operators should allow vehicles back-feeding to the utility network and a compensation programme for vehicle owners and operators should be in place (metering).
- Vehicle owners and operators should be able to set the time of charging and the battery load percentage required, in order to ensure the vehicle is ready for operation when needed.

In balancing all the different items to be considered during energy procurement process, Intelligent Systems for energy procurement play an important role when trying to obtain the optimum mix of energy sources. The Intelligent Systems for energy procurement are based on advanced algorithms and automation technology, which helps to manage energy smarter, achieving fees that are considerably lower than with traditional procedures. Thanks to digital technology and data science, energy price variability can be linked to energy demand flexibility, minimising energy purchase during more expensive periods, and - where possible - managing the discharge of the batteries to the utility grid, thus providing additional revenue streams to offset the cost of energy.

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ENERGY DISTRIBUTION

Although the autonomy and charging speeds of electric vehicles have improved substantially in recent years, it remains a challenge to define the best charging strategy for each service and the related energy distribution system. In this section, the different approaches to electric buses charging strategies and the associated technology are described. Two main different types of charging strategies can be foreseen:

1. Centralised (overnight charging at the depot)
2. Distributed (opportunity charging) along the route
   a. at terminals
   b. at certain stops

The selection will depend on a range of factors, including service route length, proximity of storage facility and vehicle battery autonomy.

Centralised charging of vehicles implies that all vehicles need to be charged at the storage facility (typically overnight). The following should be considered:

1. Large electric substation (power demand) will be required at the storage facility (HV or MV substation required)
2. A robust, centralised wired IT infrastructure based on IP (Internet Protocol) will be deployed next to the grid to connect all systems and to allow sensors to communicate with the management application and control centre. This infrastructure needs MACsec cybersecurity capability to remain cyber safe.
3. Large numbers of charging points will be required at storage facility
4. All charging points will be concentrated at storage facility. No infrastructure needed outside.
5. Long downtime will be required to recharge

On the other hand, the option of distributed charging points along the route, will imply the following:

1. Power demand can be reduced at the storage facility.
2. A wireless IT infrastructure based on IP (Internet Protocol) will be deployed to connect the distributed systems and for sensors to communicate with the management application and control centre. This infrastructure needs MACsec cybersecurity capability to remain safe and may potentially need alternative backup capability. An alternative would be to use the telecom services from a local operator - wired or wireless - with failover backup facility.
3. The amount of charging points at the depot can be reduced; however, some of them should be installed along the route
4. Infrastructure and connections with the utility company will be required along the route (extra space required at stops).
5. The downtime to recharge will be reduced.
6. Charging via pantograph will be possible along the route.

There are several ways of charging an electric bus; these can be divided in two main groups:

Plug-in chargers are typically used at depots, as they are suited for overnight charging. These are the simplest way to charge the buses, however charging speeds are lower than with other charging systems, as the level of current they can dispatch is restricted (typically up to 250A).

Another option for charging electric buses is based on a **pantograph approach**, similar to what has been used in the railway industry for a long time. Pantograph charging solutions can deal with large current loads (typical up to 1000 A), allowing a fast charge of the bus battery system. A pantograph solution is ideal for in-route charging needs, where time is a huge constraint. In addition, this approach permits charging the vehicle without the need for external manpower support. The operation can be done from the driver's seat, which also adds substantial benefits to in-route charging.

Two main types of pantograph solutions can be considered.

- For the first, the electric bus is equipped with the pantograph, and when it's located in the proper position, the driver initiates the charging process by lifting the pantograph up to the charging station contacts. This approach requires each vehicle to be equipped with a pantograph.
- For the second, the pantograph is part of the charging station, and the electric bus is only equipped with connector rails, which minimises the gauge and weight impact in the electric buses. This solution requires a reliable communication between the electric bus and the charging station, to ensure the bus is properly positioned before the pantograph lowers and contacts the connector rails.

