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Digitalization of electrified logistics systems facilitating scale-up

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Executive Summary

Opportunities and challenges in regional electrified logistics have been demonstrated in the REEL project. Compared to diesel-based truck logistics systems, the small amount of energy stored in the electric trucks, the long time required for charging them, and the limited availability of reasonably priced high electric power, new challenges are introduced for electrified logistics related to keeping track of and governing each truck and its charging strategies. Here it has been concluded that to scale-up the number of electric trucks in many applications there is a need to digitalize and integrate the management and control systems involved. To accomplish that, there is also a need to digitally characterize and map all operations and data flowing between subsystems involved. A method and process for this work has been introduced and data has been identified. Opportunities for using existing and/or creating new standards to enable interoperable subsystems and solutions have been initiated.

Keywords: Heavy Duty electric Vehicles & Buses, smart grid integration and energy management, energy management, advanced control of EVs, standardization

1 Introduction

The need of transition to electrified logistics systems, as mandated by initiatives like those of the European Union, has led to the establishment of a Swedish research and innovation (R&I) project called REEL [1]. There are also some efforts in the US to prepare for electrified logistics [2]. Currently there are gaps in R&I literature regarding electrification of this type [3,4]. This project is aimed at supporting the implementation of electrified logistics based on real-world experimental research and system innovation. A total of 45 Swedish stakeholders, including transport buyers, freight forwarders, haulers, terminal and grid operators, OEMs, national authorities, and academic partners, are participating in the project. System demonstrators have been developed involving over 70 electric heavy-duty trucks, including 18 prototype vehicles. These trucks operate various goods flows, such as food, general cargo, and bulk, enabling the evaluation of both the current benefits and challenges while laying the groundwork for future developments. The demonstrators have faced new challenges in their management and logistics systems when transitioning from diesel trucks to electrified trucks. Consequently, they adopted new approaches, which have been investigated and compiled in the project. Moreover, concepts that can enable scaled-up operations and cope with the complexities will be sought. The REEL project is funded by the participating business partners and the Swedish Vehicle Research and Innovation Program (FFI), which is supported by the Swedish

Innovation Agency, the Swedish Energy Agency, and the Swedish Transport Administration.

Compared to diesel-based truck logistics systems, the logistic system for the electrified trucks is more complex. The short driving range, long charging time, limitations in available power capacity and high truck weight are some of the major challenges contributing to the complexity. Additionally, the overall cost for electrified logistic system operations is often higher than for the corresponding diesel solutions, entailing need of optimization. Optimization of the system for the electrified logistic system will, for many applications, require innovative digitalized automation and control of the interactions between the subsystems, see Fig. 1. The aim of this paper is to describe the investigations made into how digitalization can facilitate the scale-up of the number of trucks in regional electrified logistic systems. First, the functional requirements of different actors have been investigated, that together with partner discussions has led to the creation of a general system architecture for electrified regional logistic systems, focusing on optimization through digitalization and automation. The data flows following this general system architecture and their impacts have been studied. The objectives also include mapping the development of tools and platforms that support system interaction and optimization. Additionally, it involves mapping existing standards and their impact on different interfaces within the subsystems.

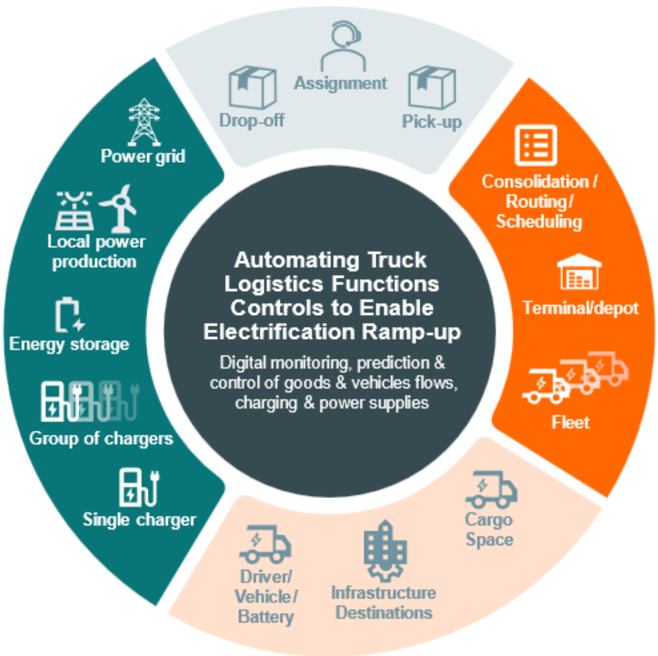

Figure 1: Elements and control in electrified truck operation.

