Recurring Aerial Imagery Acquisition Program

MSB Project No. 16-130

Report 4 of 5

Analysis of Aerial Imagery Acquisition Options

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Acronyms

AGC .... Alaska Geospatial Council
AOI .... Area of Interest
AT .... Aerial Triangulation
ASPRS .... American Society of Photogrammetry and Remote Sensing
CE90 .... Circular Error at the 90% confidence level
CIAP .... Coastal Impact Assistance Program
DEM .... Digital Elevation Model
DG .... Digital Globe
DMC .... Digital Mapping Camera
DOQQ .... Digital Orthophoto Quadrangle
DTM .... Digital Terrain Model
EPA .... Environmental Protection Agency
FEMA .... Federal Emergency Management Agency
GINA .... Geographic Information Network of Alaska
GIS .... Geographic Information System
GCP .... Ground Control Point
GSD .... Ground Sample Distance
IMU .... Inertial Measurement Unit
KE .... Kinney Engineering LLC
LiDAR .... Light Imaging, Detection, and Ranging
MSB .... Matanuska Susitna Borough
NAIP .... National Agriculture Imagery Program
NASA .... National Aeronautics and Space Administration
NMAS .... National Map Accuracy Standard
NSSDA .... National Standard for Spatial Data Accuracy
NIR .... Near Infrared
NRCS .... Natural Resource Conservation Service
QA .... Quality Assurance
QC .... Quality Control
RFQ .... Request for Qualifications
RFP .... Request for Proposal
RGB .... Red, Green, Blue
RMSE .... Residual Mean Square Error
SDMI .... Statewide Digital Mapping Initiative
UAS .... Unmanned Aerial System
USACE .... U.S. Army Corps of Engineers
USDA .... U.S. Department of Agriculture
USGS .... United States Geological Survey
URISA .... Urban and Regional Information Systems Association
WMS .... Web Mapping Services
WMTS .... Web Mapping Tile Services

Executive Summary

The purpose of this study is to analyze and compare various aerial imagery options as part of the MSB Recurring Aerial Imagery Acquisition Program. An emphasis in this report is on analyzing the advantages and disadvantages of the imagery options with a goal of determining the most appropriate options for meeting MSB needs in a cost-effective manner.

Key Findings

- **Imagery Options for a Recurring Acquisition Program:** There are a number of imagery options the Borough can consider that each have their respective advantages and disadvantages:
    - Satellite imagery can provide high quality, relatively accurate imagery that meets many of the MSB's needs. Relatively low costs, global coverage, frequent revisits are major advantages. Policies, such as no-fly zones and other logistical challenges on earth do not hinder acquisition. Atmospheric conditions, such as cloud cover, haze, and wildfire smoke can pose challenges.
    - Digital orthophotography, utilizing modern sensors, can provide extremely high spatial accuracy, and quality imagery at reasonable cost. Acquisition is highly dependent on a number of variables and needs to be budgeted for and well planned.
    - Oblique and orthogonal imagery is best for very precise mapping and measurement of small features at detailed scales. It is particularly useful for property appraisal and public safety purposes. Acquisition of this imagery can be significantly more expensive than the other options evaluated.
    - Subscription Services are online imagery services that can be used in mapping software or online maps. These services can be easily integrated into a variety of mapping systems including AutoCAD, ArcGIS, computer aided dispatch mapping, and mass appraisal software. Hosting imagery on a cloud service could also reduce local IT infrastructure, support, and expense.
    - Unmanned Aerial Systems (UAS), also known as "drones", are portable, easily deployed, and provide very high resolution imagery and surface modeling. UAS require significant ground control and data processing. Currently, UAS is most appropriate for small acquisition footprints.
- **Costs:** Imagery costs are determined by a combination of three factors; acquisition area size, imagery resolution, and accuracy requirements.
- **Resolution & Accuracy:** To determine the resolution that is needed, one should ask, "what is the smallest feature that needs to be reliably mapped?" As described in Report 2, features mapped by Borough users typically fall into either the moderate or detailed mapping scales. The imagery options reviewed in this report can meet most of these needs. Accuracy of the imagery is dependent on the level of ground control and available elevation data.
- **Imagery Vendor Considerations:** Experience and capability of a vendor especially with regard to Alaska conditions are key factors in vendor selection. Also, the vendor's

depth of personnel and equipment resources, acquisition and processing methodologies, and customer service reputation should be considered.

- **Licensing and Data Ownership:** Imagery data ownership is a major concern for local governments. The MSB is accustomed to owning the rights to imagery and being able to distribute it to an unlimited and diverse set of users. Satellite, oblique, and orthogonal imagery, as well as subscription services tend to have license agreements that are more restrictive in terms of sharing the data. By comparison, digital orthophotography and UAS imagery typically have no license restrictions, and the data is owned by the MSB.
- **Technology Advancements:** Imagery technology is rapidly advancing and constantly improving. For example, satellite coverage over Alaska has improved in recent years and sensor improvements allow for acquisition over larger areas. High quality and very accurate digital imagery can be acquired at much lower cost than five years ago. Newer digital cameras can provide a greater variety of imagery, such as true color, near infrared, and oblique. Options for acquiring digital imagery and LiDAR simultaneously are improving and becoming more affordable. UAS are advancing rapidly in their ability to acquire imagery, over larger areas, at an increased accuracy level. Mapping software programs and hardware devices are capable of integrating a greater variety of imagery products and services.

Recommendations

- **Imagery Solution:** Finding the right solution involves assessing user needs and aligning them with the appropriate imagery option. It is recommended that the Borough utilizes a hybrid approach where different options are used based on the needs of particular areas.

    a. **Digital orthoimagery** is the primary solution for the Borough for aerial imagery, at least in the Core Area, because it can be used to accurately map the features of interest in this area. Examples include, urban features such as buildings, roads, utilities, etc. See Report 2 for more information.
    b. If costs can be reduced to a competitive level with orthoimagery, **oblique and orthogonal imagery** should also be considered, especially for the urban parts of the MSB. These imagery options provide better measurement capability of features such as building dimensions. This option would provide value-added tools for property assessment, public safety, and other users.
    c. **Satellite imagery** is a very good alternative solution to orthoimagery. The MSB could get satellite imagery as part of an **imagery subscription service** which would increase the reliability of imagery refresh for the Borough.
    d. **UAS** fit the need for small footprint acquisition needs, where surface modeling or very high resolution imagery is required (e.g. landfill monitoring).

- **Update and Gather More Information:** It is recommended that the MSB issue an RFI to better assess available options and fill in knowledge gaps. The RFI should request vendors provide imagery solutions for the various MSB areas of interest (see Figure 7 in Report 2) providing detail regarding type of imagery, resolution, accuracy, refresh rate, service provided, subscription service options, service level agreement (guaranteed level of up time), and approximate costs should all be included. Report 5 will provide a recommended aerial imagery acquisition approach that should be helpful for this process.

1 Introduction

This report is intended to compare various aerial imagery options for the MSB as part of the development of a MSB recurring aerial imagery acquisition program. This is fourth of five reports. Business needs are addressed in Report 2, which is a key reference for this report.

Five aerial imagery options were evaluated for this report. Each option has advantages and disadvantages. Section 3, provides a summary regarding the following aspects:

- Costs
- Resolution & Accuracy
- Acquisition & Refresh
- Processing & QA/QC
- Imagery Types & End Products
- Licensing & Ownership
- Experience & Capability

Appendix A provides a summary matrix comparing the imagery options.

Special thanks to a varied group of professionals including those in academia, federal and state government and private industry who contributed their time and expertise to the research effort in this report. References are provided in Section 5.

2 Research Methods

This analysis of imagery options was divided into four separate tasks.

1. **Review of Existing Information:** In this task, the research started with the MSB RFI (MSB #16-059L) results from December, 2015.
2. **Online Research:** Research of technical options, industry standards, and commercial companies was completed using a variety of industry and academic websites.
3. **Interviews:** Options were investigated through interviews with specialists in private industry, academia, and local users of imagery.
4. **Analysis of Options:** Various options were compared with respect to costs, acquisition feasibility, technical specifications, and other factors and summarized in Appendix A.

Assumptions

- MSB stakeholder needs and requirements have been defined and described in Report 2.
- Technical advancements for nearly all of the imagery options evaluated in this report are occurring quickly, thus some of the analysis in this report will need frequent updating.
- Cost discussions are based on an understanding of approximate funding levels that might be available to the MSB.
- Each imagery option has inherent advantages and disadvantages.
- Many of the vendors mentioned in this report we also respondents to the MSB RFI #16-059L. Other vendors were also contacted.

3 Options for Imagery Acquisition

Five imagery acquisition options are evaluated in this report; 1) satellite imagery, 2) digital orthophotography, 3) oblique and orthogonal imagery, 4) subscription imagery services, and 5) unmanned aerial systems (UAS, aka drones).

Regardless of the type of imagery selected, map scale, accuracy, and cost are intertwined. The accuracy needed for mapping can only be defined by knowing the intended uses of the imagery.

As detailed in Report 2, imagery needs and requirements generally fall into three mapping scale levels - broad, moderate and detailed. The majority of MSB needs relate to infrastructure and asset mapping which fall into either the moderate (tier 2) or detailed scale features (tier 3).

Figure 1, shows which imagery resolutions (on the left) are needed for particular mapping tiers (in the middle). Mapping scales are shown on the right. Note: scales and resolutions shown, reference ASPRS, 2014, and USACE, 2015.

Imagery resolutions are used more frequently now with digital imagery rather than scale to assess whether the imagery can provide adequate resolution for mapping features of interest.

On the next page, Table 1, shows which imagery options meet certain resolution and scale needs.

Figure 1. Resolution and Map Scales

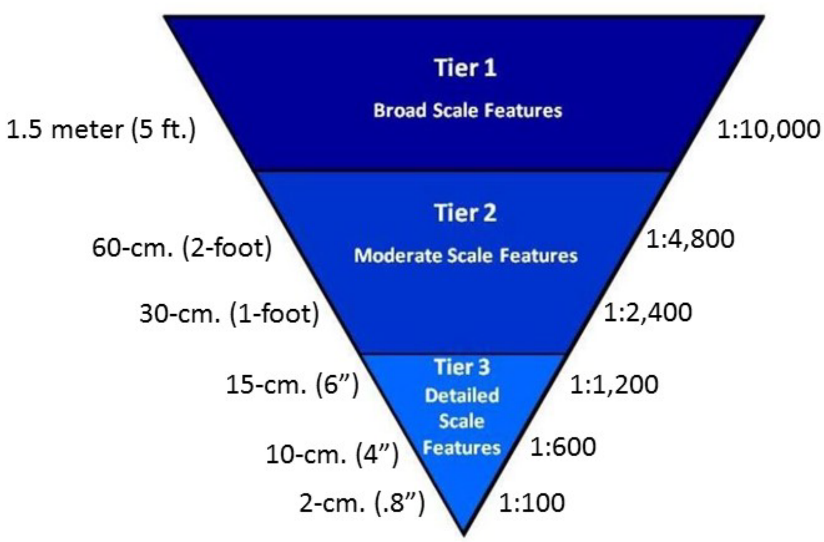


Table 1. Imagery Options

Mapping Level	Imagery Option	Pixel Resolution & Scale[1]	Horizontal Accuracy[2,3] RMSE	Pros	Cons
Tier 1 Large Sized Features	Satellite Imagery Moderate Resolution	1.5 m (5 ft) 1:10,000 1" = 833 ft	5m (15 ft)	Suitable for broad feature mapping and basic feature identification.	Resolution not suitable for detailed feature mapping.
Tier 2 Moderate Sized Features	Satellite Imagery High Resolution	30 – 50 cm (11.8 – 19.7 in) 1:2,000 to 1: 4,000 1" = 300 ft to 1" = 400 ft	60 cm – 1m (49 in)	Acquisition logistics are minimal. Potential for frequent refresh. Less expensive imagery products.	Tasking less certain for smaller customers. Licensing puts constraints on distribution. Mapping detailed features is difficult.
Tier 3 Small Sized Features	Digital Orthoimagery	7.5 – 30 cm (3 – 12 in) 1:200 to 1:2,400 1" = 50 ft to 1" = 200 ft	15 – 60 cm (5.9 – 22.8 in)	Local government standard. Resolution is good for mapping detailed features.	Complex logistics and project management.
	Oblique and Orthogonal Imagery	7.5 – 15 cm (3.0 – 12 in) 1:600 to 1:2,400 1" = 50 ft to 1" = 200 ft	5 – 60 cm (2 – 22.8 in)	Resolution is great for mapping detailed features. Minimal radial distortion.	Complex logistics and project management. Requires specialized camera equipment.
	Unmanned Aerial Systems	2 cm (0.78 in) 1:100 and larger	2 cm (1 in) Varies and subject to survey control.	Can produce very high resolution imagery and surface modeling.	Vertical accuracy can be limited in certain terrain and surface types. Acquisition limited to small footprints.

