Proposed RP [TBA] **VMRS [TBA]**

DRAFT: CHARGE CYCLE OPTIMIZATION AND ENERGY MANGEMENT GUIDELINES FOR BATTERY ELECTIC VEHICLES

PREFACE

The following Recommended Practice is subject to the Disclaimer at the front of TMC's Recommended Engineering Practices Manual. Users are urged to read the Disclaimer before considering adoption of any portion of this Recommended Practice.

PURPOSE AND SCOPE

The purpose of this Recommended Practice (RP) is to give fleets a defined process to select the optimal battery electric vehicle (BEV) battery pack size, charger/charging speed, and to maximize the available runtime with that vehicle. Over spec'ing the vehicle and/or charger can make the vehicle, along with the required supporting charger/infrastructure, more expensive than necessary therefore slowing the transition and financial return of electric vehicles. Further, not adequately planning for infrastructure demands and constraints can lead to delayed rollouts and expensive electricity demand charges.

Assets and infrastructures in scope for this RP are yard tractors, straight trucks, over-the-road tractors (day cabs – depot charging only), buses/transit vehicles, and other vehicles that are domiciled at a single site. Charging approaches include on-site/depot charging, performed both as "opportunity charging" and off-shift or overnight charging.

Assets, infrastructures, and variables that are out of scope for this RP are: Trailers, Transport Refrigeration Units (TRUs), terminal to terminal vehicles, on-road and public charging, on-site electricity storage strategies, microgrids, and vehicle-to-grid setups.

INTRODUCTION

As the transportation industry shifts and begins to adopt BEV technology as part of its operations, there are many variables for fleets to consider. While this technology rapidly evolves with options catered to different customer needs and business segments, it is important for fleets to have a framework upfront to select the optimal battery pack size, charger/charging speed, and to maximize the available runtime with their assets.

This RP serves as guidelines for fleets to consider when procuring these assets. Variables for consideration include: 1. Vehicle Acquisition Plan, 2. Battery Pack Options, 3. Energy Consumption, 4. Duty Cycle / Available Charge Time, 5. Charging Requirements, 6. Electricity Rates, 7. Site Electrical Capacity, 8. Discuss, document, and prioritize goals, and finally 9. evaluating scenarios and leveraging data for decision-making.

1. VEHICLE ACQUISITION PLAN

When creating a vehicle acquisition plan, the following variables (at a minimum) should be considered:

A. Define “acquired” for your operation. Is this the date of purchase, delivery, or deployment?
B. Understand build and delivery schedules for each truck: Once the PO is signed, how long until delivery and deployment?
    a. If using grant funds, understand grant process details and allow adequate time for grant awarding, contracting, then vehicle ordering, acquisition, and deployment
C. Capture desired vehicle types and acquisition timing
D. Consider lead times for backlogged production queues
E. If using grant funds, understand process details and order delays

	Desired Acquisition Timing						
	< 3 months	**3-6 months**	**6-12 months**	**12-18 months**	**18-24 months**	**24-30 months**	**24-36 months**
Yard Truck							
Straight Truck							
OTR Truck							
Other							

Figure 1: Vehicle Acquisition Planning Table

2. BATTERY PACK OPTIONS

For each vehicle type within your vehicle acquisition plan, it is critical to select and right-size your BEV solution to determine the most cost-effective option that can handle your duty cycle, both current and projected. The following variables (at a minimum) should be considered:

A. What battery pack size options are available for each truck type/OEM?
B. What is the cost difference?

	Battery Pack Options				**Cost Difference**
	Small		**Large**		**Large Pack - Small Pack ($)**
	Size (kWh)	**Cost ($)**	**Size (kWh)**	**Cost ($)**	
Yard Truck					
Straight Truck					
OTR Truck					
Other					

Figure 2: Battery Pack Options Planning Table

3. ESTIMATING EFFICIENCY AND ENERGY CONSUMPTION

When it comes to estimating BEV efficiency and energy consumption, the following variables (at a minimum) should be considered:

A. For each vehicle type, estimate (or measure) kWh/hr consumption in order to calculate battery run time
B. Estimate kW consumption per vehicle either per hour or per mile
    a. Consult with OEMs by requesting data from their existing deployments with similar use cases – note this can vary significantly by OEM
    b. Measure consumption from a multi-day test run on site or on routes
    c. Adjust estimates for cold/hot weather
    d. Consider cab heat estimated energy consumption during cold weather
    e. Consider battery heaters consumption rate at expected winter temperatures
    f. Consider A/C consumption rate
    g. Consult with OEMs on their experience with similar weather conditions
C. Actions that impact energy consumption
    a. Frequency of movement vs. Idle time
    b. Speed
    c. Distance
    d. Weight
    e. Grade
    f. Temperature, Wind
    g. Tire rolling resistance
    h. Driver behavior – acceleration rate, cab heat or A/C usage, etc. (see RP 1114A - Driver's Effect on Fuel Economy)

			Estimated Cold Weather Adjustments			**Estimated Hot Weather Adjustment**
	OEM-Projected Consumption (kWh/hr)	**Site-Test Consumption (kWh/hr)**	**at 32°F (+ x kWh/hr)**	**at 0°F (+ x kWh/hr)**	**at -20°F (+ x kWh/hr)**	**(+ x kWh/hr)**
Yard Truck		Test 1 data				
		Test 2 data				
Straight Truck		Test 1 data				
		Test 2 data				
OTR Truck		Test 1 data				
		Test 2 data				
Other						

Figure 3: Efficiency and Energy Consumption Planning Table

4. DUTY CYCLE/AVAILABLE CHARGE TIME

For each vehicle within your fleet's operation, document the schedule for as many duty cycles as needed for a full 24-hour period and for as many work profiles as needed (typical, peak, weekend, etc.). This information should be used to:

A. Calculate total on-site charging time available
   a. Note if available and necessary charge times overlap
   b. Calculate total amount of kWh per day to be replenished through charging, compared to times available for charging
B. Truck usage schedule, departure and return times
   a. Consider both typical and peak seasons, if applicable
C. Miles/hours
   a. Consider both typical and peak seasons, if applicable
D. Driver shift schedule and break schedule
   a. Consider both typical and peak seasons, if applicable
   b. Can driver breaks be staggered to allow for shared charger opportunity charging (recharging the battery in short intervals, whenever it is most convenient for business operations/whenever and wherever power is available which can in turn extend run times and service of battery) or must all drivers take breaks at same time?
E. How does this vary by vehicle type?
   a. Opportunity charging works for yard trucks, but not for delivery vehicles.
      i. For example: delivery vehicles complete a route, then have plenty of available charge time after – compared to some delivery vehicles that might have multiple drivers/shifts and subsequently have less available charge time.
F. When are the vehicles on site?
   a. Is this consistent? Note all available on-site time for each vehicle.
G. Where can the trucks be parked? Think about the landscape for charging setup and charging station placement.
H. Document break times, dwell times, and other down time available for charging
   a. Calculate breaks between shifts
   b. Calculate overnight unused vehicle time
   c. Can charging take place during working hours, during driver breaks, or between shifts?
I. Where is the optimal location for each truck type to be parked/charged to maximize convenience, opportunity charging, and ease/cost of electrical infrastructure installation?
   a. How does it vary for each type of truck and how it's intended to be used?
J. Do available and necessary charge times overlap?
   a. If opportunity charging is part of strategy, will a charger always be available or will shared chargers limit opportunity charging?
   b. Is there a need to prioritize which vehicles can get the charge time?

i. Some vehicles might sit on chargers longer but need to give other vehicles (e.g. yard truck) priority to get its opportunity charge. Consider demand charging rates.

1. Demand charges are based on peak power usage rather than overall energy. Demand charges are triggered when there is a spike in energy use that reaches a high level of capacity. In the context of EV charging, a demand charge could be triggered when an EV driver uses a fast-charging station. As demand charges are based on peak power, use of a fast-charging station, even just once a month, can push a charging site to its peak energy load and trigger demand charges. This can drastically impact an the savings from EV conversion.