Another challenge related to energy distribution and vehicle charging is the standardisation of chargers and the introduction of protocols for interoperability. As discussed previously, bus electrification requires a specific infrastructure, one which eventually will serve different types of vehicles. The standardisation of protocols is required to guarantee the correct communication and data exchange between the different entities in the vehicle charging process.

There are different protocols that provide sufficient flexibility to EV charging stakeholders to allow the required interoperability. One of the most commonly used is the **Open Charge Point Protocol (OCPP)**, which is an application protocol for communication between electric vehicle charging stations and a central management system. The OCPP permits the integration of charging stations from different vendors into a similar internal IT framework. It also provides the freedom to select the most suitable server IT service provider. Other protocols provide complementary features, such as **Open Smart Charging Protocol (OSCP)**, which can be used to communicate real-time predictions of the local electricity grid capacity to the charge point operator.

Electric bus equipped with pantograph

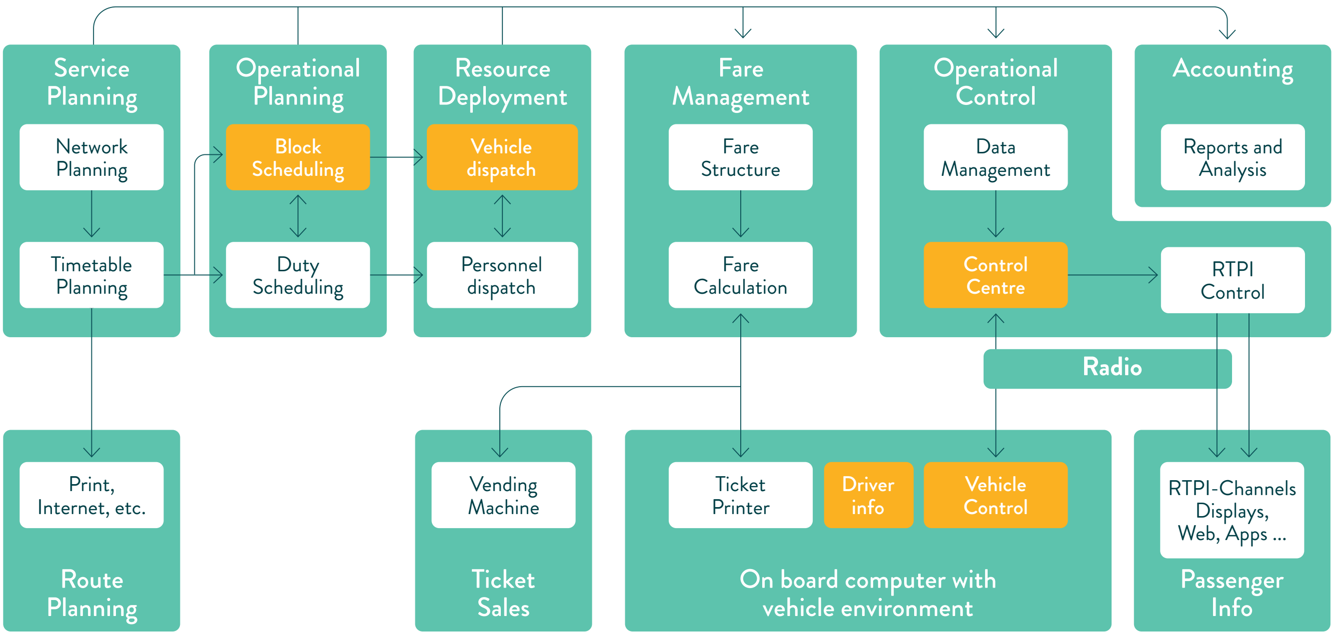
Pantograph is part of the charging station

ECOSYSTEM: ENERGY MANAGEMENT SYSTEMS

OVERVIEW

Figure 1 provides an overview of the typical IT system environment of a Public Transport Operator (PTO).[4]

Figure 1: PTO IT landscape



Each white rectangle represents a major functional module, often equivalent to a hardware and/or software system; green frames group these modules at a higher level. Arrows show the data flows between the modules; arrowheads depict the main data flow direction.