[1] NMAS, USACE, 2015;
[2] ASPRS, 2014
[3] Satellite horizontal accuracies assuming adequate ground control and elevation control.

3.1 Satellite Imagery Options

Commercially available satellite imagery started coming online in the 1990s. It has grown since and over the last five years has expanded significantly in capability and offerings in the global marketplace, including Alaska. A growing number of satellite imagery sensors and sources provide options that meet needs ranging from detailed to broad scale mapping.

Based on the surveys and interviews with MSB imagery users, it was determined that Tier 2 and 3 mapping levels are most needed. More information can be found in Report 2.

As a result, this section of the report focuses on two key commercial satellite companies: Airbus and Digital Globe, both of which actively acquire and sell commercial moderate and high resolution satellite imagery. Imagery can either be purchased directly from Airbus and Digital Globe or through a number of resellers; see Appendix A for more details.

Costs

Satellite imagery costs are typically based on the following factors:

Size of the Acquisition Area: Satellites acquire imagery along paths or “swaths” and the imagery acquisition areas vary significantly depending on the satellite. Smaller swaths mean that the satellite has to re-visit the area more to acquire the requested imagery, which can increase cost. See Appendix A for more detail regarding satellite swath widths and imagery acquisition area capabilities.

Control: Satellite imagery typically requires survey ground control points (GCP) and elevation data (for example LiDAR) to produce an accurate imagery orthomosaic. In some cases, GCPs or elevation data may need to be collected, which means additional cost.

Revisit Timeframe & Refresh Cycle: To acquire imagery during a specific timeframe, a satellite needs to be “tasked” or told where and when to acquire the imagery. Cost is tied to the amount of tasking the customer wants.

Licensing (or who can use the service): How and by whom the data can be used is based on a license agreement, which governs imagery use. Group or “enterprise” license agreements are negotiated with the vendors, and cost typically varies depending on the number of users.

Type of Product(s): Standard satellite imagery (aka “out of the box”) products are sold by the major vendors and are developed using nationally available control sources, such as the National Elevation Dataset. Raw imagery costs for Airbus and Digital Globe, range from $20-60 square mile for high resolution satellite imagery, and $15/square mile for moderate resolution imagery. Custom imagery products typically use local control data and are more expensive.

Resolution & Accuracy

The resolutions of the satellite imagery options considered in this report are shown Table 2. These resolutions need to be tempered with the need for appropriate ground and other control to produce the accuracy needed for detailed features mapping.

Airbus offers moderate resolution SPOT imagery at 1.5-meter to 2.5-meter (Figure 2 shows 2.5-meter) and high resolution Pléiades 1 imagery at 50-cm (Figure 3). Airbus has established a download receiving station in Fairbanks. This imagery is distributed through GeoNorth LLC.

Digital Globe specializes in high (30-cm to 50-cm) resolution satellite imagery with the Worldview 1,2, 3, and 4 satellites (the last of which was launched in October 2016), and has a large archive of Alaska satellite imagery dating back 10 years and longer.

Table 2. Satellite Imagery Resolution

Satellite	Panchromatic & Pan-Sharpened Resolution	Multispectral Resolution
Digital Globe - Worldview 1, 2, 3, 4	30 to 50 cm (12 in to 20 in)	1.5 to 2.5 m
Airbus Pléiades 1A and 1B	50 cm (20 in)	2 m
Airbus - SPOT 6 & 7	1.5 m	6 m

Figure 2. Moderate Resolution Satellite Imagery Example (SPOT courtesy SDMI)

Figure 3. High Resolution Satellite Imagery (Pleidades courtesy GeoNorth LLC)

The accuracy of satellite imagery is determined by the following:

Terrain factors: All imagery, regardless of the sensor used, include geometric distortions. These distortions are most noticeable in areas with sudden changes in topography, such as canyons, mountains, and areas with tall buildings. However, satellite imagery can be advantageous in that it is acquired at higher altitudes thus reducing the geometric distortion factor when compared to imagery acquired with aerial aircraft.

Quality of Elevation Control Data: Image orthorectification processing can be improved by the provision of local elevation data, especially good quality data such as a LiDAR-sourced DTM or DEM. For areas where there is existing imagery, control images can be utilized during the ortho-rectification process to improve the resulting orthoimage accuracy. Control points are extracted from the control image and applied to the new image being processed. In tests, the resulting accuracy of the generated orthophoto is within one-half to one pixel of the control image. This means that refreshed ortho-controlled imagery can quickly be produced, within several hours of the collection.

Ground Control Points: The accuracy of satellite imagery is strongly correlated with the quality, quantity and accuracy of the inputs (ground control points (GCP) and DEM) using during processing. For example, a minimum of five GCPs well distributed in a given area combined with a high accuracy can increase the accuracy of satellite imagery.

Ground control (horizontal) could be gathered from two main sources, traditional surveyed (GPS) points or from ground control collected for previous imagery or control collected for projects such as the MSB 2011 LiDAR/Imagery or the SDMI Imagery/IfSAR projects.

QA/QC Efforts: The higher the resolution of imagery the greater the level of ground control and processing effort is required. Typically, for satellite imagery control, a minimum of five well-distributed control points per image is required to achieve the highest accuracy. Additional points can be very helpful in ensuring accuracy standards are met.

Acquisition & Refresh

A satellite's acquisition capacity is determined by:

- Agility of the sensor, or ability to point the satellite sensor at the desired acquisition area.
- Sensor swath width, or how wide an area the satellite can collect imagery on in one pass.
- Revisit time of the satellite over the area(s) of interest.
- Satellite's onboard data storage and downlink capacities.

The new high-resolution imaging satellites, for example Digital Globe Worldview and Airbus Pleiades are able to acquire imagery at varying "look" angles, thus they are able to acquire imagery over large areas during one pass. These satellites are also able to orient the sensor at or near nadir (looking straight down) which reduces the distortion of the imagery. The swath width varies among the satellites (see Appendix A). Typically, the higher the imagery resolution the narrower the swath width.

Satellite imagery refresh is a function of how many visits to an area of interest the satellite makes. Acquisition has been enhanced with the addition of new high resolution satellites in the past three years (e.g. Digital Globe Worldview 3 and 4).

Digital Globe and Airbus have said their constellations of satellites support multiple daily visits in southcentral Alaska. Additionally, a new Airbus imagery download facility in Fairbanks means more imagery can be made available to customers.

Factors hindering satellite imagery acquisition include:

- Atmospheric conditions, such as fog and haze, and wildfire smoke.
- Alaska's remoteness from population centers means that imagery is not collected as frequently and competition for satellite time can be an obstacle as other requests may have higher priority.

Processing & QA/QC

Satellite imagery products are typically provided in two ways: 1) as a standard product with basic georeferencing; or 2) as a more accurate product which has been orthorectified using local control datasets.

To create orthorectified products, additional processing is required to apply survey control for imagery adjustment and place it in the proper datum and coordinate system. Typically, satellite imagery is derived from large scenes or tiles, which makes satellite orthorectification easier in some ways than orthoimagery rectification. For example, the first time an area is acquired, time must be spent to establish adequate control for processing the satellite imagery. However once this area is completed, new refreshed imagery can be orthorectified quickly using the same control points, allowing refreshed imagery to be processed and delivered quickly.

Satellite imagery processing details include processing to correct inherent distortions in the optics and viewing geometry. This can be accomplished by utilizing a satellite orbital model, a digital elevation model (DEM) and ideally photo-identifiable ground control points (GCPs).

Below is a general QA/QC process utilized for the production of satellite imagery:

- Mosaicking of multiple imagery tiles to create an orthomosaic.
- Georeferenced data is viewed, analyzed and queried with other geographic datasets to verify the orthomosaic.
- Checking edge match of imagery tiles.
- Pixel definition and unit sizing.
- Assigning the correct projection and datum for the customer's area.
- Accuracy validation that final products are in compliance with digital geospatial data accuracy standards according to NSSDA.

Delivered products should always go through a 3rd party or internal QC process to assure they meet contract requirements.

Imagery Types & End Products

Each imaging band measures different wavelengths of light. Most commercial optical imaging satellites capture panchromatic (viewed as gray scale) imagery at higher resolution which can be used for pan-sharpening. As well as four multispectral bands—red, green, blue, and infrared—at one-fourth the resolution of the panchromatic band. The near-infrared band identifies vegetation easily, making it possible to distinguish trees from structures and other elements.

Typical imagery formats for end products include:

- GeoTIFF: An uncompressed format that preserves the inherent integrity of the original imagery.
- MrSID: A compressed format that preserves the visual integrity of the imagery while compressing the file size.

Licensing & Ownership

Satellite imagery typically comes with license agreements that restrict how and to whom the data can be distributed. Typically, these are either a standard End User License Agreement (EULA) or multi-user EULA. The EULA's are designed as a vehicle to allow the customer and vendor to develop an agreement that provides imagery best meeting the customer's Use Cases.

These agreements can be complemented by a non-commercial, web viewing license that allows the imagery to be 'viewable' on public facing websites, like the MSB Parcel Viewer. Which provides view-only access of the imagery to the public.

<u>Airbus</u>
The standard EULA provides imagery for use by the customer, for example MSB, and contractors working on MSB projects.

The multi-user agreement allows for use of the imagery for one primary customer plus nine additional partners. Based on this scenario, a MSB multi-user license would allow MSB staff to utilize the imagery in addition to nine partners, for example utilities, cites, etc.

For both agreement types, derived products (e.g. hard copy maps, imagery classifications, digitized vector products, etc.) are owned by the MSB. However, it is important to note that compressed images, imagery services, and cached imagery services are not considered to be ownership of the MSB.

The MSB has the option of hosting imagery on its server platform or having a vendor host it for them and providing the imagery WMS to the MSB.