K. Is it feasible or risky to share chargers among different vehicles?

a. Consider recommendations to keep all vehicles plugged in overnight, especially during cold temperatures, so they're ready for morning runs.

i. This would suggest a 1:1 Truck: Charger ratio

						Duty Cycle: Truck is Working = W; Truck is on-site and can be Charging = C; Truck is Off = O, neither working or charging. Complete for full 24 hours ==>																																															
Vehicle ID	Vehicle Type	Work Profile	Battery Pack Size (kWh)	Energy Use Rate (kWh/hr)	Typical Annual Miles or Hours	8:00 AM	8:30 AM	9:00 AM	9:30 AM	10:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM	12:30 PM	1:00 PM	1:30 PM	2:00 PM	2:30 PM	3:00 PM	3:30 PM	4:00 PM	4:30 PM	5:00 PM	5:30 PM	6:00 PM	6:30 PM	7:00 PM	7:30 PM	8:00 PM	8:30 PM	9:00 PM	9:30 PM	10:00 PM	10:30 PM	11:00 PM	11:30 PM	12:00 AM	12:30 AM	1:00 AM	1:30 AM	2:00 AM	2:30 AM	3:00 AM	3:30 AM	4:00 AM	4:30 AM	5:00 AM	5:30 AM	6:00 AM	6:30 AM	7:00 AM	7:30 AM
Truck 1	Yard Truck	Typical, Mon-Fri																																																			
Truck 2	Straight Truck	Typical, Mon-Fri																																																			
Truck 3	OTR Truck	Typical, Mon-Fri																																																			
etc.																																																					
Truck 1	Yard Truck	Typical, Sat-Sun																																																			
Truck 2	Straight Truck	Typical, Sat-Sun																																																			
Truck 3	OTR Truck	Typical, Sat-Sun																																																			
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Other																																																						

Figure 4: Duty Cycle/Available Charge Time Planning Table

5. CHARGING REQUIREMENTS

For each vehicle type, understand all charging options and specifications available. The following variables (at a minimum) should be considered:

A. Charger compatibility: what chargers work with each truck?
    a. Has that specific truck and charger model number pair been tested/validated?
    b. Is the communication proven to work as intended during full charge rate as well as low speed charging once the state of charge (SOC) reaches 100% but might be sitting overnight plugged in?
B. How well do they match with truck voltage to maximize infrastructure capacity?
C. What is important to know about the truck's batteries?
    a. Is the battery's chemistry designed to function best when keeping the SOC at or near 100%?
        i. Is it healthy for the batteries or will it shorten their expected life?
        ii. Is there any risk of "overcharging"?
D. Vehicle voltage
E. Charging connector options
    a. What connectors are available today and what are the trends for future options?
        i. CCS – once viewed as the standard, now has its future in doubt
        ii. NACS – growing in interest with most automakers shifting in this direction
        iii. Inductive – expected to increase in popularity in the coming years
F. Document the typical and maximum recommended kW charge rate for each vehicle/OEM to consider risk to battery health and life and demand charges.
    a. What does battery supplier say is the recommended charge speed? The rate of charging or discharging is sometimes described as the portion of the battery pack's charge that is replenished in 1 hour. If the charging speed is such that the battery pack goes from empty to full in 1 hour, that would be "1C". If it is charged at a speed that refills the battery pack half way in 1 hour, that is described as "0.5C". Recommendations can vary based on the battery's chemistry, but in many cases while a full recharge in 1 hour seems attractive for operational reasons, sending that much energy into the battery that quickly could shorten the life of the battery, with a maximum rate of 0.5 C (taking 2 hours for a full recharge) being preferred for maximizing the battery life.
        i. What is the cost to replace batteries if you've charged or discharged too fast.
        ii. Will the truck derate to protect the batteries? Some vehicles will reduce their power usage when the battery gets low and notify the driver that it's time to recharge.
G. What is the recommended minimum SOC?
    a. How is this protected? (Ex: "limp mode" when the truck goes slower to reduce energy consumption and as another indicator to the driver that it's time to charge)

H. Is the battery SOC percentage shown in the vehicle proven to be reasonably accurate at any given time?
I. Where is the sweet spot on both the high and low ends?
    a. SOC window: determine minimum and maximum values
J. What are the charge speeds and infrastructure capacity implications for available/compatible chargers?
K. Calculate the total amount of kWh per shift, per day to be replenished through charging, compared to times available for charging
    a. Complete calculations as it can vary dramatically depending on available time for charging
L. Note the loss of electricity between what comes from the grid and what makes it through the charger to the truck.
    a. A rough guide is that 92% of the power makes it through, so the actual electricity bill will be based on a kWh quantity slightly higher than what the truck is consuming.
M. The worksheet below can be used as a framework to capture and calculate this information:

		Charger and Connector Considerations			Recommended Charge Rate (kW)	Recommended State of Charge (SOC) %			
	Vehicle Voltage	Charging Connector Options	Charge Speed	Infrastructure Capacity Implications	Max	Min	"Sweet Spot" High End?	Cost to Replace Batteries ($)	Will Truck Derate to Protect Batteries?
Yard Truck		Option 1							
		Option 2							
Straight Truck		Option 1							
		Option 2							
OTR Truck		Option 1							
		Option 2							
Other									

Figure 5: Charging Requirements Planning Table

6. SITE ELECTRICITY RATES

Based on your utility provider, document the full electricity rate schedule. Customize the fields below as needed.

A. Note what demand charges are, when they take effect, and how they are calculated
B. Document electricity rate schedule including Time of Use (TOU) rates, peak rates, seasonal rates, etc.
C. The worksheet below can be used as a framework to capture and calculate this information:

		Rate Period Definitions			Electricity Rates				
Period		**Months Period Applies (e.g., June-Sept)**	**Days of Week Period Applies (e.g., M-Fri)**	**Hours Period Applies (e.g., 11:01pm-3am)**	**Fixed-Fee Base Charge ($)**	**Consumption Charge ($/kWh)**	**Demand Charge ($/kW)**	**Transmission Charge ($/kWh)**	**Delivery Charge ($/kWh)**
Non-seasonal									
	Economy								
Summer	Off-Peak								
	On-Peak								
	Economy								
Winter	Off-Peak								
	On-Peak								

Figure 6: Site and Electricity Rates Planning Table

7. SITE ELECTRICAL CAPACITY

Determine the available electrical capacity of the building. The following variables, at a minimum, should be considered:

A. How much total available capacity exists today?
B. What portion of available capacity can be dedicated to EV deployments?
C. What is the timeline and cost to increase available capacity?
D. How can you maximize the current available capacity?
E. Where in the building is it located?
F. Potential for new capacity.
    a. Consider applicable timing and costs
G. Capacity usage should based on maximum potential draw of installed chargers plus 20%, not what is actually needed or used.
    a. Be cautious about unused capacity as utility companies may have feedback so you don't "reserve" more than you'll be using.
        i. Ask your provider if a "current limiter" is an option so you're not tying up more than you're using?

8. DISCUSS, DOCUMENT, AND PRIORITIZE GOALS

Rate efficiency verses truck availability and battery pack size efficiency using the points for consideration listed below:

A. Maximize truck usage
B. Minimize electrical costs
C. Costs of various battery pack sizes available for each vehicle
D. Costs of chargers and ratios of trucks to chargers
E. Future roll-out and expansion plans
F. Other Considerations:
    a. Identify highest priority deployments for operating efficiency, highest cost savings, best visibility for organizational learning, or avoiding fines/penalties (e.g. some markets have implemented penalties for sites that are not taking steps to reduce or offset emissions, and other markets are requiring a percentage of the fleet to be zero emissions)
    b. Which solutions have proven data vs. projected theoretical results?
    c. Risks and costs of under/over-spec'ing vehicles
    d. Risks and costs of under/over-spec'ing chargers
    e. Risks of Truck: Charger ratio greater than 1:1
    f. Charger availability, Flexibility to stagger breaks, Cold weather start-up
    g. Budget

9. EVALUATE SCENARIOS AND LEVERAGE DATA FOR DECISION-MAKING

Use information obtained from your research and sourcing efforts to make an informed, data-driven decision that will satisfy your operational objectives.

A. Evaluate expected and exception scenarios for electrical usage, capacity required, and costs
B. Assess if the optimal scenario available today? (Available vehicle, charger, infrastructure capacity, etc.)
C. Research if there is a current solution that can be implemented today to gain experience from and make progress while longer term optimizations develop?
D. Define what level or average of electricity cost is acceptable to achieve the minimum required ROI
E. Calculate minimum requirements for success and costs to go above minimum ROI
F. Determine ideal battery pack size
G. Determine ideal charging infrastructure – including ratio, mix, and location
H. Guide operations team(s) on how to manage the trucks and charging schedules
I. Assess improved data for Total Cost of Ownership (TCO) calculations and scenarios
J. Define recommended rollout sequence/timing/phases to fit within budget and capacity