As mentioned above, digitalization of the electrified logistic system can play an important part in ramping up the use of electrified trucks, particularly by improving the total cost of operation. Electrified truck based logistic systems will improve environmental performance by reducing harmful emissions and energy consumption, provided logistic and electric power systems can be operated on fossil free energy, and the complexities introduced can be handled in an effective way [1]. Furthermore, driver acceptance has been studied and found very positive [1].

2 Method

The real multi-stakeholder total system demonstrators that have been planned, built-up, performed, and evaluated in the REEL project, are one base for the innovation and research processes and results reported here. The work strategy includes addressing critical bottle necks to reach the overall objectives, as well as total functional system of systems design and architectural challenges. These functions (with defined variables, parameters, logics) are being processed in a system of subsystems and partly expressed as a time series of planned events e.g. for truck and charger assignments, and with operational control functions between. Often there is a need for data and information exchange between different subsystems to be able to operate these functions.

Demonstrator operations and investments made during the project have been characterized in partner interviews [1]. A trustee process has been developed in which confidential data has been accumulated, filtered and/or aggregated by neutral trustees, preserving partner competitiveness, before being made available for common analyses. Business and environmental consequences of electric compared to diesel solutions have been mapped. Total and subsystem set-ups, and operations, for the different applications, have been described. In meetings, partners and subsystem suppliers presented and discussed their solutions together addressing questions of common interest, e.g. present bottlenecks for ramp-up such as electric power access and policies supporting the transformation. General functionalities, system of subsystem architectures chosen, and available parts of the data and hard interfaces between these subsystems have been described for several cases. Capabilities, efficiencies, cost-benefits, behavioral and policy issues, bottlenecks, etc. have been investigated in partner interviews [1]. Complementary external fact-finding and state-of-the-art studies have also been done. Gaps and plans for scaled up solutions have been identified, e.g. understanding of transport operator strains, and will be pursued in complementary projects.

3 Results and Discussion

The need to scale-up electrified truck logistics has led to a consensus among leading industry players on the importance of digitizing management and control systems. This necessity stems from the complex interactions and constraints involving trucks, charging infrastructure, and power supply capabilities. Data must be generated, stored, and shared to characterize and control these resources, supported by algorithms that provide oversight and control solutions. A step-by-step system approach, with diminishing human involvement in the operational tasks is envisioned.

Fully electrified truck based logistic systems will be much more complex and sensitive to disturbances than diesel-based systems, because of the limited on-board energy storage and longer time for energy transfer compared to diesel operations. Access in the right time to chargers, and energy to acceptable cost, need to be handled to avoid logistic losses. The real-time variability in transport assignments, terminal operations, traffic flows, etc. demands flexibility and needs to be handled for ramped up electric truck operations. Automated real time re-planning services for vehicle routing, charging, and power supply schedules may then be needed, considering predicted times for terminal operations, traffic flows, vehicle cargo space and battery SoC (state of charge), charging power availability, etc. for the trucks. New and existing functions need to be connected to enable real-time decision making, which means that data interfaces and transfer between subsystems are needed.

3.1 Functional Requirements

In systems innovation and development for actual needs and opportunities, functional requirements are a basic starting point. For the type complex system of systems studied here, there will be requirements on different operational systems levels, but their implications are often also on the top operational system level. In Table 1 examples of functional requirements obtained in interviews are listed, and many of these are of that type.