In the license document, there is a distinction between PRODUCT and IMAGE. The PRODUCT is the full dataset including pixel data, and metadata. The IMAGE is a simplified version of the imagery (think JPEG with no pixel data or metadata). A PRODUCT could be used with remote sensing software, e.g. ERDAS, ENVI, for detailed spatial or other type of analysis. An IMAGE cannot be used this way; and can only be used as a backdrop for other GIS layers for example.

Digital Globe

Digital Globe imagery is licensed to the customer in a very similar way to Airbus, through an EULA. Digital Globe provides a number of options including a multi-user license for use of their imagery services, and access to the imagery using an imagery WMS.

The Digital Globe license also provides the MSB with the option of hosting imagery on its server platform or having a vendor host it for them and providing the imagery WMS to the MSB.

As with Airbus, Digital Globe licenses their data in terms the PRODUCT which can't be shared with other users; and the IMAGE which can be viewed and shared in online WMS, and utilized by users included in the EULA.

Experience & Capability

Digital Globe and Airbus have both been active in Alaska in the past 15 years. Both collect high and moderate resolution satellite imagery over a wide extent of Alaska including the interior, southcentral, and north slope. As a result, an extensive archive of satellite imagery is available.

High quality satellite imagery delivered in a requested time window may require special tasking of a satellite. This typically is done by utilizing a satellite imagery reseller to order the imagery and ensure it meets MSB needs. Satellite imagery dealers and resellers who operate in Alaska are shown in Appendix A.

3.2 Aerial Digital Orthoimagery

Imagery collected by aircraft has long been the standard for collecting aerial imagery around the globe. Technology and capabilities continue to evolve, particularly with regard to acquisition methods, imagery quality, and processing methods.

Digital mapping cameras (DMC) have become the standard in the industry for aerial imagery acquisition replacing conventional film-based aerial photography. From the photogrammetric technology perspective, advancements in airborne GPS, and inertial navigation systems contribute to the improved efficiency and quality of imagery.

Key areas in which digital orthoimagery is improving include:

- Digital camera sensors capable of collecting high resolution imagery with minimal distortion and artifacts common to film cameras.
- Sensors that collect additional bands of imagery.
- Larger footprints meaning less acquisition overlap required.
- Usage of a combination of airborne GPS, continuous operating reference stations (CORS), and improved navigational data processing means imagery can be acquired with less ground control, and sometimes without base station control.
- Faster imagery processing workflow and tools for QA/QC.

Numerous vendors provide digital orthoimagery in Alaska; see Appendix A for a summary.

Costs

Orthoimagery cost (acquisition to product delivery) in southcentral Alaska, in 2015, ranged from $160 per sq/mi for 1-foot to $250 per sq/mi for 6-inch resolution digital orthoimagery.

Advancements in camera sensors are helping lower costs. For example, new digital cameras are able to acquire higher resolution imagery at higher altitudes. This can reduce the number of exposures by almost 50 percent from cameras used five years ago.

Many factors impact the costs and overall success of aerial image acquisition:

Size of the Acquisition Area: Collecting imagery over larger areas can build an economy of scale by streamlining the production and flight plan process. One can take advantage of the initial set up costs and reduce the number of flight lines needed.

Terrain: Terrain is a cost factor because some terrain requires more complex flight lines, for example steep mountains, canyons and other features with sudden elevation changes.

Resolution: Resolution is perhaps the most critical factor in determining cost. On average, 3-inch imagery will be approximately three times more expensive than 6-inch imagery due to increased flying time, more control, and processing; and 1-inch digital orthoimagery can cost 10 times more than 6-inch imagery. To acquire 3-inch imagery, the aircraft flight altitude is typically 3,200-3,500 feet which decreases the image capture swath on the ground and results in more flight lines and images.

Survey Control and Elevation Data: These are required elements for orthorectification of aerial imagery. The amount of control and elevation data that needs to be developed will impact cost. Using preexisting control and elevation data, assuming it is suitable for orthorectification, can reduce costs.

Mobilization Costs and Weather: Mobilization involves deploying the aircraft and equipment, which for vendors located outside Alaska could add additional costs and delays. Weather is an unpredictable and major factor that can delay acquisitions. This may require the vendor fly in the next season. This can increase costs unless the contract ensures the client is not charged for these types of issues.

Figure 4. Example of 6-inch Resolution Digital Orthoimagery (courtesy MOA)

Figure 5. Example of 1-inch Resolution Digital Orthoimagery (courtesy MOA)

Resolution & Accuracy

Modern digital cameras are capable of achieving high resolutions imagery and maintaining a 12-bit per pixel resolution. The higher the number of bits per pixel, the greater the imagery depth.

Acquisition using a modern, digital mapping camera provides more consistent, and accurate, imagery due to:

- Wider acquisition footprints
- Better integration with aerotriangulation processes
- Improved integration with navigational and other instruments

The most frequently requested resolutions for digital orthoimagery are 3-inch, 6-inch, and 1-foot. 6-inch to 1-foot imagery resolution supports the 1:600 to 1:1,200 scale range which is the most common resolution for local governments.

Because improved camera sensors are able to acquire 6-inch resolution imagery more rapidly and for lower cost, the 6-inch resolution is becoming a new standard for many local governments (Figure 4).

One-inch resolutions may be required for engineering and design applications. For example, 1-inch resolution imagery was used to support planimetric mapping and modeling at detailed scales at the Port of Anchorage (Figure 5).

Compare the two figures (4 and 5) to one another. Both show the same area at 1:200 scale. Note how much more visible and clear small features are in the 1-inch vs. the 6-inch resolution image.

With proper survey control, orthoimagery will typically meet or exceed horizontal specifications for different industry standards such as NMAS and the National Standard for Spatial Data Accuracy (NSSDA).

The accuracy of imagery is strongly correlated with the quality, quantity and accuracy of the control inputs (survey control providing GCPs and DEM) used during processing. Survey control is the first step for establishing a network of basic control in the project area for imagery acquisition. This consists of horizontal control monuments and benchmarks of vertical control that will serve as a reference framework for subsequent surveys used in recurring aerial imagery acquisitions. Photo control points are photo-identifiable points that can be observed and measured on the aerial photograph and in a stereo model, and are often established as part of the ground control point.

During airborne imagery acquisition, a base station may or may not be used depending on the quality of the airborne GPS data, availability of CORS, and the quantity and quality of ground control points. Often the imagery vendor will subcontract a survey or specialized vendor to collect and process the airborne GPS datasets. The raw GPS data sets are processed. The resulting values are accurate easting-northing and height positions. Airborne GPS data is often processed using TerraPOS. TerraPOS is GPS post processing software that delivers better than 5-cm accuracy of an airborne kinematic trajectory without a base station.

Airborne GPS and IMU sources of error are important, but have been found to have minimal contribution to the overall accuracy errors when compared against the influence of DEM and GCPs.

It is recommended that the MSB refer to appropriate survey standards and specifications (e.g. USACE Manual 1110-1-1000, 2015) for guidance in designing the project control surveys. Ground control, both horizontal and vertical, is critical to ensuring aerial imagery will meet NMAS, and should be included in the acquisition project.

Acquisition & Refresh

Orthoimagery acquisition typically occurs using digital mapping cameras mounted on fixed-wing aircraft. New pushbroom type cameras enable faster acquisition and extremely fast production of digital orthophotos, DTMs and other products. Acquisition time and cost varies, and is dependent on seasonal constraints (e.g. leaf off timeframe), terrain, weather, and required resolution.

Digital mapping cameras offer numerous advantages for acquisition over film-based cameras, including the following:

- Increased accuracy of photogrammetric measurements.
- Faster turnaround time from flight to end product.
- Multispectral acquisition.
- Reduction in flight time due to being able to acquire higher resolution imagery at higher altitudes which means fewer flight lines and fewer terrain related obstacles.

Some digital mapping cameras are designed for performing simultaneous imagery and LiDAR data collection. These systems are constrained in terms of acquisition flight heights.

Imagery delivery is a key factor in digital orthoimagery projects. In Alaska, imagery delivery can often be delayed by a number of factors, including shortage of vendor processing resources, distance from Alaska, and possibly the need to re-fly the mission. To reduce imagery delivery delays, preliminary raw imagery should be delivered to the client within a couple of days of acquisition to check quality. Final delivery of all requested products should occur within 2-4 months of acquisition.

Refresh of aerial orthoimagery requires new flights and the associated planning and logistical process, which can be expensive. Costs can be reduced, however, by re-using survey and elevation control over a period of years and multi-year contracts.

Processing & QA/QC

Processed orthoimagery is characterized as follows:

- Typically, 8-bit, sometimes 16-bit
- 3 spectral bands (increasingly four bands with near infrared)
- Color corrected
- Usable in GIS with ability to separate color IR, true RGB color, and pan sharpened.
- Orthorectified using horizontal and vertical control
- Delivered as edge-joined tiles and/or orthomosaics

A first step in orthoimagery processing is aerial triangulation (AT). AT is the key to a successful aerial photogrammetric mapping project. Typically, the production of digital orthoimagery uses aerial triangulation techniques to ensure the imagery is properly referenced to terrain and the ground, and to ensure imagery meets accuracy requirements. Aerial triangulation is a well-established process enabling the data to meet the National Standard for Spatial Data Accuracy (NSSDA).

A digital terrain model (DTM) or digital elevation model (DEM) is a primary control element in the orthorectification process. Imagery processing technicians are skilled in the generation and use of DTM/DEM products used to support the production of digital orthophotos.

The use of web-based QA/QC applications can improve quality by enabling review during the processing period. Several programs (see Report 1: Spokane County, Kentucky From Above, and King County; and Summers, et.al., 2016, in References) utilize online QA/QC applications. Below are items that should be checked by the vendor before final imagery products are delivered, but some or all of these items should also be double checked through an internal or 3rd party review process.

- Atmospheric issues such as, cloud cover, smoke and haze should be absent.
- The production should be tonally balanced to produce a uniform contrast and tone across the entire project.
- Imagery should be absent of image artifacts, e.g. out-of-focus imagery, blurs, whorls, twists, color blemishes, dust or lint marks, or scratches and image compression.
- Excessive tilt in bridges, buildings, and other raised structures should be corrected.
- Misalignment of features in adjacent images, chips/tiles, or seamlines should be absent.

- Features such as radio towers, water tanks, and buildings should not be clipped at tile boundaries.
- Products should be over or under saturated as a result of image processing or histogram manipulation.
- Products should provide complete coverage of the agreed upon geographic extent, without omissions or corrupt data.
- Images should not contain background data or NODATA pixels.
- Imagery should meet the specified resolution.
- Horizontal accuracy checks, using test-point control that is completely independent of control used during data production, should be completed.
- Metadata should be complete and accurate.

Imagery Types & End Products

Typical orthoimagery deliverables and end products consist of:

- Initial imagery products for review prior to full acquisition.
- Source imagery in raw TIFF file format.
- Final processed imagery often in Geotiff and MrSid formats; typically tiled in a scheme that is most efficient for the client in terms of usability and distribution.
- DEM file used for orthorectification–in ArcGIS or CAD file format.
- Photo centers and flight lines in file geodatabase or shapefile format with attributes including date, time, flight number, etc.
- Tile index in file geodatabase or shapefile format.
- ISO or FGDC compliant metadata.
- AT report, includes a report of the RMS of the standard deviations of the residuals for each aerotriangulated ground point used to compute imagery accuracy.
- Production report.
- QA/QC report.
- Project Acquisition Report of flight control report including aerial imagery mission logs. Survey report with field work procedures. Final processed airborne GPS and IMU orientation data.

