TRANSPORTATION RESEARCH SYNTHESIS

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Power Sources for Automatic Traffic Recorders

Introduction

The Minnesota Department of Transportation (MnDOT) currently completes traffic counts, classification counts, and speed counts using a number of sources. These include road tube counters, permanent Automatic Traffic Recorder (ATR) stations, permanent Automatic Detector Recorder (ADR) stations, weigh-in-motion sites, and portable ATRs, specifically using Wavetronix SmartSensors. All of these detections methods require power, but the needs vary greatly depending on the type of detection system. The permanent stations utilize hard wired or "grid" power from local power companies. The cost of this can vary but getting onto the power grid is deemed to be worth the effort and cost to have a reliable source of power for locations that will be collecting data every day of the year for many years, such as at permanent ATR and ADR stations.

The tube detectors require much less power and are typically only set out in the field for a few days up to two weeks. The power obtained from the unit batteries is enough to supply the units for the needed time periods. The Wavetronix units are typically set out in the field anywhere from a week to a few months. Many locations in which these units are used in Minnesota don't have access to the power grid, so they must use batteries, which must be changed quite often. A portable power system is essential in such places to run portable Automatic Traffic Recorders. The objective of this study is to gather information on what other State Transportation Departments are using for power sources for these types of applications. Then, these practices can be implemented in Minnesota if they are different. Additionally, other portable sources of power will be researched for possible use in Minnesota.

Background

The focus of this research will be on portable power sources to power the Wavetronix SmartSensor HD system that MnDOT currently employs for some of their traffic counting efforts. The Wavetronix SmartSensor HD is a traffic sensor that collects traffic statistics through the use of a 24.125 GHz operating radio frequency. The SmartSensor HD is classified as a Frequency Modulated Conditions Wave (FMCW) radar. The units use up to 8.1 watts and need 10-30 Volts DC power. MnDOT currently uses 4 6-volt batteries to provide 24-volt DC power. Typically MnDOT installs the units either roadside or on a portable trailer. The roadside units are attached to poles which are then attached to existing signs in the field. The trailer units are installed on a pole which is attached to the trailer and the trailer is then located to the roadside.

The SmartSensor HD either uses DC power or AC power with Click! components. The Click! components include the 201/202 AC to DC converter, 205 AC surge module, and 206 circuit breaker and switch. The batteries that are currently used provide direct DC power whereas any connection to utility power requires 120 volts AC power for use with the converter.

The ambient operating temperature of the SmartSensor HD is -40º C to 70 º C (-40 º F to 158 º F). They are rated to operate up to 95% relative humidity (RH).

Prepared by Bolton & Menk, Inc.

Project Technical Advisory Panel (TAP) Members

The project team is comprised of individuals from the Minnesota Department of Transportation and Bolton & Menk, Inc.

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Information used in this research was obtained from the following individuals and the agency contacts included in the State of Practice.

Agency	Contact	Contact Information
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University of Minnesota-Duluth Electrical Engineering Department	Dr. Taek Kwon	tkwon@d.umn.edu 218-726-8211
Wavetronix	Cliff Joiner	801-734-7236

State of Practice

A total of 29 agencies have been contacted to determine the use of portable power sources for traffic counting. Of these 29 agencies, 21 of the agencies provided feedback on their power sources used in portable traffic counting efforts.

Agency	Contact	Contact Information
Alberta Ministry of Transportation; Alberta, Canada	Orlando Rodriguez	Orlando.rodriguez@gov.ab.ca 780-643-1723
ASTI Transportation	Noah Jenkin	noah@asti-trans.com 302-328-3220
British Columbia Ministry of Transportation and Infrastructure; British Columbia, Canada	Dale Wood	Dale.Wood@gov.bc.ca
California Department of Transportation (CalTrans)	Theresa Gabriel	Theresa_A_Gabriel@dot.ca.gov 916-654-5039
Florida Department of Transportation (FDOT)	Richard Reel	Richard.Reel@dot.state.fl.us 850-414-4709
Iowa Department of Transportation (IADOT)	Ronald Bunting	Ronald.Bunting@dot.iowa.gov 515-239-1323
Maine Department of Transportation (MaineDOT)	Traffic Count Section	Traffic.Web@maine.gov 207-624-3620
Manitoba Highway Traffic Information System (MHTIS), Manitoba, Canada	Rob Poapst	mhtis_info@umanitoba.ca 204-474-7367
Massachusetts Department of Transportation (MassDOT)	William Mitchell	William.Mitchell@dot.state.ma.us 617-973-7327
Michigan Department of Transportation (MDOT)	Jennifer Foley	FoleyJ3@michigan.gov 517-750-0431
Minnesota Department of Transportation (MnDOT)	Ralph Adair	ralph.adair@state.mn.us 651-234-7027
Montana Department of Transportation (MDT)	Peder Jerstad	pjerstad@mt.gov 406-444-9248
New York Department of Transportation (NYSDOT)	Dean Carnevale	dcarnevale@dot.state.ny.us 518-485-2007
North Dakota Department of Transportation (NDDOT)	Terry Woehl	twoehl@nd.gov 701-328-3531
North Dakota State University Advanced Traffic	Raj Bridgelall	raj.bridgelall@ndsu.edu

Analysis Center: NDSU ATAC		(701)231-8058
Pennsylvania Department of Transportation (PennDOT)	Joni Sharp	josharp@pa.gov 717-787-0186
Texas Department of Transportation (TxDOT)	Catherine Wolf Charles Koonce	512-465-7318 Charles.Koonce@txdot.gov 512-506-5116
Virginia Department of Transportation (VDOT)	ASTI Transportation Noah Jenkin	noah@asti-trans.com 302-328-3220
Washington Department of Transportation (WSDOT)	Ken Lakey	LakeyK@wsdot.wa.gov 360-570-2374
Washington DC, District Department of Transportation (DDOT)	ASTI Transportation Noah Jenkin	noah@asti-trans.com 302-328-3220
Wisconsin Department of Transportation (WisDOT)	Lewis Russell	Russell.lewis@dot.wi.gov 608-516-5754
Wyoming Department of Transportation (WYDOT)	Transportation Surveys	307-777-4190

Alberta Ministry of Transportation

Traffic Detection Equipment
Currently do not have any portable systems
Microwave on some permanent systems

Power Sources
Primary source: local utility provider
Secondary source: solar panels with batteries

Research on other Sources
No other sources have been researched or investigated.

