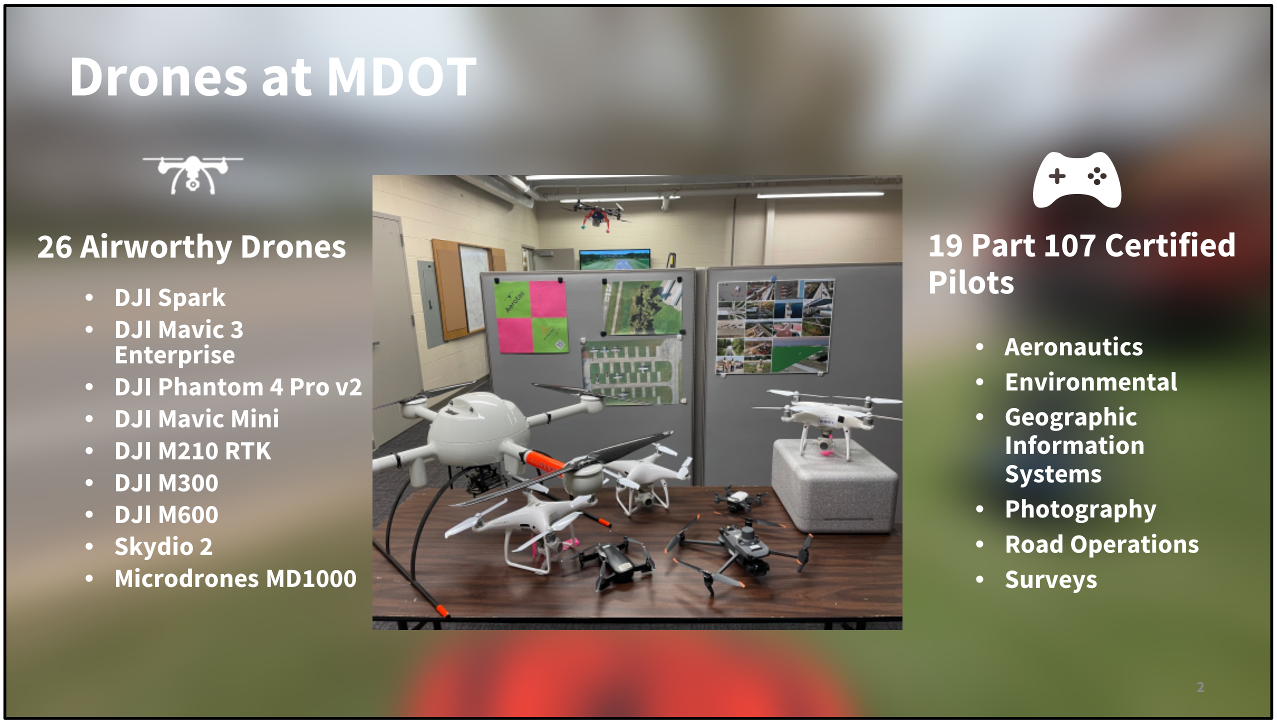
INTRO

Hello! I'm Frank Boston. I've been with MDOT's Design Survey section since 2001. Prior to that I was Vice President of Operations at Abrams Aerial Survey in Lansing. I have over 30 years of photogrammetry and remote sensing experience.

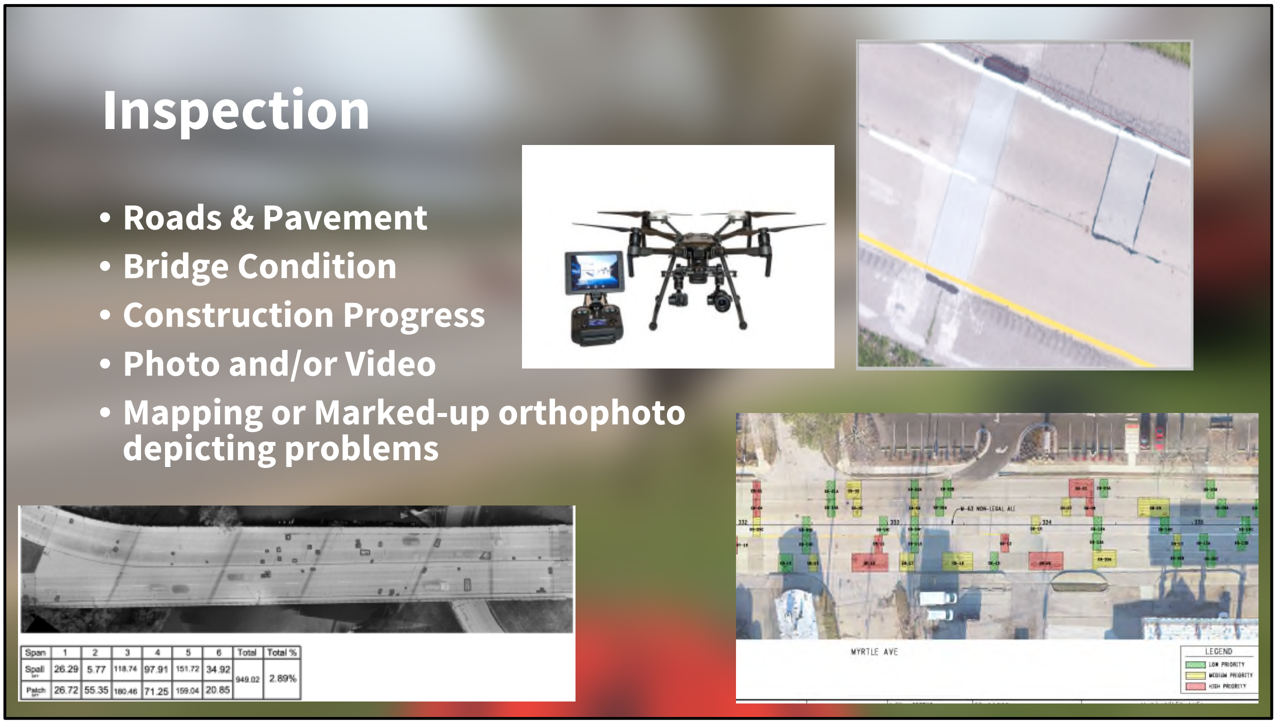
MDOT Design Survey has been using a relatively new drone-based LiDAR system. This is a joint project with MDOT Aeronautics.

I've been interested in flying drones for over 10 years, but it took a while to get buy-in from MDOT. There was initially a lot of negativity associated with the idea, even with the word "drone". The industry tried for a long time not to use that term, and rather use "UAS" or "UAV". Well, we lost that battle. "Drone" is just a better word, all things said and done. Even if it isn't entirely accurate.



At MDOT, we've been working with different workflows to see what can be done better, easier, or more safely with drones.

At last count, MDOT was up to about 26 drones and 19 certified remote pilots. Additional pilots are preparing for the certification exam.

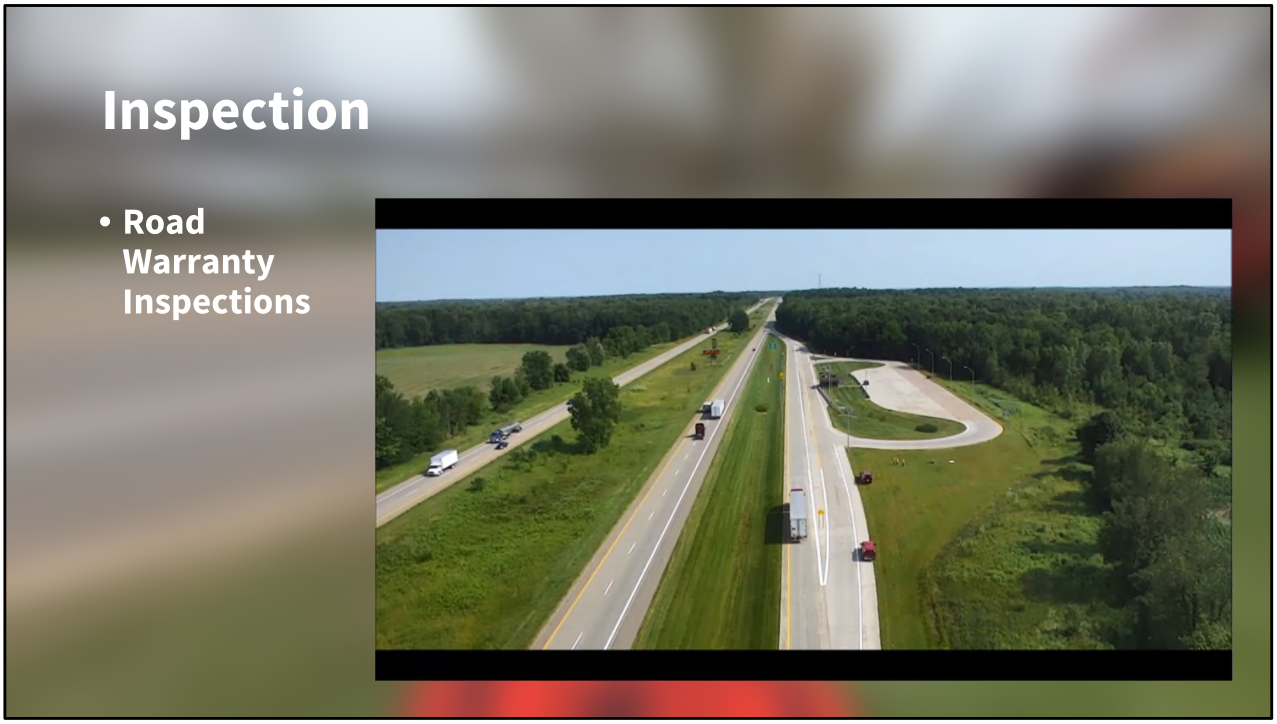


One of the many workflows that a drone can be used for in transportation is highway Inspection.

SW Surveys has been doing this using a DJI Matrice 210 RTK V2

Drone imagery gives clear picture of what needs to be completed in the field.   Using a drone to inspect concrete joint repair project has several benefits.

