TOWARDS ZERO-EMISSION BUS TRANSPORT

Source: VDL Bus & Coach bv

TNO innovation for life

THE DIESEL ERA COMES TO AN END

Late 2016, London Mayor Sadiq Khan announced to join 11 other major cities, including New York, Los Angeles, Copenhagen, Hamburg and Amsterdam, that have committed to begin moves to phase out their procurement of pure diesel buses by the end of 2020. With the initiative, major cities are working together to challenge bus manufacturers to produce more zero-emission buses and make cleaner bus technology less expensive. Together, these cities have committed to procuring 1,000 zero-emission buses using either electric or hydrogen technology over the next five years. In London, a 51-strong fleet of all-electric buses (BYD), and in Eindhoven, the Netherlands, a 43-strong fleet of all-electric buses (VDL) have started operation by the end of 2016. These initiatives are leading examples of scaling-up from proof of concept to large-scale operation of zero-emission bus transport.

Buses only make up a small share of about 2% in total transport CO_2 emissions. In cities, however, they largely contribute to CO_2 and pollutant emissions (up to 20%) and noise nuisance. While decarbonising transport mostly depends on European regulation, innovation by manufacturers and adoption by users, bus transport is typically an area in which public transport authorities and local governments have powerful instruments to accelerate the transition towards low-carbon transport. Besides, all efforts, both the few big chunks as well as many smaller CO_2 abatement options, are needed to add up to a total transport CO_2 reduction target of 60 to 75% in 2050. By choosing a cleaner and low-carbon bus solution, local governments and decision makers can contribute to the decarbonisation of urban transport and improve air quality in their cities. In the Netherlands, the Green Deal Zero Emission Bus Transport was launched in 2012 and reconfirmed *('Bestuursakkoord')* in 2016 by the National government, public transport authorities and bus transport operators. The Green Deal aims to determine how to affordably realise this transition to zero-emission bus transport, by including zero emissions as a requirement in all new public transport bus concessions to be defined. By 2025, diesel should be completely phased out in the procurement of new buses and, by 2030, the entire Dutch bus fleet of approximately 5,300 buses has to be turned into a zero-emission bus fleet. Currently, about 80% of this bus fleet consists of standard 12m buses and about 20% are articulated 18m buses. Looking at the average concession period and economic lifetime of diesel buses of about 8 years on average in the Netherlands, this transition results in a vehicle investment agenda of more than 1.5 billion euros and, in terms of total cost of ownership (TCO), probably more than 3 billion euros until the year 2025. In every next procurement, an increasing share of zero-emission buses will have to be included in tenders by public transport

"URBAN BUS TRANSPORT SYSTEMS ARE TYPICALLY SUITABLE FOR MIGRATING FIRST TO ZERO EMISSION, BECAUSE OF THE REPETITIVE NATURE OF THE OPERATION AND WELL-KNOWN TRANSPORT REQUIREMENTS"

operators. To achieve a fully zero-emission bus fleet in 2030, it is expected that already between 2021 and 2024 in probably most procurements diesel buses will have been phased out. This is illustrated by the procurement of buses for a new concession period in Eindhoven that started in December 2016, in which about 40% of the new buses were fully electric.

TRENDS, BARRIERS AND OPPORTUNITIES

Currently, more and more bus manufacturers are getting ready to scale up for mass production of battery-electric buses. For example, BYD will begin mass production of zero emission buses for the growing European market in a new Hungarian assembly plant in the first quarter of 2017. In the Netherlands, VDL is showing similar capabilities, being the supplier of the all-electric bus fleet in Eindhoven. Nevertheless, purchasing zero-emission buses is currently about twice as expensive as conventional diesel buses. Local governments and public transport operators need to make sustainable and cost-efficient decisions. When selecting the most ideal zero-emission bus system, decision-makers are faced with different types of questions, such as:

- What are the options available and which energy source/technology to choose for a bus? What are the costs of these options?
- How to secure the reliability of the system? What are the operational (energy) margins and flexibility? How to prepare for disturbances? What happens in winter conditions?
- Which fuels/energy sources require installation of additional infrastructure and what are the associated costs? Where to place and how to dimension charging infrastructure?
- What fueling or charging strategies are fitting the optimized TCO given a certain operational use? Which bus lines to electrify first? How to scale up (roll-out phase)?
- Which synergies are possible with other zero-emission mobility developments within the urban environment, like electric cars, city logistics, or, for example, regarding standardization and planning of charging infrastructure, grid enhancements, combined energy/charging and public transport hubs?
- Which synergies are possible with already existing electric transport within the urban environment (train, metro, tram), for example regarding charging of zero-emission buses?
- How should future tenders be defined and assessed? How should the warrantees of the buses be defined?