Installation
Solar panels are usually directed to the south

Issues
None

British Columbia Ministry of Transportation and Infrastructure

Traffic Detection Equipment
Microwave

Power Sources
Primary source: local utility provider
Secondary source: solar panels with deep cycle marine batteries

Research on other Sources
Have considered alternative methods to power portable traffic counting equipment

- Wind turbines – depending on location may not be the most reliable source of power, if utilized it would have to be in combination with solar. Requires maintenance and not practical for mobile applications
- Gas/propane/diesel generators – ideal for higher power requirements and naturally require routine maintenance

Installation
Permanent roadside ATRs

Issues
None

Additional
Consider marine deep cycle batteries and solar panels as the best combination available at the time due to reliability and mobility needs. They require the least maintenance out of any available options.

CalTrans

Traffic Detection Equipment
Microwave Vehicle Detection (MVDS) manufactured by either Image Sensing Systems (formerly EIS) or Wavetronix

Power Sources
Primary source: local utility provider
Secondary source when there is an absence of nearby utility power lines: solar panels with batteries

Research on other Sources
No other sources have been researched or investigated.

Installation
The units, solar panels, and NEMA cabinet are typically installed to a pole on the roadside. Solar panels are usually directed to the southern sky but may be adjusted when there is not a clear sight line to the south.

Issues
Maintenance issues with using solar as with most electrical equipment including water damage, wiring replacement, and dirt build-up on the panels. Theft issues with solar panels and batteries.

DDOT

Traffic Detection Equipment
Wavetronix SmartSensor HD

Power Sources
Primary source: local utility provider
Secondary source: solar with batteries

Research on other Sources
No other sources have been researched or investigated.

Installation
Trailers that include the SmartSensor HD and sometimes a video camera, and a weather station

Issues
None

Additional
System trailers developed by ASTI Transportation
The trailers with video cameras and weather stations are part of a hurricane evacuation system

FDOT

Traffic Detection Equipment
Wavetronix, MS Sedco, NazTec Accuwave, Image Sensing Systems (formerly EIS)
Most counts are completed by consultants

Power Sources
Primary source: local utility provider
Secondary source when there is an absence of nearby utility power lines: solar panels with batteries

Research on other Sources
No other sources have been researched or investigated.

Installation
Typically installed to a pole on the roadside

Issues
None, most portable counters are deployed less than 72 hours

Additional
Recommends permanent sensors as part of construction projects on multi-lane facilities

IA DOT

Traffic Detection Equipment
Peek ADRs with 6-volt batteries

Power Sources
Primary source: batteries only

Research on other Sources
No other sources have been researched or investigated.

Installation
Not applicable

Issues
None

MaineDOT

Traffic Detection Equipment
Approved microwave detectors. Work on an operational frequency of 10.525 GHZ, response time of 165 milliseconds, adjustable hold time of 0.5 to 5 seconds, and powered from 10 VAC to 24 VAC.

Power Sources
Primary source: solar panels with marine batteries

Research on other Sources
No other sources have been researched or investigated.

Installation
Solar panels are usually directed to the southern sky but may change based on location and preference by personnel that install the units

Issues
None

MHTIS

Traffic Detection Equipment
Don't use portable devices other than their CCS (Coverage Count Stations) loop or tube counters
PCS (Permanent Count Stations) or ATRs consist of

- Autopoll PCS
- AVC (Automatic Vehicle Classifiers)
- WIM

Power Sources
Primary source: local utility provider for permanent
Secondary source: batteries for portable

Research on other Sources
No other sources have been researched or investigated.

Installation
In pavement

Issues
None

MassDOT

Traffic Detection Equipment
International Road Dynamics (IRD) Microwave Traffic Classifiers

Power Sources
Primary source: 20W solar panels with 6-volt gel cell batteries (Trojan and EnerSys)

Research on other Sources
No other sources have been researched or investigated.

Installation
Solar panels are usually directed to the southern sky but may be adjusted when there is not a clear sight line to the south.

Issues
None

Additional
Currently upgrading sites to include modems. This requires an upgrade to 80-85 Watt solar panels to charge four (4) 110 Amp Hr. batteries connected in parallel. The power consumptions at the Dual-Use stations should be as follows:
IRD Counter: 50 milliAmps
Raven X modem: 235 milliAmps
Trafmate 7E Device Server: 100 milliAmps
TOTAL: 385 milliAmps – Say 0.4 amps

MDOT

Traffic Detection Equipment
Microwave detectors (no specific manufacturers)

Power Sources
Primary source: local utility provider
Secondary source: batteries only
Tertiary source: generator with batteries

Research on other Sources
No other sources have been researched or investigated.

Installation
Generator on a trailer which is utilized to recharge the batteries when power is needed for longer periods of time

Issues
Generator requires staff to go in the field and start the generator when the batteries need to be charged. Generator is run until the gas runs out and gives the batteries another charge for 7-10 days.

MnDOT

Traffic Detection Equipment
Wavetronix Microwave detectors

Power Sources
Primary source: local utility provider
Secondary source: solar panels with four (4) 6-volt marine gel deep cycle batteries
Tertiary source: solar panels and wind generator (1.5 kW wind turbine) with six (6) batteries

Research on other Sources
Some research into wind.

Installation
Trailer located at the side of the roadway. Panels are generally directed to the south, but may be any direction.

Issues
1.5 kW wind turbine with six batteries provides enough power approximately 30% of the time. Added a solar panel which now provides adequate power 95% of the time. Have had solar panels stolen in remote locations when installed lower. New installation is higher, welded onto tall poles that can only be reached by a ladder.

One installation for de-icing used in the winter only uses solar panels with a small wind turbine. Few watts infrequently to spray deicing solution onto I-35W.

MDT

Traffic Detection Equipment
Diamond counters

Power Sources
Primary source: solar panels with deep cycle batteries and regulators

Research on other Sources
No other sources have been researched or investigated.