Table 1: Examples of functional requirements

<table>
<tr><th>General</th><th>Charging</th><th>Tools</th></tr>
<tr><td rowspan="4">Aspects regarding energy and power are quite new for most of the transport companies and have required a substantial amount of time and effort to get familiar with.</td><td>Lack of notification when charging fails/ends unexpectedly.</td><td rowspan="3">Together with truck OEMs, simulations have been performed to find out the most feasible routes and truck specifications. In most cases the simulations have been in line with reality, but sometimes misleading.</td></tr>
<tr><td>Need to be able to monitor and evaluate the charging performance.</td></tr>
<tr><td>Integration between charging infrastructure and the truck has failed due to faulty SW or unknown reason.</td></tr>
<tr><td>Would like to evaluate local energy sources and storage to secure power and reduce costs.</td><td>Logistics losses occur in comparison with conventional trucks in the same logistics flow,</td></tr>
</table>

In an upscaled electric scenario it will become more complex due to a lot of additional factors to consider, not least the supply of energy.	Different charging manufacturers offer various specifications for various needs, for example with regards to cable length and corrosive environment.	due to e.g. load weight is lower, additional time for charging. Efficient tools to manage and control will be essential to reduce disadvantages and utilize possibilities to increase efficiency.
	Access to power is limited or very limited at many locations.	
	The monitoring, evaluation and power management is expected to rise in importance.	TMS-system used does not have any support for electrification.
Increased complexity due to additional parameters to consider in planning and control, such as e.g. adding charging and energy supply to the production needs. How to prioritize the available power in a good way will be important.	Availability of energy and power needs to be handled in another way when charging is added.	Mixed fleet lead to several different FMS-systems in parallel. A need for integration between those and the TMS is expected to arise.
	Need to be able to control the charging process.	
	Cannot rely on public charging.	Distribution planning is in some cases too defensive. More extensive data to follow-up is needed to improve the situation.
	Charger availability and uptime will be critical in the upscaled scenario.	
	The available charging infrastructure facilitates new transport routes. There are improvements but the power is too low to avoid logistic losses.	A need for an OEM-neutral modelling tool where routes and charging for electric trucks can be simulated with regards to various aspects such as weather, topography, road conditions, available power, energy prices, battery status, etc.
	Have had problems with charging that was solved by exchanging components in the charger.	
	In an upscaled scenario additional energy supply and storage are considered important.	Drivers are primarily the ones monitoring the vehicles' range in real-time. Transport companies can monitor the electric vehicles via the OEM-specific fleet management system. Some in real time but most on a weekly or monthly basis.
The larger scale-up will happen when the cost becomes more equal. Technology development and the driving range will also be important factors.	We have had problems with charging that has stopped unexpectedly. Seem to happen when some actors make software updates.	
	The electric fleet is currently small, but in an upscaled scenario there will be a need to increase the control of the chargers.	More electric vehicles lead to higher complexity that we need to manage efficiently e.g. when transport assignments need to be rescheduled when delays occur, since additional factors must be considered such as SoC as well as charger and power availability.
	When there is a problem with charging the hard part is to identify where the problem is. Hard to recive support onsite. Need to take the vehicle to the workshop.	
	Manual check is performed during nighttime to ensure that all vehicles are charged.	Need tool support for planning of charging and driver follow-up.
Some driving range anxiety exists among drivers.	An ability to influence power outtake to minimize costs related to energy and power will be crucial.	Tool support for optimized charging is interesting.
	Would like to have notifications to certain company roles related to charging problems. It is important to be able to act fast.	We would like to use historical data to improve prognostics and make better routes and charging decisions.
	Would very much like to have "plug and charge".	
	Hard to build a plan based on public charger when many chargers share the available power.	We will need to investigate how to integrate different OEM fleet management systems to be able to have access to vehicle data (also live) in one place.
	We will lack sufficient power at our terminals in an upscaled scenario.	
	Lack of overall responsibility. Vehicle providers and charge point owners blame each other when there is a problem.	

	Would like to improve communication between the charger and the grid.	Monitoring drivers' and vehicles' performance will be of importance as the driving styles have a huge effect on the vehicle range.

