Interim Report
Deliverable 2.1:
Electro-Optical Sensors for Transportation Applications of the Restricted Use Technology Study

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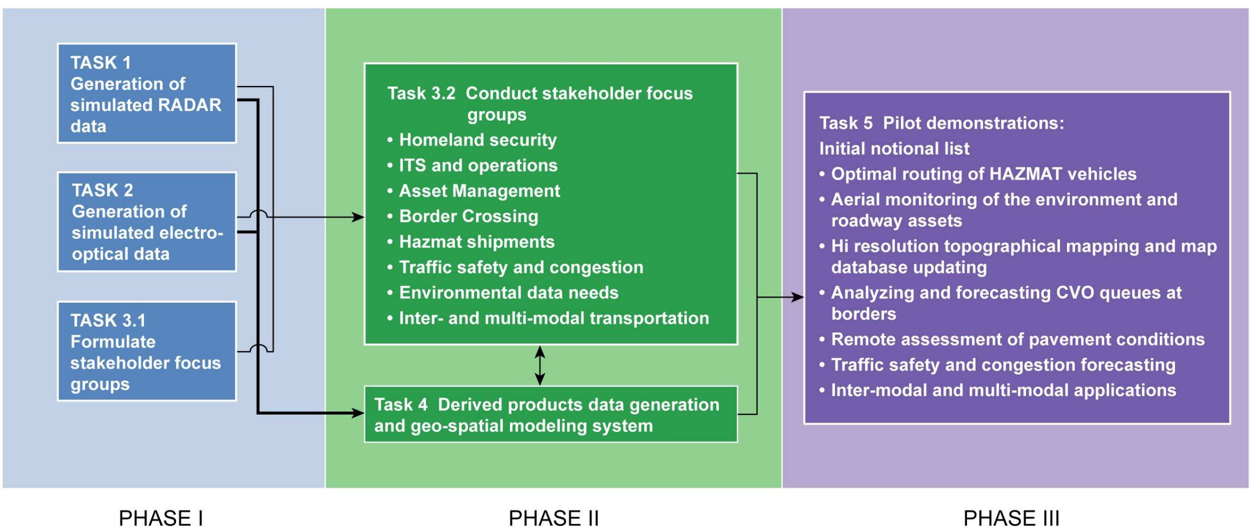
EXECUTIVE SUMMARY

The Altarum Institute, under contract to the Michigan Department of Transportation (MDOT), currently is engaged in a project called the “Altarum Restricted Use Technology Study.” This study, an 18-month effort, seeks to apply restricted use technology to the mandates of MDOT. The major phases of this project are illustrated in Figure 1.

Under Deliverable 2.1 of the Work Plan governing the Altarum Restricted Use Technology Study, the Altarum project team is required to produce an unclassified summary and comprehensive written report of Electro-Optical (EO) systems that can potentially address transportation problems. This report presents the fundamental concepts of remote sensing, reviews the categories of civil, commercial and military sensors with their platforms, and discusses potential application areas of EO systems, both in general and those specific to transportation. Together with its companion report on RADAR systems (Deliverable 1.1), this report will provide transportation experts with an overview of current resources and a foundation of potential applications.

Figure 1: Task Dependency within the Restricted Use Technology Study



EO sensing technologies have matured greatly during the last three decades. Major improvements include the transition from film to digital sensors, increased spectral coverage and resolution, the availability of high spatial resolution data from commercial satellites, LIDAR, and robust computer processing systems. EO systems may be divided into several major groups, including:

- High resolution panchromatic or multispectral sensors
- Moderate resolution multispectral
- Environmental synoptic sensors
- Hyperspectral
- LIDAR
- Thermal infrared

These sensors are found on a wide range of platforms including earth-orbiting satellites, manned aircraft, and unmanned aerial vehicles (UAVs).

EO sensors have been used for decades for surveillance, environmental research and monitoring, and mapping of cultural features. As discussed in this report, EO systems have great potential for addressing transportation issues in areas of:

- Asset Management
- Environmental Applications
- Inter- and Multi-modal Applications
- HAZMAT Shipments
- Traffic Congestion and Safety
- Border Crossings
- Homeland Security
- ITS and Operations

The Altarum team has completed this task, though the report will evolve by updates and revisions as the project progresses. The information discussed in this report will support the follow-on task of generating simulated EO data and will provide background information for the focus group sessions anticipated to be held in early 2006.

INTRODUCTION TO ELECTRO-OPTICAL SENSORS

The collection of remote sensing data began in the 19th century when cameras were first used to take aerial photographs from hot-air balloons. Even though the results were primitive by modern standards, these early pictures demonstrated the potential of remote sensing for mapping and surveillance activities.

Today, electronic sensors have largely replaced photographic film for capturing energy from the electromagnetic (EM) spectrum. These "electro-optical (EO) sensors" can collect a wealth of detailed information, both in visible and non-visible light, with great spatial and spectral detail.

Sensors may be mounted on a variety of supporting platforms, including earth-orbiting satellites, manned aircraft, or unmanned aerial vehicles (UAVs). Earth orbiting satellites provide stable platforms that can provide frequent repeat coverage at a cost comparable to airborne missions or less. Due to their high altitude, "distortions" in the imagery due to terrain effects are minimized. Airborne sensors, whether in manned aircraft or UAVs, have the advantage of being able to provide higher spatial resolution data and can be customized to a particular mission. Aircraft can be deployed at any time and are ideal platforms for collecting real time data. At this time, UAVs do not have a cost advantage over manned aircraft and there are substantial FAA safety issues involved in their operations, however they may have some potential uses for transportation, as will be discussed later

Spectral Range. EO sensors are designed to be sensitive to specific sections of the EM spectrum (see Figure 2), particularly from visible wavelengths through thermal infrared. The primary spectral regions sampled by EO sensors are provided in Table 1.