Installation
Solar panels are directed to the south as much as possible

Issues
None, the equipment is on the roadway for a week or less since it requires lots of maintenance to keep the equipment in the roadway, so the battery life isn't a major concerns

Additional
Batteries are typically tested every day when out in the field
Annual winter maintenance is performed on all sites and batteries are replaced as needed
Most of the units have timers on the modems so they may only be polled for limited time periods in the winter (usually 10:00 AM to 3:00 PM) in order to keep the batteries charged.

NYSDOT

Traffic Detection Equipment
Wavetronix device or an acoustic sensor

Power Sources
Primary source: 50w solar panel and 2 - 100 amp-hour deep cycle gel or Absorbed Glass Mat (AGM) batteries

Research on other Sources
No other sources have been researched or investigated.

Installation
Portable trailer at roadside with 35 foot mast
Solar panels are usually directed to the south but may be adjusted when there is not a clear sight line

Issues
None

NDDOT

Traffic Detection Equipment
Miovision, Peek or Diamond tube counters

Power Sources
Primary source: battery

Research on other Sources
No other sources have been researched or investigated.

Installation
Miovision unit is attached to a sign, utility pole, or signal pole, can extend up to 25 feet

Issues
None

NDSU ATAC

Traffic Detection Equipment
Wavetronix and Autoscope

Power Sources
Primary source: local utility provider
Secondary source: 12-volt marine deep cycle battery

Research on other Sources
No other sources have been researched or investigated.

Installation
Miovision unit is attached to a sign, utility pole, or signal pole, can extend up to 25 feet

Issues
Batteries tend to only last a week

PennDOT

Traffic Detection Equipment
Approved Manufacturers: MN Sedco, Naztec, Traffic Control Products Pulsar II, Wavetronix, Xtralis

Power Sources
Primary source: solar panels and deep cycle marine batteries

Research on other Sources
No other sources have been researched or investigated.

Installation
Solar panels are usually directed to the south as much as possible

Issues
None

TxDOT

Traffic Detection Equipment
Wavetronix (most reliable: SmartSensor HD)

Power Sources
Primary source: local utility provider
Secondary source: 80 Watt solar panel and batteries

Research on other Sources
No other sources have been researched or investigated.

Installation
Installed on portable trailer. Some trailers also include variable message signs
Solar panels are installed slightly south and remain in that direction no matter what time of year

Issues
Had 40 Watt solar panels originally but batteries did not stay charged.

VDOT

Traffic Detection Equipment
Wavetronix SmartSensor HD

Power Sources
Primary source: local utility provider
Secondary source: solar with batteries

Research on other Sources
No other sources have been researched or investigated.

Installation
Trailers that include the SmartSensor HD and sometimes an Earthcam video camera, and a Vaisala weather station

Issues
None

Additional
System trailers developed by ASTI Transportation and Digital Traffic Systems
The trailers with video cameras and weather stations are part of a hurricane evacuation system

WSDOT

Traffic Detection Equipment
Wavetronix, Diamond Unicorn tube counter, or Tirtl infrared

Power Sources
Primary source: local utility provider
Primary source back-up: DC style Uninterruptible Power Supplies (UPS) system which includes an appropriate step-down transformer (as needed); a 7-amp marine-grade battery charger; a low battery disconnect device; a valve-regulated, gelled-electrolyte battery; wiring; and power distribution terminal block, all enclosed within a NEMA 3R enclosure
Secondary source: solar panel with marine type batteries

Research on other Sources
No other sources have been researched or investigated.

Installation
All of the tube counters have a solar face but are typically not left in the field for more than a 1 week period
Battery in the UPS system is charged nightly when AC power is available
Solar panels are usually directed to the south

Issues
The Infrared Tirtl's have been difficult to use as a portable counter

WisDOT

Traffic Detection Equipment
Wavetronix sensors for permanent ATR sites

Power Sources
Primary source: local utility provider
Secondary source: solar with one Absorbed Glass Mat (AGM) battery

Research on other Sources
No other sources have been researched or investigated.

Installation
Solar panels are usually directed to the south as much as possible but site constraints may shift them to SE or SW

Issues
When using solar solely, typically miss one out of every three days and are not able to collect a full day is during the winter months occasionally

WYDOT

Traffic Detection Equipment
Microwave

Power Sources
Primary source: local utility provider
Secondary source: solar with deep cycle marine batteries
Tertiary source: solar and wind power with deep cycle marine batteries

Research on other Sources
No other sources have been researched or investigated.

Installation
Permanent roadside ATRs

Issues
None

Additional
Wind power has had the most success in places with sustained winds in the 15-20 mph range, but some success with ranges of 10-14 mph with solar backup.

State of Practice Summary

Agency	Count Equipment				Power Sources			
	Tube Counters Only	Microwave	Infrared	Video	Local Utility*	Battery Only	Solar with Batteries	Other
Alberta Ministry of Transportation		√			√		√	
British Columbia Ministry of Transportation and Infrastructure		√			√		√	
CalTrans		√			√		√	
DDOT		√			√		√	
FDOT		√			√		√	
IADOT	√					√		
MaineDOT		√					√	
MHTIS	√					√		
MassDOT		√					√	
MDOT		√			√		√	fuel generator
MnDOT		√			√		√	solar + wind
MDT		√					√	
NYSDOT		√					√	
NDDOT				√		√		
NDSU ATAC		√		√	√	√		
PennDOT		√	√				√	
TxDOT		√			√		√	
VDOT		√			√		√	
WSDOT		√	√		√		√	UPS system
WisDOT		√			√		√	
WYDOT		√			√		√	solar + wind

*Some agencies did not specify a local utility provider as a source of power, but a local utility provider may provide power at some locations

Currently, most other agencies are using grid power from a local utility provider or solar with batteries to power their microwave or other count systems. A couple of agencies have looked into wind power but have only had success with wind power in conjunction with solar power. The consensus from most agencies is that the current solar system with marine batteries is the most appropriate and reliable.

Deep cycle marine gel batteries are the most common battery used by agencies for portable counters and are considered to be more reliable than the Absorbed Glass Mat (AGM) batteries in the use of powering the count systems. ASTI Transportation, which has built portable trailer units for multi agencies, uses lead-acid batteries and considers them the best for cold weather climates.