3.2 General System Architecture

The REEL demonstrators have been built up and operated and have resulted in identified challenges and opportunities regarding how to operate electrified trucks in smaller fleets related to the functional requirements. Some of them seem to be crucial for a future ramped-up operation with large numbers of electrical trucks, for instance, variability in driving patterns due to variations in traffic and operational times, limitations in access to high power and reasonably priced energy, long time for charging, relatively short driving ranges, extra truck weight, and high vehicle costs. Detailed requests were also put forward, e.g. power suppliers asked for predictions of coming charge loads. All these factors need to be considered when developing working architectures, processes, soft and hardware concepts for the complex system of systems needed. New suppliers aiming to introduce software that can close the data gaps were also interviewed. All inputs were successively compiled into a block diagram, see Fig. 2. Both operational hard and software subsystems were considered, but the focus was on management and control and necessary data interactions typically between real-time and weekly, with an objective of creating high efficiency and cost effectiveness with existing adaptable hardware. Compared to diesel operation there are more hard- and software subsystems.

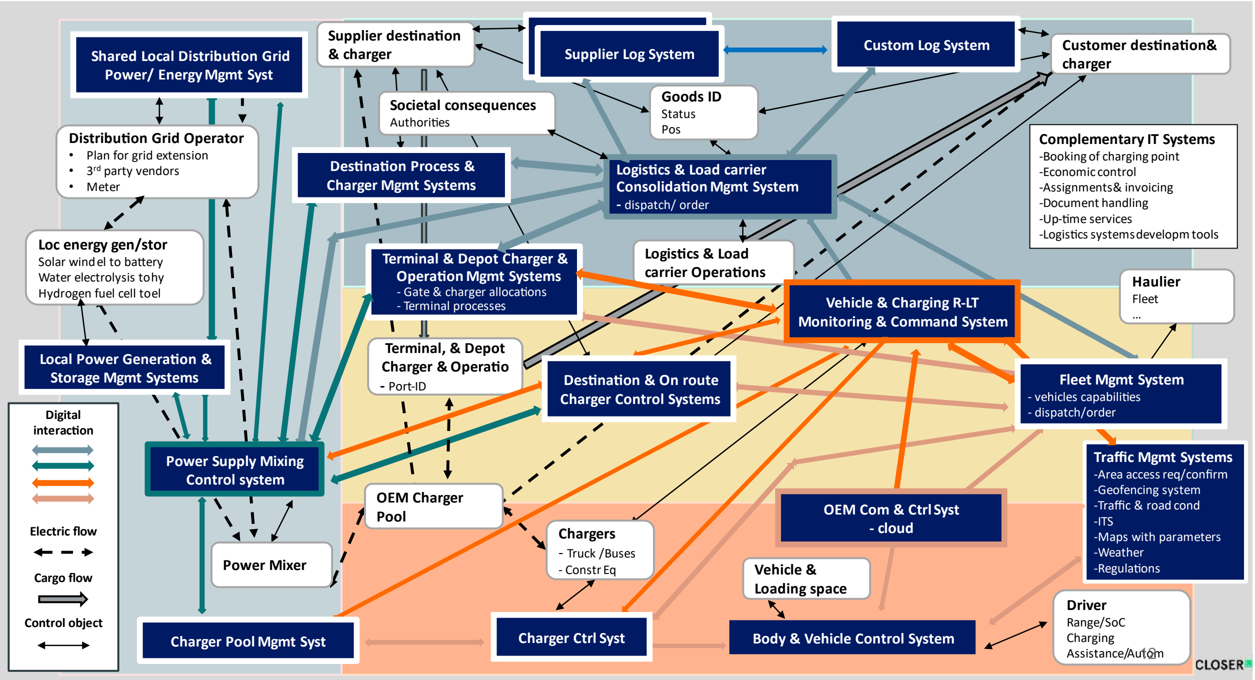

Figure 2: System of systems for management & control with typical interactions from real-time to weekly.

In the following step a more structured system architecture was developed with five subsystem domains: *Supply Chain Management and Logistics; Transport & Fleet Management; Driver and Vehicle Control; Energy & Charge management;* and *Surroundings*; see Fig. 3. These subsystems include different functions that need to interact with each other. A new system module needed for the development of a totally integrated real-time control system has been introduced, *Dynamic Dispatch based on Digital Real-Time Data and Automated control*. This module is overreaching and interacts with all subsystems in the electrified logistics system. This includes automation of larger number of administrative actions necessary for right dispatch based on performance and environmental perspectives in electrified operation. However, automation is not only restricted to the new system module but also exists in the different subsystems. The real time dynamic dispatch considering the actual status of essential variables can select the right solutions from performance and environment perspectives.