Figure 2: The Electromagnetic Spectrum

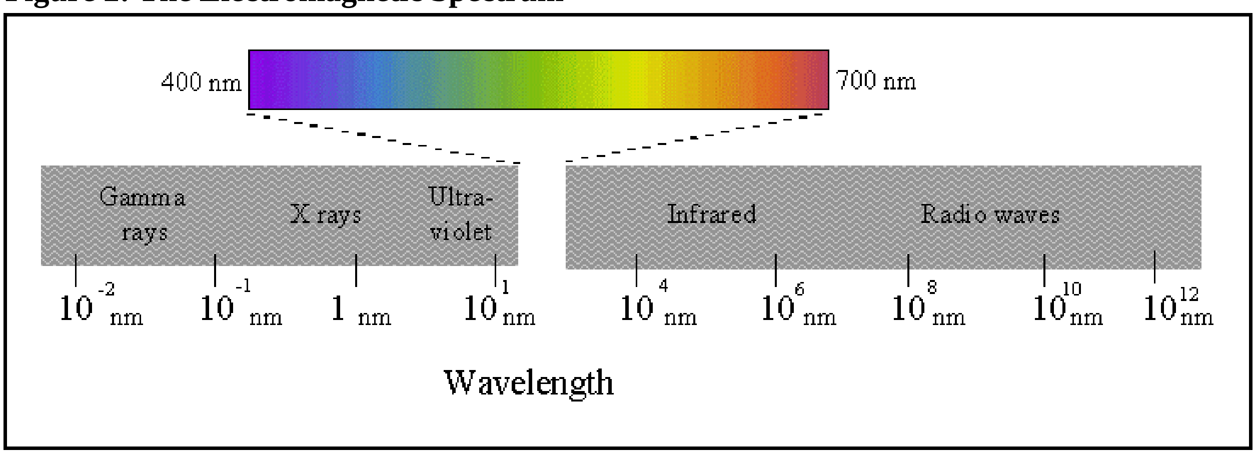


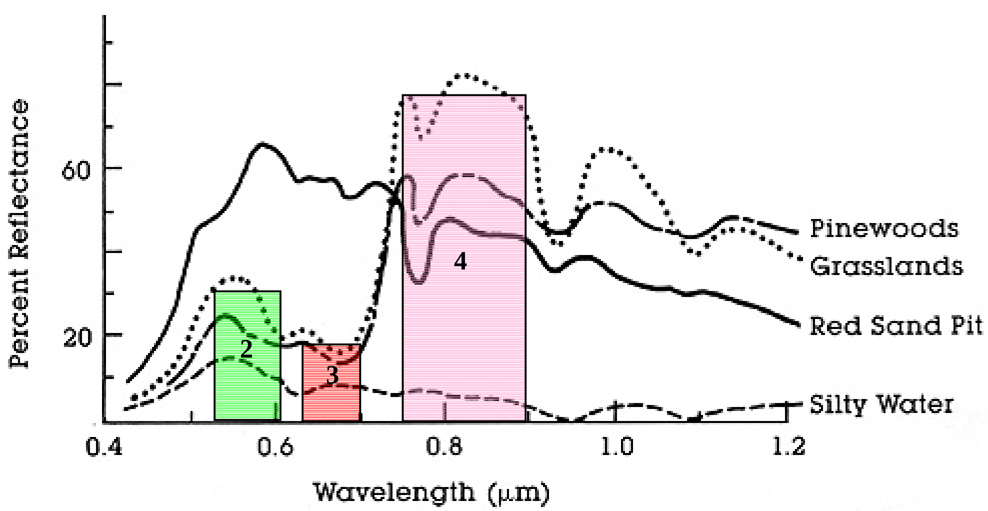
Table 1: Wavelength Ranges of Spectral Regions

Spectral Region	Wavelength Range (nm)
Visible blue	400 – 500
Visible green	500 – 600
Visible red	600 – 700
Near infrared (NIR)	700 – 1,000
Shortwave infrared (SWIR)	1,000 – 3,000
Midwave infrared (MIR)	3,000 – 6,000
Thermal infrared (TIR)	6,000 – 14,000

EO sensors may be categorized as *panchromatic*, *multispectral*, or *hyperspectral*, based on the number of bands or channels that they use to sample various slices of the EM spectrum. Panchromatic (or "pan") sensors have one broad channel responsive to visible light and often to NIR. This is analogous to a black and white photographic image. Because panchromatic sensors encompass a broad, energetic part of the EM spectrum, they are effective under dim illumination or where great optical magnification is required.

Multispectral (MS) sensors divide the spectrum into three to 40 discrete bands or channels. Multiple bands yield useful information on the composition of surfaces, based on their spectral curves (see Figure 3). In a similar way, the human eye perceives the differential reflectance of visible wavelengths as colors, however EO sensors have the advantage of seeing a much larger portion of the EM spectrum.

Figure 3: Spectral Curves for Soil, Vegetation, and Water. *Landsat ETM+ bands 2 (green), 3 (red), and 4 (NIR) are superimposed over the grasslands spectral curve.*



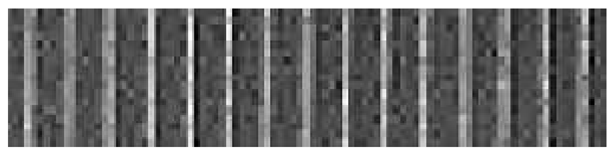
Hyperspectral sensors (HS) represent a more advanced progression of multispectral technology in which 100 to 200+ narrow-width spectral bands are collected. HS data yield much greater detail in spectral curves, which helps discriminate objects with similar spectra (e.g., pine trees vs. fir trees).

LIDAR, an acronym for *LIght Detection And Ranging,* is an optical system similar to radar in concept. LIDAR systems determine the distance to objects by measuring the time that it takes for an emitted laser beam to travel to the target and back to the instrument again. They can also measure speed and rotation of objects. One of the main applications of LIDAR is to generate highly detailed topographic data, but it has also been used effectively to measure atmospheric pollutants and to study cloud physics.

Resolution. The term, resolution, is used in several contexts within the realm of remote sensing. The four kinds of resolution include:

- Spatial Resolution – the ability to distinguish two close objects. The term is often used to describe the ground distance between the centers of two adjacent pixels (i.e., Ground Sample Distance or GSD). It should be noted that contrast has a significant impact on the ability to resolve small objects (see Figure 4). The spatial resolution of low earth orbiting sensors depends largely on their optics and electronics. With airborne sensors, altitude is an additional variable influencing spatial resolution.

Figure 4: Example of 1-m Pan Ikonos Imagery. *Ten-centimeter wide parking lot stripes are clearly visible due to their color contrast. Source: Schowengerdt, 2002*



- Spectral Resolution – the ability to approximate the true spectral curve of an object. As the number of sensor bands increase and their bandwidths decrease, spectral resolution becomes higher. Panchromatic sensors have very low spectral resolution; hyperspectral sensors have high spectral resolution.

- Radiometric Resolution – the ability to distinguish small changes in light intensity within a band or channel; also known as *quantitization*. Digital sensors convert light levels to numeric outputs, and the number of digital steps ranging from complete darkness to maximum light differs by sensor. For example, one sensor may be sensitive to 126 different levels of light (7-bit quantitization), whereas another sensor may be sensitive to 2048 levels of light (11-bit quantitization).

- Temporal Resolution – the frequency at which an area may be observed, also referred to as *revisit time*. For orbital sensors, the frequency of observation depends on its orbital parameters (e.g., altitude, inclination), swath width of an individual scene, the latitude of the target site, and whether the sensor is pointable to off-nadir targets. The temporal resolution of satellite-based sensors typically ranges from twice per day to once every 16 days. Because most remote sensing satellites are in near-polar orbits, higher latitudes are observed more frequently than areas near the equator. For airborne systems the revisit time is much more flexible, and in the near future it may be feasible to have continuous monitoring from high altitude UAVs for months at a time.

Swath Width. All sensors have technical limits to their data collection capacity, whether they are satellite-based or airborne. Consequently, high spatial resolution scenes generally have narrower swath widths than scenes with low spatial resolution (see Figure 5). For example, the scene dimensions of 4-m MS Ikonos imagery are about 11 km x 11 km, whereas the footprint size of 30-m MS Landsat ETM+ data is 185 km x 170 km. Image coverage may be increased by mosaicking several individual scenes collected over similar time periods.

Figure 5: Relationship between Spatial Resolution and Swath of Several Satellite Sensors

The swath width or footprint of a scene collected from an airborne platform varies greatly with the altitude of the aircraft and the selection of optics. For example, JPL's AVIRIS HS sensor is flown in two different aircraft: a Twin Otter turboprop airplane, flown at 13,000 ft. above ground level (AGL), and a modified U-2 aircraft flown at 65,000 ft. AGL. The corresponding swath widths of the two platforms are 2.1 km and 10.6 km, respectively.

EO Data Products. Early examinations of film-based remote sensing data relied on human interpretation to extract information. With the advent of digital EO sensors, computer systems have been used to create many useful products. Some of the more common products are:

- Data fusion – combining data from different sensors; often used to merge a high spatial resolution pan image with a lower spatial resolution multispectral image to simulate a high spatial resolution multispectral image (see Figure 6). This particular process is also sometimes known as *pan-sharpening*.

- Orthorectification – removal of spatial displacement of objects within a scene resulting from non-nadir view angles. Spatial displacement is often more severe with imagery collected from airborne sensors as opposed to orbital ones, or in locations with substantial topographic relief. Every point within an orthorectified scene appears to be viewed from directly overhead without horizontal displacement. The orthorectification process requires either, a) stereo pair images (i.e., two images from different view angles with substantial overlap), or b) a single image in combination with detailed terrain elevation data and excellent ground control.

- Digital elevation models (DEMs) – three-dimensional surface models generated from stereo-pair images in a process related to orthorectification; also a direct product of LIDAR data.