Licensing & Ownership

Aerial imagery is typically made available to the client in the public domain and licensing is rarely required. This allows the imagery to be widely distributed at no additional cost and the customer is typically given full ownership rights to derived imagery products and datasets. This is what the MSB utilized in the 2004 and 2011 imagery acquisitions, and what the Municipality of Anchorage has utilized since 2001.

Experience & Capability

Digital orthoimagery vendor resources typically include aircraft, camera sensors, and technically-expert personnel. Vendors vary with respect to depth of resources and experience. Each of the following items should be taken into consideration when selecting a vendor.

Project Management Experience: Can the vendor provide personnel with project management expertise? Is the project manager located locally, and familiar with conditions unique to Alaska?

Technical Expertise: Vendors should provide a detailed resume(s) of technical personnel who will be assigned to the acquisition project.

Aircraft Location and Availability: One vendor may have a fleet of multiple aircraft, with some located in Alaska which may provide a better capability to acquire imagery as needed and within specified timeframes. Another vendor may not have aircraft located in Alaska requiring mobilization from significant distances.

Survey Control Methods: Often an imagery vendor will have their own survey staff or work closely with a preferred survey firm familiar to establish appropriate survey ground control. Aerial acquisition firms have business models that determine which airborne platform is the most cost-effective for specific projects.

Subcontracting Plans: A vendor may subcontract aerial imagery acquisition separately from the imagery processing. The vendor should be able to show they have worked with the subcontractor previously and that there is a clear, coordinated plan for acquisition.

Equipment: The vendor should provide specific information regarding what sensors they will utilize for the acquisition and show that are using state-of-the art imagery acquisition technology. Given the rapid change in sensor technology, it would be good to have the vendor provide some, but not too detailed, info regarding their equipment.

Project Planning: The vendor’s past history with regard to project planning should indicate that they treat this phase as a critical step and the customer should be kept in the loop. Flight planning, survey control needs, scheduling, and logistics are addressed in this phase. A project kick-off meeting follows this phase to brief the client, and ensure the plan is achievable.

Work Plan: This document follows the project kick-off meeting between the vendor and client. It should contain all critical communication, technical and quality components that will be exercised throughout the project to ensure that the contractor meets the requirements. The work plan should also include details regarding all deliverables and a final schedule for the project. Digital maps of the planned flight lines and the survey control approach should also be included. For example, details may include planning the rules for overlap and sidelap as it is now much easier to acquire digital images with 80% or even 95% forward overlap for production of near “true orthophotos” in urban areas to minimize building lean. Note: in the Anchorage 2015 project, detailed planning would have reduced certain amounts of image distortion in urban core areas.

Processing: What processing methodology will the vendor utilize? What software tools could be provided to the client for their review (if so desired)?

QA/QC: These processes are very important so that final products are consistent and meet expectations. A vendor should have clear QA/QC procedures and be able to explain what tools are being utilized. A third-party QA/QC may be needed as well.

3.3 Oblique and Orthogonal Imagery

Oblique imagery is aerial imagery captured at multiple angles to provide a more natural perspective, making objects easier to recognize and interpret. Images are captured from north, south, east and west directions to provide a 360-degree view of every property and parcel. Each pixel is georeferenced, resulting in imagery that can be used to measure features. Oblique imagery provides photorealistic 3D models of buildings and other features.

Orthogonal imagery provides a top-down view and is rectified to align to a map grid. It is sometimes called “true” orthoimagery, although true orthphotos are often developed using extensive image sidelap and 3D modeling, and thus tend to be very expensive. Orthogonal imagery provides better feature footprints than traditional digital orthoimagery which may contain building lean and some distortion effects. Orthogonal imagery can prove very advantageous, especially in urban areas and landscapes with sudden elevation changes.

Only a limited number of vendors offer the acquisition of oblique and orthogonal imagery on a regional scale. A list of vendors is provided in Appendix A.

Costs

Oblique and orthogonal imagery is typically more expensive due to a higher number of flight lines at lower altitudes, more image exposures at different angles, more ground control needs, specialized camera equipment, and a more intensive processing effort. Costs of oblique imagery may be in the order of two to three times more expensive than digital orthoimagery. Additionally, vendors may not be based in Alaska, which could make acquisition efforts more expensive and challenging particularly with tight acquisition timeframes (like leaf-off). However, it should be noted that multiple view oblique imagery can be a value-added benefit to some local government users, for example assessors and public safety users find the capability of oblique imagery and the measurement capability worth the additional expense.

As with other aircraft collected imagery, costs and processing time can be reduced by using preexisting ground control and elevation datasets. For example, in 2015, a Genesee County vendor used a combination of 2004 LiDAR and 2010 orthogonal imagery to rectify their acquisition of oblique and orthogonal imagery.

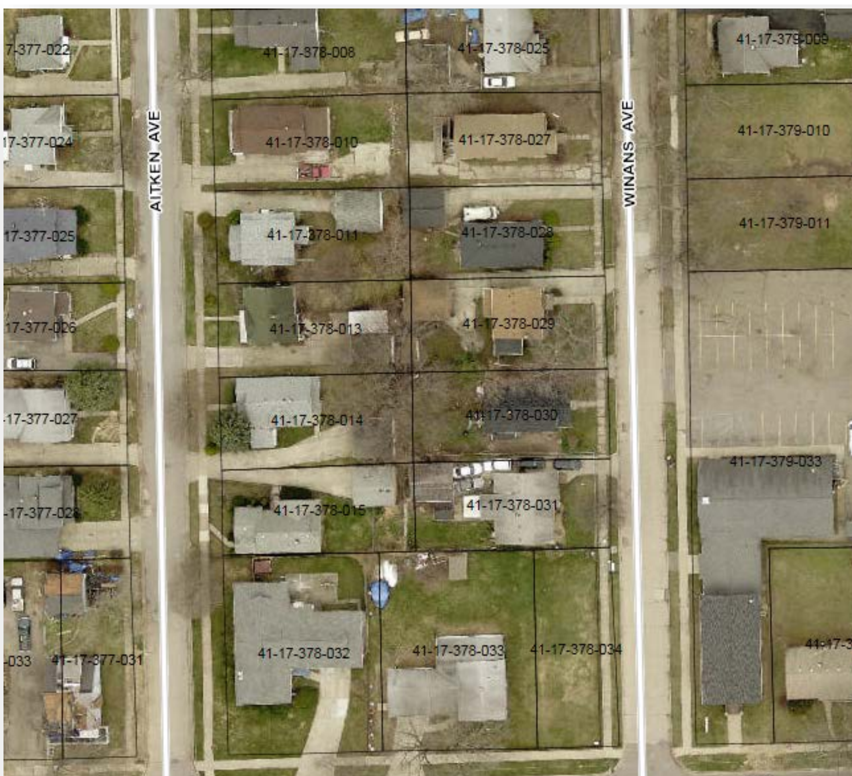
Research conducted of customers in the Lower 48 and Alaska revealed that the current cost of oblique and orthogonal imagery is approximately $320/square mile for the final delivered end product.

Resolution & Accuracy

Oblique capable cameras are most often acquired at 4, 8-inch and 12-inch resolution. Oblique and orthogonal imagery is typically acquired at higher resolutions of 3-inch, 6-inch, 9-inch pixel, and typically exceeds NSSDA accuracy standards. (Figure 6).

The oblique cameras utilized by vendors, are specialized and acquire imagery from multiple viewing angles. One of these views is at nadir (straight down), and provides what is also known as orthogonal imagery. The accuracy of oblique and orthogonal imagery is typically higher than that acquired by orthoimagery cameras, due to the airborne GPS and navigational control associated with the multiple view imagery versus control associated with frame imagery acquired in orthoimagery. This imagery is suitable for precise measurement of ground features such as buildings and bridges, and is typically acquired in urban settings, for example cities such as New York City, Spokane (see Report 1), and others nationwide.

Figure 6. Orthogonal Imagery Example (courtesy of Pictometry™)



Acquisition & Refresh

Like other aircraft collected imagery, orthogonal and oblique imagery is often most efficiently acquired in large footprints on a recurring basis. Examples include the following:

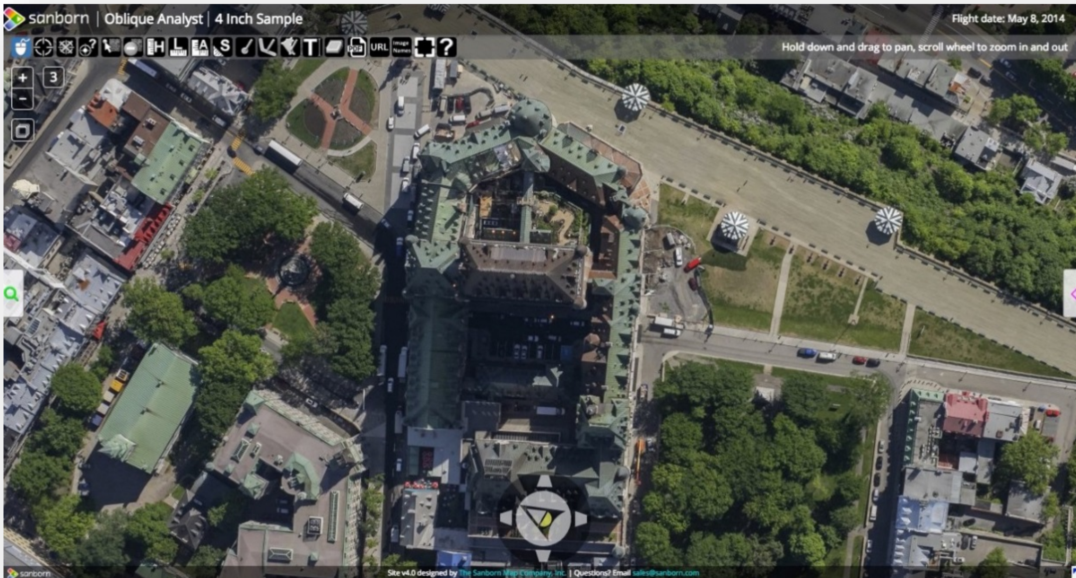
- Genesee County, Michigan: Acquired oblique and orthogonal imagery for 630 square miles at 6-inch and 9-inch resolution, with 6-inch in more urban areas, and 9-inch in rural areas. This was distributed to 40 partners in an imagery consortium. Imagery is acquired every three years for the entire area, and more frequently upon request by individual counties.
- Fairbanks North Star Borough: Acquired orthogonal and oblique imagery in 2012 and 2013, with the oblique and orthogonal acquired in urban areas and orthogonal imagery in the more rural areas. Imagery resolution was 6-inch, 9-inch, and 1-foot with the 6-inch and 9-inch in urban and semi-rural areas, and 12-inch in low population areas. This was a partnership project between the FNSB, Golden Valley Electric Association, local area boroughs (e.g. Denali Borough), and the City of Fairbanks.
- Municipality of Anchorage: Acquired Pictometry orthogonal imagery for 800 square miles in 2012 and 2013 at 6-inch resolution.
- Spokane County: The County acquires oblique and orthogonal imagery for the urban areas at 6-inch and 9-inch resolution. The 6-inch resolution imagery is collected in the city areas (City of Spokane, Spokane West Valley), and 9-inch imagery in rural areas.