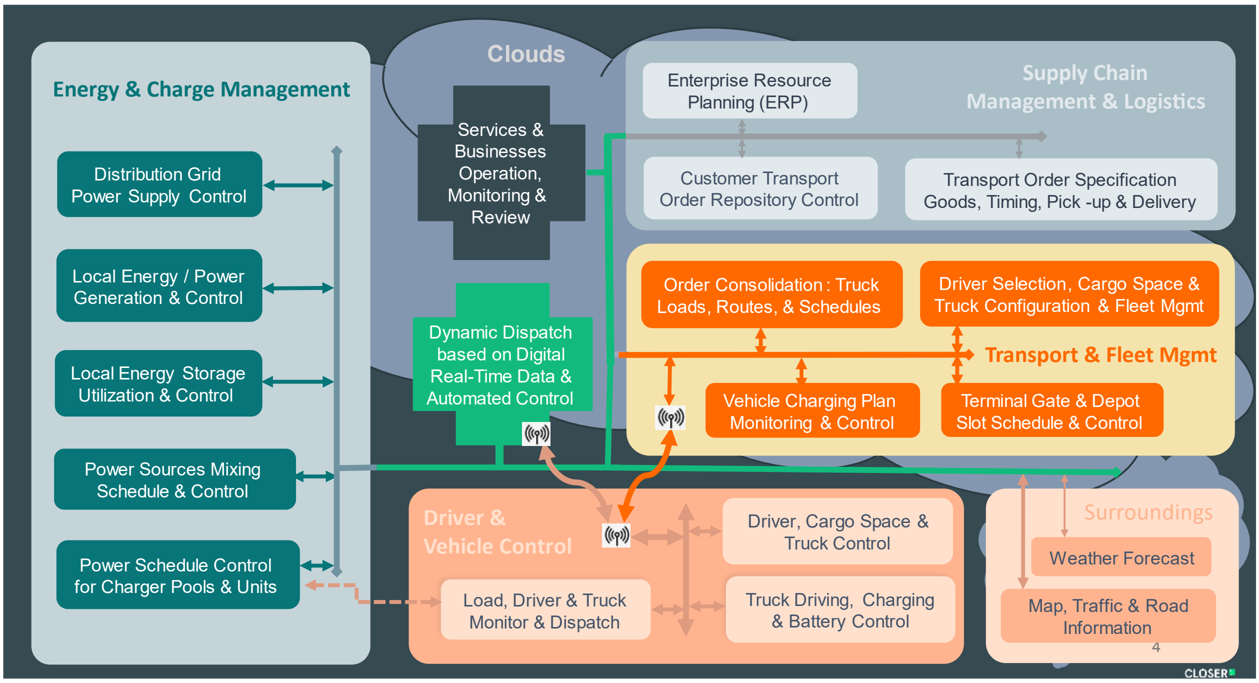

Figure 3: General real-time control architecture for automated electrified logistics systems.

There is another new system module, *Services & Businesses Operation, Monitoring & Review*, which is discussed, but not to our knowledge realized, for non-real time monitoring and control of services, business, etc. This module is overarching and collects performance data from all subsystems to be able to analyze the different KPIs (Key Performance Indicators) in the system, like efficiency, cost- benefits, acceptance, etc.

3.3 Data Flows

To implement a more digitalized system, there is a need for new types of data flows between the different subsystems in the total electrified logistic system, compared to the diesel truck system. In Fig. 4 examples of data flows between the different management and control subsystems are displayed. This data will enable advanced control of certain subsystems but also facilitate management of different systems. The new system module, *Dynamic Dispatch based on Digital Real-Time Data and Automated control*, will facilitate the handling of late real-time changes in data compared to what was used in the initial operational planning. Late transport requests making it possible to fill up empty truck cargo space, and disturbances in traffic flows, are examples behind these changes. They can e.g. alter arrival times to terminals, destinations, and chargers which can influence other flows, and the amount of energy that needs to be charged. An overall assessment is required before new dispatch data is communicated. Automated support for this work is needed. The control systems will be more adaptable to the real-world environment. However, the non-real time data are still important for making the base planning of the predicted operations.