- Image classification – extraction of land cover classes based on the spectral signatures of pixels. As was seen in Figure 3, different materials have different spectral characteristics. Image processing programs can assign pixels to specific classes (e.g., pavement, water, broad-leaf trees) based on their spectral signatures. There are two major approaches to image classification: a) *unsupervised classification*, in which the user only specifies the number of desired classes and the computer uses statistical algorithms to group data based on their spectral responses, and b) *supervised classification*, in which the user selects training sites *a priori* in the imagery that have known land cover classes, followed by the computer assigning all image pixels to the classes based on the user's input (see Figure 7).

- Change detection -- a comparison of two images of the same location, from different times. Change detection can be used to analyze changes related to urban growth, agriculture, geologic activity, and natural resources.

Figure 6: 30-m Landsat TM data (left) Pan-sharpened with 5.8-m Indian IRS Pan Data (right)

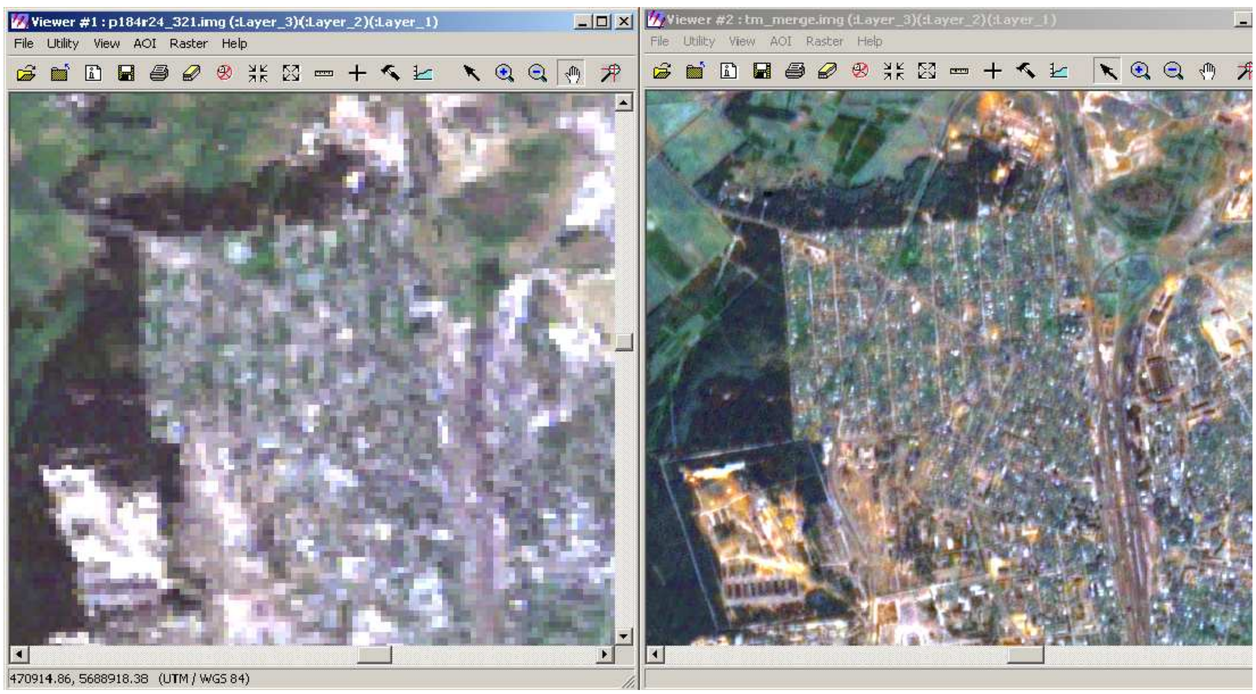
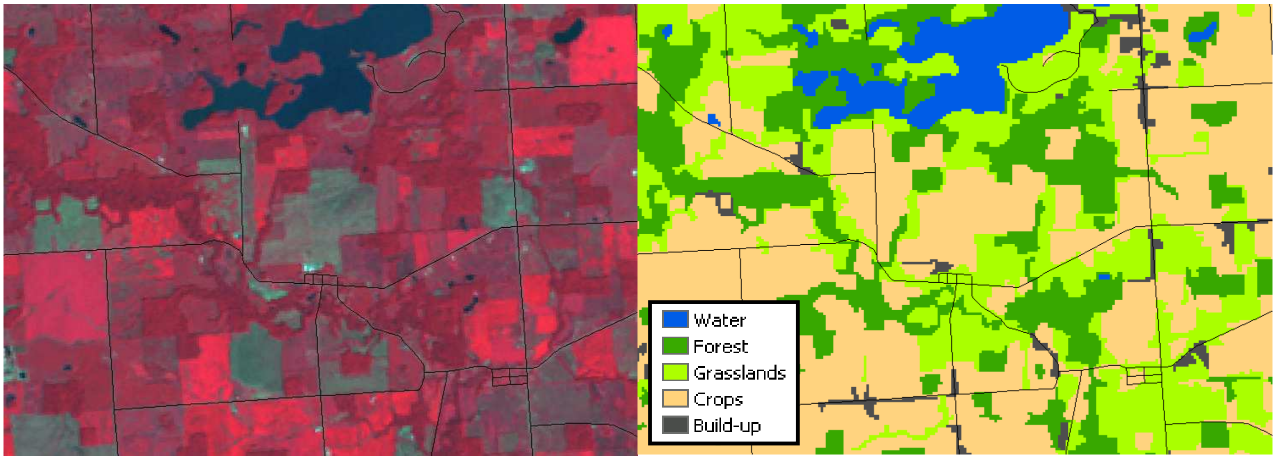


Figure 7: A 2004 Landsat 5 TM Sub-scene near Adrian, Michigan (left) and the Derived Supervised Classification (right) Showing Five Major Land Cover Types



CATEGORIES OF ELECTRO-OPTICAL SENSORS

For convenience, EO sensors may be divided into several major classes based on their spatial and spectral characteristics. These groups are summarized in Table 2. Details of prominent EO systems are given in Tables 3 - 6.

Table 2: Major Categories of EO Remote Sensing Sensors

Sensor Category	Typical Characteristics	Notable Examples	General Applications
High Spatial Resolution	Includes most airborne systems, and orbital systems with resolutions <5 m. Usually Pan or MS.	-Ikonos (Pan & MS) [1] -ADS40[2] -DMC[2] -Raven color CCD & IR camera[3]	Urban mapping Detailed DEM generation Surveillance Planning Small scale roughness
Moderate Spatial Resolution Multispectral	Includes many satellite-based sensors.	-Terra ASTER[1] -Landsat 7 ETM+[1] -IRS-1D LISS 3[1]	Vegetation mapping Wetlands Land cover mapping Change detection Plant stress Thermal detection
Environmental Synoptic / Low Spatial Resolution	Orbital MS sensors that collect global datasets for environmental research with great temporal resolution.	-NOAA AVHRR[1] -Terra MODIS[1] -DMSP OLS[1]	Weather monitoring Vegetation biophysics Water monitoring Atmospheric studies Fire detection
Hyperspectral	100 to more than 200 spectral bands with very narrow bandwidths.	-Hyperion[1] -AVIRIS[2] -Shadow HS imager[3]	Mineral exploration Vegetation discrimination Soil type Water quality Atmospheric sampling
LIDAR	Laser-based altimetry data	-ICESat GLAS[1] -ALTM 3100[2] -BATS[3]	Elevation mapping Small scale roughness Cloud physics Atmospheric pollutants Bathymetry

Notes: 1 = Satellite; 2 = Manned Aircraft; 3 = UAV

Table 3: Satellite-based EO Sensors (NA = Not Available)