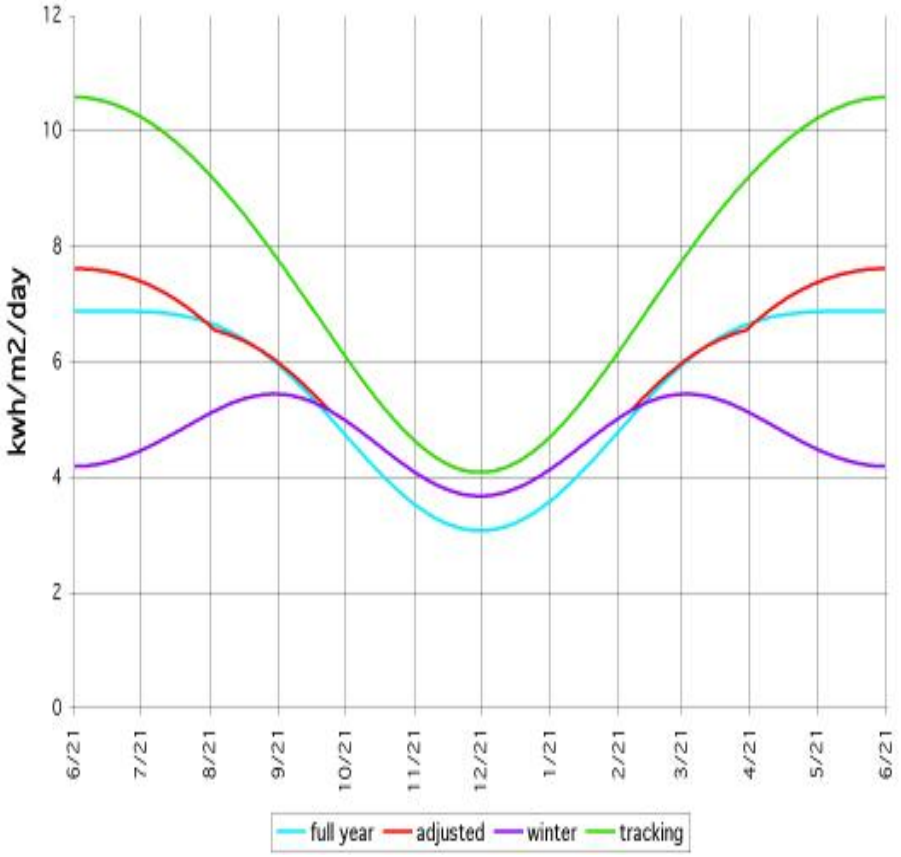
Solar panel placement is usually direct south.

Power Sources

Solar Panels

Solar power is currently used as a power source to charge batteries. The typical installation sets the panel in one direction but the tilt and actual direction is usually up to the person installing it in the field. The angle of installation is important and can be optimized to point them in the direction that captures the most sun. This would apply to fixed panels that can be adjusted versus tracking panels which follow the position of the sun. Typical tilt and direction is usually toward true south in the northern hemisphere but the tilt angle can be adjusted to get maximum benefit. The optimum tilt angles have been determined based on information from the National Renewable Energy Laboratory (NREL), US Geological Survey, NASA Langley Research Center Atmospheric Science Data Center, and the National Oceanic and Atmospheric Administration (NOAA), and compiled by researcher Charles R. Landau. The tables and graphs included here are pulled directly from Charles R. Landau's *Optimum Tilt of Solar Panels* research.

The sun is higher in the summer and lower in the winter. Consequently, more energy can be captured the entire year by adjusting the tilt of the panels by season. The following figure shows the energy production from solar panels at 40º latitude. The optimum angle for the year does not correspond to the highest potential energy capture at any time of the year as compared to the other methods. Tracking does allow for the highest capture.



If the solar panels have a fixed tilt angle, the following table has been developed for the best angle from horizontal for the panel to be tilted. Insolation in the table is a measure of solar radiation that reaches the earth's surface. It is measured by the amount of solar radiation received per square centimeter per minute. A higher insolation is indicative of higher energy capture from the panels, hence the closer to the equator the panel is located, the higher insolation.

Latitude	Full year angle	Avg. insolation on panel	% of optimum
0° (Quito)	0.0	6.5	72%
5° (Bogotá)	4.4	6.5	72%
10° (Caracas)	8.7	6.5	72%
15° (Dakar)	13.1	6.4	72%
20° (Mérida)	17.4	6.3	72%
25° (Key West, Taipei)	22.1	6.2	72%
30° (Houston, Cairo)	25.9	6.1	71%
35° (Albuquerque, Tokyo)	29.7	6.0	71%
40° (Denver, Madrid)	33.5	5.7	71%
45° (Minneapolis, Milano)	37.3	5.4	71%
50° (Winnipeg, Prague)	41.1	5.1	70%

Adjusting the tilt angle two times a year can provide significant benefits. The following table gives the best dates on which to adjust.

	Northern hemisphere	Southern hemisphere
Adjust to summer angle on	March 30	September 29
Adjust to winter angle on	September 12	March 14

The table below shows the different angles for each time of year.

Latitude	Summer angle	Winter angle	Avg. insolation on panel	% of optimum
25°	2.3	41.1	6.6	76%
30°	6.9	45.5	6.4	76%
35°	11.6	49.8	6.2	76%
40°	16.2	54.2	6.0	75%
45°	20.9	58.6	5.7	75%
50°	25.5	63.0	5.3	74%

Wind Turbines

Power from small wind turbines can provide an alternate way to charge batteries as compared to solar panels. Based on the information from other agencies and further research wind turbines are typically installed in combination with solar panels. Wind turbines are designed with both a cut-in speed and a cut-out speed. The cut-in speed is the speed at which the turbine starts to rotate and generate power while the cut-out speed is the speed at which the turbine employs a braking system to bring the rotor to a standstill to reduce the risk of damage to the rotor. Typical cut-in speeds are in the range of 7 to 9 mph and cut-out speeds are usually around 55 mph. The most successful installations for small wind turbines are in areas where there is a semi-consistent wind speed of 10-14 mph or greater with the highest power output with a stead wind speed of 30 mph or higher. The annual yearly average wind speeds can be obtained from the National Oceanic and Atmospheric Administration (NOAA). The tables below indicate the average wind speeds at different times of the year for several locations in Minnesota.