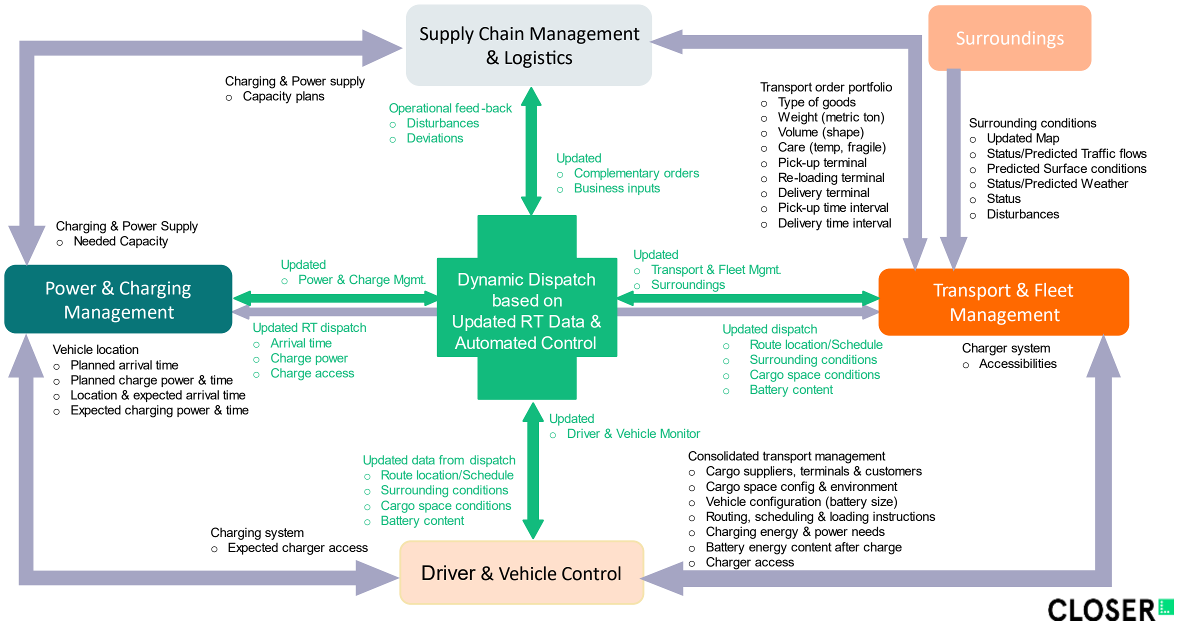

Figure 4: Examples of data flows between the different subsystems in electrified logistic systems

Data is not only important for the function of the logistic system, but also for the development and evaluation of technology and different types of descriptive and computational modules. Therefore, assembling and filtering this type of data by a trustee entity are highly beneficial. Besides economic data, there is an interest in aspects such as battery lifetime in relation to battery type and capacity, and electric power flows associated with logistic losses.

3.4 Tools & Platforms

A major part of the digitalization of the electrification logistic system is the platforms and tools that can be used. Table 2 provides an overview of the studied platforms and tools, categorized based on their core functions. These functions relate to the subsystems described above in Fig. 3. It can be observed that each tool or platform primarily focuses on one or two subsystems, with occasional functionalities extending to other subsystems. However, the various tools are dispersed across different subsystems. Some of the platforms and tools can complement each other and, together, cover a significant portion of the system. The platforms and tools discussed here have, in varied capacity, been involved in the REEL project. Therefore, this is not a comprehensive market analysis but rather a tools and platforms reflection of insights gained through the project's activities. There are discussions on suitable development tools for this type of complex system of systems. For a limited part of the overall system there is e.g. some work on digital twins that are types of simulation models [5, 6].