Satellite	Agency or Company	Civil, Commercial, or Military?	Sensor	Spectral Bands			Swath Width (km)	Revisit Interval (days)	Cost/ Image*	Data Acquisition	Orbit		Status	Launched	Projected Lifetime (yrs)	Remarks	Contact
				# Bands	Spectral Range (nm)	Spatial Resolution at Nadir (m)				Special request or existing	Alt (km)	Inclination (deg)					
High Resolution (< 5 meters)																	
Cartosat-1	ISRO (India)	Commercial	Pan	1	500 - 850	2.5	30	5	TBD	Both	618	98.9	Data not yet available	2005	5	Multiple look angles	http://www.spaceimaging.com/
Corona	DoD (USA)	Military	Pan (film)	1	visible	2 - 8	64	various	$54 - $84	Existing	106 - 508	79 - 82.3	Terminated in 1972	1962 -1967	NA	Declassified film based imagery	http://edcsns17.cr.usgs.gov/EarthExplorer/
EROS A	ImageSat Int. (Israel)	Commercial	Pan	1	500 - 900	1.8	14	2 - 3	$980 - $2,350	Both	500	97.3	Operational	2000	4		http://www.imagesatintl.com/
Ikonos 2	SpaceImaging (USA)	Commercial	Pan	1	526 - 929	1	11.3	~ 3	$850 - $2,178	Both	681	98.1	Operational	1999	7		http://www.spaceimaging.com/
			MS	4	445 - 853	4											
OrbView-3	Orbimage (USA)	Commercial	Pan	1	450 - 900	1	8	<3	$420 - $830	Both	470	97.3	Operational	2003	5		http://www.orbimage.com/
			MS	4	450 - 900	4											
Quickbird 2	DigitalGlobe (USA)	Commercial	Pan	1	450 - 900	0.61	16.5	1 - 3.5	$4,350	Both	450	97.2	Operational	2001	>5		http://www.digitalglobe.com/
			MS	4	450 - 900	2.44											
SPOT 5	SPOT Image (France)	Commercial	HRG (pan)	1	480 - 710	2.5 - 5	60	3	$3,375 - $6,750	Both	822	98.7	Operational	2002	5		http://sirius.spotimage.fr/anglais/welcome.htm
Moderate Resolution (5 to 30 meters)																	
EO-1	NASA/USGS (USA)	Civil	ALI	10	433 - 2,350	10 - 30	37	~5	$250	Both	705	98.2	Operational	2000	1	Limited collection ability; primarily research Scene length 185 km	http://edcimswww.cr.usgs.gov/pub/imswelcome/
			Hyperion	220	450 - 1,250	30	7.7	~5	$500								
IRS-1D	ISRO (India)	Commercial	PAN	1	500 - 750	5.8	70	5	$2,500	Both	736 - 825	98.6	Operational	1997	3		http://www.spaceimaging.com/
			LISS3	4	520 - 1700	23.5 - 70.5	142 -148	24	$2,500								
Landsat 5	USGS (USA)	Civil	TM	7	450 - 12,500	30 - 120	185	16	$425	Existing	705	98.2	Operational	1984	5	Functioning with limited capabilities; free archive data available 2nd & 3rd scenes $200	http://edcsns17.cr.usgs.gov/EarthExplorer/
Landsat 7	USGS (USA)	Civil	ETM+	8	450 - 12,500	15 - 60	185	16	$250 - $300	Existing	705	98.2	Unhealthy	1999	5	SLC problem since May 2003; free archive data available	http://edcsns17.cr.usgs.gov/EarthExplorer/
Resourcesat-1	ISRO (India)	Commercial	LISS3	4	520 - 1,700	23.5	142	24	$2,750	Both	817	98.7	Operational	2003	5		http://www.spaceimaging.com/
			LISS4	3	520 - 860	5.8	23.9 - 70.3	5	$2,750								
SPOT 5	SPOT Image (France)	Commercial	HRG (MS)	4	500 - 1,750	10 - 20	60	3	$3,375 - $6,750	Both	822	98.7	Operational	2002	5		http://sirius.spotimage.fr/anglais/welcome.htm
Terra	ERSDAC (Japan)	Civil	ASTER	14	520 - 11,650	15 - 90	60	8 - 16	$0 - $80	Both	705	98.2	Operational	1999	6	Limited collection ability; primarily research	http://edcimswww.cr.usgs.gov/pub/imswelcome/

** Prices may not include orthorectification, precision accuracy, data fusion, or special acquisition charges*

Table 3: (continued)

Satellite	Agency or Company	Civil, Commercial, or Military?	Sensor	Spectral Bands			Swath Width (km)	Revisit Interval (days)	Cost/ Image*	Data Acquisition	Orbit		Status	Launched	Projected Lifetime (yrs)	Remarks	Contact
				# Bands	Spectral Range (nm)	Spatial Resolution at Nadir (m)				Special request or existing	Alt (km)	Inclination (deg)					
Low Resolution (>30 meters)																	
DMSP (F13, F14, F15 & F16)	Air Force (USA)	Military	OLS	2	400 - 13,400	550 - 2,700	3,000	0.5	$40	Existing	831 - 842	98.6 - 98.9	Operational	1995 - 2003	2 - 3	Three day/night, one dawn/dusk	http://spidr.ngdc.noaa.gov/spidr/
IRS-1D	ISRO (India)	Commercial	WiFS	2	620 - 860	189	810	5	$800	Both	736 - 825	98.6	Operational	1997	3		http://www.spaceimaging.com/
NOAA-18	NOAA (USA)	Civil	AVHRR/3	6	580 - 12,500	1100	2399	1	$190	Existing	854	98.7	Operational	2005	>2	Several older systems on standy or operational	http://edcsns17.cr.usgs.gov/EarthExplorer/
Resourcesat-1	ISRO (India)	Commercial	AWifS	4	520 - 1,700	56	730	24	$850	Both	817	98.7	Operational	2003	5		http://www.spaceimaging.com/
SPOT 5	SPOT Image (France)	Commercial	Vegetation	4	430 - 1,750	1,000	2,200	1	$0 - $210	Existing	822	98.7	Operational	2002	5		http://free.vgt.vito.be/login.php
Terra & Aqua	NASA (USA)	Civil	MODIS	36	405 - 14,385	250 - 1,000	2,330	1 - 2	$0	Existing	705	98.2	Operational	1999 & 2002	6		http://edcimswww.cr.usgs.gov/pub/imswelcome/
Terra	NASA (USA)	Civil	MISR	4	425 - 847	275	360	2 - 9	$0	Existing	705	98.2	Operational	1999	6	Multi-angle imager	http://edcimswww.cr.usgs.gov/pub/imswelcome/
Future Systems																	
ALOS	EORC (Japan)	Civil	PRISM	1	520 - 770	2.5	70	46	TBD	Request	692	98.2	Pre-launch	(2005)	3 - 5	Multiple look angles	http://www.eorc.nasda.go.jp/ALOS/
			AVNIR-2	4	420 - 890	10											
Cartosat-2	ISRO (India)	Commercial	Pan	1	NA	<1	10	4	TBD	Request	630	97.9	Pre-launch	(2006)	5		http://www.isro.org
EROS B	ImageSat Int. (Israel)	Commercial	Pan	1	500 - 900	0.87	13.5	1	TBD	Request	500	NA	Pre-launch	(2006)	10		http://www.imagesatintl.com/
			MS	4	480 - 900	3.48											
NPOESS	IPO (USA)	Civil/Military	VIIRS	22	400 - 12,400	375 - 750	3000	0.25	TBD	Global collection	833	98.7	Pre-launch	(2009 - 2010)	5 - 6		http://www.ipo.noaa.gov/
NPP	IPO (USA)	Civil/Military	VIIRS	22	400 - 12,400	375 - 750	3000	0.5	TBD	Global collection	824	98.7	Pre-launch	(2008)	5	Bridge between Terra/Aqua and NPOESS	http://www.ipo.noaa.gov/Projects/npp.html
Orbview-5	Orbimage (USA)	Commercial	PAN	1	450 - 900	0.41	15.2	<3	TBD	Request	684	NA	Pre-launch	(2007)	7+		http://www.orbimage.com/
			MS	4	450 - 900	1.64											
WorldView	DigitalGlobe (USA)	Commercial	Pan	1	450 - 800	~0.5	16.8	1 - 3	TBD	Request	770	98	Pre-launch	(2006)	NA		http://www.digitalglobe.com/
			MS	8	423 - 1,050	1.8											