This IT system environment shows the system support for all main business processes of a PTO that are directly related to the core process of transport service. In addition, each PTO will have IT systems to support generic enterprise processes, such as bookkeeping and payroll accounting. These IT systems are not modelled here – normally, they are connected via interfaces to the systems being discussed here, for example to transfer fare revenue data to a general ledger within a standard ERP system such as SAP.

The modules highlighted in organge are those most affected by the introduction of electric buses:

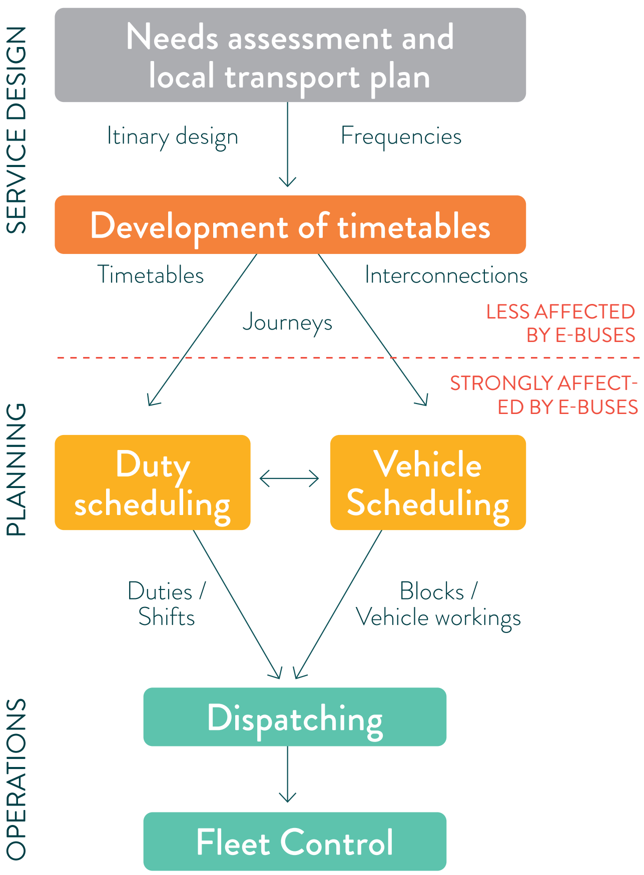
- In **Block Scheduling**, the limited range and possible opportunity charging has to be taken into account to come up with a block plan suitable for a stable operation.
- **Vehicle Dispatch** is closely related to depot management, and thus also to charge management and control, particularly for overnight charging.
- During operation, the **ITCS (intermodal transport control system = control centre + on board computer)** has to control the actual SoC and take action if the remaining predicted range becomes insufficient for the block assigned to a vehicle.

This core part of the energy management system for electric buses is shown in Figure 2 (see next page) and will be discussed in more detail in the following sections.

> *“When it comes to planning electric buses, the number of variables to consider are greatly increased compared with a diesel fleet, particularly for those elements tied to the vehicle.”*

4 This model is taken from the book “IT Systems in Public Transport” by Gero Scholz, dpunkt.verlag, Heidelberg, 2016

Figure 2: Effect of electric buses on processes / IT-Systems



Source: Philipp SINHUBER

However, Figure 1 also shows, that the core modules of the energy management system are connected to several others, which are therefore also affected by the introduction of electric buses:

- Network and timetable planning may need to be adapted for electric bus operation. For opportunity charging at least, the charge points have to be included in the network data and charging times have to be planned.
- Duty scheduling and personnel dispatch have to be adapted to the changed block planning and vehicle dispatch. Where special qualifications for operation and handling of electric buses are needed, this has to be taken into account.
- As the ITCS is also the source for real time passenger information, the effects of corrective actions due to range problems also need to be included in the predictions for passenger information.

SYSTEM DESIGN AND SERVICE PLANNING

Planning in public transport usually starts with designing the network. Once the network is established, specific itineraries and frequencies are added. This way, timetables can be created that will be used for feeding work schedules for drivers and vehicles. These schedules are dispatched to operation for services delivery.