Urban bus transport systems are typically suitable for migrating first to zero emission, because of the repetitive nature of the operation and well-known transport requirements. These favourable conditions are, for example, fixed route lengths, fixed schedules, high utilisation rates, less congestion due to designated bus lanes and many stops with regenerative breaking. On the other hand, a zero-emission bus service is also much more complex than for diesel buses. Many new parameters, interactions and trade-offs are introduced that may have a large impact on the TCO and the quality of service of the transport operator. Generally, the system design, the procurement of assets, the operation and its sensitivity to disturbances all get interrelated with electric bus fleets.

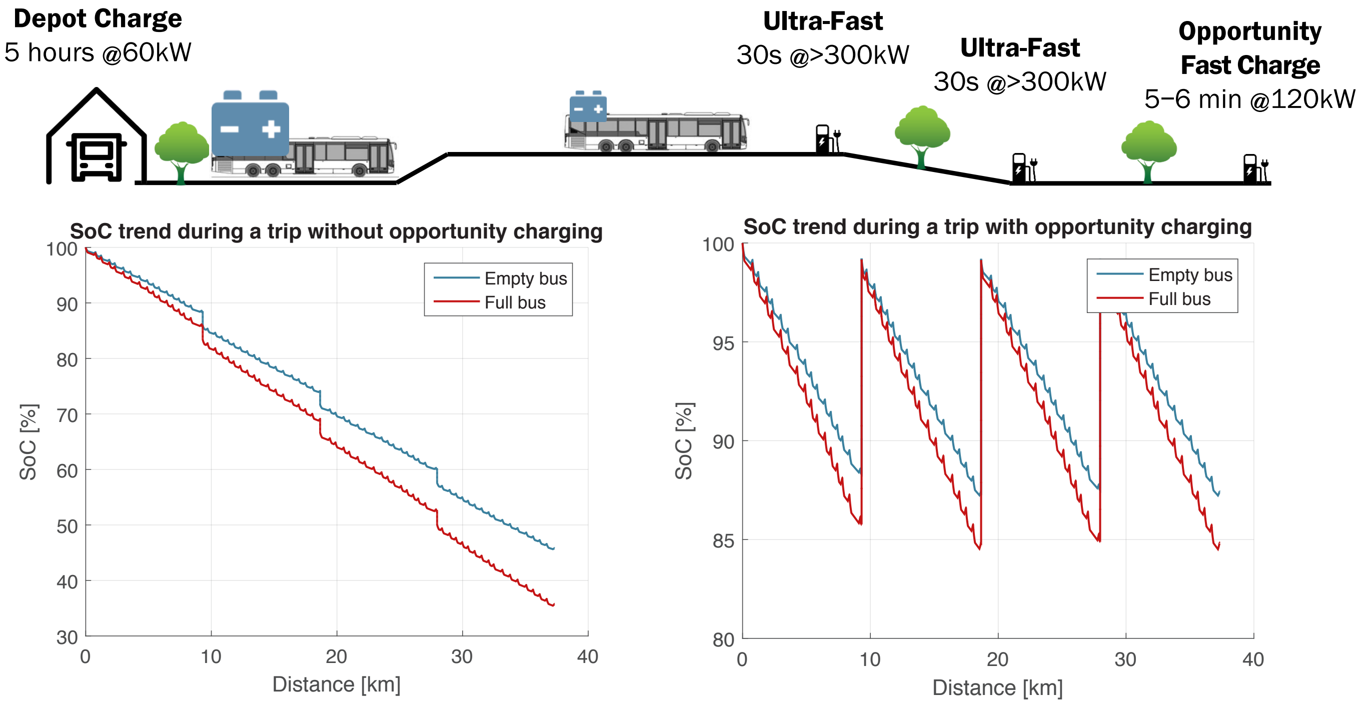

Fig. 1. System design: battery sizes and charging strategies.