** Prices may not include orthorectification, precision accuracy, data fusion, or special acquisition charges*

Table 4: EO Sensors on Manned Aircraft (NA = Not Available)

Airborne System	Organization	Sensor Type	Array Size	Spectral Bands			FOV (degrees)		Remarks	Contact
				# Bands	Spectral Range (nm)	Spatial Resolution at 5000' AGL (m)	Cross Track	Along Track		
Pan/Multispectral										
AA497 Airborne Digital Camera	Argon ST (USA)	MS	2,020 x 2,041	5	420 - 772	0.43	37	37	Use spinning filter wheel for MS	http://www.argonst.com/
ADS40 Airborne Digital Sensor	Leica (USA)	Pan	12,000 x 2	1	465 - 680	0.1	64	NA		http://gis.leica-geosystems.com/products/ads40/default.asp
		MS	12,000 x 4	4	430 - 885					
AirCam	Kestral Corp. (USA)	MS	NA	4 (5)	350 - 1,100 (1,700 - 5,000)	1.5	51	51	Can be flown at 4,570 m unpressurized	http://www.kestrelcorp.com/
CAMIS 4768p	Flight Landata, Inc. (USA)	MS	782 x 582	4	410 - 840	0.082	43.6	33.4	Can be flown at 3,050 m unpressurized	http://flightlandata.dyndns.org/products/
DIMAC	DIMACSYSTEMS (Belgium)	MS	5,400 x 4,080	4	Vis/IR	0.09 - 0.39	36.2 - 78.4	27.5 - 62.9		http://www.dimacsystems.com/
DMC	Intergraph (USA)	Pan	7,000 x 4,000	1	NA	0.16	69.3	42	Can be flown at 8,000 m unpressurized	http://www.intergraph.com/dmc/
		MS	3,000 x 2,000	5	400 - 850					
DSS	ApplAnix (Canada)	Color, CIR	4,092 x 4,077	4	400 - 920	0.25 - 0.39	37 or 55.4	37 or 55.4	Can be flown at 6,100 m	http://www.applanix.com/
Ultracam-D	Vexcel (USA)	Pan	11,500 x 7,500	1	NA	0.11- 0.18	55	37		http://www.vexcel.com/products/photogram/ultracam/
		MS	4,008 x 2,672	4	Vis/IR	0.49	65	46		
Hyperspectral										
AISA Eagle	SPECIM (Finland)	HS	1000	244	400 - 1000	1.1	39.7	29.9		http://www.specim.fi/
AVIRIS	JPL (USA)	HS	614	224	400 - 2,500	3.6 & 17*	30	NA	Primarily research	http://aviris.jpl.nasa.gov/
CASI 550	ITRES Research Limited (Canada)	HS	550	288	400 - 1,000	2	40.4	0.077	Bands are programmable; can be flown at 3,048 m unpressurized	http://www.itres.com/
HDHIS	Flight Landata, Inc. (USA)	HS	752	240	447 - 906	1.1 x 2.4	9.5	NA		http://flightlandata.dyndns.org/
HyMap	Integrated Spectronics (Australia)	HS	~520	100 - 200	450 - 2,500 3,000 - 5,000 8,000 - 12,000	1.5 - 4.5	30 - 65	NA	Can be flown at 4,500 m	http://www.intspec.com/
HyperSpecTIR	SpecTIR (USA)	HS	1024	227	450 - 2,450	1.5	~60	NA		http://www.spectir.com/
SASI 600	ITRES Research Limited (Canada)	HS	600	160	950 - 2,450	1.7	40	NA		http://www.itres.com/

* at 13,000' and 65,000' respectively

Table 5: UAVs With EO Sensors (NA = Not Available)

UAV System	Manufacturer	Sensors	Endurance (hrs)	Max. Payload (kg)	Energy Source	Altitude Capability (ft)	Cruise Speed (kph)	Range (km)	First Flight	Remarks	Contact
Micro/Mini UAVs											
Black Widow	AeroVironment (USA)	CMOS video camera (B&W/Color)	0.5	~0.006	Battery	769	48	1.8	1999		http://www.aerovironment.com/
Border Hawk I	American Border Patrol	Color video; IR camera	4	NA	Gasoline (?)	500	NA	>6.2	~2003	Border patrol applications	http://www.americanborderpatrol.com/
Desert Hawk	Lockheed Martin (USA)	3 video cameras; IR camera	1	0.5	Battery	150	92	11	2001	Onboard tape and video streaming	http://www.lockheedmartin.com/
Javelin	BAI Aerosystems, Inc. (USA)	Steerable TV camera	2 - 4	2.7	Gasoline or battery	3,000	64	8	NA		http://www.bai.aero/exdrone.html
Pointer	AeroVironment (USA)	Color or IR video	1.5	0.9	Battery	NA	29 - 80	10	1986	Man portable	http://www.aerovironment.com/
Raven	AeroVironment (USA)	CCD color video; IR Camera	1.5	1	Battery	15,000	45 - 95	10	2001	Back packable	http://www.aerovironment.com/
Close/Short Range UAVs											
Exdrone	BAI Aerosystems, Inc. (USA)	SONY EVI Electronically-Stabilized TV; Indigo "Omega" IR	2.5	11	Gasoline	10,000	144	120 - 360	1986		http://www.bai.aero/exdrone.html
Pioneer	Pioneer UAV, Inc. (USA/Israel)	MKD-200A TV; MKD-400C FLIR; 12DS EO/FLIR	5.5	45	AVGAS	15,000	147	185	1985		http://www.puav.com/intro.asp
Shadow	AAI Corp. (USA)	Advance EO-IR; Hyperspectral Imager	>5	27	AVGAS	15,000	139	59	~2000		http://www.shadowtuav.com/
Medium Altitude Long Endurance UAVs											
Aerosonde	Aerosonde Robotic Aircraft Ltd. (Australia)	Olympus still camera; Video cameras; KT11 IR sensor	40	1	Gasoline	20,000	112	3,330	1997		http://www.aerosonde.com/
I-Gnat	General Atomics (USA)	Streaming TV; Low-light TV	48	91	AVGAS	25,000	193	2,780	~1998		http://www.uav.com/
Hermes 450	Silver Arrow (Israel)	CoMPASS IV FLIR and color/BW TV	17	150	Gasoline (?)	20,000	130	2,200 (est)	before 1999	Border patrol applications	http://www.elbitsystems.com/
Hunter II	Northrop Grumman (USA)	ScanEagle A-15 (EO/IR)	29	455	Heavy fuel	28,000	130	992	2004	Border patrol applications	http://www.is.northropgrumman.com/
Predator	General Atomics (USA)	Color video FLIR	40	204	AVGAS	25,000	134	740	1995	Long military history	http://www.uav.com/
High Altitute Long Endurance UAVs											
Altus II	General Atomics (USA)	Wide angle TV; Digital multispectral sensor	24	145	Gasoline	65,000	130	735	1996	Used to detect fires	http://www.uav.com/
Global Hawk	Northrop Grumman (USA)	Electro-optical (400 - 800 nm); Infrared (3.6 - 5 microns)	35	909	Heavy fuel (JP-8)	65,000	638	22,200	1998	Has 10" telescope	http://www.is.northropgrumman.com/
Global Observer	AeroVironment (USA)	TBD	>168	455	Liquid hydrogen	65,000	NA	global	2005 (prototype)	Under development	http://www.aerovironment.com/
Hale Mercator	QinetiQ (UK)	TBD	months	2	Solar cells	60,000	NA	limitless	(2006)	Under development	http://www.qinetiq.com/

Table 6: LIDAR Systems (NA = Not Available)