Table 2: Functional overview of studied

Functions represented in tools/platforms	Panion	Vialumina	BEV_r	Monta	Virta	ChargeNode	Kempower	Vourity	Stella Futura	ABB optimax
Fleet & Vehicle Mgmt	x	x	x							
Telematics & Vehicle Data Integration	x	x	x							
Fleet electrification planning	x	x								
Infrastructure analysis	x	x								
V2X/V2G Integration		x			x					x
Smart Charging & Demand Response				x	x	x	x			x
Load Balancing & Dynamic Power Distribution						x	x			x
Virtual power plants (VPP) & Grid services									x	x
Cost Mgmt	x	x		x	x					x
Energy Mgmt									x	x
Charging infrastructure Design, Deployme nt & Site planning				x	x	x	x			
Charge network mgmt				x	x	x	x			

Charging Session Monitoring & Diagnostics				x	x	x	x			
Route planning	x	x	x							
Payment systems				x	x			x		
API & System integration	x	x	x	x	x		x			
Energy storage system									x	x
Renewable energy integration									x	x

When digitalizing and connecting different subsystems that make out a digitalized electrified logistics system, there is a need to keep in mind that for each subsystem introduced in the system, risks that might worsen the overall performance of the system are incurred. Digitalized systems-integrations are also prone to risks and cyber threats. Therefore, a crucial innovative issue moving forward will be on how to address these issues in an adequate way, without compromising functionality. New platforms and/or tools may be needed.

3.5 Standards

There is sometimes an ambition to build a combination of proprietary and non-proprietary systems so that different subsystems can be delivered in competition. This leads to the need for developing standardized data interfaces between the subsystems. For some of the interfaces in the electrified logistics systems standards exist, see Fig. 5. However, many interfaces remain unstandardized. In Fig. 5, five categories representing different areas of an electrified logistics system are listed, along with the standards that impact them. It can be observed that some standards affect multiple categories, while others are more specific. Additionally, there are differences in how adopted the different standards are, some of the standards listed are broadly implemented and recommended as industry standards. For instance, OpenADR which is recommended by the Swedish industry association Energiföretagen [7]. However, for international interoperability a corresponding official and general industry recommendation would be suitable on an EU level [8]. International standard committees IEC and their national corresponding units serve as an invaluable infrastructure for continued standardization work. In some cases, standards exist, but there is a lack of consensus on how to apply them and the communication formats to be used. Congestion steering and calling for demand response flexibility is such an area. There is a clear need for a common market platform for demand response flexibility to facilitate for all actors involved.

One important thing to keep in mind in the context of standardization is that a standard does not guarantee full harmonization [8]. It is also necessary to specify how a standard should be implemented. Currently, there is room for different “dialects”, which can lead to communication issues, even if both subsystems meet the formal requirements of the standard. To come up with a common detailed picture and guidelines for how a standard needs to be implemented, it is essential to overcome the biases of each involved actor, who may prefer the path of least resistance. Nonetheless, this kind of meta layer for standards will possibly be increasingly important as the complexity of the interacting subsystems increases. A similar need is identified for a standardized approach to utilizing standards, both in terms of which standards to combine and how to apply them in detail. For example, in the context of a common platform for demand-response, it is necessary to specify how requests should be made (timing, location), and the format for specifying power (kWh or MWh), among other details.