1. SAFETY! There is less exposure flying a UAS compared to driving a vehicle along side the road.
2. Images can be reviewed in the office and field verify, providing a better work product.
3. Obtain more accurate georeferenced patch locations. Vs. Using wheel or DMI, and spread sheet.
4. Conflicts can be reviewed on the aerial photos without needing a return trip to field.



SW Surveys has also flown projects for road warranties.

Coldwater weigh station. Approx. 3600’. During these projects they recorded several roadway videos of the distressed pavement, up to 5 minutes each

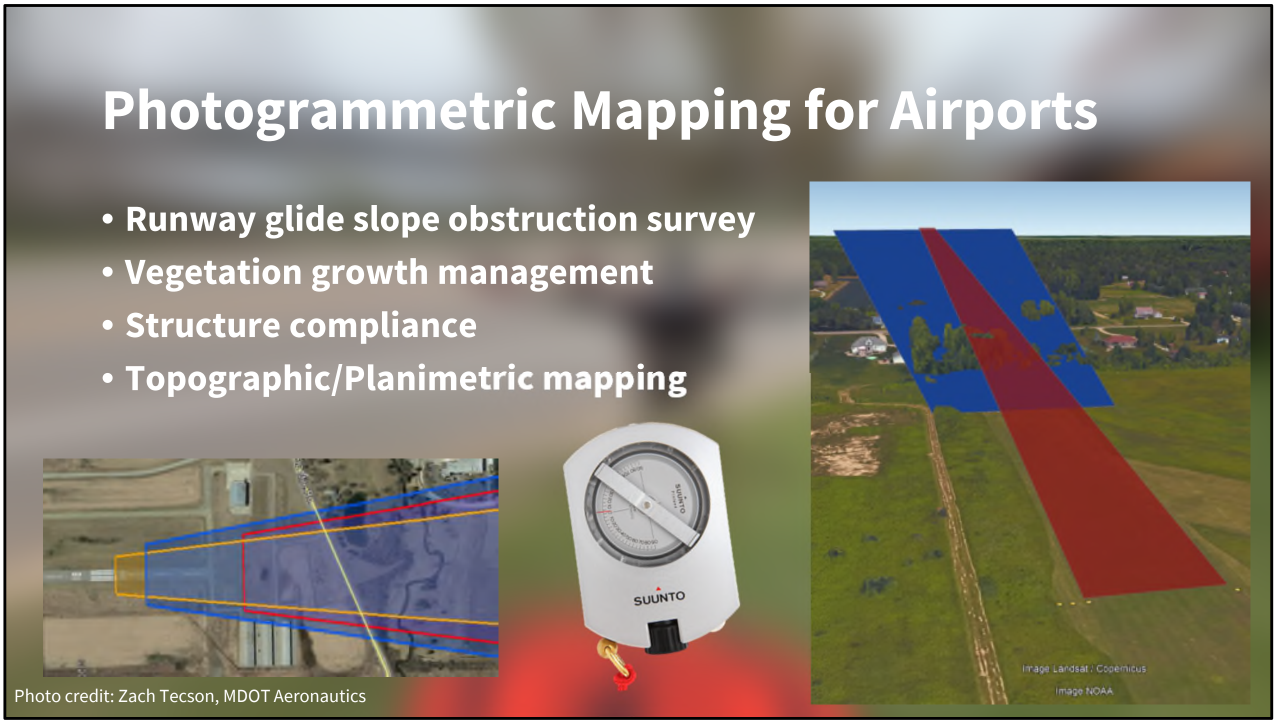
At each location they zoomed into the pavement. On future projects they plan to do a drive by to determine which locations are cracking. This would allow them to determine where to focus the video and zoom for the video. They can also add notes in video. Can do video year after year to monitor cracks.

Moving forward they can provide this video to contractors. This would make it so all parties can view the information remotely.

Drones can also be used for traffic monitoring, and analytics. This would typically be short-term, for emergency use. However, it is possible to use a tethered drone, with power being supplied along the tether. This type of drone could stay aloft for longer periods of time, if weather allowed.

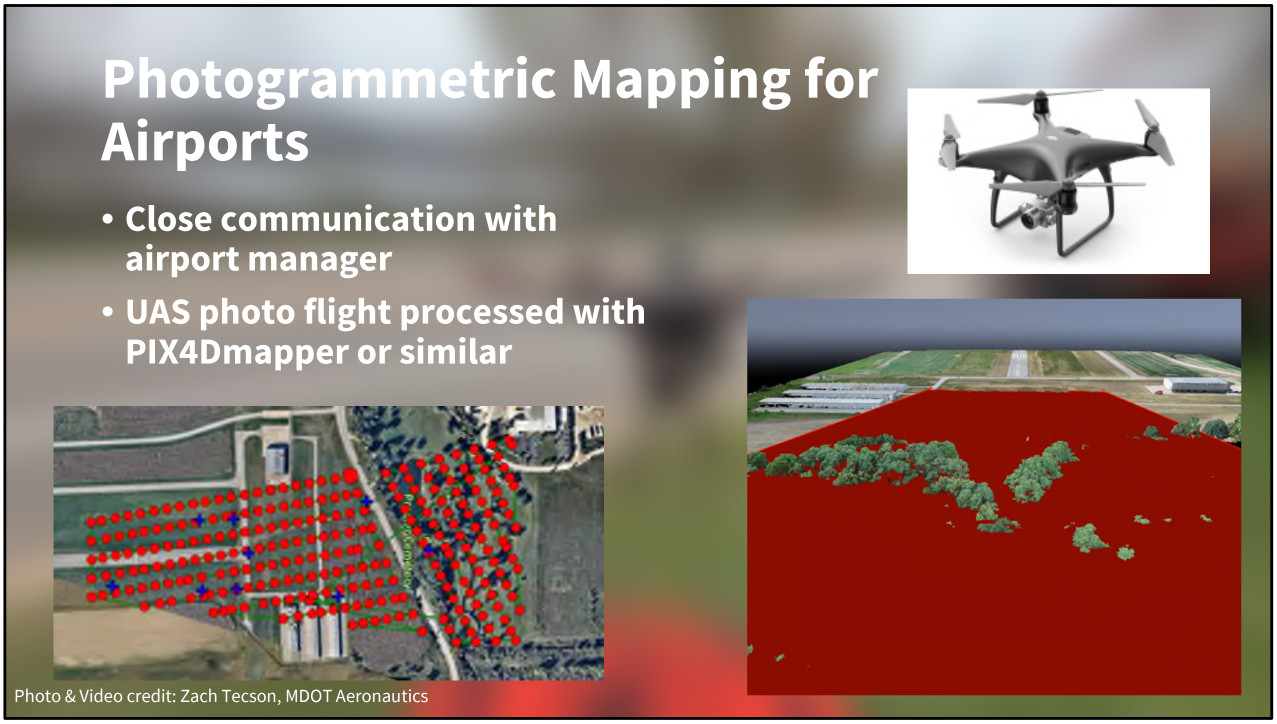
This was I-94 at Friday Road, in support of a hitch-mounted message board for Maintenance [SW Surveys]

Flying for traffic monitoring is also part of the UAS Research project with MTRI. One of MTRI’s projects is using an algorithm to identify vehicles and count them.



- Photogrammetric mapping for airports is an important use of drone mapping
- Airports must comply with State and Federal regulations with regards to keeping approaches free of obstructions, such as trees, buildings, poles, and billboards
- Before UAS, inspections were completed using hand tools. The only alternative had been to hire a manned air photo mission and manually map the obstructions, which could be cost-prohibitive
- The drone is used to capture pictures and re-create a 3D model of the approach area

- Preflight: analyze approach regulations & create 3D glide slopes



- MDOT Aeronautics uses a drone like the DJI Phantom pictured here.
- A pre-determined flight path is created for optimum data capture, while following FAA Part 107 guidelines, such as not flying over people or moving vehicles.
- In the resulting model, it's easy to highlight penetrating obstructions, and provide accurate heights and locations.
- On the left you can see the locations of each photo taken at this site, along with the blue crosses for ground control points.
- On the right, in the rotating model, you can clearly see the obstructions that are too high.

Photogrammetric Mapping for Transportation

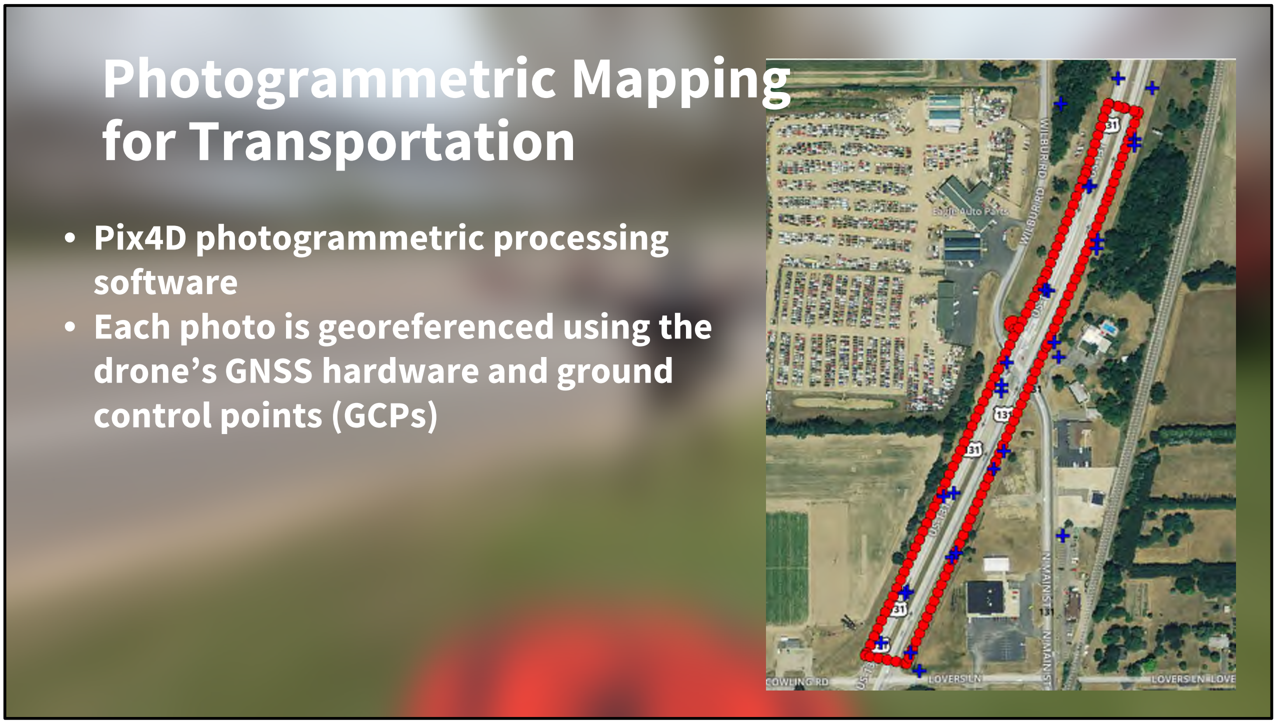
- Same final mapping products as conventional mapping
- Aerial photos & Orthophoto
- Safer than conventional mapping
- Some details cannot be seen without an aerial perspective
- Items beyond scope of project are visible
- “Scope Creep” isn’t as big a problem – you can always add additional detail without adding field work

UAS mapping for transportation really just provides a different way to collect the data. The final mapping products are the same we already provide for conventional mapping by surveyor. All planimetric features and assets are mapped.