Instrument	Manufacturer / Operator	Applications	Horizonal Resolution (m)	Vertical Accuracy	Operational Range	Maximum Swath (m)	Primary Use	Remarks	Contact
Satellite									
CALIOP	CNES (France)	Clouds & aerosols	333	30 m	705 km	90	Research	Launch expected late-2005	http://smsc.cnes.fr/CALIPSO/GP_satellite.htm
GLAS	NASA (USA)	Polar ice-sheet topography; cloud profiles	170	1 - 10 m	600 km	70	Research	On ICESat	http://icesat.gsfc.nasa.gov/
Manned Aircraft									
ABDIAL	NOAA (USA)	Air pollutants & aerosols	15 - 90	Not Applicable	2,300' - 11,500'	NO	Research		http://www.etl.noaa.gov/et2/instruments/uv_dial/
ALS40	Leica Geosystems (USA)	Topography	Variable	NA	1,600' - 15,400'	NA	Commercial		http://www.gis.leica-geosystems.com/
ALTM 3100	Optech, Inc. (Canada)	Topography	NA	15 - 35 cm	260' - 11,500'	3,200	Commercial		http://www.optech.ca/
ATM	NASA (USA)	Polar ice & glaciers	NA	NA	1,300' - 2,600'	NA	Research		http://aol.wff.nasa.gov/aoltm.html
CLS	NASA (USA)	Cloud profiles	20	7.5 m	65,000'	NA	Research	Flies in ER-2	http://virl.gsfc.nasa.gov/er2cls.html
PAS	Ophir Corp. (USA)	Aerosols	NA	10 m	50,000'	NA	Military	Installed on B-2	http://www.ophir.com/
RASCAL	NASA (USA)	Topography	1.5	5 - 20 cm	NA	NA	Research		http://denali.gsfc.nasa.gov/research/laser/rascal/index.html
SHOALS	Optech, Inc. (Canada)	Topography	2	25 cm	1,000' - 2,300'	406	Commercial		http://www.optech.ca/
		Bathymetry	2.5	25 cm	650' - 1,300'	232	Military	Max. depth 50 m	
Spectrum	Spectrum Mapping, LLC (USA)	Topography	1 - 5	30 cm	13,000'	5,000	Commercial		http://www.enerquest.com/rem-lidar-systems.html
UAV Platform									
BATS	Optech, Inc. (Canada)	Bathymetry Topography	2 - 5	NA	650' - 2,300'	NA	Military	Bathymetry to 30 m depth	http://www.optech.ca/
CDL	Lawrence Livermore National Laboratories (USA)	Cloud profiles	50	~12 cm	65,000'	NA	Research		http://www-phys.llnl.gov/V_Div/CDL/CDL.html#CDL

A description of each of the major groups of sensors follows.

High Spatial Resolution

These systems offer spatial resolutions of less than five meters, and frequently less than one meter (Figure 8). This group includes several commercial satellites, such as Ikonos 2, Quickbird 2, OrbView-3, and Cartosat-1, and virtually all airborne systems (manned and UAV). This group also includes some declassified intelligence data from the 1960s, which can be useful for historical analyses.

Sensors in this group may be panchromatic or multispectral, though usually limited to blue, green, red, and NIR. Airborne systems can capture scenes with spatial resolutions of less than 10 cm. Pan sensors on satellite platforms generally have about four times better spatial resolution than their MS counterparts. Swath widths are generally 10 to 30 km for orbital platforms and about one kilometer for airborne systems. Orbital platforms usually have pointable sensors that can acquire off-nadir targets, thus shortening the revisit cycle, otherwise the revisit time would be on the order of weeks.

Figure 8: Comerica Park in Detroit, Michigan from Ikonos 2. *Source: SpaceImaging.*

High spatial resolution data may be used to perform precise mapping tasks for urban areas, to create detailed DEM data, to conduct surveillance, and to assist with city planning. Such imagery is relatively expensive (per km^2) as compared to moderate or low spatial resolution data.

Moderate Spatial Resolution Multispectral

This category includes the earliest civilian satellite-based remote sensing systems, providing spatial resolutions between five and 30 meters. Some examples from this group of include Landsat 5 TM, Landsat 7 ETM+, Terra ASTER, and Resourcesat-1.

Moderate spatial resolution multispectral images have swath widths between 24 and 185 km, yielding scenes many times larger than the high spatial resolution sensors. Imagery is also lower cost (per km^2), and sometimes available at no cost.

The spectral bands often extend into SWIR and TIR wavelengths, giving the user more tools for distinguishing materials and temperature. These systems are particularly well suited for land cover mapping, studying plant stress, long-term change detection, and geologic studies.

Low Resolution/Environmental Synoptic

Environmental synoptic sensors are similar to moderate resolution multispectral instruments, but have much coarser spatial resolution (56 to >1,000 m) and much wider swaths, up to 3,000 km. Because of their broad swaths, these instruments have the highest temporal frequency, being able to image the entire earth within two days or less. Some notable systems include NOAA-AVHRR, Terra/Aqua MODIS, and the military's DMSP OLS sensors.

These systems are used extensively for scientific research or environmental monitoring on a global basis, including meteorological conditions, vegetation biophysics, ocean phenomena, atmospheric conditions, and fires.

A new generation of satellites, called the NPP and NPOESS missions, will have VIIRS sensors that will replace AVHRR, MODIS, and OLS. These systems are scheduled to launch from 2008 to 2010.

Hyperspectral

Hyperspectral sensors can approximate spectral curves of surface materials much more precisely than broader multispectral bands. Each band is only a few nanometers wide in contrast to multispectral bands, which are typically 50 to several hundred nanometers in bandwidth.

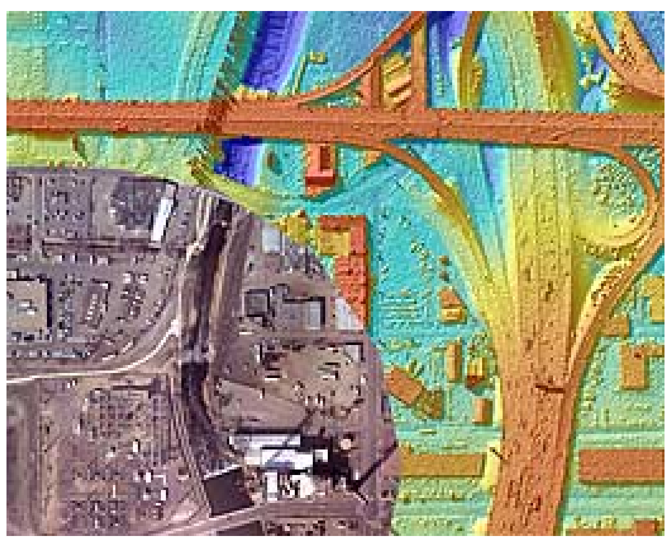
To date, most hyperspectral sensors have been limited to manned aircraft platforms, with AVIRIS being the best known. Other airborne HS sensors include AISA Eagle, CASI 550, HyMap, HyperSpecTIR, and SASI 600. The Hyperion sensor onboard the EO-1 satellite has proven the feasibility of collecting hyperspectral data from orbit. At least one UAV, the Shadow, utilizes a hyperspectral sensor within its suite of instruments.

The detailed spectral data obtained from hyperspectral sensors allows users to discriminate surface materials that are indistinguishable in multispectral data. Thus, they are robust tools for identifying minerals, building materials, vegetation, soil properties, and water quality. Though hyperspectral research has largely been in the scientific domain, it is likely that such data will find greater uses for civil and commercial applications in the near future.

LIDAR

As with hyperspectral sensors, most LIDAR systems are operated from manned aircraft. Their primary use has been for capturing detailed altimetry data, however they are also capable of collecting data on atmospheric pollutants, cloud phenomena, and bathymetry. Users have embraced this technology for topographic mapping of urban areas (Figure 9).