Although variations are possible, basically three main types of configurations exist:

1 buses with a large-size battery of about 320 kWh with overnight depot charging;
2 buses with a medium-size battery of about 180 kWh with opportunity charging at the end of lines, and;
3 buses with a small-size battery of about 80 kWh with opportunity charging at many bus stops on the street.

For opportunity charging, for instance, it is important to know whether the timetable and charging power allows enough time for recharging at bus stops to run a reliable service. For depot charging, it is, for example, important to assess the impact on the local power grid. In general, because of lower costs per km than diesel, battery-electric buses become more feasible for bus lines with a high annual mileage. The average annual mileage of buses in the Netherlands is about 75,000 km. Therefore, bus lines with annual mileages well above 100,000 km would be the most promising ones to start with. In addition, other important factors are, amongst others, the technical and economic lifetime of the vehicles, the cost of charging infrastructure and the driver costs.

Most importantly, adopting zero-emission buses does not only concern one-time decision making about purchasing the appropriate vehicle, battery and charging technologies. In addition, it will become a continuous energy management exercise and continuous TCO optimization effort, taking into account the constraints of key performance indicators like the reliability, quality and punctuality of the transport service.

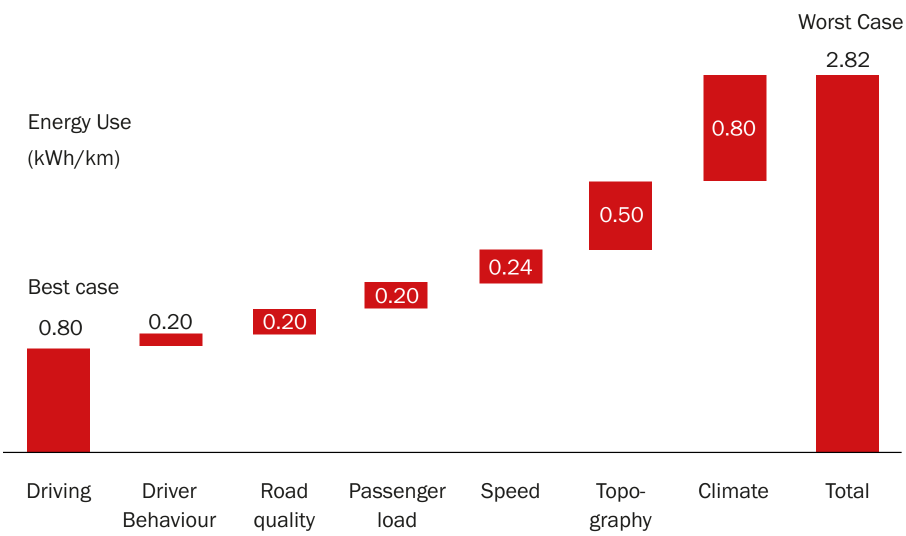

Fig. 2. Operational energy margins of zero-emission buses (source: Volvo).