Processing & QA/QC

Typically, vendors utilize a sophisticated system of imagery georeferencing required to calibrate oblique and orthogonal imagery during the imagery acquisition. All imagery is put through a rigorous QA/QC process whereby images of low quality are identified and marked for recapture. The final approved imagery is put through a verification process where common points are compared. The end result is highly controlled and accurate imagery which can provide accurate feature measurement from multiple viewing angles.

Some of the oblique imagery vendors offer desktop and online tools for review of the imagery, and measurement of features. These tools are often provided as extensions to ArcGIS or usable with computer aided drafting. (Figure 7). The customer can use the tools to review and comment on imagery quality and anomalies they observe. Figure 7 below shows an example of one of these tools, for use with oblique imagery.

Figure 7. Oblique Imagery viewed with Review Tool (courtesy Sanborn, Inc.)



Imagery Types & End Products

Typical imagery end products are RGB plus NIR geoTIFF files, tiled to client and vendor specifications. MrSid orthomosaics are often generated for public distribution and general use.

Licensing & Ownership

Policies vary, but typically oblique and orthogonal imagery products are more restricted in their licensing than digital orthoimagery. For example, Fairbanks North Star Borough imagery can only be distributed to the public as large MrSid format tiles, not as tiles in geoTIFF or the original format. Negotiation with the vendor may allow for more open distribution.

Experience & Capability

Since these are aircraft based solutions, much of the experience and capabilities information outlined in the orthoimagery section applies to oblique and orthogonal imagery as well.

Given the specialized nature of these types of imagery, some vendors may not provide these services. Aircraft and fitted sensors are very specialized; it is important to find a vendor with some depth of experience in acquiring these types of imagery. In the U.S., leading vendors for specialized oblique and orthogonal imagery include Pictometry and Sanborn, but local vendors such as Kodiak Mapping and Quantum Spatial have also started offering some forms of oblique imagery acquisition. The software tools provided by Pictometry and Sanborn in particular for feature measurement and viewing are valuable to many users (e.g. Spokane—see Report 1), and this should be considered in any evaluation of an oblique imagery vendor.

3.4 Subscription Imagery Services

Imagery subscription services offer easy access to a variety of aerial imagery sources that are hosted on vendor servers and typically made available as web mapping services (WMS) or web map tile service (WMTS). The WMS can be used by client applications. Accommodations can also be made for use in public facing applications, such as MSB Parcel Viewer.

Some vendors also offer online tools for viewing and manipulating the imagery (e.g. adjusting color and tone) as well as overlaying additional GIS data.

Subscription imagery services are relatively new in the imagery market and should be carefully evaluated before being pursued. Vendors are listed in Appendix A.

Costs

Costs are still being established by the vendors at this time, but estimates provided by vendors were in the range of $35,000/year to $100,000/year depending on the level of service. It is important to note that these programs are still relatively new and details including costs need to be worked out with vendors.

Imagery services vary in terms of the depth of imagery offerings and available tools for viewing and using the imagery. For example, a lower cost service may provide imagery that is not regularly updated or orthorectified. Pricing based on number of users may be available.

Some of the imagery subscription services include tools for hosting and manipulating imagery from satellite sources or in combination with the client's own imagery archives. Based on discussions with several vendor cost ranges from $20,000 to $50,000/year for these types of imagery services that would include:

- Access to imagery archive.
- Refreshed imagery 2-3 times a year (satellite sourced). *Note, this is dependent on weather conditions and smoke.*
- The ability to download imagery in areas of interest from a web application.
- Analysis tools such as change detection.

Since imagery services are hosted by the vendor, customers may discover some cost savings by eliminating the need for internal server hosting and support (hardware, administration, etc.).

Resolution & Accuracy

Given that the subscription services reviewed in this report are focused on satellite imagery, the resolution of imagery offered ranges from high resolution (30-50 cm.) to moderate resolution (1.5-2.5 m.) imagery. Accuracies for this imagery can be found in Table 2.

Some vendors offer options for providing customized orthorectified imagery services that exceed the typical accuracies of satellite imagery.

Acquisition & Refresh

As part of a subscription service, several of the satellite vendors, e.g. Digital Globe, Airbus, and GeoNorth LLC could provide imagery at a refresh rate of two or more times a year. Acquisition area and refresh details can be negotiated with the vendor.

Access to the customer's own imagery archives and satellite imagery can be provided by tools such as iCubed's Data Doors™ -an online service. This may be a suitable option for hosting the MSB's historical collection of aerial imagery.

Refresh is also not established with some subscription services and time stamped imagery may not be available. Some users, for example Enstar Natural Gas, use Bing imagery for general imagery reference, but not for mapping of features or precise identification of structures.

Vendors we contacted stated they could provide an annual refresh of the entire MSB using a combination of 30-cm, 50-cm and 1.5-m satellite imagery (e.g. core areas using hi-resolution, while outlying areas use lower resolution).

Processing & QA/QC

Vendors providing imagery subscription services typically utilize industry best practices for imagery processing and QA/QC. See Section 3.1 for reference.

Imagery Types & End Products

Imagery types include geoTIFF, MrSid, and online imagery services. The services can be used by various software packages, including ArcGIS and AutoCAD. The MSB and partners would consume the web mapping service provided by the vendor.

Licensing & Ownership

Subscription services are typically arranged on an enterprise level, but can be expanded to include selected partners; for example, emergency dispatch. As with satellite imagery licensing (see Section 3.1) imagery files or services cannot be shared with the public, but can be shared with partners that are part of the group (enterprise) licensing. The vendors offering these services are flexible regarding licensing arrangements and details can be negotiated contractually.

Experience & Capability

Subscription services offer significant promise to the MSB, but are relatively new in the industry and not widely used in Alaska at this time. Vendors should be carefully evaluated with regard to the support they can provide, commitment to the Alaska market, and willingness to work and collaborate with the Borough.

3.5 Unmanned Aerial Systems

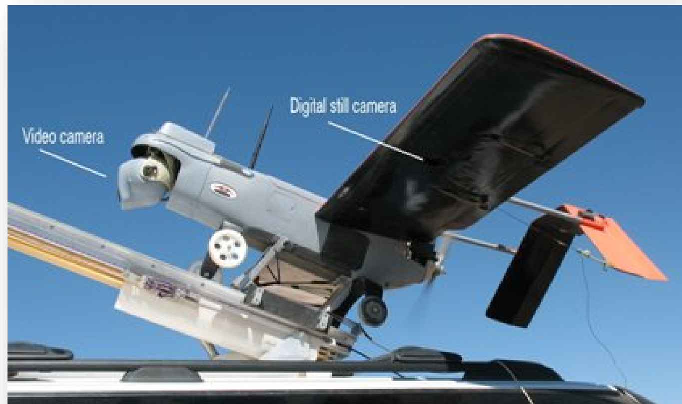
Unmanned aerial systems (UAS), aka unmanned aerial vehicles, or drones, are a variety of small aircraft, broadly separated into fixed wing (Figure 8) and rotor craft. UAS are widely used for military purposes, but civilian applications are a rapidly growing area due to their increasing availability, affordability, and the miniaturization of sensors, GPS, and associated hardware.

Advantages of UAS systems include:

- Affordable equipment
- Rapid deployment
- Easy to use
- Safety (unmanned)
- Ability to operate in wet weather (e.g. in downpours) in rugged terrain
- High resolution imagery
- Completely independent flight operation

Vendors are listed in Appendix A.

Figure 8. Example of UAS (courtesy USGS)



Cost

Costs for UAS acquisition are priced based on the application and end products required, and involve aircraft operation, sensors, operator costs, and data processing. Costs for the UAS equipment and labor associated with acquisition are substantially less than digital orthoimagery, but UAS is also limited in terms of their acquisition area or footprint. This makes it difficult to compare cost with other imagery options. For example, wide area coverage costs can be high for UAS imagery, upwards of $500+/square mile, due to the number of required flights, intensive imagery processing and other efforts required to produce an imagery mosaic and DSM.

Resolution & Accuracy

Imagery created with orthorectification processes can achieve horizontal accuracies as fine as 1-inch resolution at engineering scales. Vertical accuracies are typically limited to 1-tenth inch.

UAS imagery is typically much higher resolution (Figure 9) than digital orthoimagery products, and requires significant amounts of ground control to achieve high accuracies and an accurate orthoimage. When collecting imagery, UAS operators typically fly at an altitude of 700 feet above ground which allows for 6-cm to 13-cm pixel resolution.

Because UAS utilize processed imagery for creating the digital surface model (DSM), the surface data can lack the accuracies typically found in data acquired with LiDAR-based sensors. Areas with tree canopy are especially subject to this lack of surface accuracy.

Figure 9. Very High Resolution Imagery Example from UAS (eTerra LLC)

Acquisition & Refresh

Current regulations limit UAS flights to visual line of sight, even though many UAS are capable of operating autonomously for several hours and at large distances to the ground station.

As a result, acquisition footprints for UAS systems are typically limited to smaller areas. Some larger area applications are being considered, such as transportation projects where corridors are acquired up to one mile in length, but these require extensive coordination and phasing of the acquisition.

Personnel have to be trained in the safe operation of the UAS and have to fulfill requirements for private pilot ground school and/or private pilot licensing and FAA medical certification.

With regard to refresh, UAS are advantageous in that they are quickly deployed and are very portable, thus can readily acquire imagery within short timeframes.

As a result, UAS are starting to be used for time-dependent events such as flooding, wildfire, and other natural disaster monitoring. UAS-derived data can even be paired with site-specific hydrologic data to validate flood-extent modeling based on local river stage.

UAS are also being used for site specific efforts, such as facility site design and modeling as well as topographic modeling. Topographic survey methods including conventional total station, ground-based LiDAR, and LiDAR and digital photogrammetry from manned aerial platforms**.**

Processing & QA/QC

The image processing software utilized by UAS vendors has progressed in recent years and offer the capability to rapidly develop highly accurate image mosaics and DSMs. Development of highly accurate mapping can be problematic because the processing and orthorectification of UAS imagery is challenged by the volume of data acquired, and the high levels of survey control required. However, rapidly advancing technology may resolve some of these issues.

Imagery Types & End Products

UAS end products typically consist of image mosaics and digital surface models (DSM).

Terrain models or digital surface models (DSM) can be extracted from UAS imagery because the imagery is collected in stereo. In some cases, DSMs and corresponding imagery mosaics can be generated at two levels of detail: a coarser terrain model at 1-2m resolution, which reflects the general terrain, and a dense DSM based on a 3-dimensional point cloud extracted from the imagery pixel data. The DSM products are often developed using structure from motion (SfM) photogrammetric models. SfM is a new but proven technique for making high-resolution maps from multiple photographic images.

Licensing & Ownership

UAS Imagery and other end products are typically owned by the client.

Experience & Capability

UAS vendors are limited in Alaska, due to the fact this technology is new. However, the list of UAS providers is increasing rapidly.