Figure 9: A High Spatial Resolution Pan Image Draped Partially over a LIDAR-derived 3-D Surface (in false color). *Source: Merrick*



LIDAR systems have been tested on several earth-orbiting platforms. In 1994 experiments were conducted on space shuttle flight STS-64 to measure atmospheric parameters with LIDAR. The

ICESat GLAS sensor, launched in 2003, was the first LIDAR instrument for continuous global observations of the earth. ICESat GLAS provides topographic data for ice-sheets and the height and thickness of cloud layers. A LIDAR instrument onboard the Calipso satellite, scheduled for launch in late-2005, will also provide data on cloud and aerosol physics. LIDAR systems are also under development for UAV platforms, which could provide near-real time data in hazardous conditions.

Thermal

Many EO sensors, such as Landsat TM and ETM+, ASTER, MODIS, AVHRR, DMSP OLS, and HyMap, have bands that are sensitive to thermal infrared radiation emitted from surfaces. These bands can approximate surface temperatures and are useful for determining water characteristics and identifying wetlands. High spatial resolution data from an airborne thermal infrared sensor (e.g., HyMap) could be used to perform car counts.

TRANSPORTATION APPLICATIONS

There are many transportation issues that can be successfully addressed with remote sensing technologies in a cost-effective manner. These areas of support include asset management, environmental data, inter- and multi-modal transportation, HAZMAT shipments, traffic safety and congestion, border crossing, homeland security, and intelligent transportation systems / operations. A matrix describing how each of the major categories of EO sensors can potentially contribute to solving transportation requirements is given in Table 7. Table 7 will be updated using results from the focus groups.

Asset Management

Asset management is one of the core responsibilities of transportation departments. High spatial resolution imagery from satellites or manned airborne sensors can support detailed infrastructure mapping and accurate geolocation, especially when augmented with GPS. These data can also be used to identify roadside features and inventory structures along the right-of-way. Hyperspectral data from airborne platforms may be used to distinguish paving materials and conditions. Airborne LIDAR can provide accurate 3-D information for support of mapping activities and can generate topographic data for project planning. Moderate spatial resolution multispectral data from satellites can allow the user to quantify green space along transportation corridors and to study land cover changes on a regional scale due to development.

Worker safety is a major concern for crews who must collect asset data on site in busy transportation corridors. The use of remote sensing could reduce the need for putting transportation work crews at risk.

Environmental Data

Environmental assessments are a requirement as part of the planning and design process of major transportation projects. Traditionally, these data have been obtained by ground surveys and the literature. Remote sensing has a long history of being used to map natural resources and land cover at various scales, and is being used more for environmental reports. At a minimum, high spatial resolution scenes can provide accurate base maps for project planning and development. Multispectral and hyperspectral images can provide detailed land cover information for proposed projects. Currently, jurisdictional wetlands, must be surveyed from the ground, however with thermal infrared data and advances in sensor capabilities, this survey process may be augmented or eventually replaced by remote sensing approaches. Remote sensing surveys could also identify candidate areas for the construction of new wetlands as part of a mitigation effort.

Airborne LIDAR can provide topographic data for environmental planning and contribute to 3-D visualizations, which give planners and concerned citizens a chance to preview the environmental impacts of transportation projects before breaking ground. Differential absorption LIDAR (DIAL) systems, such as ABDIAL, have the capability of detecting atmospheric pollutants that may originate from transportation systems.

Table 7: Potential Utility of EO Systems for MDOT Application Areas (NA = Not Applicable)

Application / EO Type	Asset Management	Environmental Data Needs	Inter- & Multi-Modal Transportation	HAZMAT Shipments	Traffic Safety & Congestion	Border Crossing	Homeland Security	ITS / Operations
High Spatial Resolution (satellite, UAV, manned aircraft)	Infrastructure mapping & geolocation, infrastructure inspection, roadside features, inventories	Detailed corridor mapping, base maps	Port and shipping activities, infrastructure and facility mapping, asset assessment, utilization assessment	UAV real time monitoring of incidents	Traffic patterns, study of problematic areas, accident detection & verification, infrastructure failure, fog, avalanches, floods	Traffic queues, infrastructure inspection, parking demand	Surveillance from airborne sensors, intelligence, disaster assessment	Traffic impedance & modeling, congestion detection, travel time, parking demand
Moderate Spatial Resolution MS (satellite)	Green space, land cover change	Support of EA process, land cover classification, wetlands	Water quality, corridor studies, ATV impacts	Environmentally sensitive areas, route planning, population centers	Alternate route planning	Border mapping	Evacuation route planning, disaster planning	Corridor modeling
Environmental Synoptic (satellite)	NA	Dynamic regional changes	Water quality	Weather conditions in near real-time	NA	NA	Atmospheric dispersal	NA
Hyperspectral (manned aircraft)	Paving material & condition	Precise land cover classification, wetlands	NA	Chemical spill detection	NA	Precise land cover classification	NA	NA
LIDAR (manned aircraft)	Topography data for planning, 3-D mapping of structures	DEM analysis, project visualization, air pollution	Airport glide paths, topography, bathymetry, 3-D airport layout plans	Slope data for runoff models	Air pollution, fog, avalanches, flood risk	Infrastructure mapping	Infrastructure mapping, flood modeling	Vehicle speed, communication sites
Thermal	NA	Water parameters Wetlands	NA	High temperatures	Car counts	NA	NA	Car counts

Environmental synoptic sensors, which usually have a frequent revisit period, are a low-cost approach for monitoring dynamic environmental changes over large regions.

Inter- and Multi-Modal Transportation

Inter- and multi-modal transportation systems include water, rail, and air transport, as well as recreational access, such as bicycle paths and ATV trails. As with asset management high spatial resolution data can be used to generate detailed base maps with precise geolocation information. High altitude long endurance (HALE) UAVs could provide continuous monitoring of port activities, although there are considerable technical and safety issues to overcome before such systems will be available. Multispectral or hyperspectral systems can map corridors for scenic bike paths, detect negative impacts of ATVs, and monitor water quality near seaports.

LIDAR has been used to model 3-D structures around airports and to monitor plant growth within the glide paths of approaching aircraft. Topographic and bathymetric information can be obtained from LIDAR for planning new transportation facilities.

HAZMAT Shipments

HAZMAT issues may be divided into two phases: planning and emergency response. For planning, multispectral data can be used to map environmentally sensitive areas and population centers along HAZMAT corridors. Such data can also be used as part of the HAZMAT route planning process. LIDAR-derived topographic data can be used to generate accurate maps of slopes and drainages.

During an incident, there is a strong need for near real time data in potentially dangerous situations. Short duration low flying UAVs are ideal platforms for obtaining high spatial resolution data in real time without jeopardizing worker safety. Environmental synoptic satellites can provide weather data in near real time, which can be input into dispersion models. Thermal infrared data can identify areas with high thermal signatures.

Traffic Safety and Congestion

Maintaining traffic safety and monitoring traffic congestion are major transportation issues. As with HAZMAT applications, remote sensing can contribute to long-term planning related activities or provide more immediate needs during spontaneous events. High spatial resolution data from satellites or airborne platforms can help engineers discern consistent problematic areas and design safe solutions for improving traffic flow. LIDAR can be used to detect atmospheric pollutants that correlate with predictable traffic patterns. Thermal infrared data collected from airborne platforms can provide estimates of car counts.

Remote sensing can be extremely beneficial during unusual disruptions in traffic. Data from airborne platforms, such as the HALE UAV systems under development, could detect and verify accidents and identify alternative routes in real time. These high spatial resolution sensors and LIDAR can also detect dynamic transportation risks, such as fog, avalanches, and flooding.

Border Crossing

Managing international border crossings in Michigan combines elements of asset management, environmental concerns, traffic congestion, inter-modal transportation, and security. Michigan’s border crossings are some of the busiest in the U.S. Six percent of the U.S. gross national product (GNP) passes through the Michigan-Canada border. In rail traffic alone, rail crossings at Port Huron and Detroit rank number two and three in the nation for economic trade. Maintaining efficient, yet secure, border crossings is essential to the economies of Michigan and Canada.