Mapping with UAS means there is no reason to put surveyors on the road, so safety is greatly increased.

Since the data is collected once, there is no need to go back out to the field if additional detail is requested.

This is an example of a map and terrain model created for SW with a DJI Matrice 210 RTK.



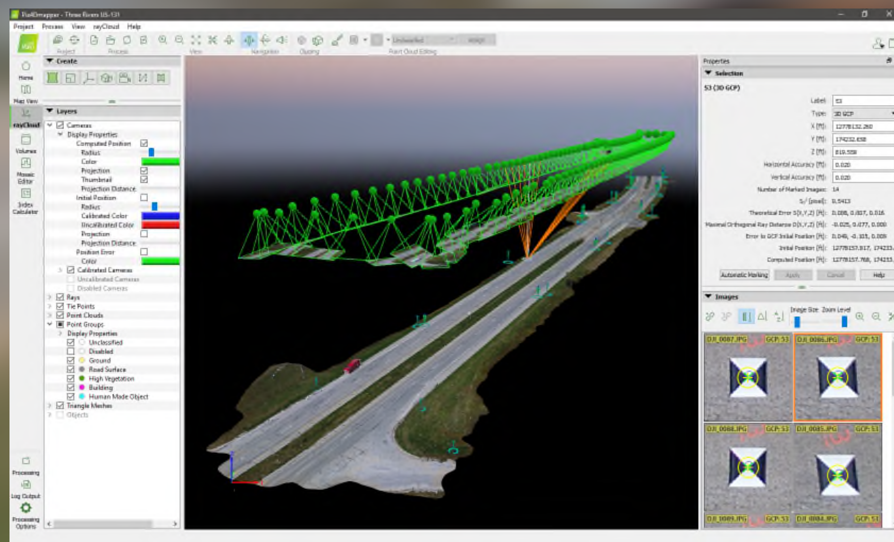
Once the mission is flown, the photos are downloaded to the computer. We currently use software such as Bentley ContextCapture, or Pix4Dmapper to process the photos, although there are other systems that do the same basic work.

This is an image from Pix4D of the US-131 & Wilbur Rd crossing. Each of the red dots represents the location of a photo, and the blue crosses are control points. As you can see, it was flown from the shoulder of the road, not over traffic. When it was necessary to cross to the other side, the visual observers on each end of the job were in contact with the pilot in command and let him know when it was safe to do so, without flying over moving traffic.

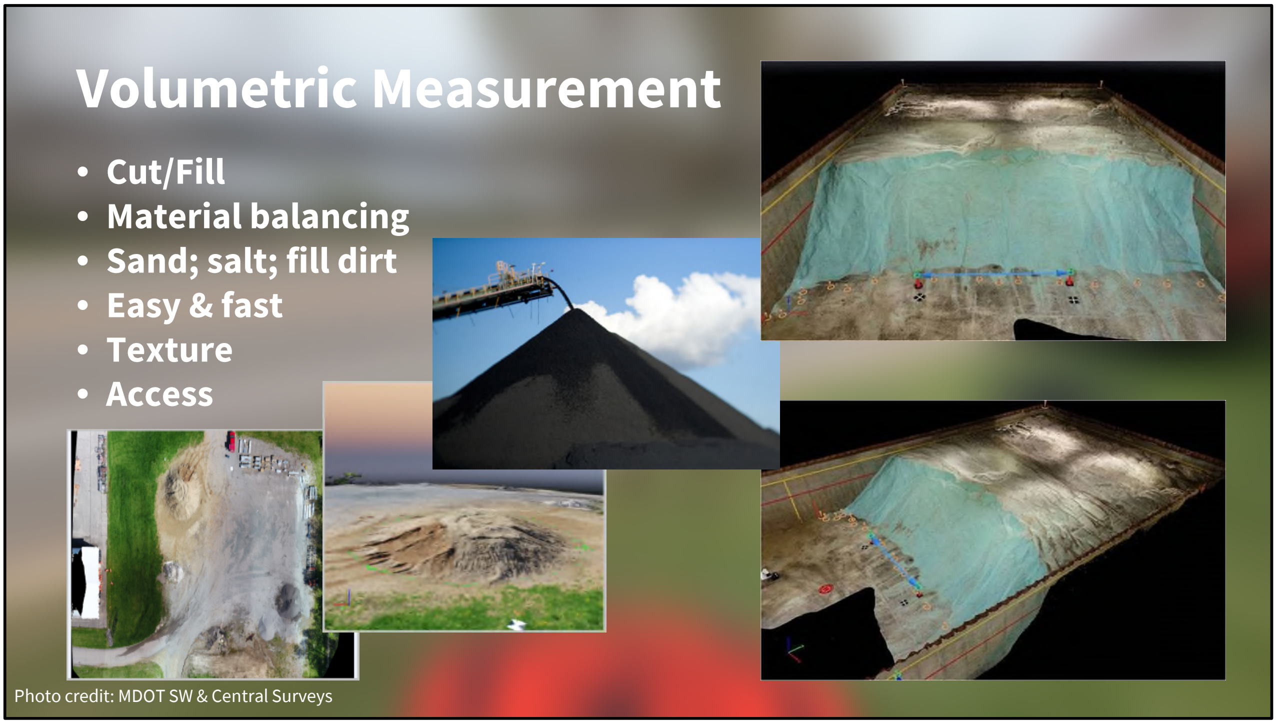
This project also taught us a little about a surprising risk in doing drone work (cropduster).

Photogrammetric Mapping for Transportation

- Pix4D maps each photo correctly
- Derived point cloud
- 3D mesh model



During processing, software correctly georeferences each photo. The direct products are a derived point cloud (different than a LiDAR directly measured point cloud), and a 3D mesh model. Here you can see a green representation of the location, roll, pitch, and yaw of each photo. The orange rays connect a control point to each photo in which is can be seen.



Stock pile volumes are easy to measure photogrammetrically in many cases. There are some cases, however, where UAS based LiDAR would be more accurate or practical. MDOT has done photogrammetric stock pile volumes on site for construction. We have done photogrammetric projects in MDOT salt storage barns. Flying in salt barns is a little tricky; it must be flown by hand due to the lack of GPS signal data. Photogrammetry works well outside, or inside if there is plenty of clearance between the salt and the roof. When the distance is tight, it is a little nerve-wracking. In the two renderings on the right, there was lots of room between the salt and the roof. Plus the salt was nicely leveled. We've flown others that were very irregular, with very little clearance below the roof. Those results weren't nearly as good.

Photogrammetry has problems however, if the material is very uniform with no discernable texture. In these cases, UAS based LiDAR would be more effective. Regardless of the texture or lack of, the 3D points returned by LiDAR will be accurate. If there is low clearance in a salt barn, the photos might be very small, so getting enough overlap for photogrammetry becomes more difficult. With LiDAR though, you would just need to fly narrow flights for full coverage.

Photogrammetry

- Photogrammetry has actually been around for many years. 1923: Ted Abrams - Abrams Aerial Survey
- Stereoplotters: Analog, Analytical, Digital