Factors to consider when selecting of a vendor include:

- Length of experience collecting UAS imagery.
- Commitment to the Alaska market, and familiarity with Alaska conditions.
- Depth of resources including management and technical personnel and equipment.
- Willingness to work with the Borough closely to ensure the appropriate solution can be developed to meet requirements.
- Certification by the Federal Aviation Administration (FAA).
- Current understanding of the rules, regulations and restrictions. UAS are restricted by a variety of rules governing where and when they can fly. Unmanned aircraft operation in the National Airspace (NAS) fall under the jurisdiction of the FAA). Public entities (local, state, and federal agencies) have to apply for a Certificate of Authorization (COA); civil entities require a Special Airworthiness Certificate.

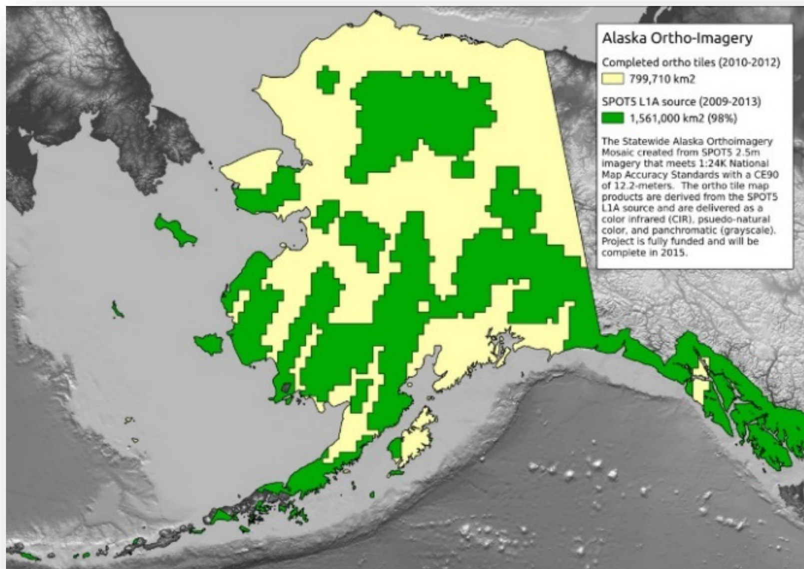
4 Imagery Available from Other Acquisition Programs

As part of this project, a number of existing recurring aerial imagery programs in the Lower 48 and Alaska were researched and outlined in Report 1.

Two of these programs provide or have the potential for providing imagery in the MSB; the Statewide Digital Mapping Initiative (SDMI), and the Natural Resources Conservation Service (NRCS) National Agriculture Imagery Program (NAIP) program.

SDMI

Figure 10. SDMI Alaska SPOT Coverage



SDMI offers digital images (tiff format) and an imagery service of 2.5-meter, SPOT 5 satellite imagery across Alaska (Figure 10). The MSB area is covered by imagery acquired in 2010.

The SDMI orthoimagery mosaic is produced to 1:24,000 National Map Accuracy Standards (NMAS) with accuracy of 12.2-meters (CE90). The SDMI program plans on refreshing imagery in much of Alaska in 2015 at 1.5-meter pixel resolution.

While SDMI does not meet the accuracy or resolution specification for many Borough needs, it can serve as a good reference for feature identification and applications such as land cover mapping.

NAIP

NAIP is a federal program that was instrumental in providing imagery for the MSB in 2004. Typically, NAIP imagery resolution is 2-foot, and true color RGB orthoimagery. It is good quality imagery, but according to the NRCS there are no specific plans to acquire NAIP imagery in the Borough at this time.

5 References

Abdullah, Qassim, 2013, The New Standard of Map Accuracy, Woolpert White Paper.

Arshat, Brad, Sanborn, Inc., 2017, pers.communication, regarding oblique imagery technical specifications and rough order of magnitude costs.

ASPRS, 2005, ASPRS Report to the U.S. Geological Survey on Digital Orthoimagery, Photogrammetric Engineering & Remote Sensing, February, 2006.

ASPRS, 2014, Positional Accuracy Standards for Digital Geospatial Data, Edition 1, Version 1, November, 2014.

Broderson, Dayne, 2016, UAF-GINA, pers.communication, regarding imagery WMTS, WMS, and current SDMI services.

Bunis, Linda, 2007, Aerial Photography Field Office – National Agriculture Imagery Program(NAIP) Suggested Best Practices – Final Report. Performed for USDA under contract: CDRL A006 SUBMITTED UNDER GSA Contract Number GS-23F-0284M, SIN 871_2, February 1, 2007

Colligan, Steve, eTerra, 2016, pers.communication, regarding UAS technology.

Cowart, Russ, 2008, Alaska Sources of Control – SDMI Task 4, presentation. Factors contributing to satellite imagery accuracy.

Darmapuuri, Srni, 2016, Michael Baker International, pers.communication re: UAS technical specifications, issues of survey control.

Duncan, Tom, 2016, Fairbanks North Star Borough GIS Manager, pers.communication regarding Pictometry project and usage.

Hale, Jeremy, Digital Globe, 2016, pers.communication, regarding Digital Globe regarding satellite imagery technical specifications and rough order of magnitude costs.

Heinsius, Jonathan, GeoNorth, 2016, pers.communication, regarding Airbus satellite imagery technical specifications and rough order of magnitude costs.

Hobson, Doug, Manager, GeoNorth LLC, pers.communication, regarding satellite imagery options and imagery web mapping services.

Kellie, Ben, K2 Dronotics, 20166, pers. regarding UAS technical specifications and rough order of magnitude costs.

Kerr, John, SurvBase, 2016, pers.communication, regarding UAS, and survey control considerations.

Kinney Engineering LLC, 2016, MSB Recurring Aerial Imagery Project--Business Needs Analysis-Report #2, prepared for the Matanuska Susitna Borough, December, 2016.

Koleda, Ken, GIS Director, Genesee County GIS, Flint, MI., pers.communication, use of Pictometry, and imagery online.

Mathur, Mita, 2014, Maximizing Orthoimagery QA/QC Procedures, Earth Imaging Journal, April, 2014.

McCollough, Adam, Quantum Spatial Inc., 2016, Anchorage, AK. regarding orthoimagery technical specifications and rough order of magnitude costs.

Nighbert, Jeffrey S., 2010, The Accuracy and Precision Revolution--What's ahead for GIS?, Esri ArcUser Magazine, Winter 2010.

North Carolina Geographic Information Coordinating Council. 2008, Traditional Aerial Film Camera vs. Digital Camera. Statewide Mapping Advisory Committee. Working Group for Orthophotography Planning.

SDMI, 2009, Alaska SDMI Imagery Whitepaper, produced by consultant team for SDMI (Michael Baker, HDR Alaska, i-cubed LLC)

GeoNorth, Inc., 2015, MSB RFI Letter of Interest #16-059L, MSB RFI.

Kodiak Mapping Inc., 2015, MSB RFI Letter of Interest #16-059L.

Merrick & Company, 2015, MSB RFI Letter of Interest #16-059L

Michael Baker International, 2015, MSB RFI Letter of Interest #16-059L

Quantum Spatial, Inc., 2015, MSB RFI Letter of Interest #16-059L

Rango, A., and A.S. Laliberte. 2010. Impact of flight regulations on effective use of unmanned aerial vehicles for natural resources applications. Journal of Applied Remote Sensing 4:043539.

Sankey, J., Buscome, D., Grams, P., 2016, Evaluation of UAS photogrammetry and comparison to ground and aerial surveys for monitoring geomorphic condition of fine sediment deposits along the Colorado River.

SDMI, 2008, Control Requirements Report, produced as part of the Alaska Statewide Digital Mapping Initiative Project Planning project.

Summers, Ashley, Jenny Todd, Josh Pendleton, 2016, Collaborative Quality Control Saves Money on Data Project, Denver Regional Council of Governments, ArcUser, Fall 2016

TerraSond, Inc., 2015, MSB RFI Letter of Interest #16-059L

U. S. Army Corps of Engineers, 2015, Photogrammetric and LiDAR Mapping, EM 1110-1-1000. 30 April 2015.

U.S. Dept. Transportation, FAA, 2016, Advisory Circular No. 107-2, Rules governing the use and operation of UAS, June, 2016.

USGS Federal Geographic Data Committee, Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data Accuracy

USGS, 2015, Digital Orthoimagery Base Specification V1.0.

Von Esson, Ian, 2016, Spokane County, pers.communication, regarding use of Pictometry

Zoltek, Michael, 2014, Relative Measurement Accuracies within Pictometry's Individual Orthogonal and Oblique Frame Imagery, Pictometry International Corp white paper.

6 Resources

Orthophoto Standards:

http://nationalmap.gov/standards/doqstds.html

Satellite Imagery:

Digital Globe:
https://www.digitalglobe.com/resources/satellite-information
High Resolution Satellite Imagery Ordering Handbook:
https://www.aaas.org/page/high-resolution-satellite-imagery-ordering-and-analysis-handbook
LandInfo, Inc. Hubing, Nick, 2013, Satellite Imagery Resource Guide.
http://www.landinfo.com/buying-optical-satellite-imagery.html

Imagery Services/Subscription Services:

Microsoft Bing:
https://www.microsoft.com/maps/licensing/licensing.aspx
Esri:
http://www.esri.com/esri-news/arcnews/spring15articles/premium-imagery-services-for-arcgis-powered-by-leica-geosystems

Oblique and Orthogonal Imagery (Pictometry and other)

Genesee County GIS, Michigan:
Website: http://www.gc4me.com/departments/gis/contact_us.php
Genesee County Online GIS Application:
App.fetchgis.com/genesee

UAS:

FAA: https://www.faa.gov/uas/
UAV.ORG: https://www.uavs.org/

Imagery Specifications; Mapping Accuracy Standards; QA/QC

USGS Fact Sheet 038-00, April 2000
Digital Orthoimagery Base Specification:
https://pubs.usgs.gov/tm/11/b5/

USGS—Data Management and QA/QC Protocols:
https://www2.usgs.gov/datamanagement/qaqc.php

Denver Regional Aerial Photography Project (includes example of QA/QC approach)
https://drcog.org/services-and-resources/data-maps-and-modeling/gis-maps/denver-regional-aerial-photography-project