	Jan	Feb	March	April	May	June	July
Duluth, MN	11.6	11.3	11.8	12.3	11.6	10.4	9.4
International Falls, MN	8.9	8.8	9.4	9.9	9.4	8.5	7.7
Minneapolis-St. Paul, MN	10.5	10.4	11.3	12.2	11.1	10.4	9.4
Rochester, MN	14.2	13.7	14.1	14.3	13.2	12.1	10.8
Saint Cloud, MN	8.4	8.4	9.0	9.8	9.2	8.3	7.1

	Aug	Sept	Oct	Nov	Dec	Average
Duluth, MN	9.4	10.3	11.2	11.6	11.2	**11.0**
International Falls, MN	7.5	8.5	9.3	9.4	8.8	**8.8**
Minneapolis-St. Paul, MN	9.2	10.0	10.6	11.0	10.4	**10.5**
Rochester, MN	10.4	11.5	12.7	13.6	13.7	**12.9**
Saint Cloud, MN	6.5	7.2	8.4	8.6	8.2	**8.3**

The wind speed tables indicate that the most successful installations are likely in southern Minnesota or Duluth. A research project completed by the University of Minnesota – Duluth into power sources for lighting street lights and some advanced warning identification signs resulted in a need for poles of 60’ in height to get wind speeds that were acceptable to produce the power needed.

Additional information from MnDOT indicated that the wind speeds at lower elevations did not provide consistent wind to provide consistent power. A 1.5 kW wind turbine by itself provided power about 30% of the time with clear wind lines (located near farm fields with no wind barriers nearby). The subject location now uses wind in conjunction with solar power which provides adequate power 95% of the time.

Batteries

Changes in the types of batteries being installed for use with solar panels and/or wind turbines may have the most benefit in terms of providing a more consistent power source. Batteries used in this manner are deep cycled and the battery can be fully discharged and recharged several times. The most important aspect when determining the correct battery size and type is to review the type of cycling and the Amp hour ratings of the battery. In the case of the Wavetronix detectors, we will be looking at continual cycling that may almost fully drain the batteries.

Wet-Cell (lead-acid) Batteries

The most prolific battery in production is the lead-acid battery. The capacity of a lead-acid battery varies upon how quickly it is discharged. The self-discharge rate, or natural discharge when not being used, of wet-cell batteries is usually around 15-20% per month but may be as much as 30% per month depending on type. Most lead-acid batteries are “starting” batteries

that can last for thousands of cycles in normal starting use but will generally fail after 30-150 deep cycles if deep cycled. The batteries may need the water to be refilled (with distilled water) due to evaporation.

Deep cycle batteries are much less susceptible to degradation due to cycling. They are designed to be discharged down as much as 80% at a time.

Wet-Cell batteries can also come in two primary variants.

Absorbed Glass Mat (AGM) Batteries

AGM batteries are made of different materials than lead-acid batteries that alleviate the need for refilling and require minimal maintenance. The batteries are sealed so that they can be installed at any angle, are shock and vibrant resistant, and submersible. They also have a low self-discharge rate (~3%).

Gel Batteries

Gel batteries are similar to AGM batteries that are designed to alleviate the need for refilling and require minimal maintenance. They are sealed and low temperature tolerant, shock and vibration resistant, and have a long life. They are resistant to over-discharge and an internal self-discharge rates of less than 1% per month.

Marine Batteries

Marine batteries usually come in both AGM and gel variations. Marine batteries are sturdier than car batteries to prevent damage from shaking and vibration. Most are not intended to discharge more than 50% capacity but deep cycle marine batteries can be discharged as much as 80%.

Sodium Batteries

The General Electric (GE) Durathon is a sodium battery that is currently being designed for use as an alternative to traditional lead-acid batteries. They are stated by GE to have a longer life, store more energy, and have improved performance in extreme conditions. They also require no cooling and minimal maintenance. GE has been installing them primarily for the telecom industry at this time in cell tower locations that rely on backup generators and batteries. The battery performs well in outdoor temperatures of -40º F to 150º F. The typical Durathon battery pack is around 300 lbs and the size of a suitcase. GE claims that it can run ten times as long and store as much energy as lead-acid batteries twice its size.

Emerging Technologies

Fuel Cells

Fuel cell batteries are becoming better known but have actually been around since the early 1800s. Today they are utilized for stationary power generation, as backup at telecommunications sites, in fuel cell powered forklifts, and in electric and hybrid vehicles. There are multiple fuel cell technologies that are currently either being utilized or studied. Examples include Polymer Electrolyte Membrane (PEMFC), direct methanol (DMFC), alkaline (AFC), phosphoric acid (PAFC), molten carbonate (MCFC), and solid oxide (SOFC). The US Department of Energy has been actively working to develop and demonstrate fuel cell power system technologies. Most of the focus of this program has been on PEMFCs and the program has begun looking into SOFCs.

The US Department of Energy has reported that the cost of fuel cell power systems must be reduced before they are competitive with conventional technologies.

Fuel cells are generally stacked to get appropriate voltage levels. A fuel stack generates electricity in the form of Direct Current (DC). Typical fuel stacks may include hundreds of fuel cells. The power from fuel cells includes power conditioning to meet the needs of application. This power conditioning and conversion reduces system efficiency by 2-6%.

PEMFCs, or hydrogen fuel cells, are the most common. They deliver high-power density with low weight and volume. They only need hydrogen, air, and water to operate. Typical installations are in transportation applications or as backup power. Hydrogen storage can be an issue, as it requires large tanks that are under high pressure. Higher density fuels can be used

such as methanol, ethanol, natural gas, liquefied petroleum gas, and gasoline, but an on-board fuel processor is required to reform the fuel to hydrogen which includes additional costs and maintenance. Currently, PEMFCs typically operate at 60% efficiency in transportation uses and 35% in stationary uses. Operating temperatures of PEMFCs are in the range of 50-100º C (122 to 212º F) with typically operating temperature of 80ºC (176º F). The advantage of PEMFCs is that the solid electrolyte reduces corrosion, has a low operating temperature, and a quick start-up. The disadvantages include expensive catalysts and sensitivity to fuel impurities.