When it comes to planning electric buses, the number of variables to consider are greatly increased compared with a diesel fleet, particularly for those elements tied to the vehicle.

The variables in play when planning for electric buses can be split in two main categories; (a) variables that are constantly present, such as road topology, battery capacity, charge point, speed profiles and stop time. These are the variables with the greatest impact on the element related to the network and infrastructure, and (b) variables that are irregular, such as load on board, weather and road condition. These all have a significant impact on electric bus range capacity. Some of them, for example the weather, can have a huge influence on the required energy to operate the bus service but have no impact on the planning of a network or its infrastructure.

Among all these variables, the ones with the greatest impact on the line network and the infrastructure are mostly the constant variables. These are all key elements that must be handled by a simulation software that emulates the network.

From those simulations, a series of scenarios must be elaborated to find the best option(s). It is vital to run those scenarios and adjust the network based on the results in order to ensure the most efficient use of the electric bus fleet. Failing to follow this procedure may end up requiring additional electric buses to handle flaws.

Aside from having good simulation software to provide different scenarios to help adjust the line network and infrastructure, there are not many actions possible in the system from the line network and infrastructure side. The larger part of the impact on the system from electric buses is from the resource management side.

RESOURCE PLANNING AND DEPOT MANAGEMENT

Resource Management in public transport mainly refers to; (a) the management of vehicles and related infrastructure, and (b) the management of drivers. In both areas, the resource management process usually is divided into two steps, something that is also often reflected in the structure of the IT systems:

- Resource Planning: In the first step - based on the trips defined in the timetable - the sequence of trips to be carried out by a single vehicle (called 'block', 'run' or 'vehicle working') and the sequence of trips or trip portions to be carried out by an individual driver (called 'duty') are computed.

  Blocks and duties are valid for all operating days with the same timetable.

- Dispatching: In the second step, for each specific calendar day, specific vehicles are assigned to specific blocks and specific drivers to specific duties.

  For vehicles, the dispatching process is closely linked to the depot management process, as the availability of vehicles depends heavily on depot activities such as maintenance, washing, fuelling and parking position.

While in general this scheme holds true independent of the drive system of the vehicles, the introduction of battery electric vehicles imposes a series of additional requirements and tasks for the resource management process and thus for the related software systems. This mainly affects the vehicle planning/dispatching and depot management processes, but also has some influence on personnel planning/dispatching.

- In block planning, range limitations have to be taken into account by calculating the energy demand for a certain block. Therefore, detailed information on the predicted energy consumption on each trip, or even each trip portion, is needed.
- In case of opportunity charging, charging times and energy gain at intermediate charging points have to be incorporated into the block planning and energy demand calculation.
- For *fully* electric vehicles, the energy consumption of all on board aggregates (in particular for heating/cooling) can be comparable to the traction energy itself, and thus has to be considered for the total energy demand of a block.
- Given the considerable energy consumption, it is highly desirable to undertake the initial heating/cooling of a vehicle (so-called 'preconditioning') while the vehicle is still connected to the external power supply in the depot. So, based on the vehicle dispatch, the depot management system has to plan, start on time and control the preconditioning process. (See also the section 'Standards and Interfaces'.)
- Between different blocks, each vehicle has to be recharged in the depot to at least the minimum SoC needed to cover the next block it has been assigned to. So, the assignment of vehicles to charge points has to be planned and controlled by the depot management system accordingly.
- Furthermore, for the whole fleet a charge plan has to calculated that takes into account the energy demand of the next assigned block for each vehicle and its current SoC, but also the characteristics of the batteries (lifetime, cell balance and so forth) and of the charging infrastructure (such as maximum charging power per charge point, overall peak power).
- Charge Plans have to be transferred to charge points and/or vehicles for execution. In turn, information on the actual charge execution and resulting SoC has to

be retrieved from the charging infrastructure to update/recalculate range and vehicle assignments accordingly. Thus, the electric depot management and charge management system needs new interfaces to the charging infrastructure. (See also the section 'Standards and Interfaces')

- In duty planning and personnel dispatch, specific skills and qualifications for the handling of electric vehicles and charging infrastructure have to be considered for both drivers and maintenance personnel.