Appendix A: Comparison Matrix of Imagery Options

Aerial Imagery Option	Potential Vendors	Satellite type	End Products	Costs (sq.mile)	Data Quality Standards	Acquisition	Acquisition Frequency	Accuracy CE90	Processing and QA/QC	Native Resolution (GSD)	Imagery Type	Unique Characteristics	Alaska Experience
Satellite	Airbus (Direct Dealer)	Pléiades 1A & 1B satellites	Standard products	Pleiades $11.60 - 20.00	NSSDA	20 km swath width	multiple times/day Plus enhanced acquisition using Alaska download facility	1m – 1.5m	Provided by vendors such as GeoNorth, i-cubed. Orthorectification options include custom using client elevation data and survey control or general using national control data sources	50 cm	five (5) separate bands one (1) Panchromatic band and four (4) Multispectral bands.	Highest acquisition frequency in Alaska due to Alaska download facility.	Varied; localized in various locations in Alaska
		SPOT 5, 6, & 7 satellites	Standard products	SPOT $4.40 - 15.00	NSSDA	60 km swath width	Weekly Plus enhanced acquisition using Alaska download facility. 2 to 3 days 1 day with full constellation	1.5m - 4m	Provided by vendors such as GeoNorth, i-cubed. Orthorectification options include custom using client elevation data and survey control or general using national control data sources	1.5 m, 2.5 m	Panchromatic green, red, infrared. B4 (SWIR: short-wave infrared, on SPOT 4 and SPOT 5)	Good quality imagery and statewide Alaska coverage available.	High due to use by SDMI. Alaska imagery download facility.
	Digital Globe (Direct Dealer)	Worldview 3,4,6 satellites	Standard products, orthomosaic, and imagery subscription services.	$20+	NSSDA	14 to 18 km swath width	multiple times/day	.75m – 1m	Provided by vendors such as DG, GeoNorth, i-cubed. Orthorectification options include custom using client elevation data and survey control or general using national control data sources.	30, 50, 60 cm	5 bands RGB + NIR 1 Panchromatic band 4 or 8 Multispectral bands.	Highest accuracy of commercial satellite options; also offer 3 high resolution satellites.	Varied; localized in various locations in Alaska
	ETerra LLC (Reseller)	Airbus	Custom products	unknown	NSSDA	See Above	See Above	See Above	Variety of custom products	See Above	unknown	unknown	17+ years working with satellite imagery.
	GeoNorth (Reseller)	Airbus & Digital Globe Satellites	Orthomosaic, custom products, and subscription services.	Depends on project scope. See above for Airbus and DG costs.	NSSDA	See Above	See Above	See Above	Provided by DG. Orthorectification options include custom using client elevation data and survey control or general using national control data sources	See Above	See above, but can customize per client request.	Remote sensing specialists.	Strong Alaska presence; works with SDMI
	Icubed LLC (Reseller)	Airbus & access to some Digital Globe	Orthomosaic and subscription services (Data Doors)	Depends on project scope. See above for Airbus and DG costs.	NSSDA	See Above	See Above	See Above	Provided by DG. Orthorectification options include custom using client elevation data and survey control or general using national control data sources	See Above	See above, but can customize per client request.	Remote sensing specialists and image processing.	Has worked in Alaska (SDMI 8-2010)
	Merrick and Company (Reseller)	Digital Globe	Custom products	unknown	NSSDA	See Above	See Above	See Above	Variety of custom products	See Above	unknown	unknown	17+ years working with satellite imagery.
	Michael Baker International (Reseller)	Airbus	Custom products	unknown	NSSDA	See Above	See Above	See Above	Variety of custom products	See Above	unknown	unknown	17+ years working with satellite imagery.

Aerial Imagery Option	Potential Vendors	Satellite type	End Products	Costs (sq.mile)	Data Quality Standards	Acquisition	Acquisition Frequency	Accuracy CE90	Processing and QA/QC	Native Resolution (GSD)	Imagery Type	Unique Characteristics	Alaska Experience
Digital Orthoimagery	Kodiak Mapping	N/A	Orthoimagery, custom products, and oblique imagery.	$160 - 300/ sq.mile. Varies depending on acquisition factors.	Products adhere to USGS, ASPRS standards and NMAS.	Utilize own aircraft; Flexible, depending on project.	Available year-round for acquisition. Have 1 local aircraft.	Varies, but typically: .15m – .75m	Utilize internal photogrammetric and associated technical resources. Can process planimetrics and other products in CAD, other formats.	Varies; capable of 3 in inch to 3 ft	High resolution 16-bit RGB, multispectral (R,G,B,NIR) imagery	Locally based in Palmer, AK. LiDAR capabilities	Extensive experience throughout Alaska.
	Merrick & Company	N/A	Orthoimagery and custom products.	$160 - 300/ sq.mile. Varies depending on acquisition factors and mobilization costs.	Products adhere to USGS, ASPRS standards and NMAS.	Utilize sub-contractors	Utilize sub-contractors for acquisition.	Products conform to NMAS	Utilize internal photogrammetric and associated technical resources. Can process planimetrics and other products in CAD, other formats.	Varies; capable of 3 in to 3 ft	High resolution 16-bit RGB, multispectral (R,G,B,NIR) imagery	Specialize in LiDAR, particularly high resolution electric utility applications.	Limited Alaska imagery experience. Exception is Anchorage, 2015
	Michael Baker International	N/A	Orthoimagery and custom products.	unknown	Products adhere to USGS, ASPRS standards and NMAS.	Utilizes sub-contractors for acquisition.	Utilize sub-contractors for acquisition.	Products conform to NMAS	Utilize internal photogrammetric and associated technical resources. Can process planimetrics and other products in CAD, other formats.	Varies	Primarily RGB orthoimagery	Engineering and geospatial capabilities. Long photogrammetric history.	Project specific in various Alaska locations.
	Peregrine Aerial Surveys	N/A	Orthoimagery and custom products.	$160 - 300/ sq.mile. Varies depending on acquisition factors and mobilization costs.	Products adhere to USGS, ASPRS standards and NMAS.	Utilize own aircraft; mobilization required from Canada.	Not based in Alaska, but work frequently in the state.	Products conform to NMAS.	Utilize internal photogrammetric and associated technical resources.	Varies; capable of 3 in to 3 ft	High resolution 16-bit RGB, multispectral (R,G,B,NIR) imagery	Imagery specialists, but support LiDAR acquisitions.	Varied; localized in various locations in Alaska. Anchorage 2015 (with Merrick)
	Quantum Spatial	N/A	Orthoimagery, custom products, and oblique imagery.	$160 - 300/ sq.mile. Varies depending on acquisition factors.	Products adhere to USGS, ASPRS standards and NMAS.	Utilize locally based aircraft; Flexible, depending on project.	Varies. Have 2 local aircraft.	Products conform to NMAS.	Utilize internal photogrammetric and associated technical resources. Can process planimetrics and other products in CAD, other formats. Provides online imagery review tools for client use.	Varies; capable of 3 in to 3 ft	High resolution 16-bit RGB, multispectral (R,G,B,NIR) imagery	Imagery and LiDAR solutions with equal capabilities	Extensive experience throughout Alaska
Oblique and Orthogonal Imagery	Pictometry	N/A	Oblique, orthogonal, custom orthomosaics, imagery subscription services.	Can be 3 to 4 times greater than orthoimagery. Varies depending on acquisition factors and mobilization costs.	Products adhere to USGS, ASPRS standards and NMAS.	Utilize own aircraft; mobilization from Lower 48.	In Lower 48, typically 3 year cycles.	Orthorectified. High accuracy detailed feature mapping (1:100) Conforms to NMAS and NSSDA.	Utilize internal photogrammetric and associated technical resources. Provides online imagery review tools for client use.	3, 4, 6 in	Oblique, orthogonal RGB	One of the few vendors specializing in oblique, orthogonal, and true orthophoto.	Anchorage 2012; Fairbanks 2012-2013.
	Sanborn	N/A	Oblique, orthogonal, custom orthomosaics, imagery subscription services.	Can be 3 to 4 times greater than orthoimagery. Varies depending on acquisition factors and mobilization costs.	Products adhere to USGS, ASPRS standards and NMAS.	Utilize own aircraft; mobilization from Lower 48.	In Lower 48, typically 3 year cycles.	Orthorectified. High accuracy detailed feature mapping (1:100) Conforms to NMAS and NSSDA.	Utilize internal photogrammetric and associated technical resources. Provides online imagery review tools for client use.	3, 4, 6 in	Oblique, orthogonal RGB	One of the few vendors specializing in oblique, orthogonal, and true orthophoto.	May be acquiring imagery in 2017 for USFWS.

Aerial Imagery Option	Potential Vendors	Satellite type	End Products	Costs (sq.mile)	Data Quality Standards	Acquisition	Acquisition Frequency	Accuracy CE90	Processing and QA/QC	Native Resolution (GSD)	Imagery Type	Unique Characteristics	Alaska Experience
Subscription Imagery Services	Digital Globe	Varies	High resolution satellite imagery.	ROM estimate: $25,000 - 50,000/year.	unknown	See Above	Variable	Customized for customer.	unknown	Small and mid-scales.	RGB imagery	unknown	unknown
	Esri (Hexagon)	Varies	High resolution satellite imagery.	Free	unknown	Utilize various satellite vendors.	Variable	Not Orthorectified	unknown	Small and mid-scales.	RGB imagery	GIS-focused; support for Esri users is especially strong.	Some local users.
	GeoNorth	Airbus & access to some Digital Globe	Varies depending on arrangement made with client.	ROM estimate: $25,000 - 100,000/year.	Products adhere to USGS, ASPRS standards and NMAS.	Negotiable. Utilize Airbus and DG satellite data.	Varies depending on arrangement made with client.	Depending on level of custom processing.	Utilize internal photogrammetric and associated technical resources.	Varies depending on source imagery.	Varies. Options for high and moderate resolution imagery.	Online mapping and remote sensing expertise.	High level
	Google	Varies, mostly Digital Globe	Variety of options, but no standard product.	unknown	unknown	See Above	Typically Annual	Not Orthorectified	unknown	Varies depending on source imagery.	Varies depending on source imagery.	Aggressively acquiring imagery nationally.	unknown
	iCubed LLC	Varies, mostly Airbus.	Data Doors online application.	unknown	Products adhere to USGS, ASPRS standards and NMAS.	See Above	Varies depending on arrangement made with client.	Depending on level of custom processing.	Utilize internal photogrammetric and associated technical resources.	Varies depending on source imagery.	Varies. Options for high and moderate resolution imagery.	Online mapping and remote sensing expertise.	Consultant on SDMI project.
	Microsoft Bing	Varies	High resolution imagery service.	$4,000/year	unknown	Not on a regular basis.	Variable	Not Orthorectified	unknown	Small and mid-scales.	RGB imagery	Microsoft based, thus large resource.	Some local users, e.g. Enstar.
	Pictometry	N/A	Oblique, orthogonal products; support 3D.	unknown	Products adhere to USGS, ASPRS standards and NMAS.	Utilize own aircraft; mobilization required from Lower 48.	Varies, typically 2-3 cycles.	Orthorectified. Conforms to NMAS and NSSDA.	Utilize internal photogrammetric and associated technical resources.	3, 4, 9 in (can be adjusted).	3 - 9 in	Oblique and orthogonal imagery expertise.	Currently, no clients using their services in Alaska.