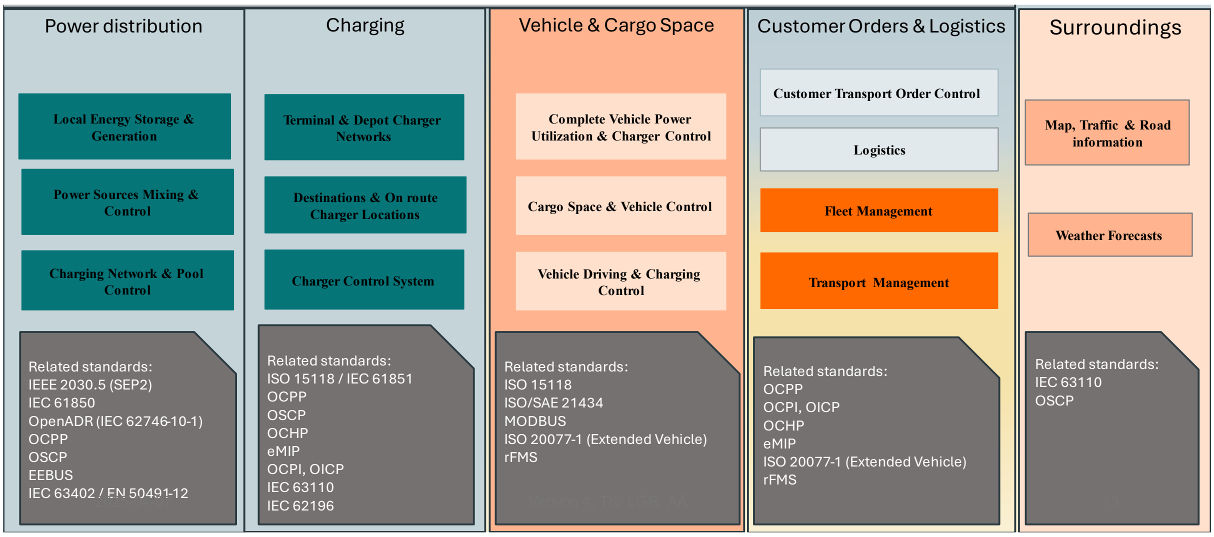

Figure 5: Subsystem related interface standards

4 Conclusions

The demonstrators for different types of applications have shown that an integrated system of systems control is needed for scale-up of electrified logistic applications with a variability in transport services, and will require logistics, transport, terminal, vehicle, driver, charger and electric power supply, digitalized data interactions. Moreover, the management of the integrated system will require a lot of manual work, which needs to be automated when possible. There may also be a need to adapt operational plans e.g. due to complementary transport orders and/or flow disturbances, which means that real-time control alterations need to be introduced.

There is a need to monitor overall system efficiency and economic outcome, which require monitoring, compilation and filtration of commercial data, by a trustee to keep the data confidential. There exist some programs and tools for electrified logistics systems that cover various parts of the system and complement each other in some ways. However, there is still a need for new and continued development of software tools to realize control functions needed to enable the scaling up of electrified logistics systems.

Continued development and harmonization of standards are vital for scaling up electrified logistics systems, ensuring efficiency, interoperability, and sustainability. Some of these systems will probably be built up as a combination of integrated proprietary and non-proprietary subsystems. At least for the first type of solutions standardized interfaces are needed. While some standards exist, many interfaces are today unstandardized, leading to inconsistencies. There is a need for international interoperability and official recommendations at EU level.

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Presenter Biography

Ted Kruse joined Lindholmen Science Park (LSP) in 2020 as Senior Project Manager with specific focus on innovation projects in the areas of digitalization, electrification and intelligent transport systems. Before joining LSP Ted worked 29 years for AB Volvo, as software engineer, project manager and the last 20 years in various manager positions responsible for technology development and advanced engineering in the areas of embedded software, electronics and data communication. Ted holds a M.Sc. in Computer Science and Engineering from Chalmers University of Technology.

Lars-Göran Rosengren joined Lindholmen Science Park (LSP) 2014 in a role responsible for new multi-lateral project developments involving industrial and societal transport system providers, operators, and academics. Pioneering system demonstrators based on logistics, public transport, geofencing, user experience, digitalization & electrification for community building have been initiated and operated. Before joining LSP Lars-Göran worked for AB Volvo in 39 years, as President for Volvo Technology in 21 years, and was responsible for setting up and operating R&I projects in engine combustion, catalysis, electric drives, electronics, human system integration, intelligent transport systems. He has also worked at Jet Propulsion Laboratory and Saab Robot & Avionics System. He holds a PhD in Electrical Engineering from Chalmers University of Technology.

Anna Åkerman joined Lindholmen Science Park (LSP) in 2023 in the role of Project Manager and Innovation Lead contributing to the system development of both the European railway sector and the electrification of heavy-duty road transportation. Anna holds a M.Sc. in Sociotechnical Systems Engineering from Uppsala University focused on power system development. Before joining LSP Anna spent eight years at the infrastructure consultancy firm AFRY as a Project Manager for large Swedish railway projects. Her responsibilities included investigating the need to expand the Railway power supply system from first thought until new power stations and grids was ready to start being built.

Johanna Odbratt joined Lindholmen Science Park (LSP), a non-economic organization hosting several R&I-programs e.g., mobility, in 2025 in the role of Innovation Lead and Project Manager, coordinating and participating in several complex innovation projects involving multiple stakeholders from the industry, academia, and public sector, with electrification of heavy-duty vehicles being the common theme. Johanna holds a M.Sc. in Mechanical Engineering.