CHARGE MANAGEMENT

Charge Management for electric buses addresses many variables of the system's design, as previously discussed. The purpose of this kind of management is to meet the need of power availability for each vehicle and efficiency of the whole system, considering its scheduled operation. Therefore, charge management should take into account:

- Power supply throughout the day, including electricity prices and electrical grid availability. These factors become critical where there are restrictions or limitations for electricity consumption. Here, planning recharging operations must take into account the time window available.
- The availability of chargers, considering their spatial distribution along the network, their quantity and type (on route and in depot chargers). These circumstances define the [maximum] capacity of charging operations at a given moment, and may act as a constraint if there are more vehicles demanding power at that given moment.
- Scheduled operation and the amount of energy required. When analysed alongside battery specifications and fleet technology, these factors are valuable for estimating the duration of the charge operation itself (usually taking minutes or hours). In this way, it becomes possible to manage the allocation between buses and chargers in line with the SoC and power consumption for the next block operation (for depot chargers) or the current block (for opportunity chargers).

It is important to note that there are many configurations for the equilibrium between chargers' availability and the demand for energy. When the quantity and location of chargers are designed to match the fleet size and distribution, there are no constraints on charging operations. However, there are many contexts where this is not possible, mainly due to spatial limitations or uneconomic investment requirements.

In this situation, a fraction of the fleet will eventually be waiting to recharge and queue management proves to be vital. Proper prioritisation criteria should be studied to optimise the progress of operation and queue management can weight the attendance of vehicles on many parameters. These can include SoC (from most- to least-critical or vice-versa), duration of the out-of-service time window and energy requirement for future operation.

Balancing the network design and the scheduled operation is fundamental to defining efficient charge management strategy. It is also important to support the management by using IT tools, which can be linked to any software designed for service planning. Another application of IT tools is real-time monitoring. In both cases, understanding the SoC of each vehicle and power consumption during its operation is crucial to prevent charging disruptions and to guarantee an optimal level of service.

Another major element to be borne in mind is the capacity of the charge management system to evolve through time, in order to be able to handle upgrades and changes to the batteries and the battery management system (BMS) on board the electric vehicles. One evolution could be a new communication mode with the BMS, in order to handle additional elements and/or dimensions not currently in place. Such a change could be provoked by the introduction of better-performing batteries or other elements - either around or in the bus - to augment overall efficiency. There are also issues related to algorithms in the charge management system that could require significant change if elements around the charging system change (such as the batteries, the BMS or the charger). In order to adjust and perform correctly, the charge management system will need to evolve, and must be designed with this in mind.

OPERATIONS CONTROL

Operations control (supported by the ITCS) for electric buses must deal with challenges that are specific to these vehicles.

1. The limited range of a vehicle that differs on a daily basis, due to conditions that impact energy consumption such as ambient temperature, solar radiation, traffic flow, passenger flow and driver behaviour.
2. The need to recharge, while at the same time adhering to the timetable or the interval, ensuring transfer options for passengers and respecting driver relief and other regulatory requirements concerning the drivers.

In order to support the dispatchers in the control room, the ITCS must permanently evaluate the impact of disruptions and of the dispatch actions to deal with them from the perspective of the SoC and the resulting driving range.

Predictions of SoC, range and runtime need to be calculated repeatedly. For this, a number of data signals must be transmitted from the vehicle to operations control in real time. These must include the SoC and the driving range as well as vital data on the traction battery, the energy consumption of traction and auxiliary consumers, and the sensor data that help characterise the conditions that govern energy usage.