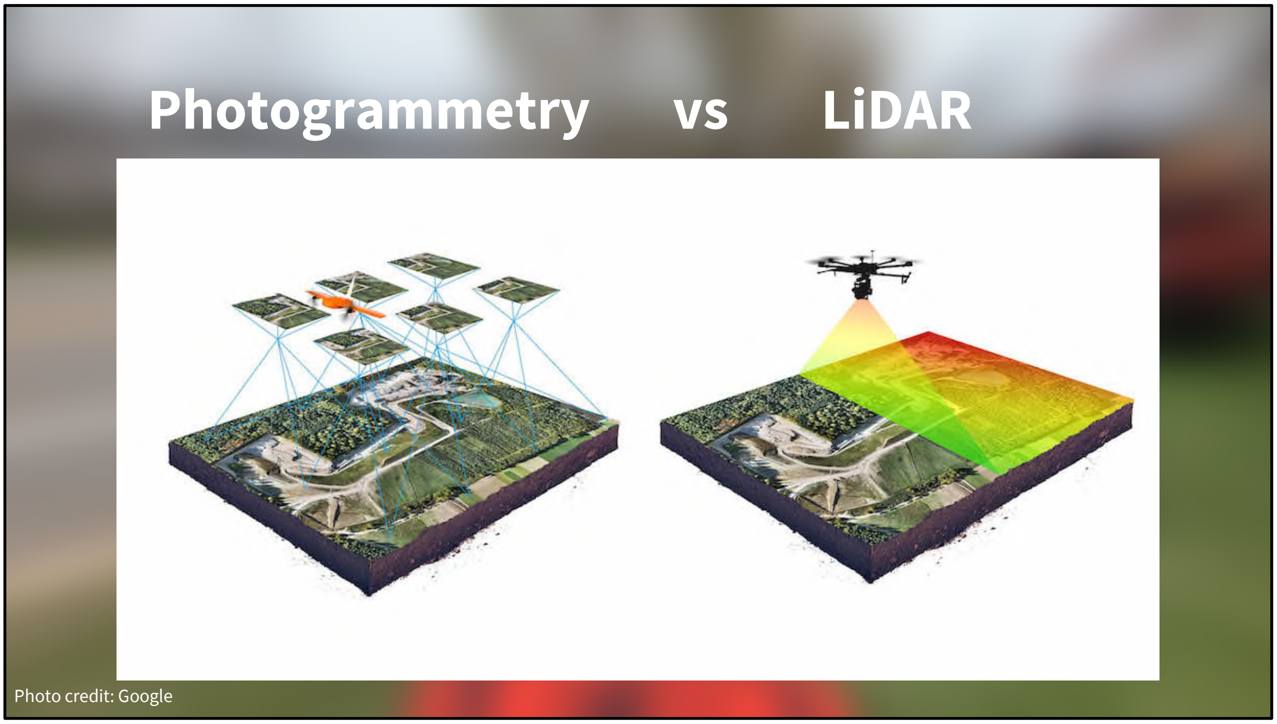
Photo credit: Google

Ted Abrams founded Abrams Aerial Survey Corporation right here in Lansing, in 1923. The original mapping was done using stereoplotters, where an operator would manually place a dot on the ground while looking at two aerial photos from a manned flight. Through a series of prisms, lenses, and mirrors, each eye would see a different overlapping photo, just as your eyes see two slightly different but overlapping scenes. Your brain converts the two images to 3D. Similarly, the stereoplotter operator "see" the ground and object elevations and place details at the correct elevation and location. They originally used a pantograph arm to draw the map in real time, but later this was replaced by x, y, & z encoders to draw directly into a CAD system.

The stereoplotter system was designed to remove lens distortion, radial distortion, and other imperfections so the map was able to be directly measured.

With the advent of affordable computers, analytical stereoplotters replaced analog ones, and then these were supplanted by fully digital machines using scanned photos.

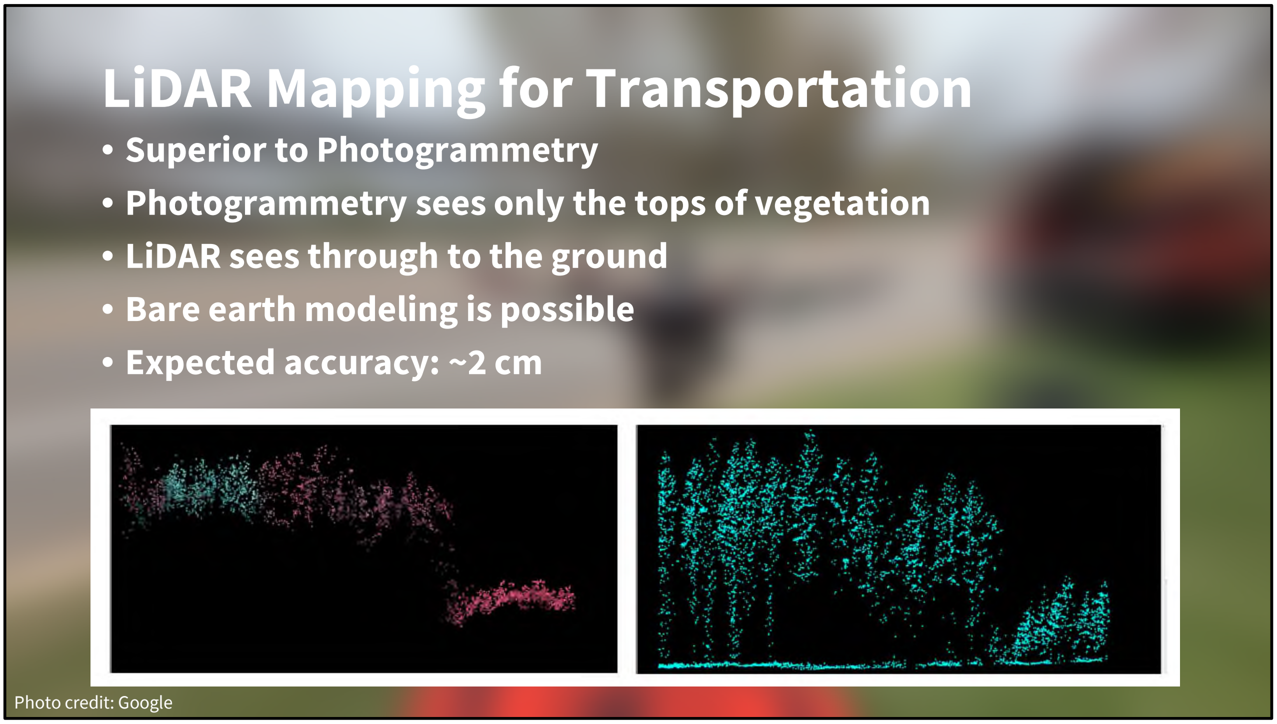
These days the computer does all of the heavy lifting. Instead of comparing two photos at a time, software such as Pix4Dmapper will look at 2, 5, 8, or maybe as many as a dozen or more photos at the same time. What used to take days now can be done in minutes.



There are two ways to collect data using a UAS. Photogrammetry uses a camera to collect many overlapping photos of the site. LiDAR uses direct scanning of the site. Photogrammetry takes more time to process back in the office, but LiDAR takes more specialized equipment to collect.

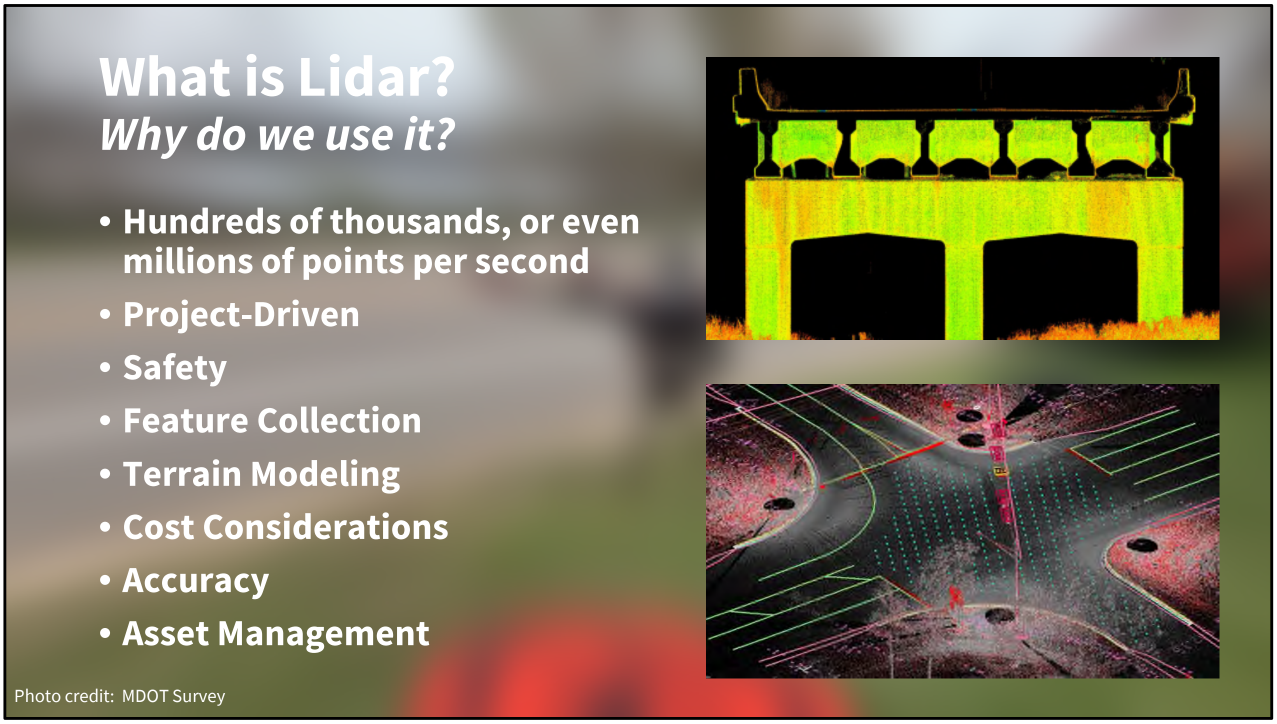
In photogrammetry, overlapping photos are analyzed and each pixel is reprojected to it's true coordinate position.

LiDAR software doesn't do as much interpretation, but must read the UAS trajectory and compare it to the GNSS data and the IMU, or Inertial Measurement Unit. Then it just reads the data collected. The camera can be used for an additional step if desired, to colorize each LiDAR point based on the real-world RGB from the images.



Unlike LiDAR, Photogrammetry doesn't penetrate vegetation well. A photogrammetric reconstruction only works when the same point can be seen in two or more photos. This is difficult with tree canopy or thick ground cover. LiDAR, on the other hand, only has to penetrate the canopy one time to collect a point on the ground. This makes bare earth modeling much more feasible with LiDAR. In the photo here, the left side shows a cross section of a wooded site collected with Photogrammetry, and the right side shows the result of LiDAR data collection. The ground can clearly be seen on the right, with the LiDAR data.

Imagine you are walking through a wooded area on a sunny day. The tree canopy shades the ground, but there are many little silver dollar sized spots of sunshine on the ground as you walk. While photogrammetry needs to see each of those spots from TWO locations, LiDAR only has to penetrate the trees a single time. These can all be combined into a terrain model of the bare ground under the trees.



LiDAR is an active data collection method. Unlike a camera, which is passive, the LiDAR scanner emits laser pulses and measures the time taken to reflect back to the sensor. Every single place that the laser reflects from becomes a XYZ point, so a scene is modeled as fully as possible. Multiple returns means that the tops of trees are measured, plus intermediate branches, ground cover, and the actual ground. MDOT has over ten years experience using this technology and creating maps and models for design engineering.