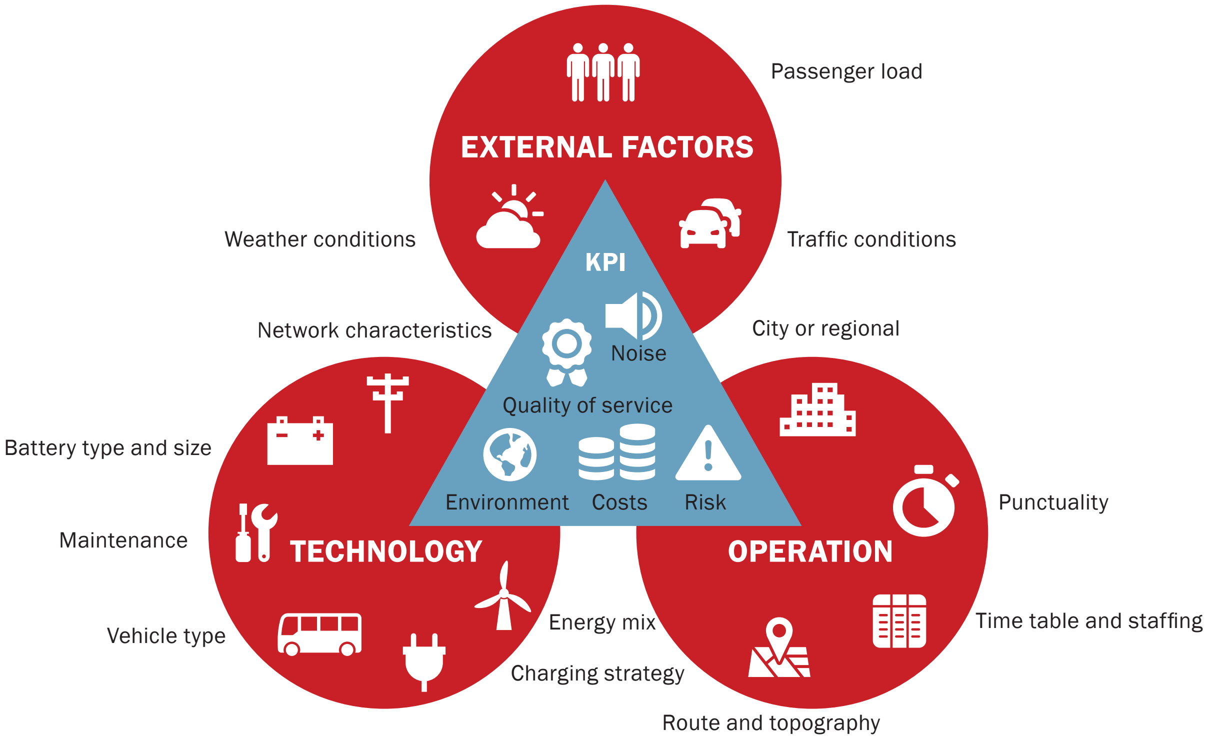

Fig. 3. TNO toolset supporting a systems approach for zero-emission buses.

There is currently a lack of wide-scale experience and a lack of validated and reliable cost and performance data, for instance with respect to the energy consumption in different environments, battery lifetime, depreciation, etc.
A great challenge for the next few years is to narrow down the current levels of uncertainty. Ultimately, this will save extra buses, extra bus drivers and extra costs, making zero-emission bus transport a feasible option for an increasing share of the bus lines. A continuous and real-time operations management approach is also relevant with respect to the future public transport system that is expected to be reacting and adapting in real-time due to varying passenger demand and circumstances, also known as Mobility-as-a-Service (MaaS). Furthermore, transitions towards autonomous vehicles will impact the future TCO; particularly with driver costs removed, and the need for automated charging.

THE WAY FORWARD

Basically, two lines of actions are needed. First, a systems innovation is required, which means innovation and policy measures should not be limited to transport technologies and costs, but should also include governance, procurement, finance, risk sharing, gainsharing and operational issues. Second, public transport operators are expressing a need to develop a strategic roadmap for the next 10 years with the best fitting bus and charging concepts and a need to develop the appropriate tooling to easily and quickly design and optimize a zero-emission bus service and to manage and control the day-to-day operation.

Replacing diesel buses by battery-electric buses does not always completely coincide with the start of a new concession period. Therefore, bus operators need to be able to make cost-effective decisions, both for new tenders as well as during concession periods. There are many trade-offs to be made between the vehicle and battery technology, the service schedule, the line characteristics and operational conditions, and the charging infrastructure and recharging strategies.

TNO developed a toolset that allows to systematically make these trade-offs and search for the optimal match between local characteristics and operational needs and the type of vehicle, battery and charging technologies. The systems approach should address many questions, such as:

1. Which inner-city bus lines to electrify first?
2. What is the passenger demand per line and what is the annual mileage of buses on that line?
3. What does the TCO look like per line?
4. Which line is feasible for depot charging and which one for opportunity charging?
5. What might become feasible in the next few years with improved battery technology, in-motion charging technology, et cetera? What are possibilities in the years after that?