Aerial Imagery Option	Potential Vendors	Satellite type	End Products	Costs (sq.mile)	Data Quality Standards	Acquisition	Acquisition Frequency	Accuracy CE90	Processing and QA/QC	Native Resolution (GSD)	Imagery Type	Unique Characteristics	Alaska Experience
UAS	CRW Engineering	N/A	Not fully defined yet.	unknown	Products adhere to USGS, ASPRS standards and NMAS.	unknown	No formally defined Use Cases.	Project Dependent	unknown	Varies depending on project.	Image mosaics	Engineering focused experience; new to UAS.	Limited UAS experience in Alaska.
	eTerra LLC	N/A	Image mosaics, DSM, CAD derivative products.	Varies. Typically UAS image products and DSM range from $500 - 1,500/square mile.	Products adhere to USGS, ASPRS standards and NMAS.	Utilize internal UAS resources.	Strategic business planning; Use Case definition.	Varies depending on project. Typically 1/10 inch scale.	Internal team performing Orthorectification using standard UAS data procedures, sFm methods, image mosaicking; CAD production.	Varies depending on project.	Image mosaics & DSM	Most experienced Alaska vendor with UAS.	Extensive experience throughout Alaska.
	K2 Dronotics	N/A	Image mosaics, DSM, CAD derivative products.	Varies. Typically UAS image products and DSM range from $500 - 1,500/square mile.	Not certified by surveyor.	Utilize internal UAS resources.	Depends on need.	Project Dependent	Internal team performing Orthorectification using standard UAS data procedures, sFm methods, image mosaicking; CAD production.	Varies depending on project.	RGB	Engineering focused firm knowledgeable in applications of imagery and DSM.	Long-time Alaska engineering base.
	Michael Baker International	N/A	Image mosaics, DSM, CAD derivative products.	Varies. Typically UAS image products and DSM range from $500 - 1,500/square mile.	Have own fleet of UAS.	Utilize internal UAS resources.	No formally defined Use Cases.	Project Dependent	Internal team performing Orthorectification using standard UAS data procedures, sFm methods, image mosaicking; CAD production.	Varies depending on project.	Image mosaics & DSM	National depth of resources; have local pilot; surveyor; processing resources.	Limited UAS experience in Alaska.
	SurvBase, Inc	N/A	Image mosaics, DSM, CAD derivative products.	unknown	unknown	Utilize internal UAS resources.	Depends on need.	Project Dependent	unknown	Varies depending on project.	RGB	Multi-disciplinary mapping, surveying, coastal zone specialists offering variety of geospatial services.	Long-time Alaska mapping firm.
	TerraSond	N/A	Image mosaics, DSM, CAD derivative products.	unknown	unknown	Utilize internal UAS resources.	Depends on need.	Project Dependent	unknown	Varies depending on project.	RGB	Multi-disciplinary mapping, surveying, coastal zone specialists offering variety of geospatial services.	Long-time Alaska mapping firm.

Appendix B: Definition of Technical Terms

Aerial photography: A series of photographic images of the ground, taken at regular intervals from an airborne craft, such as an airplane.

American Society of Photogrammetry and Remote Sensing (ASPRS): A scientific association of specialists in the arts of imagery exploitation and photographic cartography.

CE90: Circular error at 90% confidence, which is the location error. This means that locations of objects are represented on the image within the stated accuracy 90% of the time. The CE90 accuracy level measure was established by the U.S. National Map Accuracy Standard (NMAS) and can be related to Root Mean Square Error (RMSE).

Color Infrared Imagery: Color infrared (CIR), also known as near infrared, imagery includes a band of near infrared (NIR) information. NIR wavelengths are slightly longer than red, and they are outside of the range visible to the human eye. They are frequently collected as part of an aerial imagery collection and delivered as a fourth band of spectral information (in addition to red, green, and blue). Color infrared images (aka false color) are especially useful for mapping vegetation and paved surfaces in urban environments.

Digital Elevation Model (DEM): A digital cartographic representation of the elevation of the land at regularly spaced intervals in x and y directions, using z values referenced to a common vertical datum.

Digital Mapping Camera (DMC): Frame-based large format aerial camera that can capture digital aerial imagery, and enabling direct production of a wide range of mapping and image analysis deliverables, including orthophotos, digital terrain models (DTMs), and more.

Digital Surface Model (DSM): Elevation model depicting elevations of the top reflective surfaces such as buildings and vegetation. A DSM may not accurately depict the bare earth terrain if the remote sensing sensor is not capable of penetrating canopies.

Digital Terrain Model (DTM): A vector dataset composed of 3D-breaklines and regularly spaced 3D mass points, typically created through stereo photogrammetry, that characterize the shape of the bare-earth terrain. Breaklines more precisely delineate linear features whose shape and location would otherwise be lost. A DTM is not a surface model; its component elements are discrete and not continuous; a TIN or DEM surface must be derived from the DTM.

Image Resolution: Describes the linear size that an image pixel or raster cell represents on the ground. Common resolutions are 3 inch, 6 inch, 1 foot, 1 meter, etc.

Geographic Information Systems (GIS): A GIS manages spatial and tabular data in one software system; and provides tools to store, retrieve, manage, display, and analyze various types of tabular and geospatial data including aerial imagery, LiDAR, and vector data.

Ground Sample Distance (GSD): The distance between two consecutive pixel centers measured on the ground. The bigger the value of the image GSD, the lower the spatial resolution of the image and the less visible details. GSD and pixel are often used interchangeably.

Ground Control Point (GCP): GCPs are typically captured using GPS receivers to survey coordinates of photo-identifiable points on the ground. Coordinates are reported in latitude, longitude, and elevation—or northing, easting, and heights. GCPs are typically collected by surveyors who are physically sent to the location of the required control point. GCPs are used to measure and validate a position relative to photo-identifiable elements nearby, such as concrete sidewalks and buildings.

Horizontal Accuracy: The horizontal (radial) component of the positional accuracy of a data set with respect to a horizontal datum, at a specified confidence level (ASPRS, 2015).

Inertial Measurement Unit: A sensor that provides complete information about the acceleration, position, orientation, speed, of an aircraft.

Light Imaging, Detection, And Ranging (LiDAR): A technology that uses a sensor to measure distance to a reflecting object by emitting timed pulses of light and measuring the time difference between the emission of a laser pulse and the reception of the pulse's reflection(s). The measured time interval for each reflection is converted to distance, which when combined with position and attitude information from GPS, IMU, and the instrument itself, allows the derivation of the 3D-point location of the reflecting target's location.

Nadir: In aerial imagery, nadir is the point on the ground vertically beneath the perspective center of the camera lens or sensor, in other words looking straight down.

National Agriculture Imagery Program (NAIP): A program to acquire aerial imagery at one-meter pixel resolution during the agricultural growing seasons, mostly in the continental U.S.

Near Infrared (NIR): Color-infrared (CIR) imagery uses a portion of the electromagnetic spectrum known as near infrared that ranges from 0.70 µm to 1.0 µm (0.7 to 1.0 micrometers or millionths of a meter), just beyond the wavelengths for the color red. This imagery is often used to better detect differences between vegetation, water, and paved surfaces.

Oblique Imagery: Oblique imagery is imagery captured at an angle to provide a more natural perspective, making objects easier to recognize and interpret. Oblique aerial images are captured from north, south, east and west directions to provide a 360-degree view of the feature.

Quality Assurance: to ensure the end client receives the quality products it pays for, consistent with the Scope of Work.

Quality Control: Steps taken to ensure delivery of products that satisfy standards, guidelines, and specifications identified in the Scope of Work. These steps typically include procedures to ensure quality at each step of the work flow, in-process quality reviews, and/or final quality inspections prior to delivery of products to a client.

Orthogonal Imagery: Orthogonal imagery provides a true top-down view and is rectified to align to a map grid.

Orthoimagery Mosaic: a single image mosaic of multiple raw imagery tiles or files. The orthomosaic process will generate a georeferenced image mosaic and optionally a digital surface model in various different formats.

Orthorectification: The process of correcting the geometry of an image so that it appears as though each pixel were acquired from directly overhead. The topographical variations in the surface of the earth and the tilt of the satellite or aerial sensor affect the distance with which features on the satellite or aerial image are displayed. The more topographically diverse the landscape, the more distortion inherent in the image.

Orthophotographs: Aerial photographs geometrically corrected to create uniform scale and to remove displacements caused by terrain relief, sensor distortion, and camera tilt. Orthoimages are geometrically corrected ("orthorectified") such that the scale is uniform: the photo has the same lack of distortion as a map. Unlike an uncorrected aerial photograph, an orthophotograph can be used to measure true distances, because it is an accurate representation of the Earth's surface.

Orthoimagery: Typically, high resolution aerial images that combine the visual attributes of an aerial photograph with the spatial accuracy and reliability of a planimetric map. Typically, aerial imagery used for mapping consists of a rectified aerial image or orthophoto (aka orthoimage). Orthoimagery is aerial imagery or photographs that have been adjusted using survey ground control points and vertical topography, for example a digital elevation model, to ensure that the imagery is positionally accurate. Unlike an uncorrected aerial photograph, an orthophoto can be used to measure true distances, because it is an accurate representation of the earth's surface, having been adjusted for topographic relief, lens distortion, camera tilt, and other factors.

Pansharpening: Panchromatic sharpening, more commonly called pansharpening, is a process in which two raster datasets are fused together to create one high-resolution, easy to analyze raster dataset. This process utilizes one high-resolution panchromatic image and one lower-resolution multiband color image. By combining these two images, the final product not only has the higher resolution of the panchromatic dataset, but it also has the color associated with the multiband dataset, providing the user with better analysis opportunities.

Pictometry™: Pictometry is the name of a patented aerial image capture process that produces imagery showing the fronts and sides of buildings and other features. Images are captured by low-flying airplanes, depicting oblique and overhead perspectives of features. special software is needed to accurately determine objects' size and position on the maps.

Point Cloud: One of the fundamental types of geospatial data (others being vector and raster), a point cloud is a large set of three dimensional points, typically from a LiDAR collection.

Raster Data: One of the fundamental types of geospatial data (others being vector and point cloud), a raster is an array of cells (or pixels) that each contain a single piece of numeric information representative of the area covered by the cell.

Remote Sensing: The technology of acquiring multi-spectral information about the earth's surface and atmosphere using sensors mounted on airborne platform (planes, helicopter) or satellites.

Resolution: The smallest unit a sensor can detect or the smallest unit an orthoimage depicts. The degree of fineness to which a measurement can be made. Pixel resolution size as referred to in this report is the native resolution of imagery as acquired by the camera sensor. For ASPRS (2014) it is the ground size of a pixel in a digital orthoimage, after all rectifications and resampling procedures.

Residual Mean Square Error: The square root of the average of the set of squared differences between data set coordinate values and coordinate values from an independent source of higher accuracy for identical points. RMSE measures how much error there is between two datasets. RMSE usually compares a predicted value and an observed value. For example, a LiDAR elevation point (predicted value) might be compared with a surveyed ground measurement (observed value). RMSEr − the horizontal linear RMSE in the radial direction that includes both x- and y-coordinate errors. RMSEx − the horizontal linear RMSE in the X direction (Easting). RMSEy − the horizontal linear RMSE in the Y direction (Northing). RMSEz − the vertical linear RMSE in the Z direction (Elevation).

Satellite images: Images taken from satellites, which orbit the earth at much higher altitudes than airplanes. Satellites use a variety of methods to produce images, including infrared, water vapor, and visible image technologies. Satellite imagery resolution varies from 30- centimeter pixel to 5 meter plus pixel in the commercial market.

UAS (also known as UAV, drones): aircraft without a human pilot aboard. The flight of UAVs may operate with various degrees of autonomy: either under remote control by a human operator, or fully or intermittently autonomously, by onboard computers operating without an internal pilot; are tethered by a radio control link; and can be preprogrammed for both flight and payload operations prior to launch.

Vector Data: One of the fundamental types of geospatial data (others being raster and point cloud), vectors include a variety of data structures that are geometrically described by x and y coordinates, and potentially z values. Vector data subtypes include points, lines, and polygons.

Web Mapping Service (WMS): A standard protocol for serving (over the Internet) georeferenced map images which a map server generates using data from a geospatial database.

Web Mapping Tile Service (WMTS): A standard protocol for serving pre-rendered georeferenced map tiles over the Internet. The specification was developed and first published by the Open Geospatial Consortium in 2010.