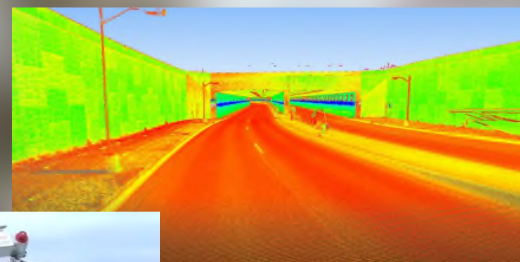
There are multiple types of LiDAR scanners. LiDAR can be collected on the ground using tripod-mounted scanners. MDOT has several of these instruments. Depending on the scan settings, this can produce the most accuracy and highest resolution. We can often see accuracies under 1/100th foot.

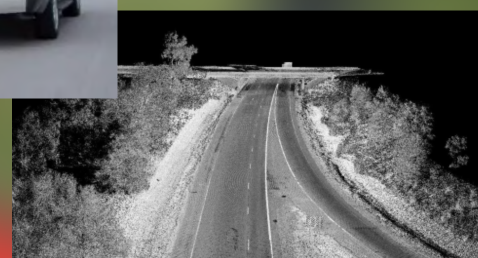
Good for small projects; bridges, intersections, not highways or broad areas.

MDOT has been using terrestrial LiDAR for over 10 years

LiDAR: Mobile

- Mounted on vehicles (like Google)
- Highway speeds
- Large-scale corridor mapping projects
- More expensive, but costs offset by speed and quantity of data collection



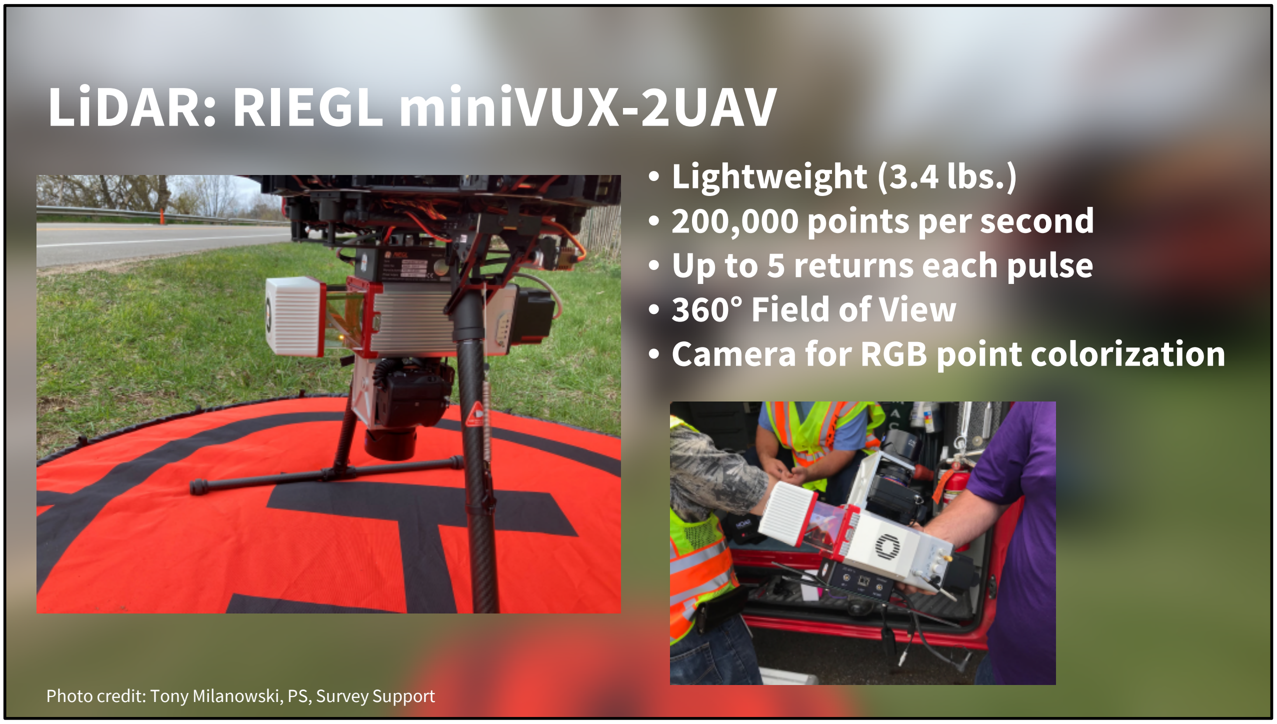


Mobile LiDAR is similar to terrestrial scanning, except the scanners are mounted on a vehicle. These vehicles can travel at or near highway speeds to collect data

Speed of collection offsets the cost, and is a very effective method to collect corridor data

Mobile LiDAR is very good for road details, but is more limited for ditches because of the low angle of incidence of the laser pulses. We have consultants that perform this surveying for us.

The UAV, Unmanned Aerial Vehicle, or drone, is another platform that can carry a LiDAR sensor. The drone we decided on is a well-tested workhorse, made by DJI, the Matrice 600 Pro. This is a very heavy-duty drone. It has 6 high-capacity smart batteries and can land even if one ever fails. It has 6 rotors, which provide the extra lifting capacity. 6 propellers means it also has redundancy and can land safely if one were to fail during flight. The landing gear retracts for flight, so the legs don't get in the way of collecting data. The GNSS/GPS positioning means we have accurate flight data, resulting in correct geolocation of every point collected. This is assisted by an IMU, or Inertial Measurement Unit, which is attached to the LiDAR sensor.



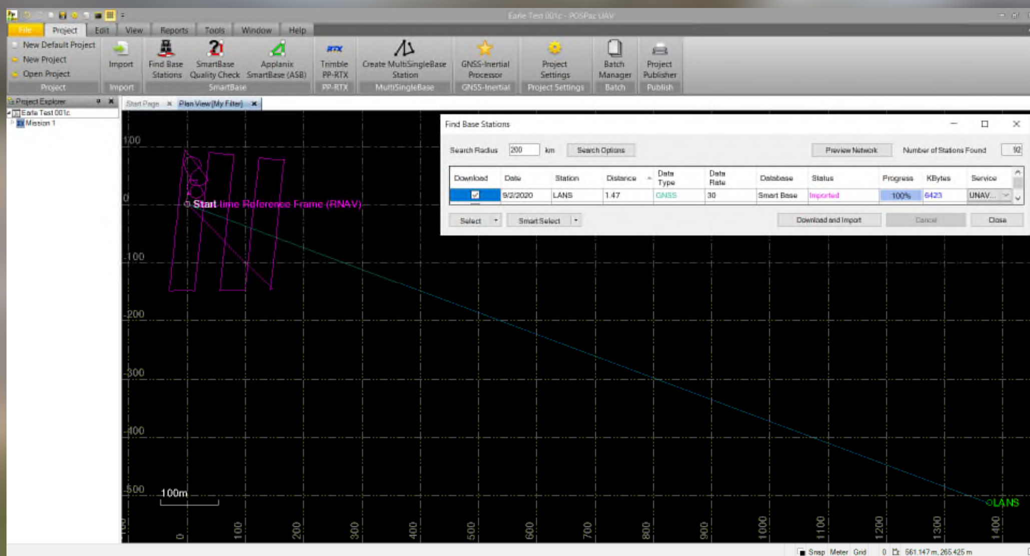
The Riegl miniVUX-2UAV was the best LiDAR scanner available for UAV use when we purchased this system. It's much more accurate than the sensors used for self-driving cars, but is still lightweight at only 3.4 pounds. This is twice as fast as RIEGL's previous sensor, collecting up to 200,000 points per second. The best feature of this scanner is that it has five returns. Multiple returns means that it won't just reflect off the first point it encounters, like the top of a tree, bush, or ground cover, but will penetrate to multiple levels and reach the ground. A camera is mounted on the scanner to collect images at the same time. These images can be used to colorize the LiDAR point cloud, and to create orthophotos of the site.

Complete UAV with LiDAR

- LiDAR scanner mounted below drone
- Camera mounted below LiDAR scanner
- IMU mounted on back of scanner
- Parachute mounted on top of drone

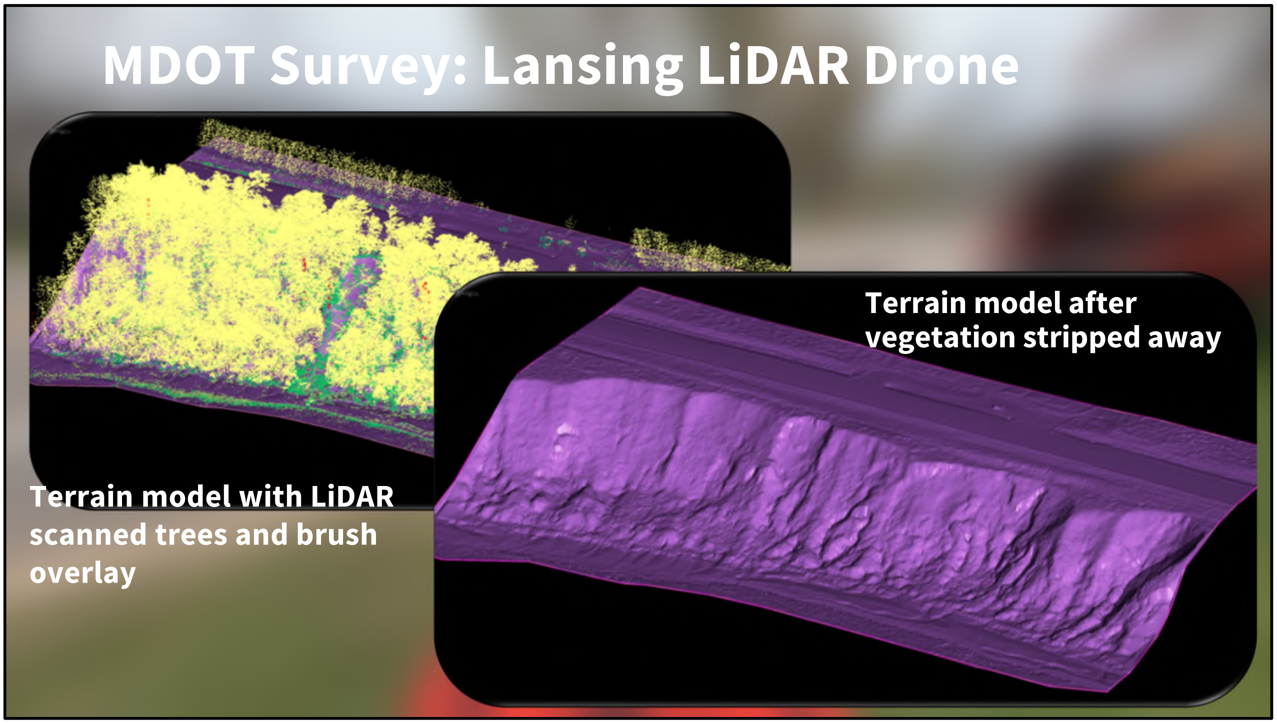
Here’s the entire unit assembled. From prop tip to prop tip, it’s about 5.5’ wide, and a couple of feet tall. The funny-looking white and black can-shaped item on the top of the drone is the parachute system. This will ensure that if a catastrophic event occurs, the drone will be able to land safely. There are several reasons why this is needed. First, in case the drone comes down near people, it will protect them. It emits a sound to warn bystanders. Obviously, a parachute also helps protect MDOT’s investment in the equipment. Lastly, it will be a necessity if we ever obtain a waiver to fly over people or traffic. The parachute will deploy if it senses a problem, or it can be deployed manually by the remote pilot.