DMFCs are powered by pure methanol mixed with steam. It is higher energy density than hydrogen but less than gasoline or diesel fuel. It is also a liquid which makes it easier to transport.

> A test in the Czech Republic in 2010 used DMFCs in combination with solar panels. The equipped trailer included a radio detector and a portable LED sign and Bluetooth connection. The equipped system allowed up to 10 days of continuous operation at full sign brightness in real world conditions.
>
> Other systems throughout the world, primarily in Europe, have been used for road weather stations and speed cameras. They have been used to provide sufficient off-grid power around the clock, especially during wintertime, with low solar intensity and low temperatures when solar alone does not supply reliable energy, especially in critical weather and the dark seasons.

The other fuel cell options including AFC, PAFC, MCFC, and SOFC have typical stack sizes that would provide more power than is necessary for the applications being proposed in this study and would not be as portable. Typical applications would be for the military, space, electric utility, and distributed generation. Additionally the operating temperatures would be above 90º C (194º F) and up to 1,000º C (1832º F) with power distributions of hundreds of kilowatts to megawatts, much more than needed for the applications being discussed in this study.

Power Sources and Costs

PEM Fuel Cells

Dantherm Battery eXtender – DBX2000

Dantherm Power systems are complete Backup Power solutions designed and configured to be installed in both in- or out-door applications for telecom and related networks. The solutions can be configured as both integrated and standalone modules. The Battery eXtender uses hydrogen fuel cell technologies with fully integrated power management and various configurations possible. The Dantherm Battery eXtender (DBX) is installed in parallel with batteries. The

DBX is ideal in environments with an unstable mains (grid) where equipment must be protected from power outages and business continuity demands reliable backup power. In case of mains power outage the batteries will provide backup instantly and the DBX-module provides support when the DC bus voltage drops or when a timer set point is reached.

Features:
Very low maintenance cost (site visits only required every 5 years)
Prevents batteries from deep discharge, thereby extending life
Very low noise, can be installed almost anywhere
No lead pollution and no harmful substances or emissions
Easy to increase backup time to 8, 12, 24, 48 or even 168 hours or more
Compact, modular and scalable systems for network growth
Programmable self-test ensures system readiness
Floating GND – can work in both -48VDC and +48VDC
Light weight. One module weighs less than one battery
Fuel storage in up to three strings for hot-swap and easy monitoring
Power output: 1,676 watts continuous

Configurations:
Mounts in 19" and 23" racks, 2 or 4 post cabinets/racks
Parallel with batteries and other modules for redundancy and higher capacity
Can be mounted in outdoor cabinets, shelters or similar
Easy to install on existing shelter sites

DBX: Dantherm Battery eXtender
2000: Nominal stack output power – End of Life
H: Hydrogen fuelled
48: 48 VDC range (fixed voltage within (45 - 57 VDC))
AC-input voltage of 110 or 230 VAC

Options:
Dantherm Instant Backup (DIB) Upgrade kit with battery-free bridge power
Fuel Regulators with fittings for local thread types
Hoses and tubing, fuel manifolds
Hydrogen storage cabinets in various sizes
Cold climate kit (for operation below -20°C and/or low load)

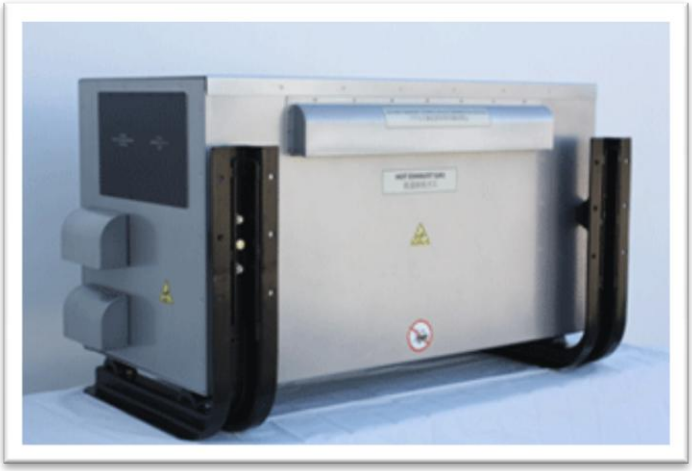
Pricing:
Unknown/Unable to make contact

Horizon PEM Fuel Cell System

Horizon's fuel cells are simple, air-breathing, air-cooled, self-humidified systems that limit peripherals to the bare minimum. The semi-integrated unit comes in a kit format for more integration flexibility.

Features:
$5,000 to $8,000 depending on exact system needs

EnerFuel High Temperature PEM Fuel Cell System



EnerFuel is a GreenTech company that designs, builds, and integrates High Temperature PEM fuel cell systems for commercial, government, and military customers. EnerFuel provides complete custom fuel cell solutions and fuel cell product integration.

EnerFuel's High Temperature Proton Exchange Membrane (PEM) fuel cell system combines our unique proprietary stack design, our proprietary advanced materials, and our focus on integration. This standard fuel cell system can be used for laboratory and prototype system development. EnerFuel's HT-PEM fuel cell system provides efficient operation within a target power range of 0.1-3kW.
Customized solutions are also available.

Features:

- Simple
  - No radiator required for cooling
  - High operating temperature eliminates water management and balance problems
- Greater Efficiency
  - Reduced ancillary loads due to reduction of balance of plant
- Low Cost
  - Simplicity - low capital costs
  - Efficiency - low recurring costs
- Operates at 140-180°C
- High CO tolerance
- Embedded control software
- Integrated power conditioning
- Serial data output
- Customized management software

Pricing:
Unknown/Unable to make contact

Fuel:
Hydrogen fuel tanks are needed with any PEM system.

Direct Methanol Fuel Cells

SFC EFOY Pro

EFOY Pro fuel cells offer a maintenance free off-grid power supply for several months. Up to 50 days of autonomy can be achieved when powering a 50 W monitoring device.