AN ELECTRIC SHUTTLE BUS WITH SOLAR PANELS

The E-Solar City II shuttle bus, from Austrian manufacturer K-Bus, has an average range of 100km. It can be increased to up to 200km, by recuperating energy downhill during journeys, flowing back into the battery. The electric Postbus offers 12 seats and can carry up to 20 people. Another special feature is the three solar panels, with a maximum power of 500 watts, installed on the roof. The energy gathered during the day flows into the auxiliary batteries needed to operate the doors, computer system, air conditioning and heating.

Currently there are three approaches in the market to providing the ITCS with the data signals from the vehicle's battery and traction system:

1. The vehicle manufacturer operates a telematics system that collects all relevant data from the vehicle components in a central service portal. Data for use in ITCS (and/or other related systems) can be retrieved from this portal through dedicated interfaces (web service, application programming interfaces – 'APIs'). Often, these portals provide not only raw data but also processed and enriched information. Usually, manufacturers charge recurring (monthly) fees for the portal operation and usage.
2. Third-party providers offer dedicated systems consisting of:

   (a) a telematics unit installed in the vehicle that retrieves the relevant data from vehicle interfaces (often CAN bus) and,

   (b) a backend system that collects and processes the data. Again, data access for use in ITCS (and/or other related systems) is available via dedicated interfaces (web service, APIs) and a recurring (monthly) fee has to be paid to use the system.
3. The ITCS on-board-unit (OBU) In the vehicle retrieves the relevant data directly from vehicle interfaces (often CAN bus). By using the existing telematics uplink of the ITCS, these data are transferred to the ITCS server. First processing steps of the data may be done in the OBU, further processing takes place in the ITCS server.

So, in approaches (1) and (2), the interface between the ITCS infrastructure and the dedicated battery and traction systems is on the server side, whereas in approach (3), it is located in the vehicle.

As shown in the chapter 'Overview', operations control interconnects with the charging management system. This is of particular importance for opportunity charging, where the decision on whether to charge or not, and how much energy to charge and for how long, is in the hands of the dispatcher in the control room. The ITCS system must support the dispatcher by adapting the charging plan to the circumstances of the day; this may include reassigning vehicles to a different charging point or extending, shortening or even cancelling a charging process.

STANDARDS AND INTERFACES

As set out in the earlier sections, planning and controlling the operations of electric buses introduces new tasks and thus new requirements to the IT landscape of public transport operators. This means that either new components, such as charging infrastructure, have to be integrated or that existing components have to be enhanced, such as introducing SoC and range monitoring in the control centre. Integration means introducing completely new dataflows and/or amending existing dataflows through new data elements and transactions. On the technical level, this requires interface protocols and APIs.