Michigan CORS Connected

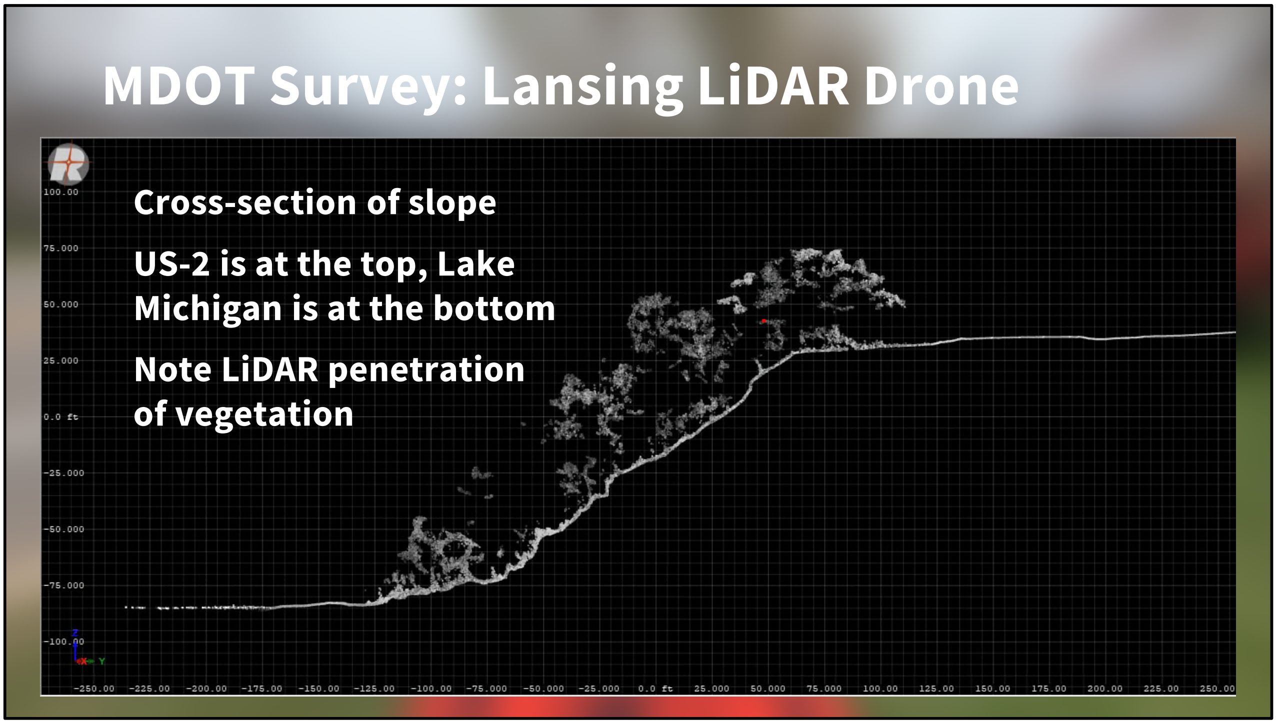


The first step of processing the data is extracting the trajectory. The IMU data along with local base station data or the statewide CORS network are used to fine-tune the trajectory. Here you can see that for this flight we connected to the Lansing LANS CORS station.

This is a project in the UP, near Brevort. US-2 is about 120’ above Lake Michigan here, and the slope is too steep for surveyors to effectively acquire data. We did climb down to set a control point on the beach, but it was tricky. You can see the main slope failure location. We flew this from a cemetery on the north side of the highway, where we could get a vantage point to see out over the trees.



We created a 3D model of the ground. Here you can see what it looks like, with the LiDAR points shown on the left, and the clear bare-earth terrain model on the right. This provides the Geotech people with the data they need to fix this and prevent future issues. In some cases, all that can be done is moving the road inland away from the erosion.



Here’s a cross-section of the LiDAR data showing just how much penetration we can get through the trees.

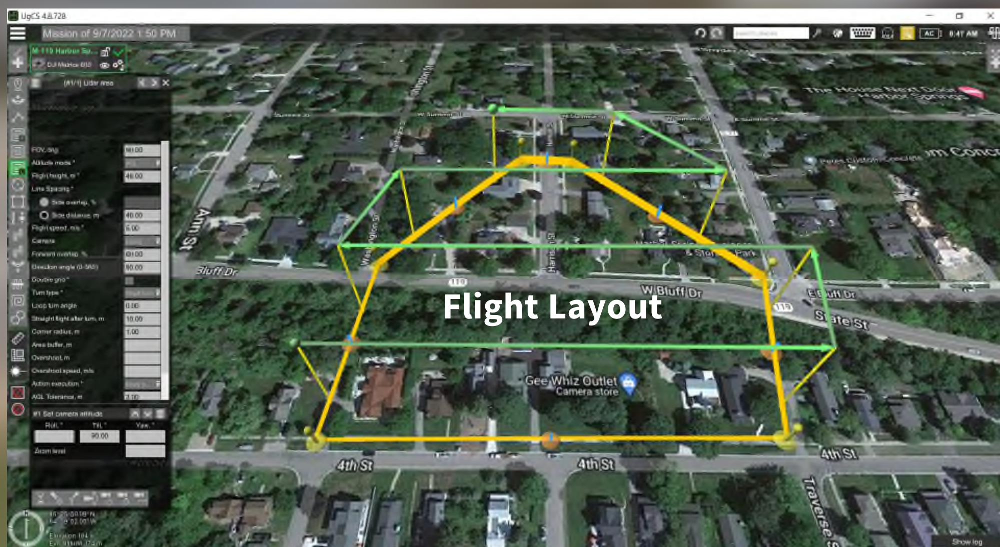
Talk about the “spot of sunshine” in the woods.

This was an interesting project. We had to scramble to get up to Harbor Springs for an emergency road washout.

Again, the hillside is too steep and heavily wooded for a surveyor to get usable data.

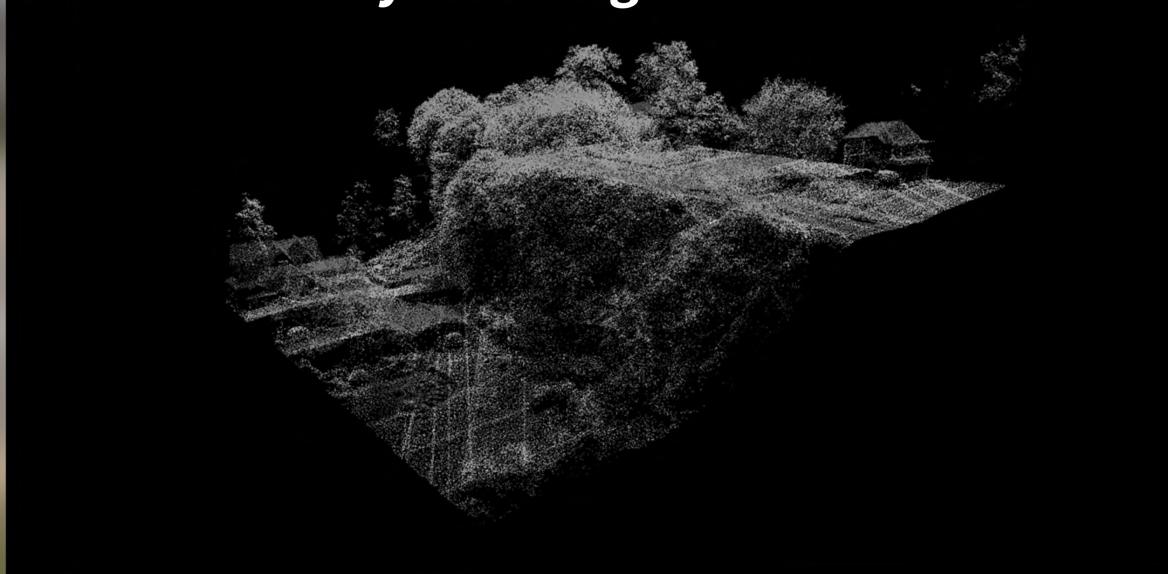
Road is 65’ above the properties below.