Remote sensing can provide information for examining existing border infrastructure and for planning and developing transportation improvements. High spatial resolution data can be used for inspecting infrastructure and for monitoring parking demand. If collected in near real time mode, such data can detect anomalous behavior, monitor traffic queues, and predict crossing times. LIDAR can produce 3-D renditions of transportation infrastructure and produce topographic or bathymetric maps for project planning. Moderate spatial resolution multispectral and hyperspectral sensors can provide land cover information for extensive border corridors.

Homeland Security

Homeland security is a prominent issue -- not only because of the threat of terrorism, but also for response to natural catastrophes. Remote sensing can provide information that is useful for advance preparation and for emergency response. High spatial resolution can be a source of intelligence and a tool for scenario development. Moderate spatial resolution data can assist with disaster planning and the identification of effective evacuation routes when combined with other regional datasets. Topographic information from airborne LIDAR sources can be used for flood modeling scenarios.

Several UAVs, including the Hermes 450 and the Border Hawk, have demonstrated their ability to detect in real time illegal aliens crossing from Mexico into Arizona (Figure 10). When equipped with IR sensors UAVs can even be effective at detecting activity at night. Plans are underway to expand the surveillance program by introducing the Hunter II.

Figure 10: Border Hawk (inset), a Low-flying Mini-UAV, Observes Vehicles and People near the U.S.-Mexico Border. *Source: American Border Patrol*

During a security crisis the appropriate sensors can be utilized to gather information rapidly from a safe distance. The ability to share geospatial data among diverse agencies at various government levels is crucial to a timely response. A formidable challenge is being able to provide continuous monitoring of dynamic events in order to provide current information to first responders. High spatial resolution imagery can be collected from airborne instruments in near real time to assess emergency situations and adjust evacuation plans. Airborne LIDAR can provide rapid assessments of damaged infrastructure. Environmental synoptic sensors can provide atmospheric data that can be used in dispersal models. A clear challenge is being able to provide continuous monitoring of dynamic events in order to provide current information to first responders.

Intelligent Transportation Systems / Operations

Adding more roadway miles has not necessarily been the most effective solution to alleviating increasing traffic pressure. Thus, intelligent transportation systems (ITS) have emerged as an alternative approach to maximizing transportation resources. High spatial resolution observations of traffic flow, congestion, travel times, parking demand, and route utilization can be input into transportation models. This information can provide feedback to drivers via traffic signs or by wireless means. Moderate spatial resolution multispectral data can be used to investigate proposed mass transit corridors (e.g., light rail). Topographic data from airborne LIDAR can be used for siting communication towers. LIDAR also has the capability to monitor vehicle speeds for transportation network models. Estimates of car counts can be obtained from high spatial resolution thermal data gathered from airborne systems, such as HyMap.

FUTURE CAPABILITIES

Within the next few years there will be several advances in remote sensing systems that will provide transportation experts with greater resources. These systems will offer improvements in spatial, spectral, and temporal resolutions. By 2007 new satellites, such Orbview-5 and WorldView, will offer panchromatic imagery with spatial resolutions of 50 cm or better and multispectral imagery between 1.6 and 1.8 m GSD with up to eight spectral bands. These spatial resolutions are in the realm of those obtained by airborne systems.

The experimental Hyperion sensor has demonstrated the feasibility of collecting detailed spectral data from orbit at reasonable spatial resolutions. The Italian Space Agency will soon launch HypSEO, a new hyperspectral sensor that will offer 20-m spatial resolution over a 20-km swath. In future years, ultraspectral sensors may be developed to give even greater spectral data than is currently possible with today's advanced hyperspectral sensors.

Progress is being made in the automatic feature extraction of roads from imagery, which will speed the conversion of raster data into a more useful format for mapping and network analysis. This task could be made more effective by mixing a low cost chemical into pavement materials that would have a characteristic spectral signature observable by multispectral or hyperspectral sensors.

One of the greatest breakthroughs for transportation monitoring would be the availability of continuous high spatial resolution real time data. While this is currently achievable on the battlefield for 24 to 35 hours, flying such UAVs in civilian airspace is currently prohibited by the FAA due to the risk of air collisions and to safety concerns. The development of lightweight HALE UAVs (Figure 11), which will fly above commercial air traffic and much of the weather, may offer a real solution for monitoring metropolitan areas and for providing uninterruptible communication. Essentially these platforms will operate like low earth satellites, but could be "parked" over a fixed area for weeks or months. In the event of an emergency they could be moved to a new location to assist with response.

Figure 11: The Global Observer is a HALE UAV, which Will Be Able to Fly at 65,000' for More Than a Week.
Source: AeroVironment, Inc.

Regardless of the technical innovations that are sure to occur, the baseline of remote sensing data grows longer each year, enhancing the potential for change analyses associated with transportation development. Multispectral data from commercial satellites extend back to 1972 with the launch of Landsat 1. Declassified high spatial resolution images are available from the 1960s, and aerial photography was collected for several decades prior to that time frame. The historical record may be important for the understanding of modern problems in traffic congestion, asset management, and threats from natural catastrophes.

CONCLUSIONS

Remote sensing technologies have matured greatly during the last three decades. Major improvements include the transition from film to digital sensors, increased spectral coverage and resolution, the availability of high spatial resolution data from commercial satellites, LIDAR, and robust computer processing systems. Relatively new UAV platforms have proved their value in military applications and may soon be used in civilian situations, such as demonstrated recently with border monitoring in the southwestern U.S. Short duration UAVs that fly below controlled airspace could be deployed in the event of a localized emergency, such as a HAZMAT spill, to provide real time video to first responders.

Significant technical obstacles remain in the collection and processing of remote sensing data for transportation applications. Transportation applications frequently demand spatial resolution and accuracy that are at the very limits of current sensor technologies. Some of the most important transportation problems, such as emergency situations, traffic congestion, and security need continuous monitoring with high spatial resolution resources. Not only is this expensive, but it creates a very severe data handling problem for filtering out important information efficiently and timely. A robust remote sensing-based monitoring system could easily generate terabytes or pentabytes of data to process and store – a daunting task even with today's computer resources.

Other considerations for EO sensors include cloud cover, which poses an observational problem for platforms that fly above the weather, and the technical expertise needed to analyze the imagery. Given the wide range of remote sensing data sources and sophisticated processing technologies, experts are frequently needed to extract the most information from the data.

Nevertheless, the potential of remote sensing to provide transportation departments with current geospatial information, often in a cost-effective manner, deserves careful consideration. Many planning and engineering activities engaged by transportation officials can benefit from basic remote sensing data. The value of remote sensing information is maximized when it is combined with other information technologies, such as GIS, GPS, wireless communications, and existing ITS technologies.

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APPENDIX A: Acronyms and Abbreviations

AGL	Above ground level
ATV	All-terrain vehicle
DEM	Digital elevation model
DIAL	Differential absorption LIDAR
EA	Environmental assessment
EM	Electromagnetic
ETM+	Enhanced Thematic Mapper
EO	Electro-optical
FAA	Federal Aviation Administration
FLIR	Forward-looking infrared
GIS	Geographic information systems
GPS	Global positioning systems
GSD	Ground space distance
HALE	High altitude long endurance
HAZMAT	Hazardous materials
HS	Hyperspectral
IR	Infrared radiation
ITS	Intelligent transportation systems
LIDAR	Light detection and ranging
MALE	Medium altitude long endurance
MIR	Midwave infrared
MS	Multispectral
NIR	Near infrared radiation
nm	Nanometer (=0.000000001 meter)
Pan	Panchromatic
SWIR	Shortwave infrared radiation
TIR	Thermal infrared radiation
TM	Thematic Mapper
UAV	Unmanned aerial vehicle
µm	Micron (=0.000001 meter or 1,000 nm)