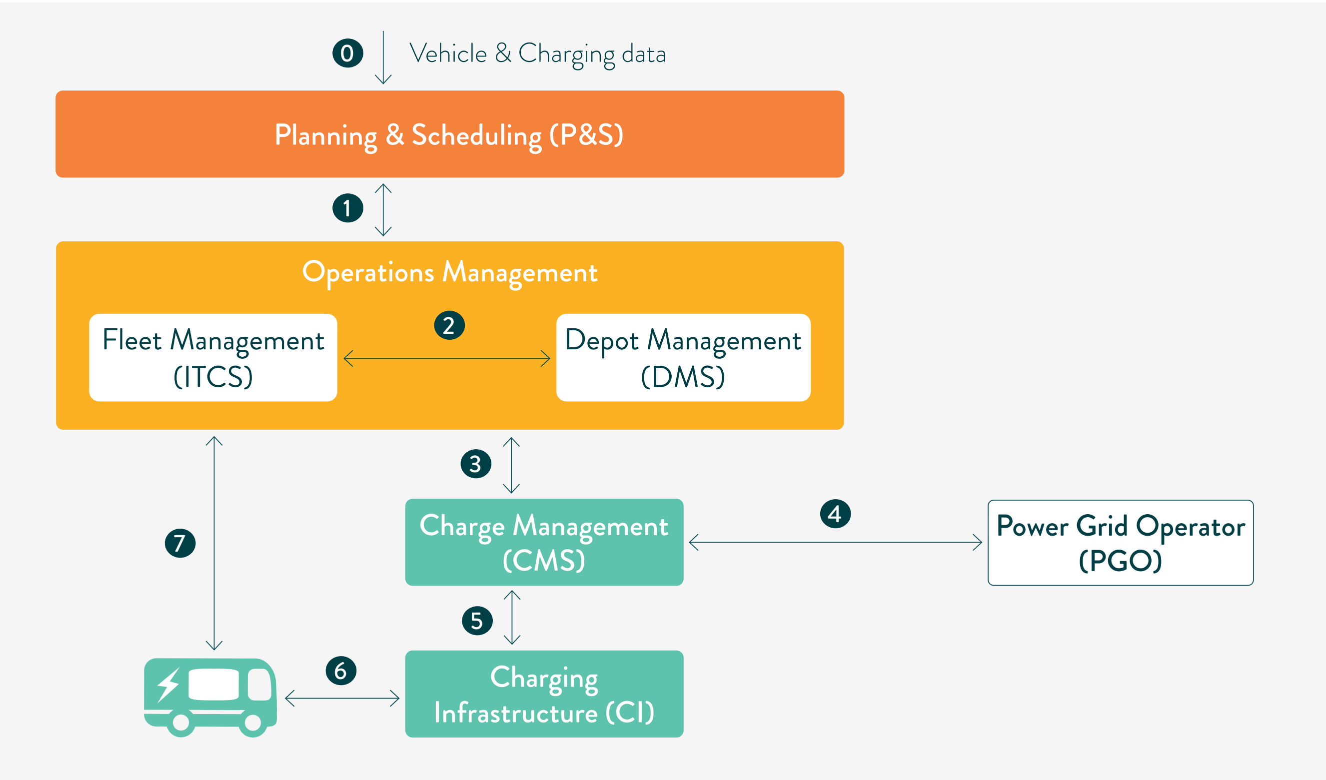
For both practical and economic reasons, it is highly desirable that interfaces are based on *open standards*, rather than being vendor-specific or bespoke project-specific implementations. This paradigm of open standards is recommended for IT architecture design, avoiding vendor lock-in and promoting flexibility and competition. However, it becomes even more important with the rapidly evolving infrastructures for electric bus operations.

- Electric bus fleets will grow quickly, as many operators aim to replace diesel buses completely within the coming years. It is highly unlikely that this will lead to homogeneous vehicle fleets as different bus technologies will be inducted in parallel. At least different technology evolution steps will be in operation in parallel – which in many cases will also mean vehicles by different vendors.
- The same holds true for the charging infrastructure. As well as different generations of a single technology, in many cases different charging concepts will be operating in parallel - depot charging and opportunity charging, plug in, pantograph (up/down) and perhaps even catenary. Again, this mixed infrastructure, probably over time, will include more than one vendor.

Nevertheless, all these differing vehicles and infrastructure elements need to operate as a single and integrated fleet in order to provide high-quality and high-performance transport services. This will only be feasible by using one integrated IT landscape to plan, monitor and control all the various vehicles and infrastructure elements. Therefore, integration by means of *open, standardised interfaces* is essential for maintaining a flexible and sustainable IT landscape for electric bus operation for the coming years and decades.

Figure 3 gives an overview of the relevant systems / modules and the data flows/interfaces involved in the daily operation of electric bus fleets.

Figure 3: Data flows and interfaces



Source: UITP IT Committee

For each interface, the following table lists the basic contents of each data flow and the appliable open standards (if available):