EFOY Pro fuel cell is a turnkey off-grid power solution which can be placed directly on site, in the EFOY ProCube or integrated into existing cabinets.

EFOY Pro fuel cells offer maintenance free off-grid power for several months. Up to 50 days of autonomy can be achieved when powering a 50 W speed camera. Due to the 100 % reliability of EFOY Pro fuel cells, downtime costs are avoided.

The EFOY fuel cell system is available from multiple sources in the United States.

The EFOY Pro 600 has a charging capacity of 600 Wh/day and 25 Watts of nominal power. The system weighs just over 17 pounds and operates from -4ºF to 113 ºF. Dimensions are 17 x 8 x 11 in.

Sirius Integrator Fuel Cell System

Pricing:
EFOY Pro 600 Set with 1 year warranty or 3000 operational hours warranty: $3,990
Extended warranty (1 year or 3000 operational hours): $180 per
M28 Fuel Cartridge (28 Liters): $199
SiriusPower Large Enclosure (fits up to two M28 cartridges): $1,899
Duocart Switch for connecting two cartridges to one EFOY fuel cell system: $1,490
SiriusPower Very Cold Enclosure: $3,999
IA1 Interface and USB Adapters: $95
M28 Adapters (2): $290
Solar Power Plastic 80Watt 12v Mountable Panel and Charger: $895
System total with all of above: $4,095

Fuel Cartridges (filled with methanol) can be shipped from other states, Maryland and Ohio currently.

Evergreen Energy Technologies Power Pod

Hybrid Solar / Fuel Cell Power Supply application for year-round outdoor conditions. General-purpose non-hazardous electrical area classification. Can work with existing solar panel array. Can be ground mounted or trailer mounted as needed.

Features:
Max Output: 600—2200 Watt Hrs / Day at 12 or 24 VDC
Fuel Consumption: 1100 Watt Hrs / Litre of Methanol (approx - varies with weather)
Ambient Operating temperature: -40C / +40C (standby and charging)
Cold Start-up Temperature: +5C / +40C (initial startup on site)
Electrical Rating: CSA Approved for Non Hazardous Area (flameless device)
Enclosure: CSA Type 3R, Insulated, with room for DCS & (2) 28L Fuel Cartridges
= up to 61,600 watt-hours of standby power
Dimensions: 25”W x 18”D X 60”H X 340 lbs installed with fuel (170-210 lbs shipping)
Automatic Antifreeze Mode, Patent-Pending Extreme Environment Protection

Basic Equipment:
Evergreen Power Pod (*) Model PP-F0600-12/24-D assembled including:
EFOY Pro 0600 Direct Methanol Fuel Cell (12/24VDC 600 Wh/day)
EFOY Pro control panel (internally mounted)
(2) 12V 35Ah AGM battery, wiring harness with fuses
Type 3R Weatherproof Enclosure (metal with insulation, CSA approved, 25”Wx18”Dx60”H ground-mount lockable type with room for fuel inside)
Evergreen Extreme Environment Protection system +40C/-40C
Operators Manual, Service Fluid, system CSA approved and marked
Wired for 24 VDC

Optional Equipment:
Fuel Cartridge Model M10 (10 liters methanol in safety container)
M28 adapter (to enable use of M28 methanol cartridge instead of M5 or M10).
Fuel Cartridge Model M28 (28 liters methanol in safety container). Requires M28 adapter.
DuoCartSwitch system (installed), allowing (2) fuel cartridges to be hooked up at the same time, emptying the first completely prior to automatically switching to the second. Compatible with M5 & M10 fuel cartridges. Requires two M28 adapters if using M28 cartridges.
GSM-2-SMS modem (installed), allowing remote monitoring of fuel cell status, alarms, and control commands via SMS text messaging (phone) and/or HyperTerminal program (computer), within appropriate (GSM type only) cellular data network coverage. A CDMA version is still under development. Requires optional serial port adapter. SimCard and cellular service plan not included.
Serial port adapter and Windows software setup instructions for laptop / modem interface.
Fuel Cartridge Level Sensor FS1 (installed), allowing remote monitoring of fuel level (alarm at fixed level only) via the optional modem.
Solar panel array 270 watts c/w ground/roof-mount angled stand (assembly and wiring by others). Approx 4’Wx4’L base area req’d.
Solar charge controller (installed) 12/24V, 20A, c/w low voltage disconnect (LVD). This LVD feature is recommended even if no solar will be used since it will turn off the load, preventing battery drainage & damage if the fuel cell runs out of fuel (or other similar failure). Fixed off/on setpoints (12V model = 11.5V/12.6V, 24V model = 23.0V/25.2V).

Pricing:
Basic Unit: $7,800
Fuel Cartridge M10 (10Liters): $180
M28 Adapter: $300
Fuel Cartridge M28: $220
DuoCartSwitch: $1,700
GSM-2-SMS modem: $1,200
Serial port adapter with software: $100
Fuel Cartridge Level Sensor FS1: $600
Solar Panel Array (270 watts): $1,900
Solar Charge Controller: $250

Methanol Fuel
Methanol Cost: $1.13 per gallon (Feb 2012 Global Spot Price)

Mobile Hybrid Power System

SkyTrailer Renewable Power Systems

SkyTrailer systems provide a hybrid solar, wind, battery, and diesel generator system built onto military-grade or other trailers. The system is built to combine mobility, rapid deployment, adaptability and high quality with relatively low maintenance. The system has been designed to deploy solar power, wind turbines, battery power, and diesel generator power in less than one hour.

The SkyTrailer stores and converts the power produced by the solar arrays and wind turbines to 120 volts, 60 Hz AC, 24 VDC, or other voltages and Hz to run user loads. All additional power produced (from the solar array, wind turbines, or the auxiliary generator) is stored in the battery banks. The diesel generator autostarts when the battery voltage falls below a preset level. Alternately, during long periods of cloudy weather, the diesel generator can share the electrical lead-acid battery bank charging load with the renewable energy sources. The generator can be switched to feed directly to the load without flowing through the battery bank.

The system generates 300W to 45kW of power depending on configuration.