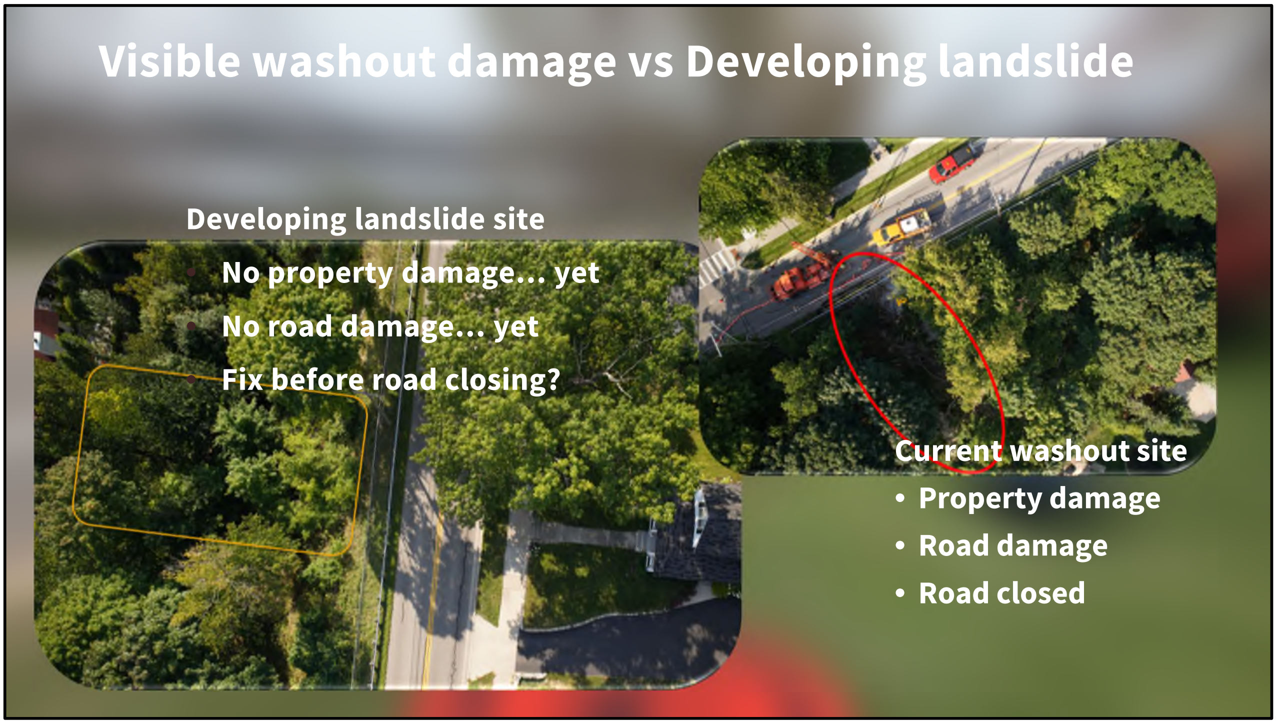
MDOT Survey: Lansing LiDAR Drone



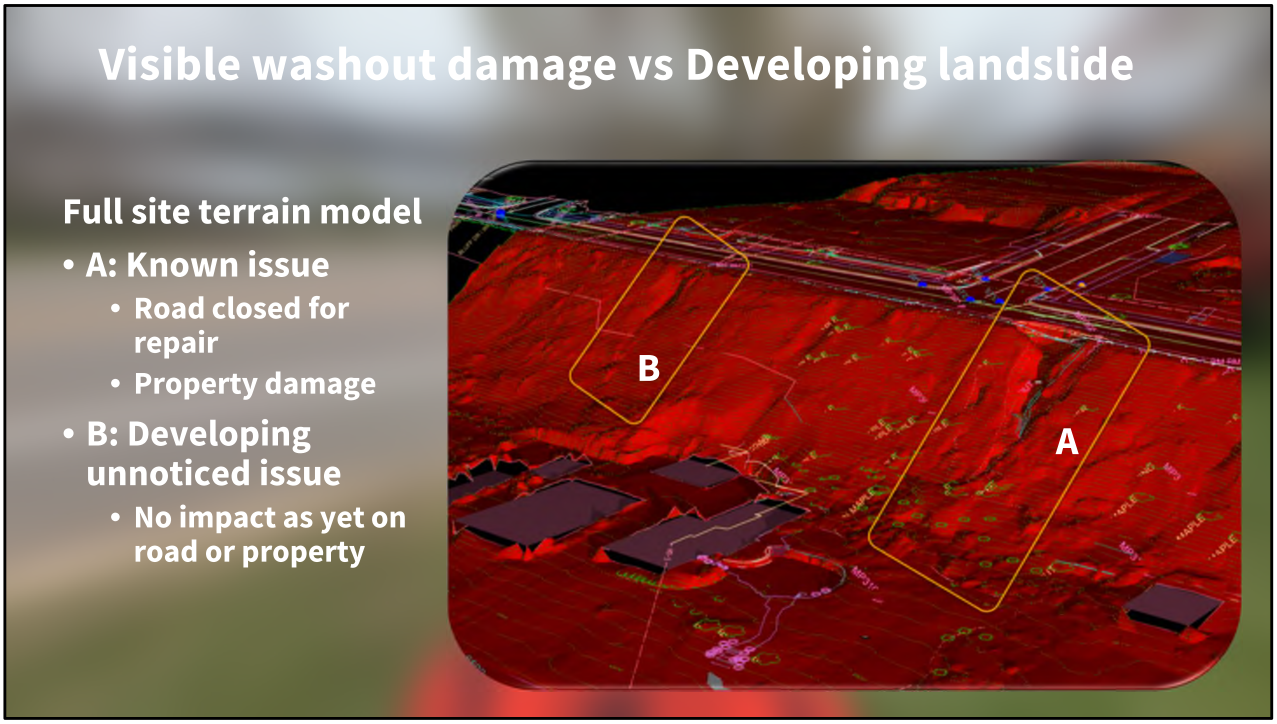
This is the planned flight layout. We typically fly at 150’ above the ground, with flight legs 150’ apart. This provides 100% overlap, so we get to see many features from both sides. We sometimes have to break projects into multiple segments for line-of-sight issues, or to avoid flying over busy roads. Ground control is planned next, and laid out so that we see as many points as possible from more than one flight.

MDOT Survey: Lansing LiDAR Drone



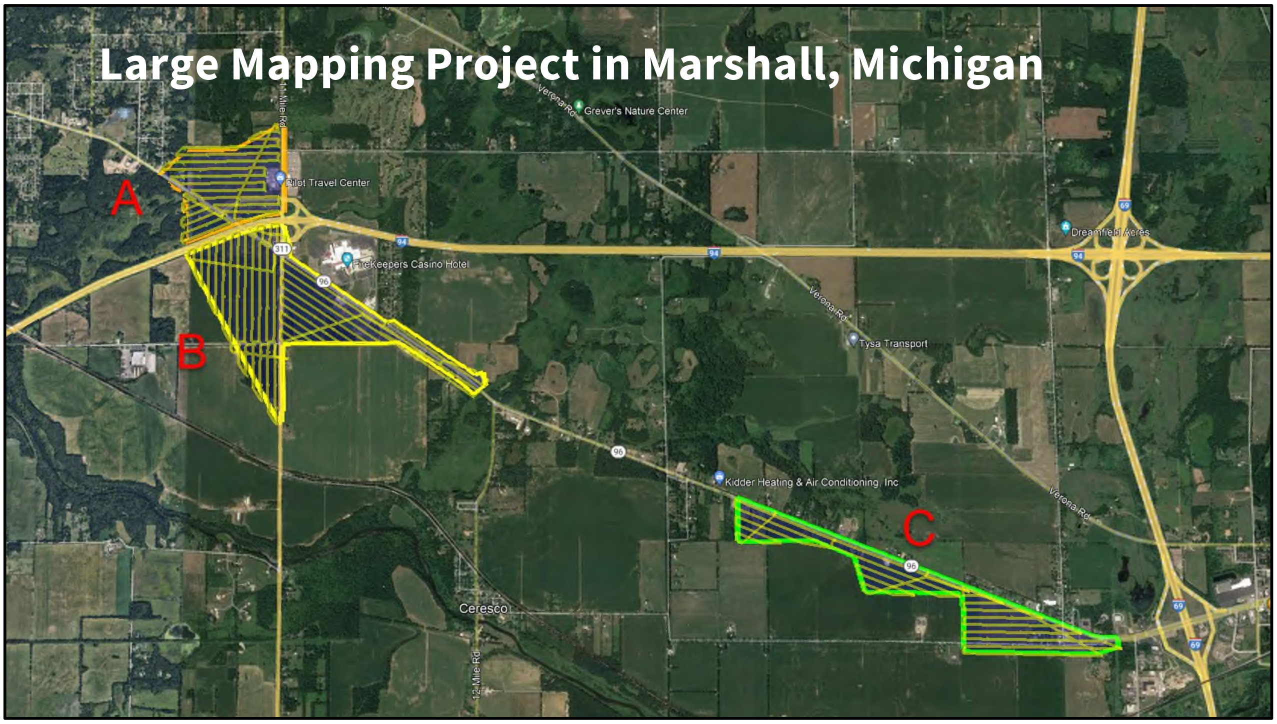


An interesting discovery during this project, was that we can maybe find evidence of future problems before they cause issues.



Note the developing potential issue. Geotech is reviewing our data to possibly prevent a failure.

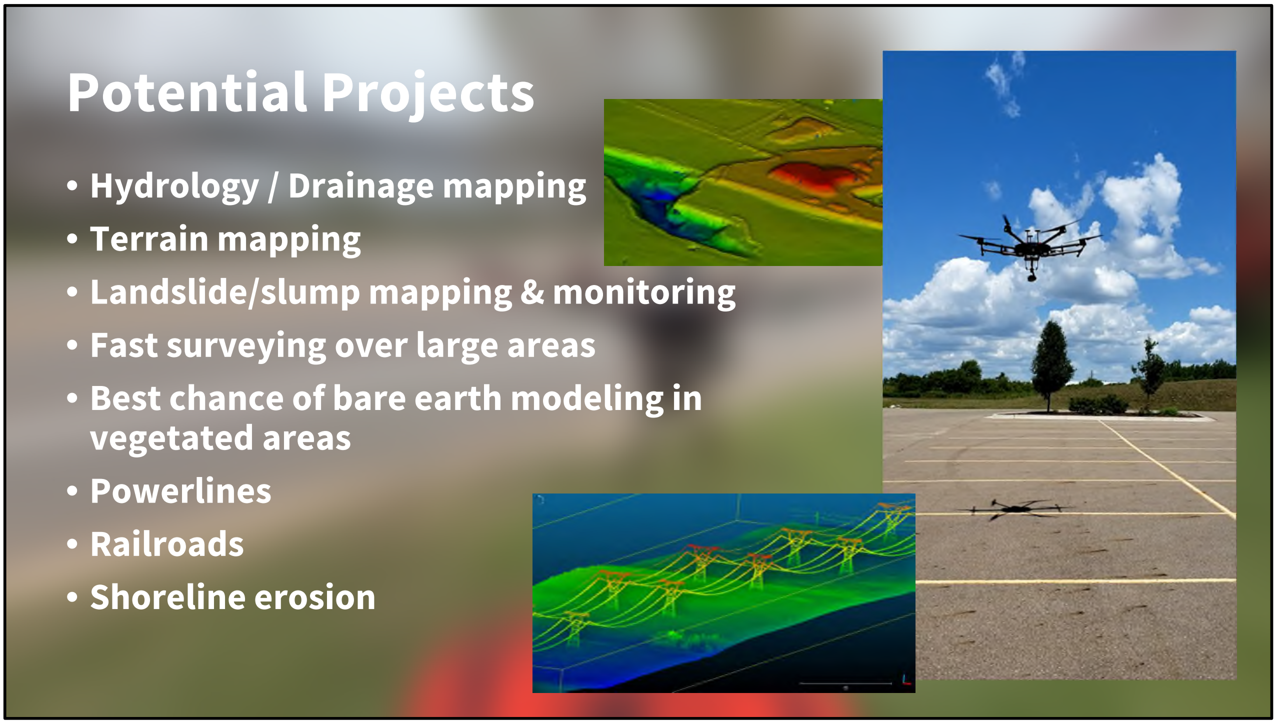
Question: WHEN DO WE FLY? WHERE? There's no budget for this kind of preventative work. Something to consider.