#	Systems		Data	Open Standard(s)
0	(Infrastr.)	P&S	→ Charging data from infra-structure supplier about: Power supply, Charging parameters, …	
1	P&S	ITCS, DMS	→ Line network, timetable, blocks, duties, vehicle dispatch, driver dispatch	VDV452, VDV455, NeTEx
1	P&S	ITCS, DMS	→ Charge plan ← Energy consumption	
2	ITCS	DMS	→ Vehicle logon/off, Arrival prediction, driver messages, vehicle status (inc. SoC) ← Driver instructions	VDV461
3	ITCS, DMS	CMS	→ Charging request ← Charging information	VDV463
4	CMS	PGO	→ Energy demand data ← Energy supply data	IEC-60870-5-104
5	CMS	CI	→ Charging instructions ← Charging status information	OCPP, VDV261
6	CI	Vehicle	←→ Vehicle-to-grid (V2G): charging process control	ISO15118
6	CI	Vehicle	←→ Value-added services (VAS) within V2G, such as preconditioning	VDV261
7	Vehicle	ITCS	→ Vehicle status (inc. SoC) ← Operational instructions	VDV238, VDV435 ITxPT[5]

5 Currently, there is a great deal of work in progress within ITxPT on electric vehicles: Based on requirements from working group RWG02, the technical working group TWG05 for Electric Vehicles is working on the specification covering fleet management, maintenance and safety requirements. The requirements will be based on existing standards such as ITxPT FMStoIP, ITxPT TiGR, CAN J1939 and FMS-Standard description Version 04. Also, with VDV liaison meetings have been conducted to synchronise the standards as much as possible. The activities are behind the original plan, expected the specification in 2nd half of 2022.

Remark: Electrification of vehicle operation is, in general, not specific to the public transport sector; it takes place in the private sector as well. In fact, it is mainly driven by the private sector, simply as consequence of the enormous number of vehicles affected. Thus for many aspects, open standards such as OCPP and ISO15118 are available.[6]

However, certain aspects are specific to the operation of electric vehicles in public transport – basically everything that is related to the operation of a large vehicle fleet according to a predefined and published schedule. Therefore, additional domain specific standards are needed, like NeTEx (published by CEN), ITxPT and VDV recommendations.

CONCLUSIONS AND OUTLOOK

Many of the elements that have been mentioned throughout the current report for planning, operating and charging electric buses all share one major element - an IT system. Modern efficient software required to operate electric buses is made from a collection of components that are now highly connectable to allow for update, data sharing and efficiency. The counterpart of this reality is that they could be more vulnerable to cyber-attack if they are improperly managed, configured and handled.

In the near future, cyber security is one of the elements that could become a major roadblock for adopting electric buses, if not handled properly. Both the manufacturers of buses and charging equipment and their operators concerned need to take responsibility for this. Manufacturers will need to ensure that the software deployed doesn't have any security holes and is developed using well-established security standards, recognised within the software industry. They will also need to develop a distribution chain to transmit software security updates to operators in a rapid, secure, and efficient manner, in order to handle incidents rapidly and safely. At the other end of the chain, the operator will have to ensure that the security updates are rapidly and efficiently deployed on the buses and various charging equipment. By introducing electric buses both manufacturers and operators are entering in a perpetual war against cyber menace.

Another element that will be key in future to the efficient use of electric buses is data exploitation. Electric buses operation will bring a massive amount of data, and operators will need to learn to use all this valuable information correctly in order to optimise energy costs, bus fleet sizes, charging times, energy distribution, battery life and health and the many other aspects of the new reality that comes with introducing electric buses. There might also be a need to merge these data with other external data sources (for example, weather) to understand how well buses perform under certain conditions and validate whether there is any need for adjustments. As for manufacturers, the more data they can collect and analyse on the vehicles, the better they can optimise energy consumption from the bus and the battery efficiency. Similar logic can be applied for the manufacturers of charging equipment. The more data they collect and analyse, the more they can improve the charging cycle. The charging cycle is probably a strong candidate for artificial intelligence application, which could be used to optimise the whole charging process.

All those potential improvements from optimal data exploitation and security updates for handling cyber threats will result in frequent software updates of the equipment, both onboard the buses and the charging equipment. Proper handling of all the distribution and deployment of those updates is a reality that will be omnipresent to correctly operate a fleet of electric buses.

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6 For a more comprehensive discussion see https://ocw.tudelft.nl/wp-content/uploads/I0wfMo-EV_Related_Protocols_v05.pdf.

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