Pricing:
$175,000 to $400,000 depending on power needs

ASTI Transportation Trailer Mounted Queue Detection

System is used successfully throughout the United States and Canada. Systems have run for over a year in -40 ºF weather in Manitoba.

Features

- Industrial grade trailer
- Microwave detection (typically the SmartSensor HD)
- Available as a portable unit or permanent mount
- Typical installation includes a 230 watt solar panel system
- Adjustable solar array for maximum exposure to sun
- Optional digital cellular communications
- Battery bank sized for 30-day autonomy (4-6 volt lead-acid batteries)

Have implemented propane generators in some border crossing locations.

Pricing:
$16,500 to 18,000 depending on capabilities
Upgrades to solar panel and trailer size available
Upgrades to include propane or diesel generators available

Grid Power

A typical cost from power companies yielded the following:
$400 to $800 for engineering and installation
$3 to $5 per foot for line extension

Wind Turbine

The two types of turbines shown have both advantages and disadvantages. The one on the left is more traditional and consequently less expensive. The one on the right takes advantage of wind from any direction and is supposedly less susceptible to being out of commission due to ice on the blades.

Pricing:
$900 to $2,200 for an appropriately sized wind turbine.

Summary of Technologies Available

Technology	Average Cost	Pros	Cons	Viable Solution?
Grid Power	$400 to $800 + $3 to $5 per foot depending on agency and location	Inexpensive to access many locations Maintenance costs for power system provided by local utility Prices increasing	High cost to access remote locations	Yes
Solar	$900 to $2,000	Known technology Inexpensive compared to some of the other options Prices decreasing	Not reliable under cloudy days Can be placed incorrectly Needs Maintenance Snow can interfere with panels	Yes
Wind Turbine	$900 to $2,200	Inexpensive to add to existing systems Can work especially well in conjunction with other systems Prices decreasing	Not reliable at all locations Need windy days Can be placed incorrectly Needs Maintenance	Yes, depending on location and in conjunction with other technologies
Wet-Cell Battery	$80 to $200	Inexpensive Sealed batteries need little to no maintenance	Non-sealed needs maintenance	Yes
PEM (Hydrogen) Fuel Cell System	$5,000 to $8,000 + fuel cost (hydrogen)	Location of count can be anywhere Fuel accessible in MN Prices decreasing	Fuel Cost Combustible Fuel Fuel under Pressure Needs Maintenance	No
DMFC (Methanol) Fuel Cell System	$4,000 to $12,000 + fuel cost (methanol)	Location of count can be anywhere Prices decreasing	Fuel Cost Combustible Fuel Needs Maintenance Fuel bought in other states	Yes
Trailer Counting System (solar)	$16,500 to $18,000	Location of count can be anywhere	Not reliable under cloudy days Can be placed incorrectly Needs Maintenance	Yes
Hybrid Power System (diesel, solar, wind)	$175,000 to $400,000 + fuel cost (diesel)	Multiple fuel types Location of count can be anywhere	Very High Cost Fuel Cost Needs Maintenance	No

Summary

Agencies throughout the United States and Canada were contacted to determine the current power sources that agencies use for powering their portable traffic count systems. Overall, the agencies have generally been connecting to the power grid through a local utility provider and then using solar panels with batteries where connecting to the local grid is impractical or costly. Solar panel size varies greatly depending on the agency. Solar panels should be sized appropriately for the area of the country and power needs.

- Massachusetts DOT: 20 Watt solar panel array
- Texas DOT: 40 Watt solar panel array was too small for needs, 80 Watt is now used
- Sirius Integrator: Typically installs an 80 Watt solar panel with their installations
- ASTI Transportation: Typically installs 230 Watt solar panel array on their systems
- Evergreen Technologies: Typically installs a 270 Watt solar panel array for their systems in conjunction with fuel cell batteries

Solar panels should be placed and oriented appropriately at least two times a year to ensure that the maximum power is attained from the solar panels. If planning for solar panel use, the traffic detection system should be placed appropriately to ensure that the panels have maximum sun exposure and are not blocked from the sun by trees, buildings, etc. This may be an opportunity to also ensure that the system is appropriately located to reduce the possibility of the system being a hazard on or near the roadway.

Wind turbines have been used or tested by some agencies, but success with them has been mixed. The most appropriate locations have consistent winds of over 10 mph and preferably up to averages near 15 mph. If used, they need to be used in conjunction with other methods, the most common of which is solar power. The tall poles necessary to obtain adequate wind speeds are a concern.

The type of batteries used in conjunction with solar power differs depending on the agency. The most success has been with gel sealed batteries but some agencies consider lead-acid batteries as most appropriate and most reliable in cold weather climates. The use of lead-acid batteries does require considerably more maintenance than gel batteries, which may be a disadvantage.

Of the types of fuel cells currently on the market, direct methanol fuel cells (DMFC) are likely the best option for use with a portable trailer. The tank size and potential hazard of hydrogen gas under pressure at the roadside likely eliminates polymer electrolyte membrane fuel cells (PEMFCs) as a reliable fuel cell solution. DMFCs run off of liquid methanol tanks that are smaller in size and can be located on the trailer to reduce the hazard. The contents are likewise not under pressure as it is a liquid. DMFC systems, while more expensive than just solar panels with traditional batteries, is less expensive than other multiple method trailer systems.

Recommendations

- Complete a training program with personnel that deploy the units to ensure appropriate:
  - Solar panel orientation
    - Reorient at least two times a year
  - Traffic detection system placement
    - Ensure trailer placement appropriate for detection system, reduce it as a roadside hazard, and ensure that solar panels have clear sight lines to the sun
- The correct sizing of solar panels should be further evaluated with solar panel manufacturers
  - Recommend that a minimum of three manufacturers be contacted as the calculations can differ between companies
- Review the type of batteries currently being deployed with units
  - Recommend testing wet-cell unsealed lead acid batteries for use in cold weather, but they must be maintained and water levels will need to be maintained at least once a month.
  - If maintenance cannot be performed regularly, continue to use gel sealed batteries
- Continue to use solar panels with batteries
- When a new trailer needs to be developed or obtained by MnDOT, develop and test the trailer with methanol fuel cells, in addition to solar panels
  - Methanol fuel cells are expected to drop in price over time

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