We recently completed a large mapping project in Marshall. This was a multi-day project. Careful prep work and planning is critical to saving time in the field. We plan our flight areas to reduce or eliminate crossing over roads and busy populated areas. As much as possible, we plan our launch sites before heading out. We have to plan for the best visibility without trees blocking our view, and we have to keep the drone from flying too far away to see. In good visibility, we can see the drone up to about 3800' away. (Smaller drones get lost at around 1200 or 1800'.) We did have one flying day on this project where the wildfire smoke from Canada reduced our visibility significantly.

We have 4 sets of 6 batteries, each set providing up to about 20 minutes of flight time. Projects like this become almost as much about battery management than the flight and data collection. We have a large inverter in our new UAS van, and we can charge three sets of batteries simultaneously. We also have a backup generator which can charge two sets when needed.

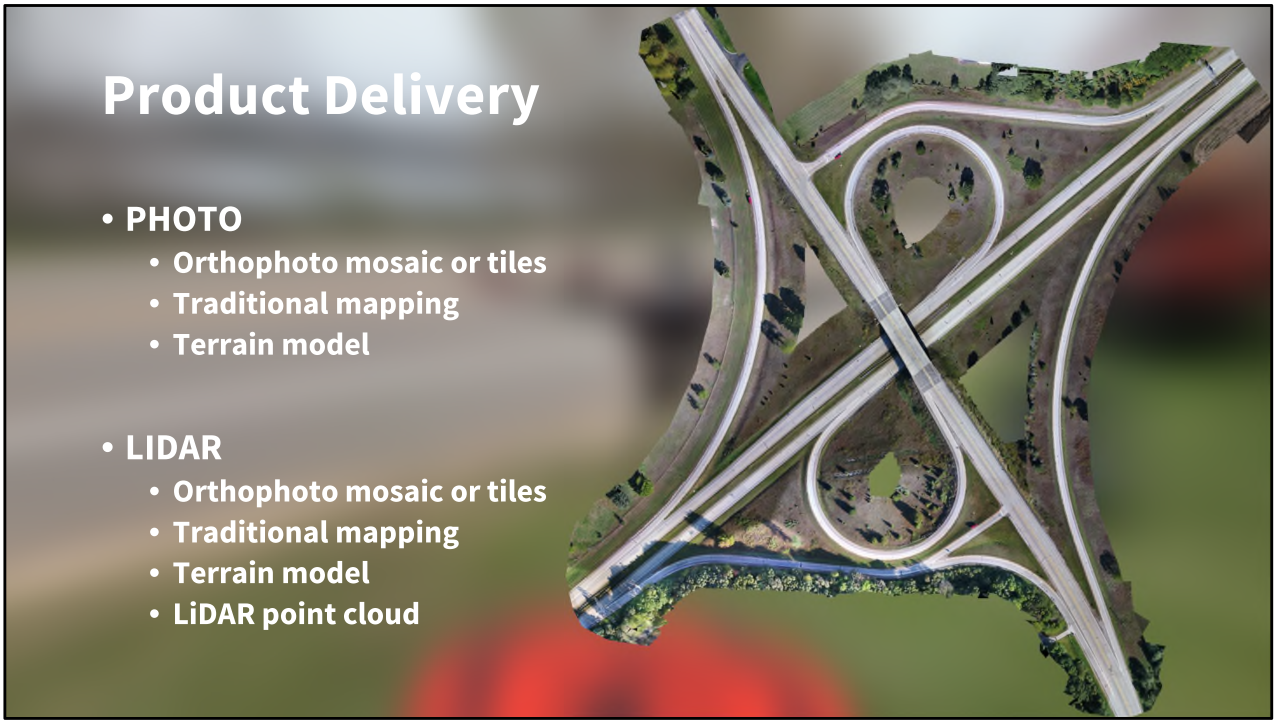
This project was about 7 miles from tip to tip. Some mobile LiDAR was used as well, by a consultant.



There are many, many types of projects that can benefit by collecting data with an aerial LiDAR unit. For now we may be limited in collecting data in densely populated areas, with large numbers of people or moving vehicles, but the FAA has recently loosened some of the restrictions on those types of flights. We're pursuing waivers for future work, but that may take a little while.

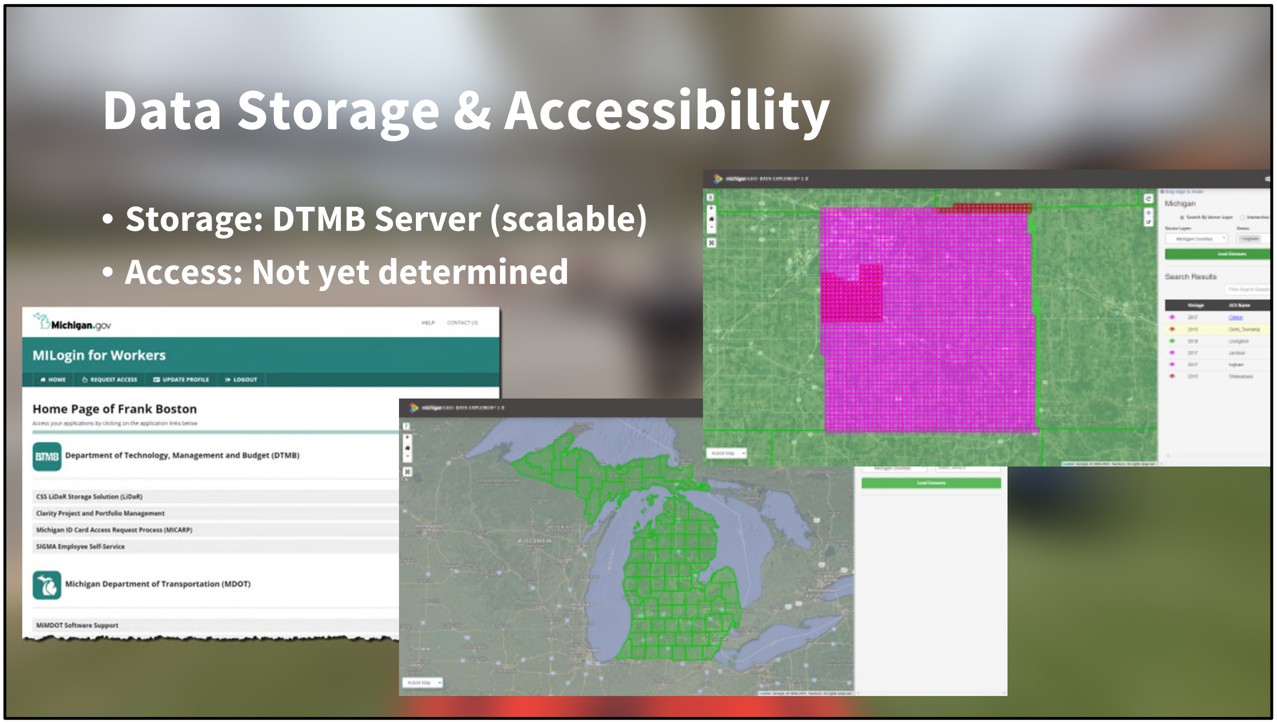
I foresee one of the best ways for MDOT map highway corridors might be to collect the hard surface data and assets with mobile mapping and use the UAS LiDAR system to pick up the surrounding terrain and the orthophotos.

This would also be perfect for things like hydrological studies or drainage mapping; really, ANY kind of terrain mapping; it is perfect for landslides or slowly slumping ground for Geotech; LiDAR penetrates many large wooded or overgrown areas; powerlines can easily be captured with LiDAR, unlike photogrammetric data collection; railroads; shoreline erosion; and many, many more.



For photogrammetric mapping, products will typically include an orthophoto or tiles of the site. Mapping may also be requested, which would be completed internally in the same manner as traditional mapping. Ideally, there will be few differences. If there are significant areas with dense foliage or ground cover, supplemental mapping may be required.

For UAS LiDAR projects, the deliverables would typically be the same as photo mapping, but could potentially include the LiDAR files. Many engineers are not versed in working directly with LiDAR data yet, but it's possible that could become a standard deliverable eventually.



LOTS OF DATA!! (One project was 3 BILLION points.)

Data storage is an issue that has been resolved, for the moment. We pay for scalable storage from DTMB.

We're still working on accessibility. Part of the issue is that we don't know who will need to access our data. We have investigated a couple of systems, but haven't found anything we like. It's possible that it may eventually be similar to what CSS has set up with Sanborn for the MiSAIL Statewide LiDAR, pictured here. If nothing else, we hope to be able to share data between regions. It may end up being a web-based system, or could be something more proprietary. We're definitely working towards a searchable geographical index of some type.

MICHIGAN DEPARTMENT OF TRANSPORTATION

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Thank you!

Questions?

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