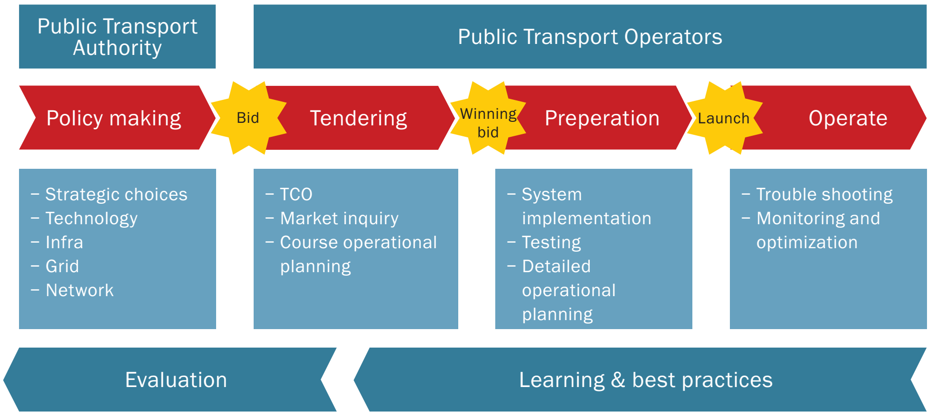

Fig. 4. The life cycle of a bus concession.

"TNO'S TOOLSET ALLOWS TO BENCHMARK PLANNED AND ACTUAL PERFORMANCE AND FLAG SITUATIONS WITH AN INCREASED RISK AT ANY EARLY STAGE. WITH THE RESULTS, TRAFFIC CONTROL CAN TAKE ADEQUATE MEASURES ON TIME"

The transition towards zero-emission bus transport is not only characterized by a technological transition with new products, but especially by a broad impact that spans all parts of a bus concession life cycle, see figure 4. Dealing with the limitations of the new technology and stronger dependencies between the technological and operational choices makes this transition complex.

Key in making the right choices in the transition is to account for all involved parameters. Making the complexity manageable is TNO's key market proposition. By combining our expertise from the fields of vehicle technology, batteries, logistics and (smart-)grids, we are able to capture the relevant relationships for adequate choices from a technological, operational or economic point of view.

This expertise is captured in modelling and simulations that are brought together for application in any of the phases of a concession.

In the policy making phase, TNO offers a holistic modelling approach that captures all relevant aspects in a suitable level of detail that allows decision makers to make trade-offs on a system level. Local situations and ambitions are embedded in the toolset's assessment framework that allows for back-to-back benchmarking of transport solutions.

The tendering follows the policy making phase. The public transport organizations are preparing bids that are economically viable given the local transport requirements and opted transport system. In that process, some very specific and new choices have to be made:

- Which vehicle and charger does best fit the transport system and transport requirements?
- How do I account for the operational limitations and interdependencies of the new technology?

Since the majority of the market has only experience with pilots on a limited scale and usually in a controlled environment, challenges are dealt with in a conservative way. This leads to sub-optimal solutions. It is expected that planned redundancy will be minimized as soon experience is obtained on fleet level in real operation. Until then, TNO's assessment tools can well reflect the limitations of zero-emission transport in the public transport organization's planning processes, such as HASTUS. This will allow for less redundancy in the operation and hence more competitive bids.

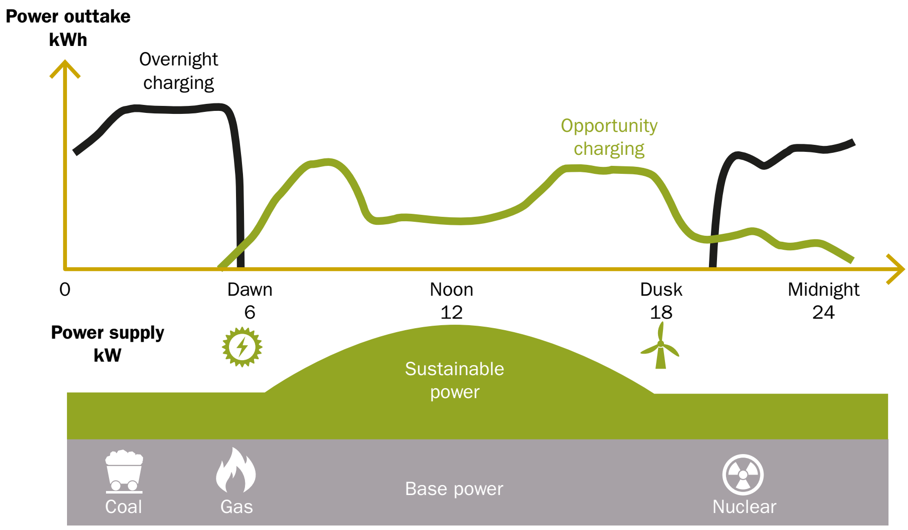

Fig. 5. Sustainable power supply and consumption by zero-emission buses (source: Volvo).

In case a concession is won, the detailed operational and technical preparation will start. Specific vehicle and charger technology has to be selected and integrated into the planned operation (scheduling of drivers, busses and chargers). TNO tools, based on operational simulation, allow the public transport organization to perform a risk analysis for this specific situation. Schedules can be refined to reduce risks upfront.

Once the zero-emission fleet is in service, monitoring is required to capture the experience for future design and planning purposes. On a shorter timescale, monitoring allows to identify unplanned deviations from the schedule. A day of bad weather may, for example, lead to an increased energy consumption from the bus's HVAC system and more passengers in the bus. TNO's toolset allows to benchmark planned and actual performance and flag situations with an increased risk at an early stage. With the results, traffic control can take adequate measures on time.

We foresee that after a couple of years of zero-emission bus transport, operational margins will be reduced because of the increased understanding of zero-emission bus transport experience. Moreover, real-time monitoring will allow to in-situ act on varying situations in the transport demand, congestion, weather conditions and varying prices in the energy market. TNO's fleet-level optimization technology will leverage the potential for TCO, robustness, quality of service or sustainability optimization.

Generally, public transport operators are very well capable of tackling many of these issues themselves. However, due to the complexities, there is a need for support on the specifics of zero-emission transport.

Being currently in the early adoption phase, the lack of experience and validated data results in over-dimensioning: extra electric buses (capital expenses) and extra bus drivers (operational expenses) are needed to assure the electric bus service is as reliable as the diesel bus service it replaces. TNO's toolset addresses the growing need for large numbers of modelling iterations and real-time control of the bus service and energy system.
The toolset aims to provide a simulation modelling framework based on predictive modelling and real-world measurement. It will enable to quickly assess the impact of adjustments in the service schedules in planning software, such as HASTUS, and to develop operating envelopes to improve the system's reliability, to minimize disturbances and to reduce over-dimensioning.

Furthermore, the systems innovation will require new roles and new approaches to how public bus transport is organized.
A modernized concession system that allows for innovation and collaboration is needed. Public transport authorities

Source: VDL Bus & Coach bv

probably have to rethink to what extent they want to decide about a bus solution themselves and to what extent they allow flexibility for the market (operators and manufacturers) to find innovative solutions. This requires new forms of knowledge sharing and partnerships to exploit the best practices from different stakeholders. Early 2017, the Dutch public transport authorities published a market consultation discussing the system innovations mentioned above. The consultation explores several options, the first of which is extending concession periods to 10 or 15 years to increase payback periods for the large upfront investments in battery-electric buses. Another option is to have flexible concession periods in tenders to facilitate competition and to see what is feasible in the market. Organizational innovation could, for example, mean that timetables no longer have to be fixed one year in advance. This would allow adjustments by bus transport operators based on their increasing experience and optimization of the zero-emission bus service.

Finally, local governments and grid operators might also look for societal benefits and opportunities by linking bus transport with local solar power generation, stationary battery energy storage, grid balancing and peak shaving. Societal benefits may well justify co-financing by local government.

“THE TOOLSET AIMS TO PROVIDE A SIMULATION MODELLING FRAMEWORK BASED ON PREDICTIVE MODELLING AND REAL-WORLD MEASUREMENT”

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LIVING ENVIRONMENT

As part of the Living Environment theme, we apply ourselves to devising innovations for vital urban regions. We work together with partners to create solutions for today and opportunities for tomorrow to enhance the viability, accessibility and competitiveness of these urban regions.

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